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運用穩定同位素探討合歡山地區

兩個小鼠群聚的食物資源區隔

Using Stable Isotopes to Analyze Food Partitioning of Two Small Rodent Communities in He-huan Mountains

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本論文係葉威廷君（R98B44005）在國立臺灣大學生態學與演化生物學研究所所完成之碩士學位論文，於民國 101 年 5 月 30 日承下列考試委員審查通過及口試及格，特此證明

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摘要

共域的物種在食物資源的使用上可能會有不同的生態棲位。本研究使用穩定碳與氮同位素分析探討合歡山地區箭竹草原與冷杉林兩種不同棲地內的共域小型哺乳類（台灣高山田鼠 *Microtus kikuchii*、台灣森鼠 *Apodemus semotus* 與高山白腹鼠 *Niviventer culturatus*）在不同季節的食物資源分配。我們於合歡山冷杉林及箭竹草原設立樣區，進行生長季（春夏季）與非生長季（秋冬季）小型哺乳類毛髮的採樣，並採集可能的食物來源（植物葉片、真菌與無脊椎動物）。各樣本以同位素分析儀得到穩定碳與氮同位素值，並以 SIAR（Stable isotope analysis in R）運算可能食物來源對小型哺乳類的食物貢獻比例，資料分析分為三個方向：棲地性、季節性及物種間差異，同時亦利用同位素值計算各物種的棲位寬度與變異程度。結果顯示，共域的物種在棲地間存在差異：兩個季節，台灣高山田鼠的草原個體均較森林個體取食較多植物；而台灣森鼠的森林個體不同於草原個體，兩個季節均以真菌為主要的取食對象。季節性的差異僅存在於森林的台灣高山田鼠與高山白腹鼠族群：在非生長季的時候會較生長季取食較多的無脊椎動物。在物種間的比較發現，台灣高山田鼠不論季節或棲地，均較其他鼠類取食較多的植物，相較森林的其他鼠類則取食較少的真菌；此外高山白腹鼠在非生長季的時候會較其他鼠類取食較多的動物性資源。運用同位素計算棲位寬度與變異程度，整體來說森鼠在兩個棲地擁有最廣的棲位寬度與最高的變異程度，但各物種在季節間存在著差異。結果支持三種共域的物種在食物資源的使用上有不同的生態棲位，而真菌可能在合歡山冷杉林內小型哺乳類的取食上扮演一個重要的角色。

關鍵字：食物資源分配、穩定同位素、台灣高山田鼠、台灣森鼠、高山白腹鼠

Abstract

Coexisting species may occupy different ecological niche in food resource utilization. We used stable carbon and nitrogen isotope techniques to analyze the food partitioning of rodent communities (Taiwan vole: *Microtus kikuchii,* Formosan mouse: *Apodemus semotus,* and White-bellied rat: *Niviventer culturatus*) in the alpine meadow and fir forest in the He-huan mountains. Rodent furs and potential food sources (plants, fungi, and invertebrates) were sampled in growing and non-growing seasons during 2009-2010 in both habitats, followed by carbon and nitrogen isotopic analyses. SIAR (Stable isotope analysis in R) was used to calculate the percentage contribution of food sources to the consumers. Three aspects were examined: habitat, seasonal, and species differences, along with food niche width measures to reveal variations within the populations. Habitat difference focused on coexistent species: Taiwan voles had similar trends in both seasons, with meadow individuals consuming more plants than forest ones. Formosan mice in the forest differed from the meadow ones, with forest individuals using fungi as their main food sources. Seasonal difference in diets only existed in Taiwan voles and white-bellied rats in forest, with more invertebrates consumed in non-growing than growing seasons. For species comparison, Taiwan voles ate more plants than other species in both habitats and less fungi in the forest. Besides, white-bellied rats consumed more animal sources than others in non-growing seasons.

Formosan mice had wider food niche width than other species in both habitats, but seasonal differences existed. Overall, the three species did partition their food resources. The results also revealed that fungi might play an important role in rodents' diet in the forest in He-huan mountains.

Keyword: food partitioning, stable isotopes, *Microtus kikuchii*, *Apodemus semotus*, *Niviventer culturatus*

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Introduction

The concept of ecological niche was formally established by Joseph Grinnell. He proposed the “role niche” concept to describe a species’ character in an ecosystem (Grinnell 1917). The concept has evolved over time. G. E. Hutchinson brought up the “population - persistence niche” that focus on the environmental conditions that could sustain the population of a species (Hutchinson 1957). Later, Robert MacArthur and Richard Levin, proposed the “resource-utilization niche”, which advocates that different species in a certain area use different resources, and it is the difference that sustains the population (MacArther and Levin 1964). Ideally, a “resource-utilization niche” can be operationally defined by measuring the distributions of different resources utilized by a population. The resources often refer to different food available to the consumers, although space and other abiotic characteristics of the environment are also considered important axes of a species’ niche.

The analyses of food resource utilization reveal feeding relationships among species in an ecological community. They provide the basic information of animal interactions, including exploitative and competitive relationships in an ecological community. The multiple relationships among species could be linked to produce a food web. The investigation of food partitioning pattern, using diet analyses, among coexisting species could be further investigated. Early analyses of feeding relationships relied on direct observations of foraging behaviors, or indirectly through stomach content and fecal analyses. However, the above methods were known to be easily biased by uncertain time scale, space variation, and food digestibility (Polunin *et al.* 2001). In the past decade, the stable isotope technique has been widely used to trace diet source (Bearhop 2002). The technique uses heavy and light stable isotope ratio of a biologically important element, such as carbon and nitrogen, to trace the movement of the element from an organism's environmental source to the organism. By comparing animal tissue isotopic values with those of potential food source, possible food sources can be determined (DeNiro and Epstein 1978 and 1981). Furthermore, isotopic values, especially nitrogen value, often rises with the increase of trophic levels, so can be used to measure the trophic positions of species (Cabana and Rasmussen 1996). Trophic structures can thus be built and understood in ecological communities (Doucett *et al*. 2007, Codron *et al.* 2010, Flaherty *et al.* 2010, Hyodo *et al.* 2010).

In recent years, isotopic theories and models have been developed to help specifically construct and modify diet relationships and trophic structures, for example, the development of multi-source mixing models to calculate the percentage of contribution of different food sources (Post 2002, Caut *et al.* 2008, 2009, 2010, Robbins *et al.* 2009, Wolf *et al*. 2009, Auerswald *et al.* 2010, Doucette *et al.* 2010, Boecklen *et al.* 2011). Different tissues of an organism have different metabolic rates, therefore measure stable isotope ratios with different time scales (Passey *et al.* 2005). For example, muscle tissue represents weekly diet change, bone tissue can record large time scale such as the whole life time, and fur tissue is in between (Wang *et al.* 2004). For small mammals, the turnover rate of hairs is about 1-2 months (Tieszen *et al.* 1983), suitable for seasonal diet investigation (McIlwee and Johnson 1998).

The alpine ecosystems of Taiwan host many endemic species or subspecies. The two most prominent ecosystems are Taiwan fir forest and alpine meadows. The vegetations there are mainly comprised of Taiwan fir (*Abies kawakamii*) and Yushan canes (*Yushania niitakayamensis*) in the forests, and Yushan canes and alpine silver grass (*Miscanthus sinensis*) in the meadows. Small rodents (張 1997), including Taiwan voles (*Microtus kikuchii*), Formosan mice (*Apodemus semotus*), and white-bellied rats (*Niviventer culturatus*) co-exist in both ecosystems, though the latter species are primarily found in forests.

Few studies have focused on food habits of the three rodent species. For Taiwan voles, 呂 (1991) discovered the reproductive cycles of Taiwan voles might be related to their food sources, especially the growth of Yushan canes. Besides, 賀 (2009) assessed the interactions between Taiwan voles and dominant plants in the alpine meadow, and the results showed that different plants had different palatability to voles, and Taiwan voles consumed greater amount of plants with greater cover areas. For other rodents, 甘 (1995) found that seeds and animal sources contribute higher percentages in the stomach contents of Formosan mice in Wulin (~2000 m in altitude in central Taiwan), and 李 (1988) found that white-bellied rats might consume the seeds, shoots, and rhizomes of plants. Previous studies indicated these rodents might use plants as one of their food sources. However, the researches that revealed their diets in high-altitude areas remained unclear. The meadow and forest small rodent communities shared species members yet have otherwise very different biotic and abiotic environments. The comparison of the two communities in terms of food partitioning among coexisting rodents should reveal habitat-dependent community structures that will further our understanding of the unique alpine ecosystems.

Research Objectives

I aimed to construct the diet relationships of Taiwan voles, Formosan mice, and white-bellied rats in an alpine meadow and a forest in the He-huan mountains. I asked three questions. First, how do the feeding relationships among the three species differ between the two communities? Second, do the relationships change seasonally? Finally, can the feeding relationships be explained by ecological factors such as resource availability or species abundance? I approached the questions by measuring the stable carbon and nitrogen isotope values of small rodents and their potential food sources in both communities (Fig. 1).

Material and Methods

Study Site

The field study was conducted in an alpine meadow (24°08’36.4”N, 121°17’17.4”E) near the Little Qi-lai Trail, and a Taiwan fir forest (24°09’41.1”N, 121°17’10.4”E) near the High Altitude Experimental Station of the Endemic Species Research Institute, ~3000 m in altitude at the Hehuan Mountains, Nantou County, in central Taiwan. The climate can be divided into wet (May–October) and dry (November–April) seasons, with sporadic snows during January ~ February. The monthly average temperature is 7.0 ℃, and monthly rainfall 366 mm.

The meadow site was comprised mainly of herbaceous *Yushania niitakayamensis* (玉山箭竹), *Miscanthus sinensis* (高山芒), and several other herb species in low coverages. Woody plants, *Pinus taiwanensis* (台灣二葉松), and woody shrubs, *Juniperus formosana* (刺柏) and *Rhododendron pseudochrysanthum* (玉山/森氏杜鵑), interspersed in the meadow. The forest site was comprised mainly of woody plants *Abies kawakamii* (台灣冷杉) and *Tsuga chinensis* (台灣鐵杉), along with herbaceous *Yushania niitakayamensis* (玉山箭竹), *Elatostema obtusum* (裂葉樓梯草), and several ferns and moss.

I set up a sampling grid at the meadow and forest site in October 2009. The meadow had a 7 x 7 trapping stations with seven parallel lines and seven stations in each line. The lines and stations were 10 m apart. The forest had a 6 x 6 trapping stations, with a similar spacing layout (Fig. 2).

Small Mammal and Potential Food Survey

(1) Small mammal survey

I conducted small mammal survey in October 2009 and January, April, July, and November in 2010 approximately once every three months. I used the capture-mark-recapture method to assess the population sizes of small mammals. Animals were trapped with one Ugglan Special live trap (250 × 78 × 65 mm) and one squirrel trap (310 × 170 × 110 mm) at each station. Traps were baited with rolled oats and diced yam mixed with peanut butter. Traps were checked twice a day in the morning (0700-1000 h) and in the afternoon (1530-1730 h) for three consecutive days, with a total of 5 trap checks. Upon capture, new individuals were given unique ear tags (one on each ear) for future identification. The following information was recorded for all individuals: trap station, species, tag number, sex, body weight, reproductive condition (testes scrotal or abdominal for males; vaginal perforated or non-perforated, and signs of pregnancy and nursing for females), and health condition (occurrence of parasites and scars). I clipped hairs on lower back at the base of hairs from each animal, then released the animal immediately at the station where they were captured. The population sizes were estimated by using the program MARK (Cooch and White 2010).

(2) Potential food survey

The leaves of major plant species (Table 1) in both habitats were sampled. Phenology of major plant species was recorded by field observation, and supplemented by looking up Flora of Taiwan (2nd edition) (Table 1). Fungi abundance was determined by the species numbers of fungi each season regardless of their edibility to voles. I sampled fungi carpophores at the forest, but not meadow, site. Very few fungi carpophores were observed at the meadow site.

I sampled invertebrates using both pitfall traps and sweep nets. A pitfall trap (a 650 C.C. plastic cup) was placed at 10 randomly selected stations each in both study sites for sampling ground surface invertebrates. For invertebrates on the vegetation, I used sweep net to collect samples along randomly selected transects among trapping stations. The total length of transects was about 200m at both sites. The abundance of invertebrates was determined by weight.

<u>Stable Isotope Analyses</u>

All samples, including hairs, vegetation leaves, and invertebrates, collected were washed with deionized water and dried at 60 ℃ for more than 48 hours to achieve constant weight. Animal samples were first sonicated with deionized water for 30 minutes, then sonicated with petroleum ether for another 30 minutes, and air-dried for 24 hours. The procedures removed excessive lipids, which would affect isotopic values, from samples (Doucette *et al.* 2010).

All samples were ground into fine powder, and their $\delta^{13}C$ and $\delta^{15}N$ measured using a mass spectrometer, coupled with an elemental analyzer (Thermo DELTA5, Technology Commons, College of Life Science, National Taiwan University). Results are expressed in the standard δ notation as parts per thousand (‰) relative to international standards: PeeDee Belemnite (PDB) for carbon and atmospheric nitrogen (N_2) for nitrogen as follows: $\delta X = ((R\text{ sample}/R\text{ standard}) - 1)/1000$, where X is ^{13}C or ^{15}N, and R is the corresponding ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$.

Data Analyses

Due to small sample sizes of several types of samples, I combined seasons into two seasons, growing (March-August) and non-growing (September-February) seasons, based on the phenology of plant resources. Analyses of isotopic values were performed and described in three ways: (1) stable isotope ratio of potential food sources, (2) food partitioning, and (3) diet composition.

(1) Stable isotope ratio of potential food sources

I used the carbon and nitrogen isotopic values of samples to build two-dimensional plots to describe the relationships between consumers and resources, as well as among consumers in different seasons and habitats. I used isotopic carbon values to trace diet carbon source, such as C3 and C4 sources. I used isotopic nitrogen values to describe the trophic relationships of sources: the difference in $\delta^{15}N$ between successive trophic levels is about 3-3.4‰ (Minagawa and Wada 1984). I used standard deviations to describe isotopic uncertainties.

(2) Food partitioning

I used three-way MANOVAs and three-way ANOVAs to examine the effects of species, habitat, and season on carbon and nitrogen isotopic values for Taiwan vole and Formosan mouse. Information of white-bellied rats was not included because over the course of study, they were only captured once at the meadow site. I also performed two-way MANOVAs and two-way ANOVAs to determine the effects of species and season on isotopic values of all three rodent species in the forest habitat.

The variation in isotopic values was used to describe the food niche width of species.

Five community-wide niche-width measurements were calculated: $\delta^{15}N$ range (NR), $\delta^{13}C$ range (CR), variance of $\delta^{15}N$ (Var N), variance of $\delta^{13}C$ (Var C), and the variance of distances to centroid (Var CD). The distances to centroid represented the Eulcidean distances from each data point to the mean of all carbon and nitrogen isotopic values of a species in a habitat. No statistical tests could be performed on community-wide niche-width measurements because the community types were not replicated. Only descriptive results are presented.

(3) Diet composition

I first categorized potential food sources from the two habitats into three groups: C3 plants, C4 plant, and invertebrates for the meadow habitat, and C3 plants, fungi, and invertebrates for the forest habitat. There was no C4 plant in the forest. Then, I used the analytical software SIAR (Stable Isotope Analysis in R) to calculate the percentage of each potential food group in composing the diet of a consumer in a given habitat/season. Based on previous studies (DeNiro and Epstein 1978, 1981, Milakovic and Parker 2011), the discrimination factors I used in the SIAR model were 2.00 (SD=0.2) and 3.20 (SD=0.3) per mille for carbon and nitrogen, respectively. The SIAR yielded the median and the 5-95 percentiles for the percentages of different food groups. The differences in diet composition between habitat, season, and species were compared using ANOVAs. All statistical tests were performed using SAS unless mentioned otherwise.

Rodent Abundance Estimation

I used the MARK software to estimate rodent population sizes. Four variables: survival rate, natural increase rate, capture/recapture rate, and species numbers, were input into estimation models (Pradel Models Including Robust Designs) for each sex, each species. The Alkaike Information Criterion in MARK selected better models (with $\Delta AIC < 7$). Based on chosen models, population sizes were estimated for Taiwan voles, Formosan mice, white-bellied rats in the forest, and Taiwan voles and Formosan mice in the meadow.

Results

Rodent Abundance Estimation

In both habitats, Taiwan voles were the most abundant species. Population sizes in the meadow in growing and non-growing seasons were: 40 and 34, 15 and 20 for Taiwan voles and Formosan mice, respectively (Table 2). Only one white-bellied rat was captured in the meadow during the period of study. Population sizes in the forest in growing and non-growing seasons were: 15 and 35, 6 and 30, 6 and 12 for Taiwan voles, Formosan mice, white-bellied rats, respectively (Table 2).

Stable Isotope Analysis for Small Mammals

(1) Stable isotope ratio of potential food sources

All potential food source groups of small rodents clearly separated from each other in either $\delta^{13}C$ or $\delta^{15}N$ isotopic values in both growing (Fig. 3A and 4 A) and non-growing (Fig. 3B and 4B) seasons in both meadow (Fig. 3) and forest (Fig. 4) habitats. Plants at the meadow site could be divided into C3 and C4 plants (Table 3A). The $\delta^{13}C$ values were C4 plants > Invertebrate > C3 plants; while the $\delta^{15}N$ values were invertebrate > C3 plants ≧ C4 plants in both growing and non-growing seasons. At the forest site all plant species seemed to belong to C3 plants, while fungi had distinct values from plants (Table 3B). The $\delta^{13}C$ values were fungi ≧ invertebrate > C3 plants; while the $\delta^{15}N$ values were invertebrate > fungi ≧ C3 plants in both growing and non-growing seasons. Table 4 gives the mean (‰, ±1sd) isotopic values of rodents at the meadow and forest sites.

(2) Food partitioning patterns

The result of 3-way MANOVAs (species x habitat x season) comparing isotopic values between Taiwan voles and Formosan mice indicated strong species x habitat and species x season interactions (3-way MANOVA, species x habitat interaction, $F_{2, 122}$ = 7.80, p = 0.0006; species x season interaction, $F_{2, 122}$ = 3.60, p = 0.0303, Table 5A). Besides, the result of 2-way ANOVAs (species x season) comparing isotopic values among Taiwan voles, Formosan mice, and white-bellied rats in the forest habitat over two seasons showed significant differences between species and seasons. (2-way MANOVA, species effect, $F_{4, 188}$ = 77.94, p <.0001; season effect, $F_{2,94}$ = 4.70, p = 0.0114, Table 5B).

The result of 3-way ANOVAs (species x habitat x season) comparing carbon and nitrogen isotopic values between Taiwan voles and Formosan mice in the two habitats over two seasons indicated strong interactions (Table 6A). Formosan mice had higher $\delta^{13}C$ values than those of Taiwan voles in both meadow (Table 4A) and forest (Table 4B) habitats, yet the difference in $\delta^{13}C$ values between the two species was greater at the forest site (3-way ANOVA, species x habitat interaction, $F_{1, 123}$ = 6.85, p = 0.01, Fig. 5A). Formosan mice also had higher $\delta^{15}N$ values than those of Taiwan voles in both meadow (Table 4A) and forest (Table 4B) habitats, and the difference in $\delta^{15}N$ values between the two species was greater at the meadow site (species x habitat interaction, $F_{1, 123}$ = 8.74, p = 0.0037, Fig. 6B). A significant interaction also existed between species and season. The difference in $\delta^{13}C$ values between Formosan mice and Taiwan voles was much greater in growing than non-growing season (species x season interaction, $F_{1,}$

$_{123}$ = 7.17, p = 0.0084, Fig. 5C). The rest of main effects and interactions were not significant (p > 0.05, Table 6A).

The result of 2-way ANOVAs (species x season) comparing carbon and nitrogen isotopic values among Taiwan voles, Formosan mice, and white-bellied rats in the forest habitat over two seasons indicated a strong species x season interaction in $\delta^{13}C$ values, and strong species and season main effects in $\delta^{15}N$ values (Table 6B). Generally, the ranks of $\delta^{13}C$ values were rats > mice > voles, but the difference between species was greater in non-growing than in growing season (species x season interaction, $F_{5, 95}$ = 4.45, p = 0.014, Fig. 6A). For the $\delta^{15}N$ values, the species effect indicated the ranks were rats > mice > voles (species effect, $F_{5, 95}$ = 10.77, p <.0001, Fig. 6B); whereas season effect indicated the ranks were non-growing > growing season (season effect, $F_{5, 95}$ = 8.69, p = 0.004, Fig. 6C). The rest of main effects and interactions were not significant (p > 0.05, Table 6B).

The community-wide food niche-width measurements showed that in the meadow, Formosan mice had greater width than Taiwan voles in nearly all measurements (only CR remained similar, Table 7A) in both seasons. In the forest, Formosan mice had the greatest niche width among three rodent species in all measurements when two seasons were combined. However, there were seasonal differences. In growing seasons, Taiwan voles and white-bellied rats had much higher NRs than Formosan mice, and white-bellied rats had the highest Var N; while Formosan mice and white-bellied rats both had higher CRs than Taiwan voles, with Formosan mice having the largest Var C. In non-growing seasons, Formosan mice had the greatest niche-width in all measurements. Overall, the white-bellied rats and Formosan mice had the greatest niche-width in growing and non-growing seasons, respectively (Table 7B). The variance of centroid distance (Var CD) is a measurement that combine the variation in both carbon and nitrogen food sources. The results showed that Formosan mice had the highest Var CD values among rodent species at both meadow and forest sites in non-growing season, while Taiwan voles had the highest Var CD at forest sites in growing season.

(3) Diet composition

The diet composition analyses by SIAR showed that in the meadow Taiwan voles were herbivores, with about 90% of diet composed of C3 plants, followed by 8% C4 plants and merely 2% invertebrates in both growing and non-growing seasons. The diet of Formosan mice was composed of about 65% of C3 plants, followed by 25% C4 plants and 10% invertebrates in both growing and non-growing seasons, with a rise in invertebrate food (20%) during the non-growing season (Table 8A). In the forest, the diet of Taiwan voles was composed of about 70% of C3 plants, followed by 25% fungi and 5% invertebrates in the growing season, with a rise in invertebrate food (13%) during the non-growing season. The other two rodents showed similar trends, consumed a lot more fungi, (80~85% and 60~70% in the growing and non-growing seasons, respectively, Table 8B).

Without statistical tests, I now attempt to use the 5-95 percentiles to describe the dynamic of diet change over seasons. In the meadow, both the diet compositions of Taiwan voles and Formosan mice remained relatively constant over seasons. Both species tended to consume slightly more invertebrate food in non-growing season. Also, the variation in diet composition of Formosan mice seemed greater in the non-growing than growing season. , The C4 food source was replaced by fungi in the forest habitat. In the forest, Taiwan voles consumed mainly C3 food (54~77 %) in both seasons, but the percentage of invertebrate food increased 2~3 folds from growing (2~7 %) to non-growing (10~16 %) seasons. Similarly, white-bellied rats consumed mainly fungi (50~90 %) in both seasons, but the percentage of invertebrate food increased 2 folds from growing (7~24 %) to non-growing (25~47 %) seasons. The diet compositions of Formosan mice remained relatively constant over seasons in the forest. Overall, in the growing seasons, Taiwan voles consumed more plants (both C3 and C4 plants) than Formosan mice in the meadow, and much less fungi than other rodents in the forest. In the non-growing season, white-bellied rats consumed a lot more invertebrates than other rodents in forest.

Resource Abundance Estimation

(1) Plant phenology

The investigation on the phenology of plants in both forest and meadow showed that the sprouting and flowering period of nearly all species occurred during March-August (Table 1 and Fig. 7). We thus define the period "growing season".

(2) Invertebrates abundance

The total biomass of invertebrates was 2.41g at the meadow site (1.54g and 0.88g in the growing and non-growing seasons, respectively), and 0.61g at the forest site (0.39g and 0.22g in the growing and non-growing seasons, respectively). Seasonal differences existed with total biomass in growing seasons higher than non-growing seasons in both habitats.

(3) Fungi abundance

The number of morpho-species of fungi at the forest site was 7 and 14 in the spring and summer (growing season), respectively, and 6 and 4 in the fall and winter (non-growing season), respectively.

Discussion

1. The ecological perspective of rodents' food partitioning in Hehuan mountains

Overall, the three species did partition their food resources. Habitat and species differences existed in both meadow and forest rodents, while seasonal differences existed in only forest ones. Taiwan voles ate more plant foods than other species did, and white-bellied rats consumed more animal sources than other rodents did. The food partitioning of Taiwan voles were different from other species in both communities, while Formosan mice and white-bellied rats shared similar food sources in the forest.

The food partitioning results of the rodent community might reveal the functional roles of small mammals in ecosystems. For example, SIAR results showed that rodent community in forest consumed large amount of fungi, suggesting that it might be an important food source for rodent community in He-huan mountains. Lin (1992) studied the stomach contents of Formosan mice in the forests in Alishan and found that in wet season (August) Formosan mice did consume fungi. Besides, 張 (2004) found the presence of spores of arbuscular mycorrhizal fungi (AMF) in the feces of the three rodent species in this study. Moreover, the direct evidence of fungi consumption came from the bite marks on some fungi species in our field observations. The results might confirm the fungi utilization by rodents and indicated that rodent community in the forest might help interconnect the above- and below-ground systems through fungi feeding.

Furthermore, previous studies on the influences of Taiwan voles on the plant community in Hehuan mountains indicated positive and negative effects. 賀 (2009) found that Taiwan voles consumed greater amount of plants with greater cover areas, and the selective foraging may prevent dominant species from over-dominating. However, 許 (2011) discovered the vole latrines not only quickly returned nutrients back to soil, but also enhanced decomposition rates of soil organic matters, thus play a crucial role in alpine ecosystems. The diet results of Taiwan voles might confirm their ability to influence and alter the dynamics of plant populations as well as to further affect the transition processes of alpine meadow and forest by combining much higher percentage in plant consumption with their dominance in both meadow and forest areas, yet the effects and mechanisms require further researches and information.

2. Linking food partitioning patterns to ecological factors

Ecological factors such as food availability, species relative abundance, and body size might be linked to food partitioning patterns of the rodent communities (Smythe 1986, Ernest 2005, Jorgensen 2004).

Food availability can be divided into two parts: season-dependent food availability and habitat-dependent food availability. First, food resource did differ between growing and non-growing season though the information was limited. The phenology of plants differed between growing and non-growing season, which matched Taiwan voles' seasonal differences in plant consumption, with plant contribution percentage higher in growing than non-growing season in both habitats. Besides, Taiwan voles are known to consume the shoots and leaves of plants, while Formosan mice and white-bellied rats can eat seeds and fruits. Consuming different parts of plants might also influence the use of plant resources. Moreover, diet estimation results showed higher contribution percentage of fungi in growing season (higher than 80% in Formosan mice and white-bellied rats), while in non-growing season the percentage dropped with fungi abundance decreased.

Second, habitat differences between two rodent communities might affect the food partitioning as well. For example, Yushan canes (*Yushania niitakayamensis*) are widely distributed both in the meadow and forest in Hehuan mountains, but the forest ones have higher average in heights than the meadow ones based on field observation, which might primarily affect Taiwan voles' diet choice. Furthermore, based on the results of plant and invertebrate abundance, forest site has less plants and invertebrate abundance comparing to meadows. However, forest site are suitable for fungi growth, which might be a good alternative source for forest rodent community.

Species relative abundance by MARK might represent differences in competition intensity and interaction strength, which might relate to variations in diets in rodent communities (Stueck and Barrett 1978). For example, results showed that in forest Taiwan voles and Formosan mice had larger population size in non-growing than growing season, which might indicate the increasing competition intensity for food resources. This might have connection with the food niche width results that Taiwan voles and Formosan mice had higher indicators (NR, CR, Var C and Var N) in non-growing than growing season, suggesting the increasing food source competition might lead to diet shifts or requests for alternative source. Furthermore, the presence of white-bellied rats in the forest might reduce the availability of food for Formosan mice due to inter-specific competition for similar food sources, which could be confirmed by habitat comparison in food niche width measures in Formosan mice.

Body size can affect the food items and choices of the consumers. Hutchinson and MacArther (1959) proposed that sympatric and similar species should be regularly spaced along a size sequence, separated by a constant ratio (2.0 for body weight and 1.3 for body length). The measurement of body weight during trapping sessions suggested that white-bellied rats have at about three to four times larger body size than other rodents in Hehuan mountains, indicating broader food choices, which might be related to the coexistence with other rodents, especially Formosan mice.

3. Community structures and variations within population

Overall, Formosan mice had wider food niche in both meadow and forest rodent communities, which indicated that they might be “generalists” in diets. Lin (1992) and 甘 (1995) discovered that Formosan mice could use plants, seeds and animals as food sources. 甘 (1995) further compared the stomach contents of three rodent species in Wulin, and found that Formosan mice had most diverse animal sources than other rodents. The large food niche width of Formosan mice might also be one of the reasons that explained why they are “generalists” in microhabitat use (彭 1995).

Taiwan voles were herbivorous specialists in meadow, with plants contributing about 90 percent of their diets. Their individual variation in isotopic values within population was expected to be smaller than the omnivorous Formosan mice. On the contrary, it shall exhibit opposite trends in forest, with Taiwan voles having larger variation in isotopic values than other rodents which mainly consumed fungi for more than 80 percent of their diets.

Results of food niche width measures (Var CD) confirmed the prediction for both seasons in the meadow, and for growing season in the forest as well. However, results for non-growing season in the forest showed different patterns that Formosan mice had larger niche width compared to other rodents. The possible explanation for this difference was that fungi abundance decreased in non-growing seasons, which might lead to diet shifts in Formosan mice. The alternative food sources (e.g. plants or invertebrates) resulted in more omnivorous food habits, thus increased the variability in isotopic values.

The seasonal differences in food niche width of Taiwan voles and Formosan mice in forest might be an interaction of both intra- and inter-specific competitions since the population sizes of both species increased in non-growing season. The increasing inter-specific competition might cause the specialized food partitioning of different species, while the increasing intra-specific competition might suggest diverse food choices of individuals within populations. That is, inter-specific competition might decrease the breadth of food niche of each species, while intra-specific competition might raise it. Thus the increasing food niche measures of Taiwan voles and Formosan mice in non-growing season might indicate larger effects of intra-specific competition than inter-specific competition.

Fry (2003) had mentioned when an error term is used with averages, the coefficient of variation or CV, needs to be calculated using the atom % or *F* notation (see Appendix A.2 in Fry 2003). Use of δ notation for CV calculations leads to incorrect CV results (e.g., Lancaster and Waldron 2001). Based on such descriptions, I re-examined the results of carbon and nitrogen variance for community-wide measures. The stable isotope values of rodent community were transformed to atom %, and CVs of both carbon and nitrogen were derived. The results (not included in this study) showed identical patterns to the variance results of isotopic values, suggesting that errors in δ did not affect the variation patterns of rodent community in Hehuan mountains.

4. Characteristics of potential food sources

During the potential food survey only one C4 plant species (*Miscanthus transmorrisonensis*) was found in the alpine meadow, and none was found in the forest. The plant community surveyed was comprised of plants and ferns in the meadow, and plants, ferns, and moss in the forest. The isotopic signatures of ferns and moss all belonged to C3 plants.

Based on the isotopic results, fungi were the lighter carbon source in the forest. Besides, the nitrogen isotopic values of fungi exhibited great variations between species, which might be a result of different substrates.

Invertebrates were mainly composed of arthropods: insects such as coleoptera, Diptera, Hymenoptera, etc and spiders (Araneae). The invertebrates used in isotopic analyses excluded the primary consumers due to their low abundance and disturbance in isotopic signatures. That is, the grouping of invertebrates as one of the food sources focused on secondary or higher consumers and detritivores.

5. Tissue-specific discrimination in isotopic signatures

The time scale that hair tissues reflect dietary information varied among researches. Early researches (Tieszen et al. 1983, McIlwee and Johnson 1998) suggested that hairs were suitable for seasonal diet estimation. However, recent researches (Roth and Hobson 2000, Milakovic and Parker 2011) indicated that hair shall reflect the diet of an individual over the period that the hair was grown, so the hair turnover time is not exactly precise for seasonal diet estimation.

I conducted feeding experiment to reveal the turnover time of hair tissues on the rodents in Hehuan mountains (Appendix 3). Though the sample size was small, the results suggested the hair-recovered time at about two and a half months with rapid turnover rate in isotopic signatures. The results supported that hair tissues may be suitable for seasonal diet estimation for seasonal-molting species. However, whether the rodents in Hehuan mountains molt seasonally was still unknown.

Furthermore, in this research we defined growing and non-growing season based on the phenology of plant community, so it was difficult to tell which season should the hair tissues represent. Due to the uncertain turnover time of hair and obscure analytical process of season combination, I chose to match the hair tissues with resources at the same season.

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Table 1. Phenology of dominant plants at the meadow and forest site in Hehuan mountains.

Species name (meadow)	Plant phenology
Yushania niitakayamensis (玉山箭竹)	4~6 月萌芽及新葉 (7~8 月茂盛)
Miscanthus transmorrisonensis (高山芒)	3~4 月萌芽，6~9 月與 10~12 月開花
Deschampsia flexuosa (曲芒髮草)	4~5 月萌芽，6~8 月開花
Aletris formosana (台灣粉條兒菜)	3 月出芽，6 月開花，7~8 月結果
Carex satzumensis (薹屬(油薹))	4~5 月萌芽，6~8 月開花，7~9 月結果
Gaultheria itoana (高山白珠樹)	4~5 月萌芽，6~7 月開花，8~9 月結果
Berberis morrisonensis (玉山小蘗)	4~5 月萌芽，5 月下旬到 7 月開花
Ainsliaea reflexa (玉山鬼督郵)	4 月抽芽，5~7 月開花，5~11 月結果
Lycopodium pseudoclavatum (假石松)	6 月間抽芽，10 月開始孢子飛散
Lycopodium obscurum (玉柏)	5~6 月抽孢子囊穗 ，10 月底至 11 月孢子飛散
Lycopodium veitchii (玉山石松)	6 月初抽孢子囊穗，10~11 月孢子飛散
Viola senzanensis (尖山堇菜)	5~9 月開花
Veronica morrisonicola (玉山水苦竇)	6~8 月開花
Species name (forest)	**Plant phenology**
Yushania niitakayamensis (玉山箭竹)	4~6 月萌芽及新葉 (7~8 月茂盛)
Elatostema trilobulatum (裂葉樓梯草)	4 月抽新葉，5~7 月開花，8~9 月結果，10 月落果
Abies kawakamii (台灣冷杉)	5、6 月葉芽開展，花期 5 月底至 6 月中，7 月毬果生成
Tsuga chinensis (台灣鐵杉)	5~6 月間開花，11~12 月結果
Dryopteris expansa (闊葉鱗毛蕨)	4 月萌芽，5 月展新葉，7~8 月孢子囊熟裂
Dryopteris lepidopoda (厚葉鱗毛蕨)	常綠性，無顯著生長週期變化

Table 2. Estimated population size of different rodent species at the meadow and forest sites in the Hehuan mountains.

			Growing season				Non-growing season			
			spring (Apr. 2010)		summer (Jul. 2010)		fall (Nov. 2010)		winter (Jan. 2010)	
Habitat	Species	sex	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Meadow	Taiwan vole	male	5.6	0.8	13.6	0.8	7.6	0.8	7.6	0.8
		female	7.7	0.8	11.7	0.8	8.7	0.8	8.7	0.8
		Total	13.3		25.3		16.3		16.3	
	Formosan mouse	male	NA	NA	5.0	NA	10.6	7.4	4.7	2.5
		female	NA	NA	9.9	4.3	3.9	3.6	0.0	0.0
		Total	NA		14.9		14.5		4.7	
Forest	Taiwan vole	male	5.3	0.8	3.3	0.8	8.3	0.9	10.3	0.8
		female	4.3	0.8	3.3	0.8	8.3	0.9	9.3	0.8
		Total	9.6		7.6		16.6		19.6	
	Formosan mouse	male	0.0	0.0	2.5	1.3	11.3	2.2	7.3	1.7
		female	3.4	1.1	1.0	0.4	7.6	1.8	3.5	1.2
		Total	3.4		3.5		18.9		10.8	
	White-bellied rat	male	1.0	0.0	4.4	1.1	7.4	1.1	1.0	0.0
		female	0.0	0.0	1.0	0.0	4.1	0.7	0.0	0.0
		Total	1.0		5.4		11.5		1.0	

Table 3. Isotopic values (‰, means and standard deviations) of potential food sources at the (A) meadow and (B) forest sites.

(A)

			$\delta^{13}C$		$\delta^{15}N$	
Food sources	Season	n	Mean	SD	Mean	SD
C_3 plants	Growing season	22	-27.97	1.81	-1.15	1.79
	Non-growing season	20	-28.88	1.62	-1.06	2.02
C_4 plants	Growing season	2	-12.52	0.24	-3.02	0.88
	Non-growing season	2	-12.42	0.40	-0.68	0.97
Invertebrates	Growing season	14	-23.12	1.48	6.15	4.01
	Non-growing season	12	-23.46	2.24	4.41	3.50

(B)

			$\delta^{13}C$		$\delta^{15}N$	
Food sources	Season	n	Mean	SD	Mean	SD
Plants	Growing season	27	-30.71	2.06	-1.45	1.26
	Non-growing season	25	-30.60	1.82	-1.47	1.21
Fungi	Growing season	21	-24.06	1.69	3.17	4.06
	Non-growing season	10	-23.44	1.59	0.89	3.78
Invertebrates	Growing season	10	-25.03	1.57	7.75	4.38
	Non-growing season	10	-25.16	1.32	6.92	2.33

Table 4. Isotopic values (‰, mean±1sd) of rodents at the (A) meadow and (B) forest sites in Hehuan mountains during Oct. 2009-Nov. 2010.

(A)

Species	Season	n	$\delta^{13}C$	SD	$\delta^{15}N$	SD
Taiwan voles	Growing season	20	-25.04	0.99	3.45	0.76
	Non-growing season	20	-25.06	0.89	3.31	1.08
	2 seasons combined	40	-25.05	0.92	3.38	0.92
Formosan mice	Growing season	8	-21.52	1.02	5.50	2.20
	Non-growing season	8	-22.28	1.19	5.94	3.17
	2 seasons combined	16	-21.90	1.14	5.72	2.65

(B)

Species	Season	n	$\delta^{13}C$	SD	$\delta^{15}N$	SD
Taiwan voles	Growing season	20	-26.54	0.65	5.31	1.10
	Non-growing season	20	-26.01	0.90	6.52	1.33
	2 seasons combined	40	-26.28	0.82	5.91	1.35
Formosan mice	Growing season	15	-21.77	0.81	6.39	0.90
	Non-growing season	20	-22.52	1.44	6.65	2.22
	2 seasons combined	35	-22.20	1.26	6.54	1.76
White-bellied rats	Growing season	16	-21.75	0.71	7.17	1.24
	Non-growing season	10	-21.69	0.47	8.26	1.04
	2 seasons combined	26	-21.73	0.62	7.59	1.27

Table 5. Results of (A) three-way MANOVA that examined the effects of species, habitat, and season on carbon and nitrogen isotopic values of Taiwan vole and Formosan mouse and (B) two-way MANOVA that examined the effects of species and season on carbon and nitrogen isotopic values of Taiwan vole, Formosan mouse, and white-bellied rats.

(A)

Factors	Wilk's Lambda			
	Num d.f.	Den d.f.	F value	*p* value
Species	2	122	197.87	<**.0001**
Habitat	2	122	23.73	<**.0001**
Season	2	122	2.02	0.1373
Species x Habitat	2	122	7.80	**0.0006**
Species x Season	2	122	3.60	**0.0303**
Habitat x Season	2	122	0.74	0.4787
Species x Habitat x Season	2	122	1.09	0.3411

(B)

Factors	Wilk's Lambda			
	Num d.f.	Den d.f.	F value	*p* value
Species	4	188	77.94	<**.0001**
Season	2	94	4.70	**0.0114**
Species x Season	4	188	2.31	0.0599

Table 6. Results of (A) three-way ANOVA that examined the effects of species, habitat, and season on carbon and nitrogen isotopic values of Taiwan vole and Formosan mouse and (B) two-way ANOVA that examined the effects of species and season on carbon and nitrogen isotopic values of Taiwan vole, Formosan mouse, and white-bellied rats.

(A)

	$\delta^{13}C$					$\delta^{15}N$				
Source	SS	DF	MS	F	*p*	SS	DF	MS	F	*p*
Model	435.85	7	62.26	62.39	**<.0001**	235.24	7	33.61	13.80	**<.0001**
Error	122.75	123	1.00			299.45	123	2.43		
Total	558.59	130				534.68	130			

	$\delta^{13}C$					$\delta^{15}N$				
Source of variation	SS	DF	MS	F	*p*	SS	DF	MS	F	*p*
Species	374.69	1	374.69	375.46	**<.0001**	61.49	1	61.49	25.26	**<.0001**
Habitat	15.25	1	15.25	15.28	**0.0002**	78.32	1	78.32	32.17	**<.0001**
Season	1.77	1	1.77	1.77	0.1859	5.51	1	5.51	2.26	0.1350
Species x Habitat	6.83	1	6.83	6.85	**0.0100**	21.28	1	21.28	8.74	**0.0037**
Species x Season	7.16	1	7.16	7.17	**0.0084**	0.24	1	0.24	0.10	0.7549
Habitat x Season	0.52	1	0.52	0.52	0.4727	2.41	1	2.41	0.99	0.3221
Species x Habitat x Season	0.53	1	0.53	0.53	0.4663	4.07	1	4.07	1.67	0.1986

(B)

	$\delta^{13}C$					$\delta^{15}N$				
Source	SS	DF	MS	F	*p*	SS	DF	MS	F	*p*
Model	453.73	5	90.75	105.31	**<.0001**	66.61	5	13.32	6.49	**<.0001**
Error	81.86	95	0.86			195.00	95	2.05		
Total	535.59	100				261.62	100			

	$\delta^{13}C$					$\delta^{15}N$				
Source of variation	SS	DF	MS	F	*p*	SS	DF	MS	F	*p*
Species	445.45	2	222.73	258.47	**<.0001**	44.21	2	22.11	10.77	**<.0001**
Season	0.07	1	0.07	0.08	0.7770	17.83	1	17.83	8.69	**0.0040**
Species x Season	7.66	2	3.83	4.45	**0.0143**	4.57	2	2.29	1.11	0.3327

Table 7. Measurements of food niche width for rodent species in the (A) meadow and (B) forest site. NR = range of $\delta^{15}N$ range, CR = range of $\delta^{13}C$, Var N = variance of $\delta^{15}N$, Var C = variance of $\delta^{13}C$, Var CD = variance of distances to centroid.

(A)

Species	Season	n	$\delta^{13}C$		$\delta^{15}N$		Var CD
			CR	Var C	NR	Var N	
Taiwan field vole	Growing season	20	3.03	0.97	2.73	0.58	0.69
	Non-growing season	20	3.82	0.78	4.24	1.16	0.44
	2 seasons combined	40	3.95	0.86	4.54	0.85	0.56
Formosan mouse	Growing season	8	2.94	1.04	6.9	4.83	1.17
	Non-growing season	8	3.82	1.42	7.37	10.06	1.49
	2 seasons combined	16	5.17	1.30	7.92	7.00	1.31

(B)

Species	Season	n	$\delta^{13}C$		$\delta^{15}N$		Var CD
			CR	Var C	NR	Var N	
Taiwan field vole	Growing season	20	2.45	0.42	4.02	1.22	0.77
	Non-growing season	20	4.46	0.81	5.15	1.77	0.62
	2 seasons combined	40	4.46	0.67	5.51	1.83	0.77
Formosan mouse	Growing season	15	2.78	0.68	2.59	0.85	0.60
	Non-growing season	20	6.92	2.08	10.20	4.95	1.97
	2 seasons combined	35	6.92	1.58	10.20	3.11	1.39
White-bellied rat	Growing season	16	2.79	0.51	4.01	1.55	0.36
	Non-growing season	10	1.50	0.22	3.17	1.07	0.72
	2 seasons combined	26	2.79	0.39	5.65	1.61	0.49

Table 8. Seasonal diet composition (%) of rodents in the (A) meadow and (B) forest sites in Hehuan mountains during Oct. 2009-Nov. 2010.

(A)

		% diet composition					
		C3 plants		C4 plants		Invertebrates	
Species	Season	Median	5-95% percentile	Median	5-95% percentile	Median	5-95% percentile
Taiwan field vole	Growing season	91	87-95	7	3-11	2	1-3
	Non-growing season	87	84-90	11	8-14	2	1-3
Formosan mouse	Growing season	65	53-71	26	18-31	9	5-25
	Non-growing season	58	38-70	20	9-28	21	6-51

(B)

		% diet composition					
		C3 plants		Fungi		Invertebrates	
Species	Season	Median	5-95% percentile	Median	5-95% percentile	Median	5-95% percentile
Taiwan field vole	Growing season	69	61-77	26	17-35	5	2-7
	Non-growing season	60	54-67	27	20-33	13	10-16
Formosan mouse	Growing season	4	0-11	85	75-93	10	3-19
	Non-growing season	12	5-20	73	64-81	15	9-22
White-bellied rat	Growing season	3	0-10	82	72-90	14	7-24
	Non-growing season	3	0-9	61	50-72	35	25-47

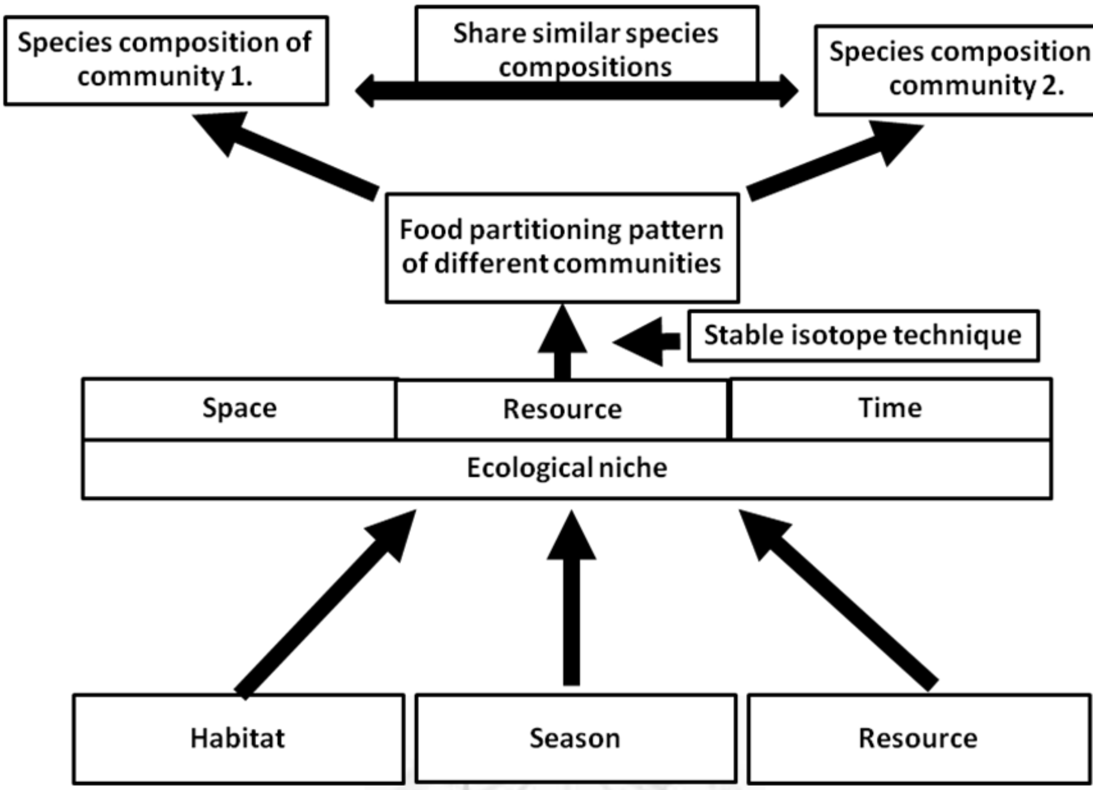
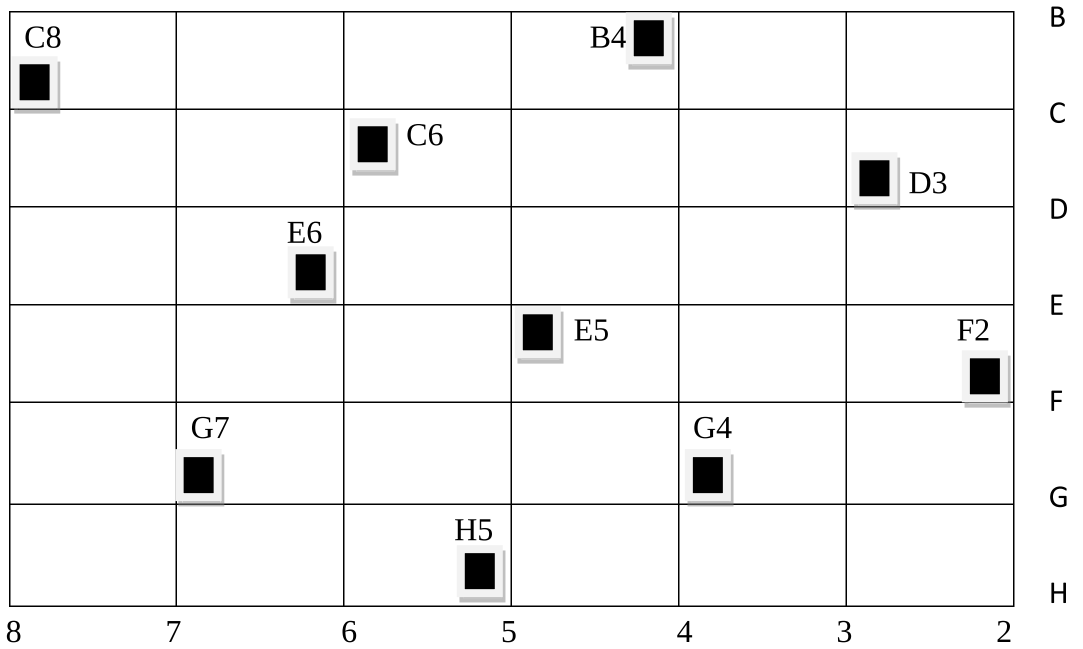


Figure 1. A concept map that describes the logic of the current study. The arrows represent cause and effect of linked two blocks.

(A)



(B)

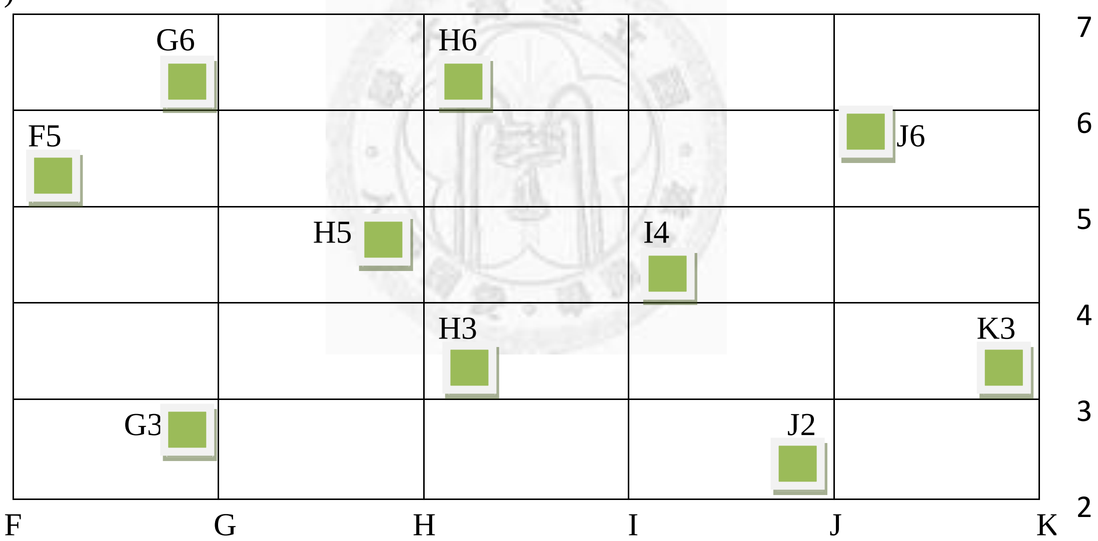
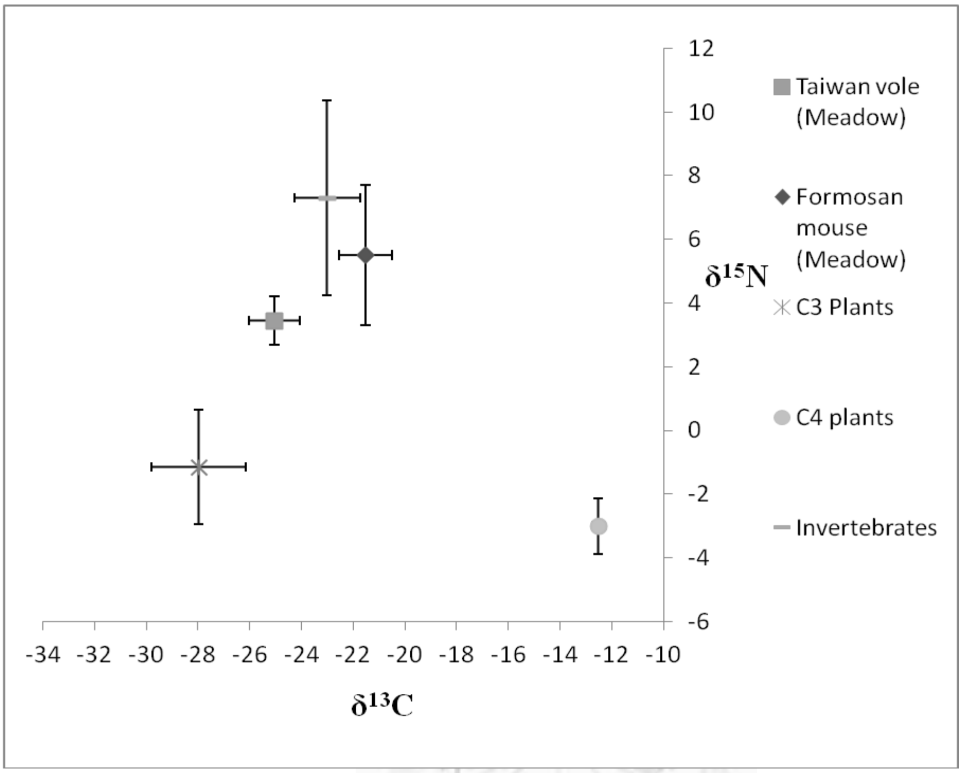


Figure 2. The layout of sampling grids at the (A) meadow and (B) forest sites. The shaded blocks indicate the location of pitfall traps for surface invertebrate sampling.

(A)



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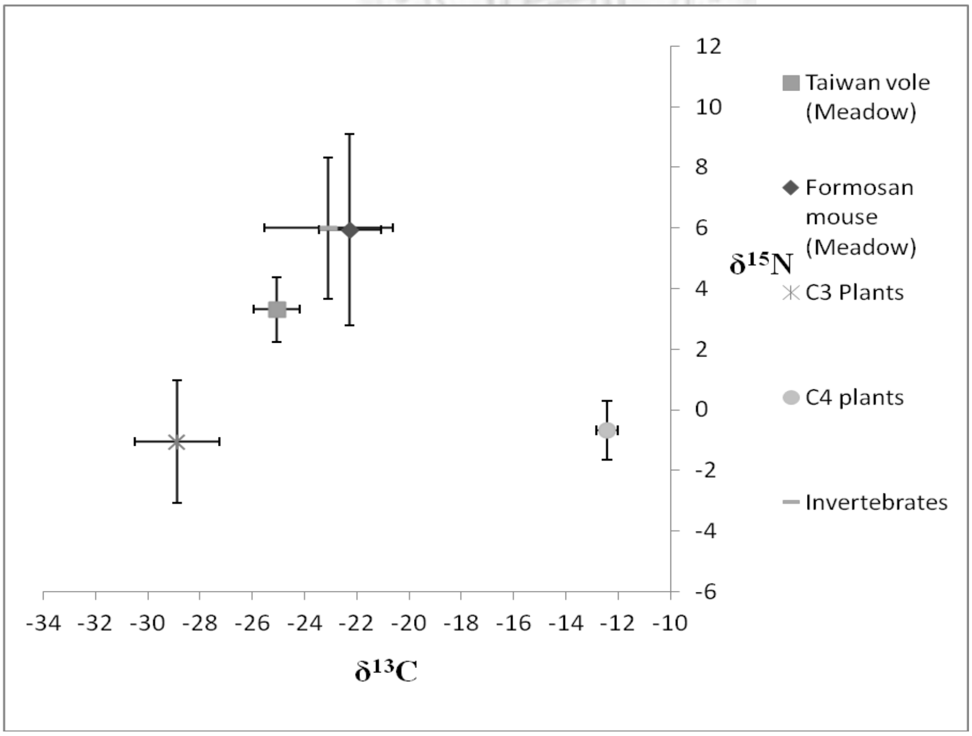


Figure 3. Isotopic values of carbon and nitrogen for the meadow community in (A) growing and (B) non-growing season. Error bars give standard deviations.

(A)

(B)

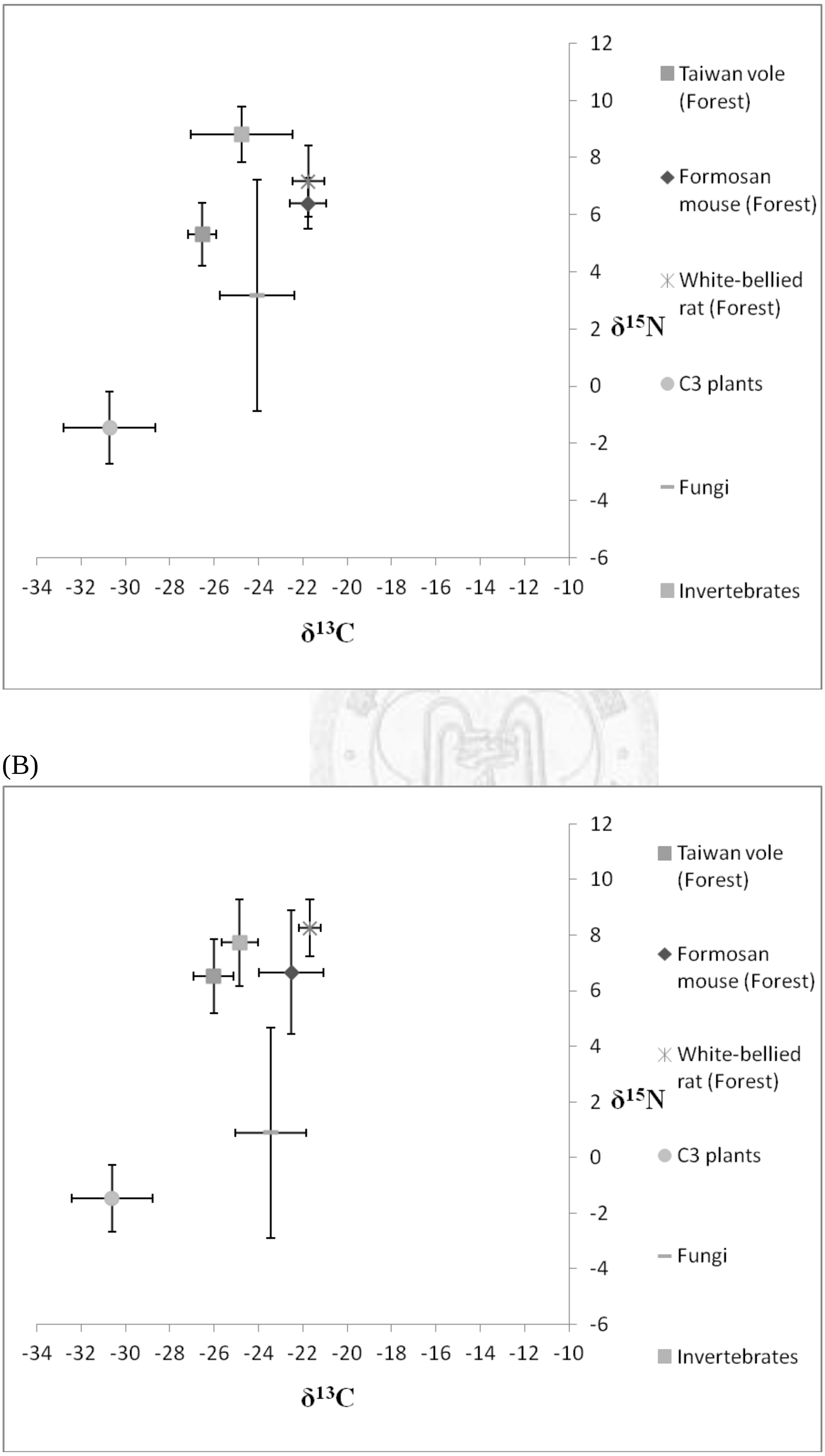
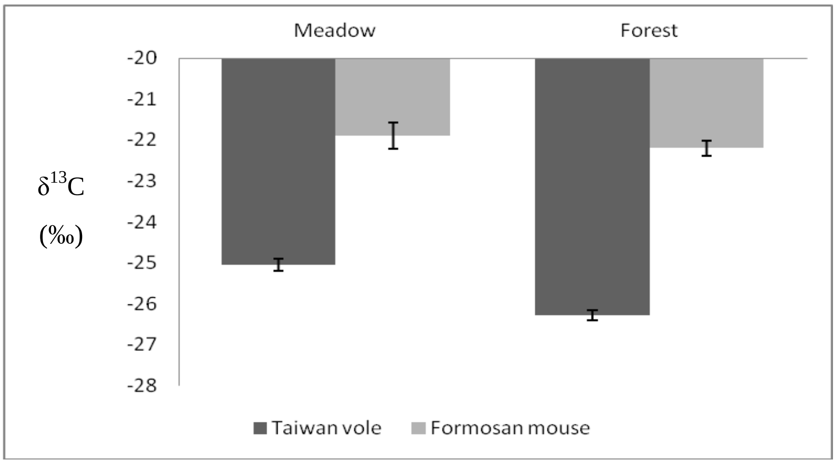


Figure 4. Isotopic values of carbon and nitrogen for the forest community in (A) growing and (B) non-growing season. Error bars give standard deviations.

(A)



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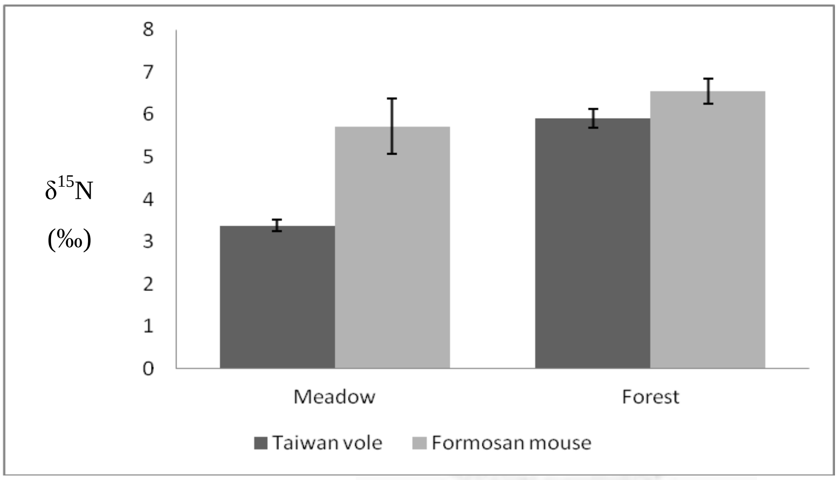


(C)

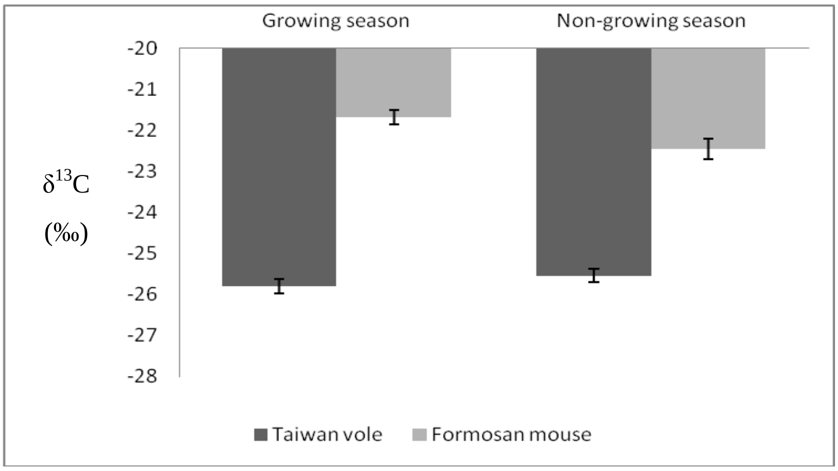


Figure 5. (A) carbon and (B) nitrogen isotopic values (mean±1se) of Taiwan voles and Formosan mice between meadow and forest, and (C) carbon isotopic values between growing and non-growing season in both habitats.

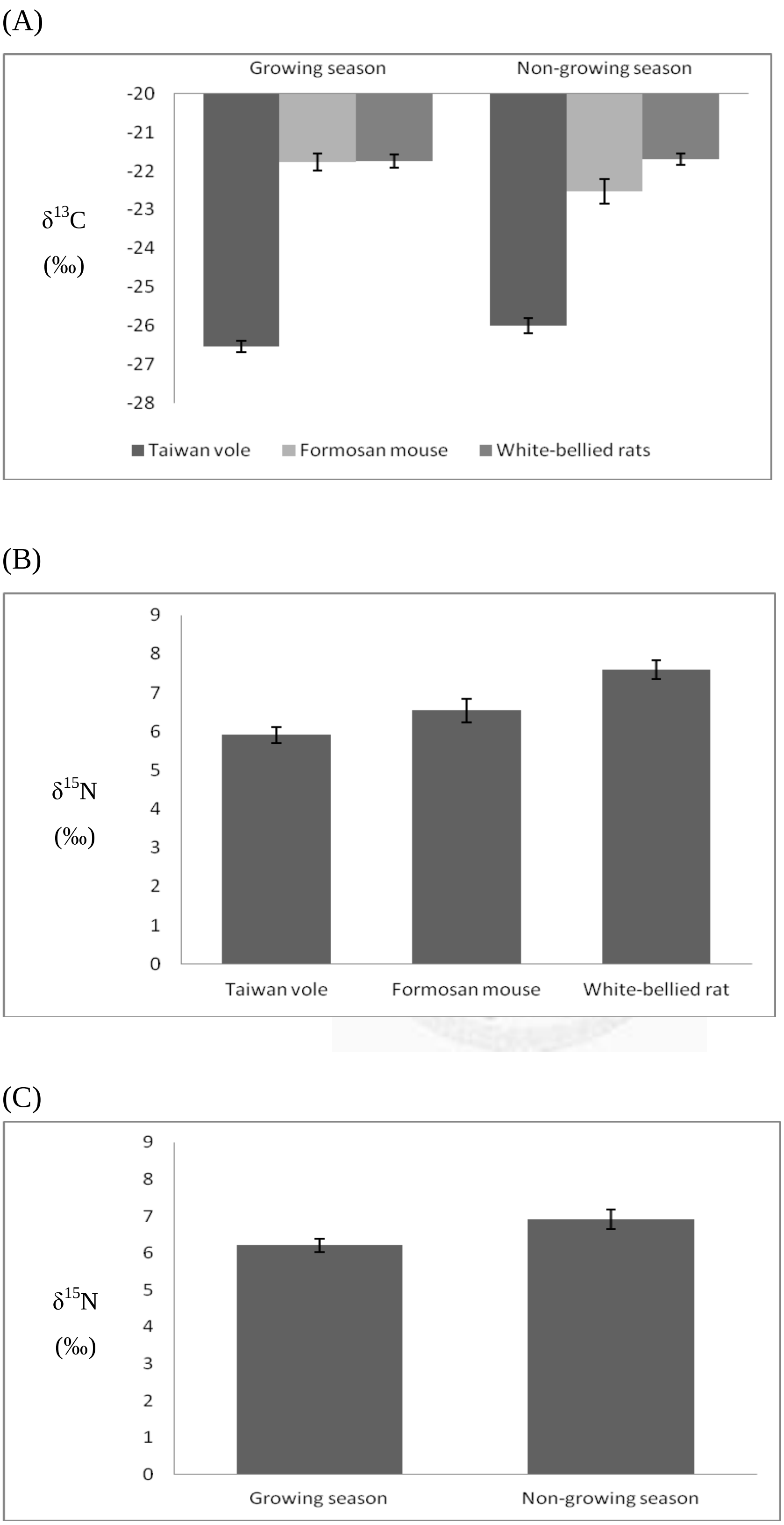


Figure 6. (A) carbon isotopic values (mean±1se) of Taiwan voles, Formosan mice and white-bellied rats between growing and non-growing season, and nitrogen isotopic values (B) among species and (C) between seasons in the Taiwan fir forest.

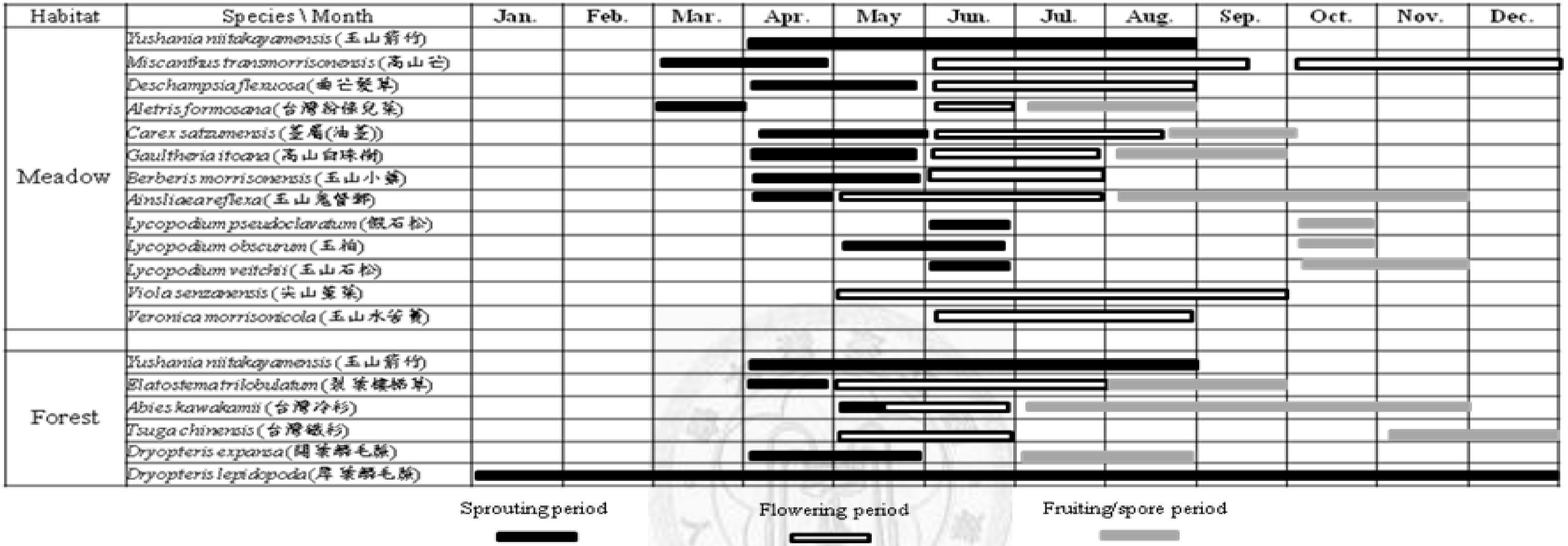


Figure 7. Phenology of plants in the forest and meadow. Black bar = sprouting period, hollowed bar = flowering period, and gray bar = fruiting/spores period.

Appendix

Appendix 1. Isotopic data

Appendix 1.1. Isotopic signatures (‰) and elemental concentration (%) of meadow rodent community (V: Taiwan vole, *Microtus kikuchii*; A: Formosan mouse, *Apodemus semotus*; R: White-bellied rat, *Niviventer culturatus*) in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
V01	4.270	13.34	-26.232	46.96
V02	4.181	13.62	-24.642	45.78
V03	3.339	13.39	-26.581	45.88
V04	3.149	13.41	-26.732	45.50
V05	4.277	13.60	-25.548	45.34
V06	4.519	14.06	-25.667	46.04
V07	3.150	13.50	-25.450	45.57
V08	3.241	13.44	-26.534	45.86
V09	3.408	13.72	-24.516	45.33
V10	2.907	13.69	-25.339	45.11
V11	4.016	13.77	-24.655	46.89
V12	2.689	13.93	-25.369	45.44
V13	1.791	14.22	-23.791	46.71
V14	2.864	14.27	-23.968	46.01
V15	4.117	14.18	-23.758	47.07
V16	2.761	14.23	-23.956	46.48
V17	3.418	14.09	-24.472	47.08
V18	4.015	14.16	-23.699	45.71
V19	2.361	13.83	-24.555	46.16
V20	4.496	14.08	-25.368	45.63
A01	5.472	14.62	-21.389	45.73
A02	4.452	14.72	-22.035	46.80
A03	6.700	14.85	-21.468	44.94
A04	1.345	14.78	-20.648	44.43
A05	6.205	14.99	-22.342	45.89
A06	8.241	14.72	-22.462	45.54
A07	7.510	14.75	-22.332	46.16
A08	4.111	14.70	-19.521	43.96

(B)

ID	d15N	Amt%	d13C	Amt%
V01	3.380	8.70	-26.599	33.59
V02	2.498	14.13	-25.209	45.73
V03	2.796	13.79	-25.607	47.33
V04	3.742	14.18	-22.778	46.34
V05	2.622	14.05	-25.718	45.26
V06	2.820	14.24	-25.666	45.38
V07	3.379	14.09	-25.032	47.56
V08	3.871	14.08	-25.092	45.55
V09	2.852	13.88	-25.292	44.39
V10	2.197	14.01	-25.153	47.04
V11	3.196	14.59	-24.233	45.79
V12	3.016	14.21	-25.145	45.60
V13	2.219	14.27	-24.478	46.03
V14	2.096	14.68	-24.614	45.57
V15	3.443	14.14	-24.452	47.97
V16	6.334	14.23	-26.264	45.87
V17	3.760	14.43	-24.346	46.43
V18	3.273	14.31	-24.605	45.71
V19	5.785	14.25	-26.474	45.77
V20	2.935	14.14	-24.463	46.17
A01	3.223	13.98	-24.692	45.46
A02	1.898	15.07	-21.375	45.49
A03	1.915	14.77	-20.875	45.36
A04	9.263	14.92	-21.601	45.70
A05	8.558	15.07	-22.151	46.22
A06	5.782	14.67	-23.135	46.17
A07	8.471	14.75	-22.390	46.37
A08	8.427	14.90	-21.991	48.74

Appendix 1.2. Isotopic signatures (‰) and elemental concentration (%) of forest rodent community (V: Taiwan vole, *Microtus kikuchii*; A: Formosan mouse, *Apodemus semotus*; R: White-bellied rat, *Niviventer culturatus*) in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
V01	7.199	14.12	-26.180	45.32
V02	6.349	13.95	-26.141	47.34
V03	5.189	14.08	-26.229	47.12
V04	6.285	13.81	-26.128	45.04
V05	5.151	14.05	-27.002	44.97
V06	3.734	14.14	-27.594	46.94
V07	6.151	14.70	-25.925	44.58
V08	5.515	14.04	-27.634	47.02
V09	5.577	10.74	-28.204	35.00
V10	3.394	14.01	-25.946	45.50
V11	6.245	14.17	-25.894	46.49
V12	5.335	13.94	-26.166	44.16
V13	5.007	13.98	-26.552	46.40
V14	3.669	13.80	-26.610	45.45
V15	4.632	14.00	-26.550	45.25
V16	3.177	13.87	-26.828	44.04
V17	5.503	13.40	-26.882	43.63
V18	5.607	13.82	-26.298	44.78
V19	6.176	13.10	-25.755	46.29
V20	6.317	13.82	-26.309	45.79
A01	5.902	14.95	-21.911	45.22
A02	8.235	15.15	-21.278	45.99
A03	5.643	14.93	-21.458	44.74
A04	5.912	14.83	-21.330	46.87
A05	6.875	14.96	-21.833	46.29
A06	5.659	14.98	-20.688	46.79
A07	5.715	15.00	-20.603	47.59
A08	5.826	14.62	-21.332	44.26
A09	5.875	14.76	-21.685	45.48
A10	6.137	14.85	-22.019	43.82
A11	7.558	14.70	-22.471	45.15

A12	6.991	14.67	-23.381	43.91
A13	5.689	14.78	-20.958	43.72
A14	5.855	14.71	-23.091	46.12
A15	7.972	14.65	-22.446	44.89
R01	7.766	15.72	-21.514	45.03
R02	6.493	15.45	-21.871	46.90
R03	5.851	15.53	-22.005	45.02
R04	7.765	15.78	-21.157	46.73
R05	4.457	15.26	-22.789	46.29
R06	8.184	13.39	-21.652	40.40
R07	7.000	12.68	-22.168	38.77
R08	7.300	15.24	-22.087	46.73
R09	7.923	15.50	-20.746	46.53
R10	7.772	15.49	-20.949	46.45
R11	8.422	15.47	-20.401	45.83
R12	8.466	15.18	-21.922	43.80
R13	7.636	14.98	-22.201	44.85
R14	4.719	14.81	-23.189	45.17
R15	8.266	15.26	-21.703	44.35
R16	6.687	15.22	-21.703	45.32

(B)

ID	d15N	Amt%	d13C	Amt%
V01	8.387	14.20	-24.804	47.37
V02	7.553	14.63	-25.438	45.88
V03	6.255	14.32	-26.676	45.85
V04	6.762	14.26	-26.176	46.61
V05	4.884	14.20	-26.211	45.41
V06	6.451	14.41	-25.995	45.65
V07	6.765	12.44	-25.863	39.66
V08	5.789	14.30	-26.184	45.34
V09	4.408	14.40	-28.720	48.83
V10	6.157	14.32	-26.516	47.62
V11	6.670	14.71	-25.795	45.63
V12	3.531	14.26	-24.260	44.71
V13	5.651	14.13	-26.252	46.70
V14	8.179	14.07	-25.472	45.89

V15	6.060	14.04	-26.929	46.51
V16	5.719	14.05	-26.499	46.57
V17	7.850	14.29	-25.328	46.12
V18	6.928	13.99	-26.030	47.75
V19	8.682	14.19	-25.542	48.20
V20	7.634	14.28	-25.612	47.54
A01	5.873	14.19	-21.761	44.41
A02	7.166	15.07	-22.735	45.13
A03	5.909	15.01	-21.893	44.98
A04	6.063	14.71	-23.444	44.61
A05	5.914	15.25	-21.795	47.00
A06	7.113	14.15	-22.928	42.88
A07	6.367	14.75	-22.296	44.43
A08	2.364	9.20	-23.268	28.79
A09	6.563	15.05	-21.373	45.39
A10	7.179	14.33	-25.834	46.98
A11	7.793	15.00	-18.918	44.10
A12	9.736	14.90	-24.458	46.51
A13	9.626	14.93	-21.405	45.05
A14	4.378	15.30	-24.517	45.11
A15	6.891	15.25	-21.765	45.67
A16	12.559	15.39	-21.768	45.42
A17	7.404	15.48	-22.035	45.38
A18	5.556	15.22	-22.862	44.89
A19	4.309	15.10	-22.164	47.22
A20	4.276	15.22	-23.204	47.05
R01	7.852	15.79	-21.388	45.52
R02	6.933	15.53	-22.139	45.97
R03	6.973	15.71	-22.466	46.38
R04	9.076	15.50	-20.970	45.08
R05	10.106	15.57	-22.262	46.80
R06	8.948	15.74	-21.661	46.80
R07	8.583	15.64	-21.271	45.84
R08	8.938	15.42	-21.414	43.56
R09	7.749	15.65	-21.553	43.92
R10	7.416	15.55	-21.742	45.82

Appendix 1.3. Isotopic signatures (‰) and elemental concentration (%) of meadow invertebrates in (A) growing and (B) non-growing seasons.

(A)

1. Sweep net

ID	d15N	Amt%	d13C	Amt%
鞘翅目	1.943	13.08	-19.932	46.05
	8.295	13.06	-20.376	48.59
同翅目	-1.592	13.37	-24.477	46.50
	-2.955	11.94	-25.588	51.04
雙翅目	6.582	12.88	-22.143	45.22
	8.619	14.15	-21.183	48.82
膜翅目	2.010	13.6	-24.797	49.19
蜘蛛目	5.989	14.76	-24.273	47.55

2. Pitfall traps

ID	d15N	Amt%	d13C	Amt%
膜翅目	4.214	12.07	-23.130	51.08
	6.317	13.50	-23.098	48.68
	4.556	13.90	-22.058	48.99
	4.452	14.24	-22.076	48.94
	4.782	13.84	-22.964	46.95
	4.290	14.43	-23.199	50.42
鞘翅目	6.876	12.67	-22.696	48.51
	8.373	12.03	-21.706	49.66
	8.516	13.50	-22.815	48.03
	7.257	11.81	-25.057	50.55
	6.926	12.30	-25.252	50.12
	6.544	12.70	-24.907	49.94
雙翅目	14.225	13.38	-22.565	51.46
	12.438	13.75	-24.396	49.87
	15.062	13.49	-22.446	49.37
蜘蛛目	5.577	14.40	-23.199	48.40
	4.967	13.43	-24.333	49.28
	5.659	14.68	-22.367	47.78

(B)

1. Sweep net

ID	d15N	Amt%	d13C	Amt%
同翅目	-2.728	11.74	-24.745	51.24
	-2.406	12.98	-25.759	47.58
雙翅目	9.560	11.41	-23.783	47.08
	1.548	12.93	-24.74	48.15
膜翅目	5.359	10.14	-26.015	49.03
鞘翅目	0.093	9.31	-25.434	50.10

2. Pitfall traps

ID	d15N	Amt%	d13C	Amt%
膜翅目	4.521	12.22	-23.180	48.62
	4.564	12.95	-22.867	46.92
	4.668	13.28	-17.812	49.44
	5.187	10.66	-19.793	48.68
	4.864	9.72	-21.441	46.32
	4.695	13.21	-18.062	51.61
雙翅目	7.113	12.94	-25.744	48.58
	7.811	13.00	-25.700	45.73
	5.931	13.34	-25.674	50.16
	3.500	13.42	-26.046	49.17
	7.080	13.57	-24.890	48.76
	13.24	13.14	-24.363	47.97
蜘蛛目	6.774	14.14	-23.155	46.82
	6.860	14.29	-21.435	45.98
	6.598	13.94	-21.873	47.45
	3.234	12.94	-23.050	48.54
	4.164	13.34	-23.645	48.36
	4.260	13.25	-23.383	47.70
鱗翅目	-0.221	11.03	-23.431	49.12
	1.911	12.23	-23.574	45.43
	0.872	13.05	-23.880	47.57

Appendix 1.4. Isotopic signatures (‰) and elemental concentration (%) of forest invertebrates in (A) growing and (B) non-growing seasons.

(A)

1. Sweep net

ID	d15N	Amt%	d13C	Amt%
鞘翅目	-0.422	13.16	-26.816	48.30
同翅目	0.996	14.10	-27.197	48.03
雙翅目	0.505	13.92	-26.831	48.75

2. Pitfall traps

ID	d15N	Amt%	d13C	Amt%
雙翅目	9.080	10.88	-23.696	45.14
	14.052	14.33	-24.009	46.69
	10.639	14.51	-23.433	47.29
	18.341	14.27	-23.745	49.63
	10.165	13.39	-25.602	49.98
	11.610	12.89	-24.943	51.72
鞘翅目	6.338	14.93	-23.903	47.18
	7.442	13.34	-24.638	49.01
	6.967	14.37	-23.503	46.24
	7.421	12.67	-26.265	49.34
	8.568	13.12	-25.681	49.31
	7.113	8.84	-29.585	37.78
革翅目	11.090	13.07	-23.757	49.09
	11.308	12.09	-26.105	49.27
	11.335	12.49	-25.743	49.53
蜘蛛目	7.850	12.85	-24.958	50.50
	7.512	14.76	-25.414	47.82
	7.469	14.43	-24.660	46.66
倍足鋼(馬陸)	4.158	6.07	-23.693	25.29
	3.006	6.90	-23.171	28.44
	3.535	3.92	-23.383	23.25

(B)

1. Sweep net

ID	d15N	Amt%	d13C	Amt%
膜翅目	6.880	11.70	-26.150	49.94
	6.656	12.09	-25.083	48.65
雙翅目	8.710	7.82	-26.592	45.42
蜘蛛目	5.239	15.53	-25.347	47.04

2. Pitfall traps

ID	d15N	Amt%	d13C	Amt%
雙翅目	8.780	14.66	-24.270	47.45
	8.668	13.75	-24.449	49.09
	8.426	14.40	-24.701	50.15
	10.177	11.53	-24.409	42.13
	7.647	13.41	-24.180	45.50
	9.518	13.00	-24.776	46.83
鞘翅目	8.174	12.09	-23.814	47.55
	10.505	12.36	-23.835	50.05
	4.674	12.25	-24.118	50.08
鱗翅目	2.307	9.33	-25.724	47.01
	3.841	11.83	-30.040	45.09
	2.126	9.86	-25.716	45.82
彈尾目	3.976	13.22	-25.015	46.07
蜘蛛目	7.083	14.70	-24.571	45.55
	8.252	14.35	-24.573	48.07
	7.751	14.59	-24.684	46.02
	6.604	13.33	-25.431	48.03
	7.485	14.05	-24.822	46.64
	5.719	12.69	-26.444	48.92

Appendix 1.5. Isotopic signatures (‰) and elemental concentration (%) of meadow plants in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
玉山箭竹	-1.723	2.58	-26.924	42.89
	-2.187	2.83	-27.208	42.26
	-2.117	2.37	-26.998	42.96
	-3.882	2.2	-27.221	43.07
	-4.122	2.22	-27.362	43.72
	-4.177	2.09	-27.114	42.42
薹屬	2.634	1.26	-29.272	40.99
	1.484	1.46	-28.185	41.11
	0.762	1.42	-29.522	40.46
	0.713	1.30	-28.962	43.88
	-0.212	1.20	-28.426	43.04
	-0.862	1.19	-24.576	43.18
高山白珠樹	-1.654	0.82	-30.323	39.03
	-1.005	1.24	-30.660	46.32
	-1.195	1.17	-30.209	46.60
	-1.662	1.11	-30.136	48.37
	-1.815	1.06	-29.994	48.23
	-1.913	1.08	-29.702	48.92
台灣粉條兒菜	-0.860	2.37	-27.568	43.61
	-0.527	1.49	-28.379	44.57
	-0.676	1.93	-28.635	43.09
	-1.240	1.86	-29.532	43.97
	0.128	1.71	-28.897	44.44
	-1.820	1.55	-30.726	41.83
曲芒髮草	-1.331	0.93	-29.300	42.53
	-0.287	1.08	-28.573	41.95
	0.246	1.2	-27.548	42.56
	-2.094	1.19	-28.230	43.49
	-0.800	1.26	-28.269	44.27
	-0.812	1.35	-28.714	45.3
石松科	2.544	1.15	-28.699	44.07
	2.332	1.28	-28.680	45.48
	2.769	1.38	-28.114	45.13

	2.956	1.47	-29.506	45.8
	1.989	1.4	-28.161	46.08
	2.132	1.63	-28.957	46.21
玉山小蘗	-0.685	0.97	-27.487	47.43
	-0.387	1.18	-26.581	47.79
	0.207	1.2	-26.637	47.76
	-0.589	1.18	-25.810	49.31
	-1.074	1.24	-26.323	49.43
	-1.083	1.16	-26.168	51.14
高山芒	-4.457	1.11	-12.732	45.18
	-2.351	1.22	-12.778	44.68
	-3.390	1.15	-12.711	45.63
	-2.839	1.62	-12.339	45.89
	-3.125	1.32	-12.272	45.68
	-1.938	1.52	-12.302	45.63
尖山堇菜	-2.895	1.64	-31.371	41.98
	-1.375	1.34	-30.308	40.16
	-0.416	1.33	-31.539	40.89
苔類 2 (物種名稱待確認)	-3.164	0.71	-27.332	44.05
	-2.620	0.72	-27.327	44.11
	-2.546	0.97	-28.654	44.87
	-3.417	0.75	-30.458	46.78
	-2.587	0.94	-27.260	45.52
	-2.831	0.95	-30.599	45.28
苔類 3 (物種名稱待確認)	-3.228	0.81	-26.905	43.03
	-3.057	0.93	-26.594	43.73
	-3.272	0.77	-26.575	43.56
	-2.672	1.06	-25.425	44.30
	-2.793	0.93	-26.854	44.86
	-2.490	1.00	-25.495	44.15
苔類 4 (物種名稱待確認)	-3.537	0.64	-27.271	46.82
	-2.795	0.79	-26.824	47.87
	-2.364	0.88	-26.154	43.87
苔類 5 (物種名稱待確認)	-2.936	0.61	-24.145	41.98
	-2.274	0.52	-22.853	42.53
	-1.459	0.58	-23.491	43.20
逆鱗鱗毛蕨	-0.142	1.33	-28.134	45.78

	0.426	1.64	-28.376	47.46
	0.225	1.27	-28.045	45.97

(B)

ID	d15N	Amt%	d13C	Amt%
玉山箭竹	-3.034	1.94	-27.853	43.12
	-3.025	1.66	-28.281	42.34
	-3.192	1.92	-27.632	42.21
	-2.414	2.00	-28.488	45.81
	-2.240	2.07	-28.995	43.71
	-3.311	2.09	-29.575	43.57
薹屬	2.634	1.26	-29.272	40.99
	1.484	1.46	-28.185	41.11
	0.762	1.42	-29.522	40.46
	0.713	1.30	-28.962	43.88
	-0.212	1.20	-28.426	43.04
	-0.862	1.19	-24.576	43.18
高山白珠樹	-1.654	0.82	-30.323	39.03
	-1.005	1.24	-30.660	46.32
	-1.195	1.17	-30.209	46.60
	-1.662	1.11	-30.136	48.37
	-1.815	1.06	-29.994	48.23
	-1.913	1.08	-29.702	48.92
台灣粉條兒菜	2.116	1.44	-28.019	42.41
	1.512	1.34	-29.256	42.76
	1.606	1.30	-28.972	41.73
	-0.317	1.20	-31.766	43.35
	0.791	1.11	-31.240	43.76
	-0.275	1.35	-31.411	43.85
曲芒髮草	-1.331	0.93	-29.300	42.53
	-0.287	1.08	-28.573	41.95
	0.246	1.20	-27.548	42.56
	-2.094	1.19	-28.23	43.49
	-0.800	1.26	-28.269	44.27
	-0.812	1.35	-28.714	45.30
石松科	2.544	1.15	-28.699	44.07
	2.332	1.28	-28.680	45.48

	2.769	1.38	-28.114	45.13
	2.956	1.47	-29.506	45.80
	1.989	1.40	-28.161	46.08
	2.132	1.63	-28.957	46.21
玉山小蘗	-0.685	0.97	-27.487	47.43
	-0.387	1.18	-26.581	47.79
	0.207	1.20	-26.637	47.76
	-0.589	1.18	-25.810	49.31
	-1.074	1.24	-26.323	49.43
	-1.083	1.16	-26.168	51.14
高山芒	0.869	1.32	-12.111	43.83
	-0.805	0.91	-12.302	43.60
	-0.140	1.05	-11.85	43.52
	-1.550	1.18	-12.847	46.12
	-0.639	1.26	-12.842	44.41
	-1.788	1.12	-12.578	45.66
尖山堇菜	-2.895	1.64	-31.371	41.98
	-1.375	1.34	-30.308	40.16
	-0.416	1.33	-31.539	40.89
玉山水苦賈	-3.694	0.68	-31.185	45.88
	-2.751	0.69	-32.135	45.98
	-1.260	0.66	-32.329	45.78
苔類 2 (物種名稱待確認)	-2.791	0.91	-27.681	43.13
	-3.205	1.05	-28.008	41.97
	-3.597	0.90	-27.909	42.19
	-2.739	0.89	-30.251	44.57
	-3.612	0.80	-30.471	44.59
	-3.632	0.90	-29.283	45.38
苔類 3 (物種名稱待確認)	-3.151	0.86	-28.891	42.05
	-3.172	1.10	-28.601	42.35
	-3.025	0.97	-28.279	41.69
	-4.291	0.63	-27.442	44.89
	-3.055	0.75	-26.927	44.86
	-4.316	0.65	-27.015	45.00

Appendix 1.6. Isotopic signatures (‰) and elemental concentration (%) of forest plants in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
玉山箭竹	1.897	2.57	-32.466	39.55
	1.281	2.55	-31.573	42.35
	1.398	2.69	-32.114	42.69
	-0.157	2.66	-30.826	44.35
	0.253	2.76	-31.111	42.97
	0.272	2.66	-31.446	43.30
裂葉樓梯草	-0.991	2.11	-34.791	37.21
	-0.199	2.31	-35.050	37.47
	-1.192	1.97	-34.915	35.78
	-0.969	1.96	-34.181	38.07
	-0.700	2.16	-34.493	37.31
	-1.137	2.43	-34.840	37.51
台灣冷杉葉	-0.697	1.23	-29.003	46.89
	-1.108	1.20	-29.141	50.78
	-0.968	1.35	-28.848	50.75
台灣鐵杉葉	-2.711	1.24	-28.188	54.99
	-2.590	1.09	-29.025	52.74
	-2.789	1.12	-28.631	52.16
台灣冷杉毬果	-1.962	0.70	-27.010	50.61
	-3.050	0.61	-26.977	48.40
	-2.818	0.79	-26.751	51.34
	-1.962	0.70	-27.010	50.61
	-3.050	0.61	-26.977	48.40
	-2.818	0.79	-26.751	51.34
逆鱗鱗毛蕨	-1.589	1.51	-31.882	44.25
	-1.208	1.51	-31.744	44.57
	-1.182	1.53	-31.755	44.78
	0.000	1.89	-31.598	43.79
	-1.455	1.66	-32.018	42.51
	-0.332	1.69	-30.988	43.45
玉山擬鱗毛蕨	-2.827	1.67	-31.990	45.29
	-2.977	1.86	-31.722	46.17
	-2.191	1.88	-32.389	45.29

闊葉鱗毛蕨	-0.578	2.10	-31.435	43.57
	-0.651	1.94	-30.840	43.95
	-0.796	2.14	-31.439	46.26
厚葉鱗毛蕨	0.562	1.52	-32.881	43.58
	-0.539	1.24	-32.483	44.32
	0.337	1.61	-33.410	44.18
逆羽蹄蓋蕨	-0.733	1.90	-34.186	40.91
	1.172	1.94	-33.661	41.20
	0.451	2.17	-33.246	41.02
苔類 1 (物種名稱待確認)	-1.487	2.77	-30.919	41.30
	-1.432	2.49	-30.561	41.76
	-0.66	2.62	-31.000	42.99
	-1.488	2.55	-31.176	44.48
	-1.269	2.17	-31.677	45.36
	-1.186	2.44	-32.193	43.77
苔類 2 (物種名稱待確認)	-2.569	1.49	-29.624	42.70
	-2.652	1.42	-30.025	42.64
	-2.120	1.30	-28.790	43.67
	-3.442	1.53	-29.644	43.84
	-2.777	1.77	-32.022	43.97
	-3.772	1.57	-29.996	43.07
苔類 4 (物種名稱待確認)	-3.103	1.03	-29.158	47.31
	-2.664	1.30	-29.113	46.83
	-2.599	1.16	-29.130	45.63
苔類 7 (物種名稱待確認)	-2.291	1.17	-28.433	42.29
	-3.104	1.10	-28.008	42.24
	-2.404	1.15	-28.999	43.01
	-3.067	1.18	-28.834	42.61
	-2.126	1.24	-29.905	43.80
	-2.645	1.21	-29.144	43.13
苔類 9 (物種名稱待確認)	-2.610	1.27	-29.657	41.43
	-2.109	1.27	-29.745	41.58
	-2.189	1.18	-29.569	42.86
	-2.610	1.27	-29.657	41.43
	-2.109	1.27	-29.745	41.58
	-2.189	1.18	-29.569	42.86
苔類 10	-1.926	1.47	-29.657	44.55

(物種名稱待確認)	-2.050	1.49	-29.622	45.03
	-2.070	1.54	-29.310	44.72
	-1.926	1.47	-29.657	44.55
	-2.050	1.49	-29.622	45.03
	-2.070	1.54	-29.310	44.72

(B)

ID	d15N	Amt%	d13C	Amt%
玉山箭竹	1.402	2.09	-31.493	40.86
	0.535	2.21	-31.985	40.62
	1.156	2.49	-31.762	41.07
	0.791	2.46	-31.031	41.27
	0.990	2.88	-31.003	42.12
	0.469	2.24	-31.057	41.33
裂葉樓梯草	-0.254	2.44	-31.989	40.28
	0.230	2.11	-32.758	37.96
	-0.779	1.92	-32.443	37.59
	-1.631	2.56	-33.746	35.86
	-0.647	1.93	-33.653	38.86
	-1.017	1.65	-33.777	36.59
玉山鬼督郵	-2.506	1.85	-33.381	41.17
	-1.985	2.37	-33.558	41.94
	-3.082	1.73	-33.283	40.84
台灣冷杉葉	-0.697	1.23	-29.003	46.89
	-1.108	1.20	-29.141	50.78
	-0.968	1.35	-28.848	50.75
台灣鐵杉葉	-2.711	1.24	-28.188	54.99
	-2.590	1.09	-29.025	52.74
	-2.789	1.12	-28.631	52.16
台灣冷杉毬果	-1.962	0.70	-27.010	50.61
	-3.050	0.61	-26.977	48.40
	-2.818	0.79	-26.751	51.34
	-1.962	0.70	-27.010	50.61
	-3.050	0.61	-26.977	48.40
	-2.818	0.79	-26.751	51.34
逆鱗鱗毛蕨	0.000	1.89	-31.598	43.79
	-1.455	1.66	-32.018	42.51

	-0.332	1.69	-30.988	43.45
	-1.589	1.51	-31.882	44.25
	-1.208	1.51	-31.744	44.57
	-1.182	1.53	-31.755	44.78
玉山擬鱗毛蕨	-0.590	2.20	-31.974	45.06
	-0.240	2.24	-31.736	45.50
	0.484	2.69	-31.746	44.53
	-2.334	2.00	-31.946	44.37
	-2.494	1.82	-31.333	45.16
	-1.954	1.96	-31.588	46.03
闊葉鱗毛蕨	-0.578	2.10	-31.435	43.57
	-0.651	1.94	-30.840	43.95
	-0.796	2.14	-31.439	46.26
厚葉鱗毛蕨	0.562	1.52	-32.881	43.58
	-0.539	1.24	-32.483	44.32
	0.337	1.61	-33.410	44.18
苔類 1 (物種名稱待確認)	-1.487	2.77	-30.919	41.30
	-1.432	2.49	-30.561	41.76
	-0.660	2.62	-31.000	42.99
	-1.488	2.55	-31.176	44.48
	-1.269	2.17	-31.677	45.36
	-1.186	2.44	-32.193	43.77
苔類 2 (物種名稱待確認)	-2.569	1.49	-29.624	42.70
	-2.652	1.42	-30.025	42.64
	-2.12	1.30	-28.790	43.67
	-3.442	1.53	-29.644	43.84
	-2.777	1.77	-32.022	43.97
	-3.772	1.57	-29.996	43.07
苔類 3 (物種名稱待確認)	-2.255	1.93	-30.091	43.78
	-1.631	1.49	-28.948	45.04
	-1.349	1.91	-29.834	45.82
苔類 7 (物種名稱待確認)	-2.291	1.17	-28.433	42.29
	-3.104	1.10	-28.008	42.24
	-2.404	1.15	-28.999	43.01
	-3.067	1.18	-28.834	42.61
	-2.126	1.24	-29.905	43.80
	-2.645	1.21	-29.144	43.13

苔類 8 (物種名稱待確認)	-1.028	1.19	-30.816	41.83
	-1.436	1.16	-31.466	42.00
	-1.696	1.77	-31.660	45.75
苔類 9 (物種名稱待確認)	-2.610	1.27	-29.657	41.43
	-2.109	1.27	-29.745	41.58
	-2.189	1.18	-29.569	42.86
苔類 10 (物種名稱待確認)	-1.926	1.47	-29.657	44.55
	-2.050	1.49	-29.622	45.03
	-2.070	1.54	-29.310	44.72

Appendix 1.7. Isotopic signatures (‰) and elemental concentration (%) of fungi in (A) growing (04: Apr., 07: Jul.) and (B) non-growing seasons (10: Oct., 01: Jan.).

(A)

ID	d15N	Amt%	d13C	Amt%
04FG1	-2.370	2.98	-24.967	45.71
04FG2	-0.406	4.36	-23.521	45.29
04FG3	-1.055	2.97	-22.677	46.78
04FG4	0.027	3.73	-24.780	44.87
04FG5	-0.576	1.60	-19.855	46.59
04FG6	0.950	4.34	-21.954	42.87
04FG7	-0.526	4.47	-24.660	46.42
07FG1	3.060	3.43	-25.231	43.82
07FG2	3.215	2.90	-24.102	44.08
07FG3	7.465	4.22	-23.541	41.34
07FG4	5.379	3.71	-25.280	49.38
07FG5	8.055	3.41	-26.250	44.15
07FG6	5.303	2.77	-25.503	49.10
07FG7	8.698	5.10	-24.351	41.32
07FG8	9.538	3.76	-25.012	44.24
07FG9	1.148	7.20	-24.701	43.98
07FG10	7.843	4.02	-24.857	40.79
07FG11	-1.228	1.09	-20.889	46.37
07FG12	7.892	5.26	-24.757	42.36
07FG13	-1.930	3.30	-22.066	41.22
07FG14	6.150	4.45	-26.248	41.42

(B)

ID	d15N	Amt%	d13C	Amt%
10FG01	6.574	5.46	-23.848	42.05
10FG02	-0.177	4.82	-21.643	40.34
10FG03	7.259	6.51	-25.074	44.28
10FG04	-0.721	1.03	-23.129	51.57
10FG05	-1.788	1.99	-21.248	39.30
10FG06	2.018	4.45	-21.773	41.87
01FG01	2.507	4.78	-24.647	42.13
01FG02	-5.018	0.49	-23.010	45.71
01FG03	-1.093	1.89	-26.093	42.75
01FG04	-0.666	3.73	-23.951	42.54

Appendix 1.8. Isotopic signatures (‰) and elemental concentration (%) of shrews (SS: short-tailed shrew, *Anourosorex yamashinai*; LS: long-tailed shrew, *Episoriculus fumidus*) in the meadow in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
SS01	8.121	14.06	-20.260	47.43
SS02	6.693	9.26	-23.036	30.68
SS03	6.104	14.24	-22.584	45.32
LS01	8.865	14.35	-22.397	45.07
LS02	8.200	14.17	-22.993	47.76
LS03	8.084	14.15	-21.912	46.55
LS04	9.518	14.58	-18.932	46.24
LS05	7.935	14.37	-23.015	47.12
LS06	7.256	14.28	-23.210	47.00
LS07	6.688	13.27	-21.532	47.33
LS08	8.203	14.37	-21.015	46.60
LS09	8.464	14.20	-21.002	46.59

(B)

ID	d15N	Amt%	d13C	Amt%
SS01	7.896	12.15	-19.956	37.52
SS02	6.609	14.96	-20.284	45.78
SS03	6.509	14.65	-20.904	45.40
SS04	5.862	14.79	-21.024	46.22
SS05	6.160	14.71	-18.135	46.98
SS06	5.210	14.69	-22.537	45.27
SS07	6.670	14.02	-21.333	42.74

Appendix 1.9. Isotopic signatures (‰) and elemental concentration (%) of shrews (SS: short-tailed shrew, *Anourosorex yamashinai*; LS: long-tailed shrew, *Episoriculus fumidus*) in the forest in (A) growing and (B) non-growing seasons.

(A)

ID	d15N	Amt%	d13C	Amt%
SS01	6.523	14.40	-22.417	46.48
SS02	6.180	8.65	-22.642	27.01
SS03	7.809	14.80	-22.393	43.93
SS04	6.378	14.40	-22.867	44.65
SS05	7.610	14.18	-21.997	45.10
LS01	8.826	14.55	-23.132	45.23
LS02	6.501	13.04	-23.927	44.29
LS03	6.023	14.34	-23.678	45.21
LS04	6.895	13.74	-24.180	43.51
LS05	8.013	14.15	-23.703	47.22
LS06	6.797	13.45	-24.025	44.84
LS07	8.621	14.40	-23.085	46.88
LS08	7.795	14.19	-23.918	45.27
LS09	8.705	14.33	-23.410	46.58

(B)

ID	d15N	Amt%	d13C	Amt%
SS01	6.279	13.72	-23.542	43.25
SS02	5.729	11.20	-23.637	34.41
SS03	6.414	14.42	-23.554	45.12
SS04	6.770	14.91	-22.666	44.98
SS05	9.283	14.69	-21.615	46.95
SS06	6.332	14.92	-23.090	45.64
SS07	7.083	14.97	-22.581	46.41
SS08	6.648	14.72	-22.944	44.17
SS09	7.717	15.10	-21.624	45.00
LS01	6.499	14.52	-23.463	44.83
LS02	6.584	14.60	-23.722	48.35
LS03	7.092	14.26	-23.835	45.78
LS04	6.668	11.90	-23.955	37.53
LS05	6.593	14.29	-23.976	44.36
LS06	6.936	14.57	-23.623	45.68
LS07	7.000	14.50	-23.988	46.06

Appendix 1.10. Isotopic signatures (‰) and elemental concentration (%) of the (A) animal and (B) plant standards (fish muscle and glutinous rice flour, respectively).

(A)

Standard	mean	SD		mean	SD
δ15N	9.200	0.078	Amt[N]	14.71	0.62
δ13C	-25.130	0.118	Amt[C]	47.14	0.93

(B)

Standard	mean	SD		mean	SD
δ15N	3.273	0.125	Amt[N]	1.31	0.03
δ13C	-27.500	0.048	Amt[C]	41.39	0.77

Appendix 2. The diet analyses of shrews

Appendix 2.1. Seasonal diet composition (%) of shrews in the meadow and forest sites in Hehuan mountains during Oct. 2009-Nov. 2010.

					% diet composition					
			Signature (‰)		C3 plants		C4 plants		Invertebrates	
Habitat	Season	n	$\delta^{13}C$	$\delta^{15}N$	median	5-95% percentile	median	5-95% percentile	median	5-95% percentile
Meadow	Growing seasons	12	-21.824	7.844	61	50-68	21	14-26	17	12-33
	Non-growing seasons	7	-20.596	6.417	20	12-28	64	53-74	15	8-27
Forest	Growing seasons	14	-23.341	7.334	52	39-60	33	25-40	13	8-33
	Non-growing seasons	16	-23.238	6.852	23	17-29	57	51-64	19	14-25

Appendix 2.2. Measurements of food niche width for shrews in the meadow and forest site. NR = range of $\delta^{15}N$ range, CR = range of $\delta^{13}C$, Var N = variance of $\delta^{15}N$, Var C = variance of $\delta^{13}C$, Var CD = variance of distances to centroid.

			$\delta^{13}C$		$\delta^{15}N$		
Habitat	Season	n	CR	Var (C)	NR	Var (N)	Var (CD)
Meadow	Growing seasons	12	4.28	1.76	3.41	0.97	1.84
	Non-growing seasons	7	4.40	1.86	2.69	0.69	2.13
	2 seasons combined	19	5.08	2.06	4.31	1.32	1.85
Forest	Growing seasons	14	2.18	0.49	2.80	0.96	0.38
	Non-growing seasons	16	2.37	0.59	3.55	0.61	0.69
	2 seasons combined	30	2.57	0.52	3.55	0.81	1.02

Appendix 3. Feeding experiment

(1) Introduction

Using stable isotope technique to study diet relationships requires the information of turnover time, which means the time it takes to change tissue's isotopic values into diet's ones. When using hair tissues as samples for isotope analysis, growth time is another important factor to be considered. The sum of these two factors equals the total time tissues' isotopic values matching with diets'.

(2) Materials and Methods

In order to understand the growth and turnover time, rodents were captured by ugglan traps and brought back to the laboratory animal room. Each animal was marked and kept in a rearing tray. It was uniformly cut a small piece of area near its tail, and then fed with specific food every week. The food using as C3 source is sweet potato, and C4 sources are maize and job's tears. Besides, mineral, vitamin, and protein (Yellow mealworms fed with C3/C4 sources) supplies were provided.

Every two weeks the hair growth conditions were recorded, which include weight, hair length for both shaved and unshaved area. The total process lasted 3 months, and at the end of the period, the newly-grew hair was collected and continued to opposite diet treatment (C3 to C4 and C4 to C3) for another 3 month process.

The hair samples were segmented into 3 pieces based on monthly-grew length, that is, the top part of the hair is the length grew from the first month. All the hair samples and food sources were processed for stable isotope analysis for turnover time estimation, and hair growth data were used to calculate the growth time. The hair samples were first bathed in chloroform-ethanol solutions (at a ratio of 2 to 1) for two hours, then washed with ddH2O. Finally, they were dried at 60℃ and then grounded into powders for isotopic analysis, with animal standard as fish muscle and GRF as plant standard.

(3) Results

[1] Feeding process

Six Taiwan voles (marked V1, V2, to V6), four Formosan mice (marked A1, A2, to A4), and one white-bellied (marked R1) rat were captured from He-huan mountains and raised for feeding experiments. It was separated into three periods with three months each (first period: 2010.05.11 to 2010.08.11; second period: 2010.08.11 to 2010.11.11; third period: 2010.11.11 to 2011.02.8).

During the experiments, all of the Taiwan voles were dead and only V6 survived through a three month period (second period); one wood rat escaped and the rests recovered their hair in certain periods (A3 in first period, A4 in second period, and A2 in third period); the only white-bellied rat got its fur fully recovered in second period. The total fur collections included one Taiwan vole (V6), three Formosan mice (A2, A3, and A4), and one white-bellied rat (R1).

[2] Growth time

The average growth rate for Taiwan voles is 9.73E-03 cm/day, 5.22E-03 cm/day for Formosan mice, and 8.72E-03 cm/day for white-bellied rat (App-Table 1.1). The growth rate is translated into recover time, which means the total time small mammals grows their hairs completely as unshaved ones (App-Table 1.2). App-Table 1.2 shows that average recover time for Taiwan voles is 140 days, 349 days for Formosan mice, and 219 days for white-bellied rat.

However, only 4 rodents had their fur fully recovered in this study, and that made the average data with huge variance and very unspecific. As a result, four rodents' data were taken out and analyzed (App-Table 1.3). It shows that the rodents are able to grow their fur back in three months, with an average about two and half months (76 days) for Formosan mice.

[3] Isotopic data analysis and turnover time

The isotope data includes both small mammals and food sources (Table 2). The results show that tissue carbon isotopic value can reflect its source's, that is, rodents fed with C3 food would have carbon isotopic values inside the range of C3 sources (App-Fig. 1.1). Besides, different parts of hair of the same rodent are close, indicating rapid turnover time (App-Fig. 1.2).

T test is used to test whether different parts of hair have their carbon isotopic value different statistically. Due to little sample size of Taiwan vole and white-bellied rat, Formosan mouse is the only species that put into analysis. Comparing each pairs of hair parts shows that there are no difference between medium part and bottom part of Formosan mice' hair (p = 0.1381), same as the comparison between top part and medium part (p = 0.5254). However, there are significant difference between top part and bottom part of hair in Formosan mice (p = 0.0420). That is, for Formosan mice the newest hair (bottom part) carbon isotope values are closer to its food isotopic value than the old one (top part).

Though different parts of fur are different in their carbon isotopic values statistically, the values vary within 0.22 per mil. The small variation suggests that as the new hair grows, almost immediately it reflects its diet in isotopically, indicating a very short turnover time that can be ignored.

App-Table 1.1. Fur growth rates (fur length per day, cm/day) of small mammals (V for Taiwan voles, A for Formosan mice, and R for white-bellied rats) for each period (Growth rate1: 2010.05.11-2010.08.11; Growth rate2: 2010.08.11-2010.11.11; Growth rate3: 2010.11.11-2011.02.08; Growth rate total: 2010.05.11-2011.02.08).

	Growth rate1	Growth rate2	Growth rate3	Growth rate total
A2	3.18E-03	7.61E-04	1.03E-02	4.74E-03
A3	1.41E-02	4.02E-03	9.09E-04	6.34E-03
A4	4.35E-03	8.08E-03	1.31E-03	4.58E-03
R1	5.06E-03	1.77E-02	3.43E-03	8.72E-03
V1	8.33E-03			8.33E-03
V2	1.54E-02			1.54E-02
V3	5.88E-03			5.88E-03
V6	4.35E-03	1.42E-02		9.30E-03
A total				5.22E-03
V total				9.73E-03

App-Table 1.2. Fur recover time (days for fur to fully recovered, days) of small mammals for each period (Recover time1: first period; Recover time2: second period; Recover time3: third period; Recover time total: the whole feeding experiments).

	Recover time1	Recover time2	Recover time3	Recover time Total
A2	324	1051	71	482
A3	78	174	627	293
A4	237	78	502	272
V1	144			144
V2	78			78
V3	187			187
V6	244	59		151
R1	297	64	282	214
A total				349
V total				140

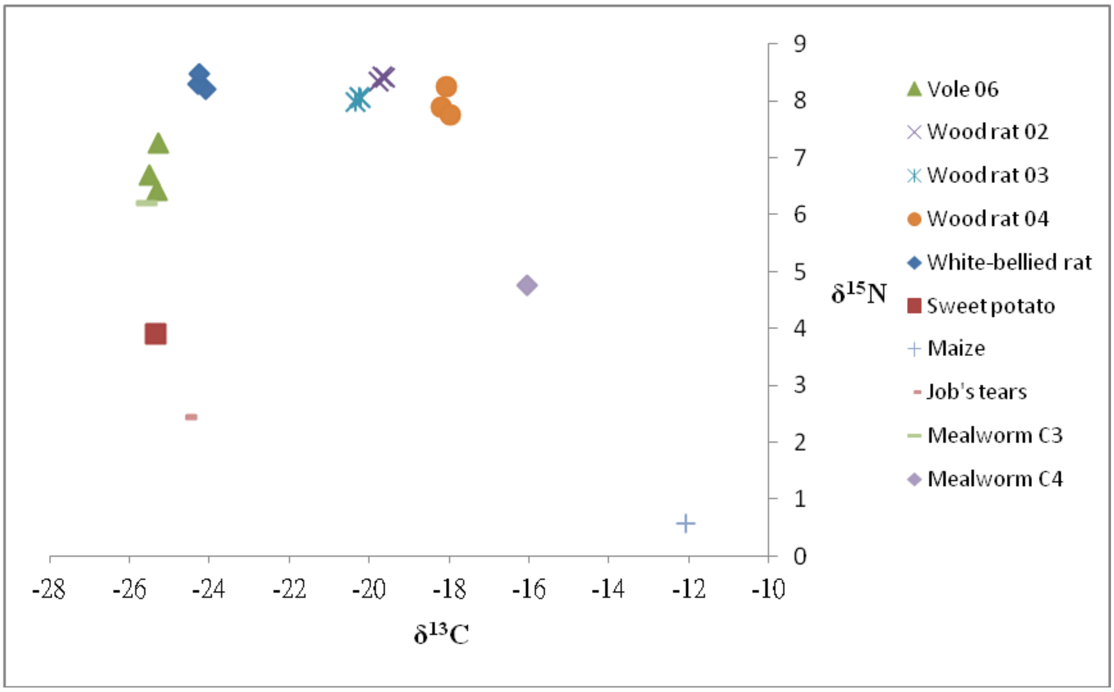
App-Table 1.3. The recovery time of the rodents with hair completely recovered.

<table>
<tr><th></th><th>Sex</th><th>Site</th><th>Recover time</th><th></th></tr>
<tr><td>A3</td><td>Male</td><td>Meadow</td><td>78 days</td><td rowspan="3">AVG: 76 days</td></tr>
<tr><td>A4</td><td>Female</td><td>Meadow</td><td>78 days</td></tr>
<tr><td>A2</td><td>Female</td><td>Forest</td><td>71 days</td></tr>
<tr><td>R1</td><td>Male</td><td>Forest</td><td>64 days</td><td></td></tr>
</table>

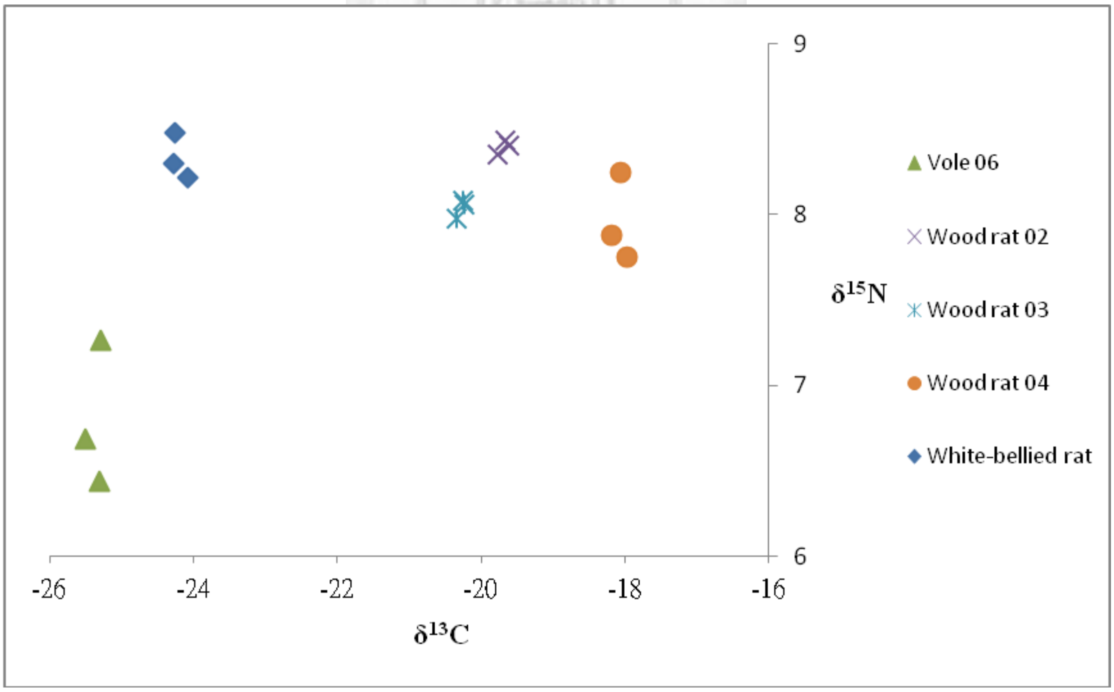
App-Table 2. The stable isotope values (‰) and elemental concentration (%) for fur samples and food sources in feeding experiments.

Ident	d 15N	Amt%	d 13C	Amt%
V06	6.36	13.02	-25.80	45.96
V06-1	6.44	13.07	-25.30	44.61
V06-2	6.69	12.93	-25.50	44.80
V06-3	7.26	12.63	-25.28	44.83
A02	5.56	13.91	-21.21	44.61
A02-1	8.43	14.00	-19.67	45.00
A02-2	8.35	13.51	-19.77	43.49
A02-3	8.41	14.20	-19.62	45.32
A03	6.10	13.66	-20.02	45.16
A03-1	7.98	13.79	-20.33	45.00
A03-2	8.08	14.02	-20.25	45.01
A03-3	8.06	13.82	-20.22	45.01
A04	4.96	13.72	-20.77	45.10
A04-1	8.25	14.07	-18.05	44.83
A04-2	7.88	13.90	-18.18	45.01
A04-3	7.75	14.02	-17.96	45.25
R01	7.41	14.27	-21.61	45.22
R01-1	8.22	14.41	-24.08	45.15
R01-2	8.30	14.61	-24.27	46.01
R01-3	8.48	14.52	-24.26	46.05
Mealworm(C3)	6.21	7.40	-25.56	56.30
Mealworm(C4)	4.77	7.94	-16.04	56.52
Sweet Potato	3.907	0.98	-25.333	39.39
Maize	0.564	2.46	-12.075	46.45
Job’s tears	2.441	1.15	-24.571	41.07

Standards					
Animals		Fish muscle (n=19)			
(mean±S.D)		δ15N	9.200±0.122	Amt[N]	14.01±0.24
		δ13C	-25.130±0.088	Amt[C]	47.21±1.07
Plants		GRF (n=21)			
(mean±S.D)		δ15N	3.230±0.137	Amt[N]	1.31±0.02
		δ13C	-27.500±0.037	Amt[C]	41.04±0.37



App-Fig. 1.1. Stable isotope data for fur samples and food sources in feeding experiments.



App-Fig. 1.2. Stable isotope data for fur samples of small mammals.

Appendix 4. Demographic results by MARK

Appendix 4.1. The capture and recapture rate of the rodent communities in Hehuan mountains during Jan. 2010-Nov. 2010.

			Growing season				Non-growing season			
			spring (Apr. 2010)		summer (Jul. 2010)		fall (Nov. 2010)		winter (Jan. 2010)	
Habitat	Species	sex	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Meadow	Taiwan vole	male	0.31	0.04	0.31	0.04	0.31	0.04	0.31	0.04
		female	0.31	0.04	0.31	0.04	0.31	0.04	0.31	0.04
	Formosan mouse	male	0.15	0.10	0.18	0.07	0.16	0.09	0.12	0.08
		female	0.16	0.11	0.19	0.08	0.16	0.10	0.21	0.08
Forest	Taiwan vole	male	0.29	0.05	0.28	0.07	0.30	0.04	0.30	0.04
		female	0.29	0.05	0.28	0.07	0.30	0.04	0.30	0.04
	Formosan mouse	male	0.29	0.05	0.29	0.05	0.29	0.05	0.29	0.05
		female	0.29	0.05	0.29	0.05	0.29	0.05	0.29	0.05
	White-bellied rat	male	0.40	0.06	0.40	0.06	0.40	0.06	0.40	0.06
		female	0.40	0.06	0.40	0.06	0.40	0.06	0.40	0.06

Appendix 4.2. The survival and recruitment rate of the rodents in the (A) meadow and (B) forest sites in Hehuan mountains during Jan. 2010-Nov. 2010.

(A)

			Survey interval					
			Jan. 2010-Apr. 2010		Apr. 2010-Jul. 2010		Jul. 2010-Nov. 2010	
Species	Sex	Parameters	Estimate	SE	Estimate	SE	Estimate	SE
Taiwan vole	male	Survival rate	0.32	0.11	0.32	0.11	0.32	0.11
		Recruitment rate	0.81	0.17	0.85	0.22	0.82	0.17
	female	Survival rate	0.56	0.10	0.56	0.10	0.56	0.10
		Recruitment rate	0.43	0.13	0.46	0.25	0.43	0.12
Formosan mouse	male	Survival rate	0.00	0.00	0.07	NA	0.00	0.00
		Recruitment rate	0.24	0.49	NA	NA	1.46	1.05
	female	Survival rate	0.00	0.00	0.07	NA	0.00	0.00
		Recruitment rate	NA	NA	NA	NA	0.71	0.69

(B)

Species	Sex	Parameters	Survey interval					
			Jan. 2010-Apr. 2010		Apr. 2010-Jul. 2010		Jul. 2010-Nov. 2010	
			Estimate	SE	Estimate	SE	Estimate	SE
Taiwan vole	male	Survival rate	0.42	0.14	0.48	0.12	0.53	0.18
		Recruitment rate	0.42	0.20	0.40	0.23	0.90	0.57
	female	Survival rate	0.42	0.14	0.48	0.12	0.48	0.18
		Recruitment rate	0.42	0.20	0.40	0.23	0.90	0.57
Formosan mouse	male	Survival rate	0.00	0.00	0.00	NA	0.00	0.00
		Recruitment rate	0.00	0.00	NA	NA	3.88	3.04
	female	Survival rate	0.39	0.34	0.00	0.00	0.00	0.00
		Recruitment rate	0.67	0.65	0.39	0.45	5.18	5.59
White-bellied rat	male	Survival rate	0.93	0.20	0.93	0.20	0.29	0.24
		Recruitment rate	0.00	0.00	4.08	4.72	1.41	0.96
	female	Survival rate	0.34	NA	0.28	NA	0.00	0.00
		Recruitment rate	NA	NA	NA	NA	3.61	4.03