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## Feeding ecology of the common sun skink, *Eutropis multifasciata* (Reptilia: Squamata: Scincidae), in the plains of central Vietnam

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We studied the feeding ecology of *Eutropis multifasciata* in the tropical plains of central Vietnam to understand better the foraging mode, spatiotemporal and sexual variation in dietary composition, and rarefaction curves of prey-taxon richness for males and females. Stomach contents ( $n = 161$ ) were collected from October 2013 to May 2014 using a nonlethal stomach-flushing technique. A total of 680 food items (624 animal items and 56 plant items) was found in 161 stomachs of skinks, representing 19 unique animal categories. We found that the diet of *E. multifasciata* is composed mainly of small, sedentary and clumped prey and that this skink specialises on spiders, insect larvae, snails, grasshoppers and crickets (with a combined importance index of 60%). Dietary composition, prey size and total prey volume in *E. multifasciata* changed between dry and rainy seasons and among regions. The total volume of food items consumed by males was larger than that of females, and the diversity and evenness index of prey categories were larger in males than in females. However, using rarefaction curves revealed that females have the higher prey-taxon richness after points between 130 and 140 prey items for frequency, and between 160 and 170 prey items for number of items, and the differences were not statistically significant. The foraging behaviour of *E. multifasciata* best fits a ‘widely foraging’ model.

**Keywords:** diet; feeding; food; foraging mode; lizards; skinks

### Introduction

Ecosystems in central Vietnam have been heavily impacted by land conversion (either by being converted to different land uses or by being replanted with commercial monocultures), timber harvest, urbanisation and water manipulation (Nguyen et al. 2005). Similarly to other landscapes in this area, habitats in the plains of Thua Thien Hue Province have been transformed and manipulated in many different ways. On the other hand, the mid-central Coastal Plains of Vietnam is a region of high biodiversity (Nguyen et al. 2009) and is considered to be one of the biodiversity hotspots of the world (Myers et al. 2000). Reptiles constitute a vital component and play significant roles in natural ecosystems, and form the second largest of the vertebrate assemblages in abundance and biomass, across all habitats. However, the

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vast majority of studies on lizards have been conducted on fewer than 10% of extant species (Reilly et al. 2007).

Studies of reproductive ecology, sexual size dimorphism and feeding performance of scincid skinks from Malaysia (Goldberg 2013), southern China including Hainan Island (Ji et al. 2006; Lin et al. 2008; Sun et al. 2012), and Taiwan (Huang 2006; Kuo et al. 2013), represent important progress towards the understanding of these lizards. Information on the feeding ecology of the common sun skink, *Eutropis multifasciata*, a terrestrial viviparous skink, is lacking even though its terrestrial habitats have been identified as important to herpetological conservation programmes (Weyrauch and Grubb 2004; Reilly et al. 2007; Vitt and Caldwell 2009). Thus, studies of feeding ecology, including an estimate of spatiotemporal variation in dietary composition of *E. multifasciata*, would provide insight into the ecology and population status of, and inform management and conservation plans for, this species in central Vietnam.

Studies on lizards' feeding ecology suggested that the six most important factors influencing lizard diets are lizard body size, thermoregulatory tactics, time of activity, physiological constraints, foraging mode and resource availability (Parker and Pianka 1974; Pianka and Pianka 1976; Vitt et al. 2003; Vitt and Pianka 2005). Foraging mode influences the prey categories that a lizard encounters. Sit-and-wait foragers hunt visually and hence only encounter mobile prey as the prey move past ambush stations, whereas widely foraging predators encounter a greater number and variety of potential food items because they search for hidden and sedentary prey (Huey and Pianka 1981; Reilly et al. 2007). In general, larger lizards tend to consume prey from larger size categories. Lizards that are generalists (e.g. *Ameiva ameiva*) tend to consume a wide variety of prey sizes and prey size is often associated with lizard size, whereas prey size of lizards that are dietary specialists (e.g. lizards of *Phrynocephalus* or *Plica umbra*) varies less and is not associated with lizard body size (Reilly et al. 2007).

Comparison of diurnal versus nocturnal lizard diets indicates that nocturnal lizards eat more nocturnal insects (such as moths, crickets and certain spiders) than do diurnal lizards (Pianka and Pianka 1976; Avery 1981; Doughty and Shine 1995; Vitt 1995; Vitt and Zani 1997). Differences in resource availability between day and night provide the best explanation for such dietary differences. However, the behaviour of some nocturnal geckos suggests that the maintenance of higher body temperatures during the day than those experienced at night may increase digestion efficiency and possibly facilitate other metabolic processes (Autumn et al. 1999; Huey et al. 1989; Reilly et al. 2007). The effects of low body temperature on feeding physiology in squamates include effects on the efficiency of capturing and handling prey (Greenwald 1974; de Queiroz et al. 1987), effects on the efficiency of absorption (Harwood 1979; Beaupre et al. 1993), effects on foraging (Ayers and Shine 1997; Reilly et al. 2007) and effects on hunger (Alexander et al. 2001).

The abundance of prey categories in the stomachs of insectivorous lizards is positively correlated with the relative prey abundance or general availability of prey of the appropriate size and type in the habitat (Reilly et al. 2007; Vitt and Caldwell 2009). However, the effects of resource availability on lizard diets are very complex. Many researchers assert that lizards are opportunistic feeders, eating whatever is available in their environment. Some species, however, are specialists, feeding on just a few prey categories to the exclusion of others, regardless of time of season or year, or locality (Reilly et al. 2007). Various lizard species have evolved such

specialisations for eating ants (Pianka and Pianka 1970; Pianka et al. 1998; Anderson 1999), termites (Huey et al. 1974, 2001; Pianka and Pianka 1976; Pianka and Huey 1978) and scorpions (Pianka 1986). The Burton's Legless Lizard, *Lialis burtonis*, preys almost exclusively on large vertebrate prey, especially skinks (Reilly et al. 2007). Many lizard species have diets that vary among seasons (Vitt and Caldwell 2009; Ngo et al. 2014). However, within assemblages, dietary differences among species are often maintained despite seasonal or annual variation in diets (Vitt 1991) and dietary differences among species are the rule rather than the exception (Pianka 1973, 1986; Vitt and Zani 1996).

In the present study, we investigated the feeding ecology of *E. multifasciata* from different habitats in the plains of central Vietnam. We examined: (1) spatiotemporal (among localities and seasons) variation in feeding ecology; (2) variation between the sexes in prey composition; and (3) quality and quantity of prey consumption in different habitats. We also compared the diet of this species with the diets of other congeneric species for which feeding habits have been recorded.

### Materials and methods

This study was conducted in the plains of Thua Thien-Hue Province ( $15^{\circ}59'30''$ – $16^{\circ}44'30''$ N,  $107^{\circ}00'56''$ – $108^{\circ}12'57''$ E), central Vietnam (Figure 1). This region is characterised by a tropical climate and seasonal monsoons, with an annual average temperature of  $24.9 \pm 0.51^{\circ}\text{C}$  (ranging from  $19.5 \pm 1.06^{\circ}\text{C}$  in January to

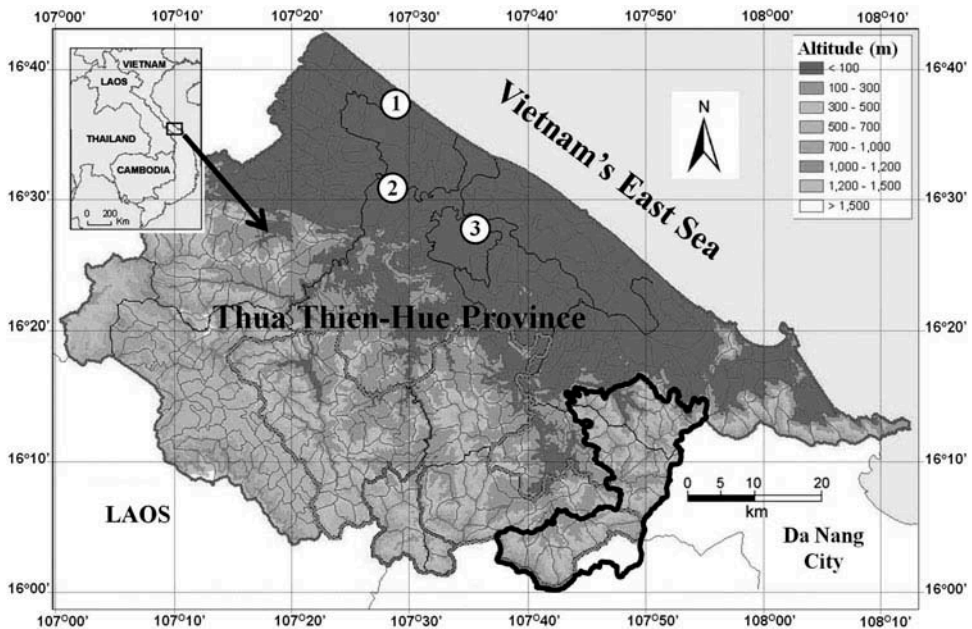


Figure 1. Map of Thua Thien-Hue Province in central Vietnam showing the three localities – (1) Quang Dien; (2) Huong Tra; (3) Xuan Phu – where the stomach contents of *Eutropis multifasciata* skinks were collected for this study.

29.2 ± 0.44°C in June), an annual average precipitation of 3243.2 ± 780.6 mm and an annual average humidity of 86.8 ± 1.05% (data obtained from the General Statistics Office of Vietnamese Government; Nguyen et al. 2013). This region has a relatively dry period (dry season) that extends from February to July each year, with monthly rainfall ranging from 47.8 to 98.7 mm (75.6 ± 17.9 mm) and monthly average temperature of 25.9 ± 0.73°C (ranging from 21.1 ± 2.21°C in February to 29.2 ± 0.44°C in June). A wet period (rainy season) extends from August to January (approximately 6 months), with monthly rainfall exceeding 100 mm in more than 75% of the months in the observational sequence (Nguyen et al. 2004). Most precipitation is restricted to the rainy season, with monthly precipitation ranging from 153.6 to 904.8 mm (465.1 ± 118.7 mm) and monthly average temperature of 23.9 ± 0.41°C (ranging from 19.4 ± 1.06°C in January to 28.2 ± 0.49°C in August).

We collected stomach contents of *Eutropis multifasciata* at the following localities in Thua Thien-Hue Province: (1) Quang Dien (16°38'25.1"N–107°29'33.5"E); (2) Huong Tra (16°31'05.3"N–107°29'08.3"E); and (3) Xuan Phu (16°28'05.1"N–107°36'05.0"E). To determine foraging mode, we recorded the skinks' behaviours (e.g. time spent moving and stationary, feeding attempts and whether feeding attempts were made by skinks that detected prey while the skinks were immobile or while searching actively). We generally watched *E. multifasciata* from a distance of ≥ 3 m, which was sufficient to avoid disturbing the skinks (Ngo et al. 2014). We began recording data 5–10 min after finding a skink to minimise the observer effects associated with our arrival. For each minute of observation (a total of 10 min for each individual observed if possible, but sometimes less if the skink moved out of sight behind wood piles or rocks, in vegetation, or into crevices or holes), we recorded the frequency of movements made by the skinks (i.e. number of moves per minute) and the behaviour of an individual (including active hunting of prey, sit-and-wait behaviour, basking and other relevant behaviours). From each skink's movement data, we calculated the number of moves per minute and the percentage of time spent moving. We limited observations obtained from 09:30–16:00 h in the analyses for the 'widely foraging' versus 'sit-and-wait' pattern because these skinks usually bask before 09:30 h and are not active.

We conducted daytime surveys at each site (especially after sunny days with optimal weather for skink activity) from 08:00–16:00 h. At these sites, we collected stomach contents along transects, approximately 3–4 km in length for each transect. We visually searched for skinks and collected specimens by hand, using a noosing pole (a method used to collect lizards), and pitfall traps, then placed them into individually labelled cloth bags. We collected throughout the villages, open areas, riparian forest, forestry plantations and fields. After capture, we measured snout-vent length (SVL), tail length (TL) and mouth width (MW) using digital callipers (Mitutoyo Corporation, Kawasaki, Japan) to the nearest 0.01 mm. To measure body mass (BM), we used an electronic balance (Prokits, Taipei, Taiwan) to the nearest 0.1 g.

We determined sex by secondary characteristics such as the number of scale spots on each lateral side of the body (from the foreleg to the hindleg) and the presence or absence of a brown–yellow line on each flank. We recorded site, date, time, and ambient temperature and relative humidity for each individual we caught. We obtained monthly precipitation data from local weather stations in Thua Thien-Hue Province. For each site, we took coordinates with datum WGS 84 using a global

positioning system (GPS) unit (Garmin Colorado 400t, Garmin Corporation, Taipei County, Taiwan) to determine the distance among sites and the distribution of *E. multifasciata* in the plains of Thua Thien-Hue Province.

We used a nonlethal procedure modified from Griffiths (1986) of Rivas et al. (1996) and the typical stomach-flushing technique (Legler and Sullivan 1979; Gittins 1987; Leclerc and Curtois 1993; Barreto-Lima 2009) to obtain stomach contents without sacrificing skinks. We used different sizes of soft catheter tubes (3 or 4 mm inner diameter) with appropriately sized syringes and different amounts of clean water (80 or 120 mL) for skinks of different SVL sizes ( $\leq 90$  mm or  $> 90$  mm, respectively) for stomach-flushing to minimise the stress to skinks. Stomach contents were collected within 60 min of capture due to rapid prey digestion in lizards (Reilly et al. 2007). The stomach contents were then directly fixed in 70% ethanol for later laboratory analyses. After collecting stomach contents, we used visible implant elastomer tags (Losos et al. 2004; Hoffmann et al. 2008; Schmidt and Schwarzkopf 2010) to mark each skink, and skinks observed to be in good condition were then released within 90 min, roughly where they had been captured. Each lizard was stomach-flushed only once, and we followed the guidelines approved by the American Society of Ichthyologists and Herpetologists (Beaupre et al. 2004) for animal care and use throughout our procedures.

In the laboratory, we sorted and identified prey items in each stomach sample to the lowest possible taxonomic level (mostly order, but identifications were made to family when possible). We consulted and followed keys and descriptions in Thai (2001) and Pechenik (2014) and the nomenclature follows that of Johnson and Triplehorn (2005). We measured the length from head to thorax and the width at the widest section of the body (Ngo et al. 2014) of each identified prey item with a digital calliper to the nearest 0.01 mm, or made a best estimation for incomplete items. We considered plant matter food, whereas other materials such as sand, stones and plastic parts were assumed to have been ingested accidentally and were excluded from the analyses.

We estimated the volume (V) of food items using an ellipsoid formula (with  $\pi = 3.14159$ ; Biavati et al. 2004; Caldart et al. 2012; Borges et al. 2013; Ngo and Ngo 2013):

$$V = \frac{4\pi}{3} \times \left(\frac{\text{length}}{2}\right) \times \left(\frac{\text{width}}{2}\right)^2$$

We used the index of relative importance (IRI) to determine the importance of each food category in the feeding ecology of *E. multifasciata*. This quotient (IRI) provides a more informed estimation of food item consumption than any of the three components alone (frequency, number or volume), by using the following formula (Biavati et al. 2004; Bonansea and Vaira 2007; Leavitt and Fitzgerald 2009; Ngo et al. 2014):

$$\text{IRI} = \frac{\%F + \%N + \%V}{3}$$

where IRI is relative importance index for each food category, F is the frequency (number) of stomachs that contain a particular food type, N is the total number of that food item in relation to all food items (Silva et al. 2014), and V is the total volume of that food item. Vegetation in stomachs could be properly counted (N), and, therefore, was considered in the calculation of IRI.

To estimate heterogeneity of food items among localities and between sexes, we used the Simpson's index of diversity (1949) as follows:

$$D = \sum_{i=1}^s \frac{n_i(n_i - 1)}{N(N - 1)}$$

where  $n_i$  is the number of food items in the  $i$ th taxon category,  $N$  is the total number of food items and  $S$  is the number of prey taxa in the sample (Krebs 1999; Magurran 2004). We also adopted the reciprocal Simpson's index,  $1/D$ , to calculate dietary heterogeneity of *E. multifasciata* from the plains of central Vietnam. The reciprocal Simpson's heterogeneity index varies from 1 (low dietary breadth) to  $S$  (high dietary breadth).

To estimate prey evenness, we used the Shannon's evenness. Evenness is calculated from the equation  $J' = H'/H_{\max} = H'/\ln S$ , where the maximum diversity ( $H_{\max}$ ) that could possibly occur where all taxa have equal abundance ( $H' = H_{\max} = \ln S$ ),  $S$  is the total number of prey taxa and  $H'$  is the Shannon–Weiner index of taxon diversity. Here, the value of  $H'$  is calculated from the equation  $H' = -\sum p_i \times \ln p_i$ , where the quantity  $p_i$  is the proportion of total food items belonging to the  $i$ th taxon for the total food items of the sample (Pielou 1975; Magurran 2004; Muñoz-Pedreros and Merino 2014).

We used the rarefaction method to estimate the diversity of diet between males and females. Comparing prey taxon richness in the diet of males and females only based on raw food item counts produces incorrect results because of differences in sampling effort between sexes or among populations (Colwell et al. 2004; Hahn et al. 2014), and different sample sizes (Krebs 1999). Therefore, we estimated expected prey taxon accumulation curves (sample-based rarefaction curves; Krebs 1999) and interpolated their 95% confidence intervals using the Software for Ecological Methodology (Version 7.2, Exeter Software, Setauket, New York, USA). We standardised all diet samples from the rarefaction method using the modified algorithm by Hurlbert (1971) and Simberloff (1972) as follows:

$$E(S_n) = \sum_{i=1}^S \left[ 1 - \frac{\binom{N - N_i}{n}}{\binom{N}{n}} \right]$$

where  $E(S_n)$  is the expected number of prey taxa in a random sample of  $n$  prey items,  $S$  is the total number of prey taxa in the entire collection from stomach contents,  $N_i$  is the number of prey items in the  $i$ th taxon,  $N$  is the total number of prey items in the entire collection ( $= \sum N_i$ ),  $n$  is the value of sample size (number of prey items) chosen for standardisation ( $n \leq N$ ) and  $\binom{N}{n} = N!/n!(N-n)!$  is the



number of combinations of  $n$  prey items that can be chosen from a set of  $N$  prey items. For the variance of the expected number of prey taxa,  $var E(S_n)$  in the random sample of  $n$  prey items in this present study was calculated following Heck et al. (1975; reviewed in Krebs 1999, p. 415).

To statistically analyse prey data and morphological measurements of skinks, we used SPSS 16.0 software (SPSS Inc., Chicago, Illinois, USA) and STATISTICA 10.0 (StatSoft Inc., Tulsa, Oklahoma, USA) for Windows 7 and set the significance level to  $P \leq 0.05$  for all analyses. We used one-way analyses of variance (ANOVAs) to examine the number of stomachs collected between sexes and seasons and among localities. We used two-factor ANOVA (season and site) on the residuals of SVL, BM, and MW and used two-factor multivariate analysis of variance (MANOVA) to examine the effects of season and site on the volumes of major food items. We tested for correlations between body size (SVL, BM and MW) and prey size (length, width and volume) to determine if prey size was correlated with skink size. We tested the possible effects of climatic factors on feeding ecology and prey volume with multiple linear regressions between the monthly scores of precipitation (mm), mean temperature ( $^{\circ}\text{C}$ ), relative humidity (%) and prey volume.

To statistically compare food item size (length and width) and volume between sexes, between seasons and among localities, we first log-transformed the data of food items to meet normality assumptions and homogeneity of variance and used one-way ANOVA. We also  $\log_{10}$ -transformed the data on mean size of food items per skink to approximate normal distribution prior to performing statistical analyses. All data are presented as mean  $\pm$  standard deviation (SD) unless otherwise noted.

## Results

We made at least five visits per month from October 2013 to May 2014 (a total of 8 months) and collected 161 stomach contents (86 males and 75 females) of *E. multifasciata* from three localities in the plains of central Vietnam. The number of stomach contents collected was not significantly different between seasons ( $F_{1,23} = 1.491$ ,  $P = 0.235$ ), localities ( $F_{2,23} = 1.403$ ,  $P = 0.268$ ) or sexes ( $F_{1,15} = 1.272$ ,  $P = 0.279$ ). The largest male was 125.2 mm SVL and the largest female 115.7 mm SVL (Table 1). The smallest reproductive male was 93.2 mm SVL and 90.1 mm SVL in female. The average SVL was significantly larger in adult males ( $105.2 \pm 1.07$  mm,  $n = 53$ ) than in adult females ( $101.5 \pm 0.97$  mm,  $n = 47$ ; ANOVA,  $F_{1,99} = 6.554$ ,  $P < 0.05$ ; Table 1). When SVL was taken into account with  $\log_{10}$  (SVL) as a covariate, the analysis showed that the TL, MW and BM of adult males were also significantly greater than those of adult females (analysis of covariance (ANCOVA), all  $P$ -values  $< 0.05$ ; Table 1).

On average, skink SVL in the dry season ( $98.46 \pm 11.18$  mm,  $n = 87$ ) was larger than in the rainy season ( $92.36 \pm 13.02$  mm,  $n = 74$ ), and significant between seasons ( $F_{1,160} = 12.623$ ,  $P = 0.001$ ). However, SVL was not significantly different among localities ( $F_{2,160} = 0.952$ ,  $P = 0.387$ ), and there was no interaction between season and locality ( $F_{2,160} = 1.461$ ,  $P = 0.235$ ). A two-factor ANOVA revealed that the season factor was significantly different in the residuals of BM ( $F_{1,160} = 9.681$ ,  $P = 0.002$ ) or MW ( $F_{1,160} = 14.834$ ,  $P < 0.001$ ), whereas locality or interaction between locality and season showed no significant differences (BM: locality,  $F_{2,160} = 1.102$ ,  $P = 0.337$  or

Table 1. Summary of morphological measurements in *Eutropis multifasciata* from the plains of central Vietnam. The result from one-way analysis of variance (ANOVA) tests for SVL on the residuals. The results from analysis of covariance (ANCOVA) tests with snout-vent length (SVL) as a covariate for tail length (TL), mouth width (MW) and body mass (BM). Morphological measurements are in millimetres (BM is in grams). Statistical tests were performed on  $\log_{10}$ -transformed data prior to using an ANOVA or ANCOVA on the residuals.

| Trait | Adult males ( $n = 53$ ) |            | Adult females ( $n = 47$ ) |            | $F$     | $P$     |
|-------|--------------------------|------------|----------------------------|------------|---------|---------|
|       | Mean $\pm$ SE            | Range      | Mean $\pm$ SE              | Range      |         |         |
| SVL   | 105.2 $\pm$ 1.07         | 93.2–125.2 | 101.5 $\pm$ 0.97           | 90.1–115.7 | 6.554   | 0.012   |
| TL    | 126.8 $\pm$ 5.81         | 21.3–190.6 | 109.3 $\pm$ 6.49           | 15.3–197.2 | 4.382   | 0.039   |
| MW    | 15.4 $\pm$ 0.21          | 12.6–19.1  | 14.31 $\pm$ 0.21           | 10.1–17.3  | 38.301  | < 0.001 |
| BM    | 33.9 $\pm$ 1.12          | 17.3–55.3  | 31.41 $\pm$ 1.15           | 17.2–50.5  | 147.652 | < 0.001 |

interaction,  $F_{2,160} = 2.223$ ,  $P = 0.112$ . MW: locality,  $F_{2,160} = 0.493$ ,  $P = 0.613$  or interaction,  $F_{2,160} = 1.154$ ,  $P = 0.321$ ).

Approximately 5.59% (nine stomachs) of the 161 stomachs of *E. multifasciata* were empty. We identified a total of 680 food items (624 animal items and 56 plant items) in the diet of *E. multifasciata*, and prey items represented 19 unique animal categories (Table 2). The number of food items in males (368 items) and females (312 items) was not significantly different ( $F_{1,151} = 0.545$ ,  $P = 0.463$ ). The number of food items in the dry season (349 items) and the rainy season (331 items) was also not significantly different ( $F_{1,151} = 0.953$ ,  $P = 0.331$ ). In total, there were 19 prey categories consisting mainly of invertebrates, but also some vertebrates (e.g. skinks and small frogs; Table 2). The mean number of food items per individual was  $4.22 \pm 2.398$  (ranging from 0 to 13). Mean food item length was  $12.11 \pm 8.41$  mm (ranging from 0.15 to 53.11), and mean food item width was  $5.02 \pm 2.58$  mm (ranging from 0.18 to 17.38).

We found 19 prey categories and plant material (Table 3), and the total dietary breadth of *E. multifasciata* from the plains of central Vietnam was 8.41 (Simpson's index of diversity); Shannon's evenness was 0.82. The broadest dietary breadth was found at the Huong Tra location (9.36) with an evenness of 0.88; whereas the narrowest dietary breadth was found at the Xuan Phu location (7.36) with an evenness of 0.82 (Table 3). The population in the Quang Dien location showed intermediate dietary breadth (7.91) and evenness (0.81). Skinks of the two populations at the Quang Dien and Xuan Phu consumed food items in 17 categories, while the population at the Huong Tra consumed 16 food categories. All three populations of the lizards from the plains of Thua Thien-Hue Province, central Vietnam, consumed spiders, cockroaches, beetles, true flies, aphids, ants, larvae of insects, butterflies, dragonflies, grasshoppers and crickets, woodlice, earthworms, snails, skinks and small frogs, and plant items, with a combined numeric percentage of approximately 97% (Table 3).

Although the index of diversity of prey categories was larger in males (8.84 with an evenness index of 0.86) than in females (7.97 with an evenness index of 0.82), prey-taxon richness at mid-curve points to late-curve points was higher for females than for males in both frequency ( $F_{1,63} = 0.002$ ,  $P = 0.992$ ; Figure 2A) and number of

Table 2. The dietary composition of *Eutropis multifasciata* ( $n = 152$  stomach contents) in percentage frequency of occurrence (F), number of items (N) and volume (V, mm<sup>3</sup>), and the index of relative importance (IRI) of each taxon, identified for *E. multifasciata* sampled in the plains of central Vietnam. \*Number of stomachs containing food item and  $IRI = (\%F + \%N + \%V)/3$ .

| Prey category                 | Frequency (F) |       | Number (N) |       | Volume (V)           |       | IRI   |
|-------------------------------|---------------|-------|------------|-------|----------------------|-------|-------|
|                               | F*            | %F    | N          | %N    | V (mm <sup>3</sup> ) | %V    |       |
| ARACHNIDA: Araneae            | 160           | 24.69 | 160        | 23.53 | 18,221.2             | 9.26  | 19.16 |
| INSECTA: Blattodea            | 26            | 4.01  | 27         | 3.97  | 8572.9               | 4.36  | 4.11  |
| Coleoptera                    | 26            | 4.01  | 26         | 3.82  | 8325.3               | 4.23  | 4.02  |
| Diptera                       | 12            | 1.85  | 12         | 1.76  | 1429.7               | 0.73  | 1.45  |
| Hemiptera                     | 13            | 2.01  | 13         | 1.91  | 6365.8               | 3.24  | 2.38  |
| Hymenoptera                   | 28            | 4.32  | 29         | 4.26  | 7574.6               | 3.85  | 4.14  |
| Insecta larvae                | 97            | 14.97 | 97         | 14.26 | 43,261.7             | 21.98 | 17.07 |
| Isoptera                      | 2             | 0.31  | 2          | 0.29  | 181.1                | 0.09  | 0.23  |
| Lepidoptera                   | 19            | 2.93  | 19         | 2.79  | 3632.5               | 1.85  | 2.52  |
| Odonata                       | 7             | 1.08  | 8          | 1.18  | 3415.2               | 1.74  | 1.33  |
| Orthoptera                    | 64            | 9.88  | 85         | 12.50 | 33,143.2             | 16.84 | 13.07 |
| Phasmatodea                   | 1             | 0.15  | 1          | 0.15  | 13.5                 | 0.01  | 0.10  |
| MALACOSTRACA:                 | 9             | 1.39  | 9          | 1.32  | 252.7                | 0.13  | 0.95  |
| Decapoda                      |               |       |            |       |                      |       |       |
| Isopoda                       | 28            | 4.32  | 28         | 4.12  | 1217.9               | 0.62  | 3.02  |
| CLITELLATA:                   | 18            | 2.78  | 18         | 2.65  | 6659.6               | 3.38  | 2.94  |
| Lumbriculida                  |               |       |            |       |                      |       |       |
| DIPLOPODA: Julidae            | 4             | 0.62  | 4          | 0.59  | 137.7                | 0.07  | 0.43  |
| GASTROPODA:                   | 77            | 11.88 | 77         | 11.32 | 15,422.9             | 7.84  | 10.35 |
| Achatinidae                   |               |       |            |       |                      |       |       |
| AMPHIBIA: Dicroglossidae      | 2             | 0.31  | 2          | 0.29  | 4558.8               | 2.32  | 0.97  |
| REPTILIA: scincidae           | 6             | 0.93  | 7          | 1.03  | 28,564.7             | 14.52 | 5.49  |
| ANGIOSPERMAE: Plant materials | 49            | 7.56  | 56         | 8.24  | 5828.1               | 2.96  | 6.25  |

items ( $F_{1,66} = 0.025$ ,  $P = 0.881$ ; Figure 2B). Using the rarefaction curves for prey-taxon richness allowed a comparison between the expected number of prey taxa in a fixed number of prey categories by moving vertically through Figure 2A–B at any fixed number of prey items. The comparison can be taken at the point at which the abundance level of the larger sex matches the level in the smaller one. Despite the fact that prey-taxon curves for males and females intersected at a point between 130 and 140 prey items for frequency (Figure 2A) and between 160 and 170 prey items for number of items (Figure 2B), the differences were not significant (all  $P > 0.05$ ), because all the 95% confidence limits of the expected taxon accumulation curves overlapped for the two sexes (Figure 2A–B).

The most abundant prey categories (i.e.  $IRI \geq 10.4$ ) of *E. multifasciata* were spiders, insect larvae, crickets and grasshoppers, and snails, accounting for 61.42% of occurrence frequency, 61.62% of the number of prey items and 55.93% of the total volume, with an IRI of 59.65% (Table 2; Figure 3). Based on the IRI (Table 2), Araneae, Orthoptera, Achatinidae, insect larvae, small

Table 3. Comparison of the dietary breadth, index of evenness and occurrence of prey items, plant materials and unidentified items in *Eutropis multifasciata* in Vietnam. QD = Quang Dien ( $n = 49$ ); HT = Huong Tra ( $n = 47$ ); XP = Xua Phu ( $n = 56$ ). (1) The total number of stomach contents in the current study ( $n = 152$ ) and (2) results referred from the dietary composition of *E. multifasciata* in the Central Highlands of Vietnam ( $n = 149$ ; Ngo et al. 2014).

| Prey and indexes  | Location of the current study |       |       | (1)   | (2)   |
|-------------------|-------------------------------|-------|-------|-------|-------|
|                   | QD                            | HT    | XP    |       |       |
| Niche breadth     | 7.91                          | 9.36  | 7.36  | 8.41  | 9.91  |
| Index of evenness | 0.81                          | 0.88  | 0.82  | 0.82  | 0.82  |
| Araneae           | 18.45                         | 22.89 | 28.86 | 23.53 | 11.90 |
| Blattodea         | 4.29                          | 4.48  | 3.25  | 3.97  | 2.04  |
| Coleoptera        | 2.58                          | 3.48  | 5.28  | 3.82  | 4.09  |
| Dermaptera        | –                             | –     | –     | –     | 2.25  |
| Diptera           | 0.86                          | 1.49  | 2.85  | 1.76  | 0.41  |
| Hemiptera         | 1.29                          | 2.49  | 2.03  | 1.91  | 3.89  |
| Hymenoptera       | 5.58                          | 6.97  | 0.81  | 4.26  | 8.59  |
| Insect larvae     | 21.46                         | 9.95  | 10.98 | 14.26 | 7.36  |
| Isoptera          | 0.86                          | –     | –     | 0.29  | 17.80 |
| Lepidoptera       | 1.29                          | 2.99  | 4.07  | 2.79  | 1.64  |
| Mantodea          | –                             | –     | –     | –     | 0.82  |
| Odonata           | 1.72                          | 0.50  | 1.22  | 1.18  | 0.20  |
| Orthoptera        | 15.02                         | 11.44 | 11.38 | 12.65 | 18.80 |
| Phasmatodea       | –                             | –     | 0.41  | 0.15  | –     |
| Decapoda          | –                             | 1.00  | 2.85  | 1.32  | –     |
| Isopoda           | 4.29                          | 7.96  | 0.81  | 4.12  | 6.54  |
| Lumbriculida      | 0.86                          | 3.98  | 3.25  | 2.65  | 3.48  |
| Haemadipsidae     | –                             | –     | –     | –     | 0.61  |
| Julidae           | 1.72                          | –     | –     | 0.59  | 1.64  |
| Achatinidae       | 11.59                         | 9.45  | 12.60 | 11.32 | 1.02  |
| Vertebrates       | 0.86                          | 1.49  | 1.63  | 1.32  | 1.84  |
| Plant materials   | 7.30                          | 9.45  | 7.72  | 8.09  | 1.02  |
| Unidentified      | –                             | –     | –     | –     | 4.09  |
| Total categories  | 17                            | 16    | 17    | 19    | 24    |

vertebrates and plant materials were the most important food items (IRI  $\geq 6.25\%$ ) in the diet of *E. multifasciata*. Using two-factor MANOVA to examine the effects of season and site on the variance in the volumes of major food items (i.e. IRI  $> 4.0$ ) revealed that volumes of food items varied significantly between seasons (Wilks'  $\lambda = 0.103$ ,  $F_{9,10} = 9.631$ ,  $P = 0.001$ ) but not among sites (Wilks'  $\lambda = 0.168$ ,  $F_{18,20} = 1.602$ ,  $P = 0.154$ ), and that there was no evidence of site–season interaction (Wilks'  $\lambda = 0.226$ ,  $F_{18,20} = 1.227$ ,  $P = 0.327$ ). Prey categories such as Diptera, Hemiptera, Isoptera, Lepidoptera, Odonata, Phasmatodea, Decapoda, Isopoda, Lumbriculida and Julidae were less important in the diet, comprising 16.76% of the total number of prey items with an important index of 15.35%. The remaining prey items, such as Hymenoptera, Coleoptera and Blattodea, were of intermediate importance as prey items, with an important index of 12.28% (Table 2).

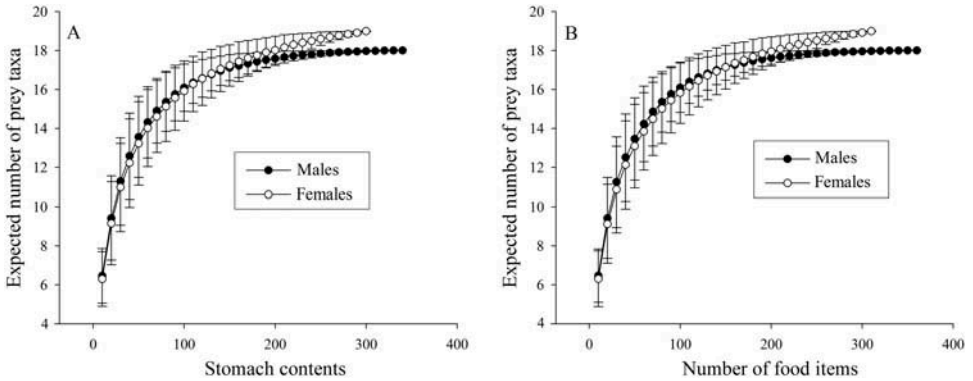


Figure 2. Expected prey-taxon accumulation curves from the data of (A) stomach contents and (B) food item counts consumed by *Eutropis multifasciata* in the plains of central Vietnam. Circles represent the expected mean values, and the graphs show the 95% confidence intervals for male (filled circles) and female (open circles) skins.

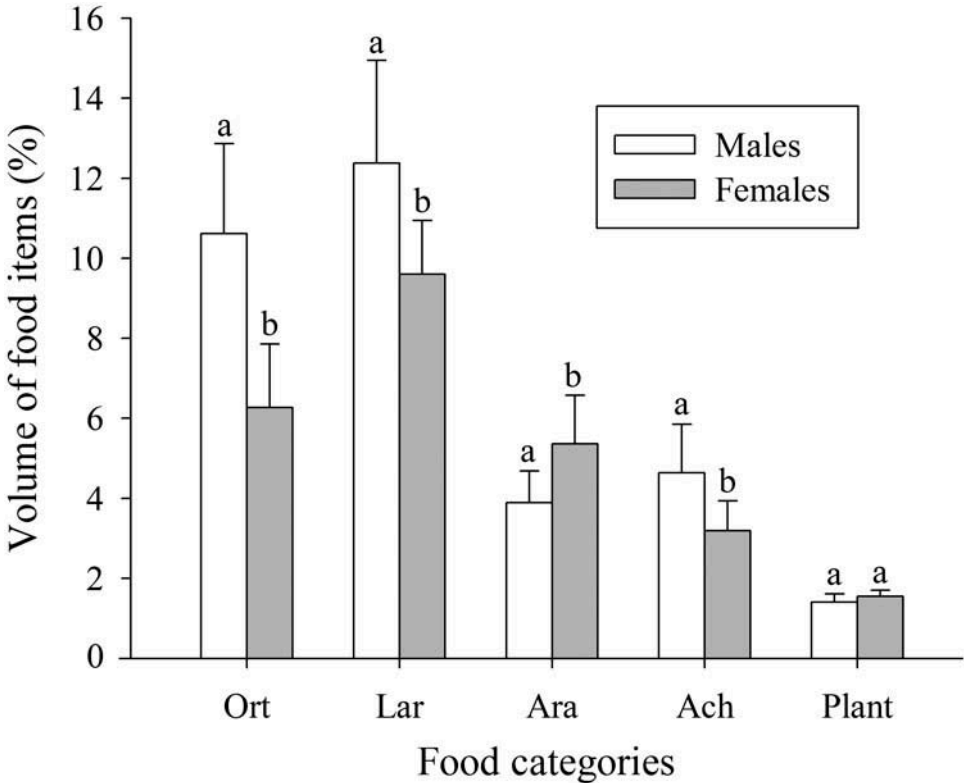


Figure 3. Percent volumes of major food items (mean  $\pm$  standard error, SE) in the diet of *Eutropis multifasciata* from the plains of central Vietnam. Ort = Orthoptera; Lar = insect larvae; Ara = Araneae; Ach = Achatinidae; Plant = plant materials. Different letters above the two lizard groups for the same food item indicate a significant difference ( $P < 0.05$ ) in proportional volumes. The remaining prey categories in Table 2 were excluded from this analysis due to low frequencies of occurrence (i.e. %F < 5%).

Table 4. The volume of food items (V, mm<sup>3</sup>) consumed by male and female *Eutropis multifasciata* from the plains and seasons in central Vietnam.

| Category     | n   | Mean ± SD       | Range         | Total (mm <sup>3</sup> ) |
|--------------|-----|-----------------|---------------|--------------------------|
| Males        | 80  | 1360.1 ± 3027.7 | 26.7–26,384.4 | 108,806.9                |
| Females      | 72  | 1221.8 ± 1193.1 | 58.3–4727.3   | 87,971.9                 |
| Rainy season | 331 | 215.3 ± 658.6   | 0.01–8144.9   | 71,247.6                 |
| Dry season   | 349 | 359.7 ± 790.2   | 0.01–11,221.0 | 125,531.2                |
| Quang Dien   | 240 | 1780.9 ± 3821.4 | 0.01–11,221.0 | 87,263.3                 |
| Huong Tra    | 203 | 1296.6 ± 1192.3 | 26.7–8144.9   | 60,939.6                 |
| Xuan Phu     | 237 | 867.4 ± 829.9   | 70.6–4308.5   | 48,575.9                 |

Note: SD = standard deviation.

Average volume per male individual was  $1360.1 \pm 3027.7$  mm<sup>3</sup>, compared to  $1221.8 \pm 1193.1$  mm<sup>3</sup> in females (Table 4). Width and volume of food items consumed by males were significantly different to those of females (width:  $F_{1,679} = 9.983$ ,  $P = 0.002$ ; volume:  $F_{1,679} = 8.674$ ,  $P = 0.003$ ; Table 4); whereas length of food items consumed did not differ significantly between males and females ( $F_{1,679} = 3.004$ ,  $P = 0.084$ ). The total volume of food items consumed in the dry season was larger than in the rainy season (Table 4). The size (length and width) and volume of food items were significantly different between seasons (length:  $F_{1,679} = 15.393$ ,  $P < 0.001$ ; width:  $F_{1,679} = 85.042$ ,  $P < 0.001$ ; volume:  $F_{1,679} = 50.314$ ,  $P < 0.001$ ; Table 4). Size and volume of food items also differed significantly among localities (length:  $F_{2,679} = 8.493$ ,  $P < 0.001$ ; width:  $F_{2,679} = 24.632$ ,  $P < 0.001$ ; volume:  $F_{2,679} = 23.042$ ,  $P < 0.001$ ; Table 4).

In both seasons, we observed the foraging behaviour of *E. multifasciata* in the field. A total of 678.3 min (47 individuals with 418.5 min in the dry season and 36 individuals with 259.8 min in the wet season) was observed to calculate the foraging mode of skinks. In the rainy season, the percentage of time spent hunting prey was 63.8% compared to 75.2% in the dry season. The percentage of time spent basking was 9.5% in the dry season compared with 20.7% in the rainy season. The percentage of time spent in the 'sit-and-wait' foraging mode was low for both the dry (4.2%) and wet (7.2%) periods. Other behaviours of skinks were 8.3% in the rainy season and 11.2% in the dry season. Therefore, the foraging behaviour of *E. multifasciata* in this region best fits a 'widely foraging' or 'active forager' model with 69.5% of individuals falling into that category compared with only 5.7% 'sit-and-wait' or basking in the sun (with 15.1%); the percentage of time used for other behaviours was 9.7%.

There was a significant correlation between MW and prey width consumed ( $r = 0.182$ ,  $P = 0.027$ ); whereas neither MW and prey length nor MW and prey volume were significantly correlated (length:  $r = 0.083$ ,  $P = 0.335$ ; volume:  $r = 0.071$ ,  $P = 0.392$ ). Positive correlations between SVL and prey sizes were similar to those found between MW and prey sizes (between SVL and prey length:  $r = 0.112$ ,  $P = 0.183$ ; between SVL and prey width:  $r = 0.165$ ,  $P = 0.045$ ; and between SVL and prey volume:  $r = 0.073$ ,  $P = 0.379$ ). SVL and MW are considered the predictor variables in the diet, because there were strong positive correlations between the morphological measurements (between SVL and MW:  $r = 0.775$ ,  $P < 0.001$ , Figure 4A; between MW and BM:  $r = 0.793$ ,  $P < 0.001$ , Figure 4B; and between

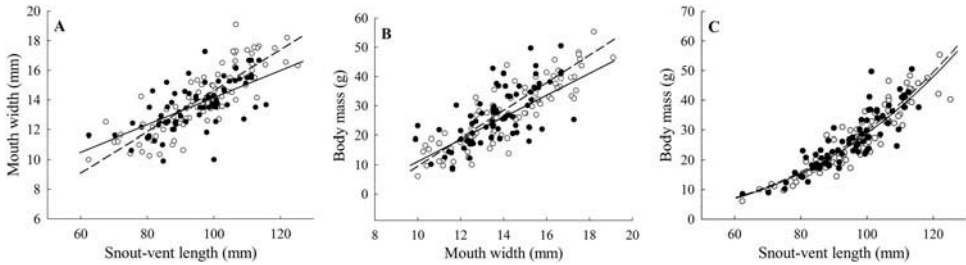


Figure 4. Dispersion diagrams from Pearson's correlations between (A) snout-vent length and mouth width ( $r = 0.775$ ,  $P < 0.001$ ), (B) mouth width and body mass ( $r = 0.775$ ,  $P < 0.001$ ) and (C) snout-vent length and body mass ( $r = 0.902$ ,  $P < 0.001$ ), of male (open circles and broken lines) and female (filled circles and solid lines) *Eutropis multifasciata* in the plains of central Vietnam.

SVL and BM:  $r = 0.902$ ,  $P < 0.001$ , Figure 4C). Results of multiple linear regressions between prey size (length, width and volume) and body size (SVL, BM and MW) were not significant (prey length:  $r^2 = 0.031$ ,  $F_{3,151} = 1.612$ ,  $P = 0.191$ ; prey width:  $r^2 = 0.041$ ,  $F_{3,151} = 2.104$ ,  $P = 0.102$ ; prey volume:  $r^2 = 0.021$ ,  $F_{3,151} = 1.034$ ,  $P = 0.383$ ).

The results of multiple regressions for possible effects of temperature, moisture and precipitation on prey size (length, width and volume) were significant (prey length:  $r^2 = 0.308$ ;  $F_{3,151} = 21.932$ ,  $P < 0.001$ ; prey width:  $r^2 = 0.224$ ;  $F_{3,151} = 14.213$ ,  $P < 0.001$ ; prey volume:  $r^2 = 0.136$ ;  $F_{3,151} = 7.764$ ,  $P < 0.001$ ). Of these three, temperature had the largest effect on prey sizes. The multiple regression results for the effects of temperature, relative humidity and precipitation on the number of food items indicated no significant effect (overall:  $r^2 = 0.022$ ;  $F_{3,151} = 1.112$ ,  $P = 0.346$ ; temperature:  $r^2 = 0.023$ ;  $F_{1,151} = 3.362$ ,  $P = 0.069$ ; relative humidity:  $r^2 = 0.006$ ;  $F_{1,151} = 0.964$ ,  $P = 0.329$ ; precipitation:  $r^2 = 0.004$ ,  $F_{1,151} = 0.582$ ,  $P = 0.447$ ).

## Discussion

In general, these data support prior studies indicating that *E. multifasciata* feeds primarily on spiders, insect larvae and grasshoppers (Truong 2005; Le 2008; Ngo et al. 2014). The occurrence of snails and plant items in the diet of *E. multifasciata* represents the first report of such large food items consumed by *Eutropis* (*E. longicaudata* and *E. macularia*). We considered plant materials as food items of *E. multifasciata* because this species has been observed to consume a large number of plant categories such as banana, rice, papaya and raspberry seeds, under artificial feeding conditions (Phung 2013). Plant items were also found in stomachs of other skinks belonging to the genus *Eutropis*, such as the long-tailed sun skink, *Eutropis longicaudata*, and the bronze grass skink, *Eutropis macularia* (Truong 2005, 2013; Le 2008; Phung 2013). This evidence reveals that *E. multifasciata* is an omnivorous species.

Another study from the Central Highlands of Vietnam indicated that termites were the dominant prey item consumed by *E. multifasciata* at one locality (Ngo

et al. 2014), which implies that *E. multifasciata* may specialise on particular prey taxa within parts of its distribution. Other skinks of *Eutropis* (formerly *Mabuya*) such as *Eutropis arajara* from the Araripe Plateau, Northeastern Brazil, and *Eutropis triata* in Zambia, Africa, also specialise on termites (Simbotwe and Garber 1979; Ribeiro et al. *Forthcoming*); while two other studies on the diet of *E. longicaudata* from Orchid Island, Taiwan, and *E. macularia* in Buon Don District, Dak Lak Province, Vietnam, did not show evidence of termite consumption (Huang 2006; Truong 2013).

Previous studies show that lizard species inhabiting tropical and moderate regions mainly eat insects and several other invertebrates (Truong 2005; Reilly et al. 2007; Le 2008). We found that spiders, insect larvae, snails, grasshoppers and crickets were the most important prey categories for the populations that we studied. Araneae, Achatinidae and Orthoptera are very abundant in the habitats occupied by *E. multifasciata* (Table 5) and are certainly prey items for *E. multifasciata*. The specialisation by *E. multifasciata* on spiders, insect larvae, snails and orthopterans could be a response to natural fluctuations in prey populations. Recent studies on the diet of lizards indicated that variation among diets of populations may be due to the difference in lizards' sizes and prey availability in the habitat (Truong 2005; Reilly et al. 2007; Le 2008; Ngo et al. 2014). Besides prey categorised as invertebrates, *E. multifasciata* consumed vertebrate prey such as dicroglossid frogs and small skinks.

Skinks in this study showed sexual size dimorphism (SSD) between adult males and females. Adult males had larger average SVL, TL, MW and BM than did adult females. These results are consistent with the data reported in skinks and in many other lizard species worldwide (Clemann et al. 2004; Schwarzkopf 2005; Huang 2006; Ji et al. 2006; Gifford and Powell 2007). The data for SSD in *E. multifasciata* of this study are similar to those reported for *Mabuya*

Table 5. Richness of potential prey available in the habitat of *Eutropis multifasciata* in the plains of central Vietnam shows that spiders, grasshoppers and crickets, snails and wood lice were the most abundant prey in the study sites. QD = Quang Dien; HT = Huong Tra; XP = Xuan Phu. \*Including Diptera, Hemiptera, Odonata and Phasmatodea.

| Prey              | QD    | HT    | XP    | Total region |
|-------------------|-------|-------|-------|--------------|
| Achatinidae       | 12.62 | 14.60 | 12.16 | 13.07        |
| Araneae           | 23.03 | 25.66 | 22.97 | 23.79        |
| Blattodea         | 5.36  | 5.31  | 9.46  | 6.54         |
| Coleoptera        | 4.42  | 10.62 | 9.91  | 7.84         |
| Hymenoptera       | 3.47  | 0.88  | 3.15  | 2.61         |
| Insect larvae     | 1.58  | 0.44  | 3.15  | 1.70         |
| Isopoda           | 16.72 | 15.49 | 9.91  | 14.38        |
| Julidae           | 1.26  | –     | 2.70  | 1.31         |
| Lepidoptera       | 2.52  | 1.77  | 4.95  | 3.01         |
| Lumbriculida      | 3.79  | 3.54  | 2.70  | 3.40         |
| Orthoptera        | 21.77 | 20.80 | 17.12 | 20.13        |
| Other categories* | 3.47  | 0.88  | 1.80  | 2.22         |
| Total             | 100   | 100   | 100   | 100          |



*multifasciata* in China (Ji et al. 2006), but contrast with those reported for the two viviparous lizards, *Sphenomorphus indicus* (Ji and Du 2000) and *Phrynocephalus vlangalii* (Zhang et al. 2005), in which adult females are the larger sex.

In both seasons, we observed the foraging behaviour of *E. multifasciata* in the field, and the foraging mode of skinks appears to fit the widely foraging model. They tend to unpredictably consume small, sedentary and clumped prey (e.g. spiders, snails and grasshoppers). This foraging mode is similar to that reported in some lizard species such as *Aspidocelis tigris*, *Dipsosaurus dorsalis*, *Eulamprus heatwolei*, *Eumeces fasciatus*, *Gallotia galloti*, *Podarcis lilfordi*, *Psammodromus algirus* and *Varanus exanthematicus* (Reilly et al. 2007).

For most reptile species inhabiting tropical regions, fewer animals are captured during the wet season compared to the dry season (Reilly et al. 2007; McConnachie et al. 2009; Vitt and Caldwell 2009). In this study, we collected relatively equal proportions in both dry (87 stomachs) and wet (74 stomachs) seasons, with a relatively equal proportion between the sexes (75 stomachs in females and 86 stomachs in males). On average, prey size and volume consumed by males was larger than for females, and prey volume in the dry season was larger than in the wet season. In fact, this species reproduces in the dry season (Lin et al. 2008; Phung 2013; Truong 2013). Pregnancy impairs feeding performance and locomotion in adult females, but such impairments do not persist after parturition (Lin et al. 2008). In many lizard species, there is a positive correlation between body size (mouth width and snout-vent length) and prey size (Reilly et al. 2007; Truong 2013). Experimental studies on *E. multifasciata* and other lizards suggest that the size of the meal in *ad libitum* conditions is related to mouth width and the stomach capacity of lizards, and that the urge to eat is largely conditioned by daily and annual rhythms (Reilly et al. 2007; Le 2008; Truong 2013).

Although both the index of diversity and the evenness index of prey categories were larger in males than in females, one striking result of an examination of the rarefaction curves is that females have the higher curves (prey-taxon richness per fixed number of individuals is higher in this sex) for frequency after between 130 and 140 prey items, and for number of items after between 160 and 170 prey items. This is because new prey categories became progressively relatively rarer in males, while prey items were added at a constant ratio for both sexes (Sanders 1968; Simberloff 1972). One essential problem in community ecology that frequently appears in comparing the samples of communities is that they are based on different sample sizes (Sanders 1968; Hurlbert 1971; Simberloff 1972; Magurran 2004). In fact, to compare community samples, we do not know immediately which community has higher species richness if we only know the number of species and the number of individuals in each collection. One way to overcome this problem is to standardise all samples from different communities to a common sample size of the same number of individuals (Krebs 1999). Therefore, using the rarefaction method (rarefaction curves) for prey-taxon richness could allow for comparisons in terms of the expected number of prey taxa in a fixed number of prey categories. This comparison is appropriate because sampling methods are similar for two samples.

Summarising, the common sun skink *E. multifasciata* is an omnivorous species. The most common prey items of this species were spiders (Araneae), insect larvae, grasshoppers and crickets (Orthoptera), and snails (Achatinidae). Our present study documents one of the most diverse diets for tropical skinks ever recorded

(Simbotwe and Garber 1979; Vrcibradic and Rocha 1996; Huang 2006; Rocha et al. 2009; Ribeiro et al. *Forthcoming*). Both the index of diversity and the index of evenness of prey categories were higher in males than in females. The average volume of food items of each skink was higher in males than in females, and the total volume of food items consumed by skinks in the dry season was larger than in the rainy season. Ambient temperature, relative humidity and rainfall significantly influenced the size of prey items and volume consumed by skinks.

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