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Interspecific Differences in Diet between Introduced Red-eared Sliders and Native Turtles in China

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Abstract Although the alien Red-eared slider (*Trachemys scripta elegans*) is generally argued as an invasive species that competes with native turtles, the field evidence on its diet is controversial. Field studies conducted at the Gutian Nature Reserve of Guangdong and along the Wanquan River in Hainan, China show that *T. s. elegans* is an opportunitic omnivore, consuming a wide variety of food items. Consumption varies throughout its range; more plant material is consumed in Guangdong, compared to a more carnivorous diet in Hainan; and juveniles are also found to have a more carnivorous diet than adults. This implies a high adaptability to new environment. Sympatric native *Mauremys sinensis* shows a more herbivorous diet and a narrower niche breadth (0.0260) in Hainan, plus a low niche overlap (0.3048) with *T. s. elegans*, providing a potential empty niche for the invasive *T. s. elegans*. Red-eared slider is also known to consume large quantities of native prey species to disrupt the ecological balance. It is imperative to understand the invasive nature of this species and the mechanisms by which it affects native ecology.

Keywords invasive species, food habit, Gutian Nature Reserve, *Trachemys scripta elegans*, *Mauremys sinensis*

1. Introduction

Red-eared slider, *Trachemys scripta elegans*, is a common invasive species of freshwater turtle originating from the Mississippi Valley of Central-South United States of America. It has been widely introduced to 62 countries of six continents around the world (Global Invasive Species Database, 2011).

Two species competing for the same resources cannot coexist if other ecological factors are constant, leading to either the extinction of one competitor or an evolutionary or behavioral shift towards a different ecological niche (Gause, 1934). For example, leopard cat (*Prionailurus bengalensis*) coexists with other sympatric carnivores by eating more birds in Japan (Masaya and Teruo, 1994). However, native species do not share a co-evolutionary history with alien species. For example, an invasive weevil can replace native floral herbivores by out-competing for resources (Louda *et al*., 2011), or feral cats which prefer rodents, does not threaten the indigenous insectivorous fox (*Urocyon littoralis*) (Pillips *et al*., 2007).

Experimental studies suggest that the introduced *T. s. elegans* shows a more aggressive eating behavior than the native turtles in Europe (Polo-Cavia *et al*., 2010). However, field evidence from different areas makes this a controversial claim. Lee and Park (2010) think that *T. s. elegans* co-inhabits and shares dietary items with native *Mauremys reevesii* and *Pelodiscus sinensis* in South Korea. But Chen (2006) did not find clear evidence to claim that *T. s. elegans* competed for food resources with sympatric turtles (*Mauremys sinensis* and *M. mutica*). The studies in northern Taiwan, China indicate that *T. s. elegans* ingests animal material more frequently than plants (Chen and Lue, 1998a), but Cadi and Joly (2003) believe it forages mainly on plants in France, then Prevot-Julliard *et al.* (2007) revised this, stating that *T. s. elegans* adults are omnivorous and occasionally act as a

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necrophagous species.

Mauremys spp. form the predominant part of the chelonian fauna of China, play an important role in Chinese culture as food, pets, traditional medicine, and mascots (Lau and Shi, 2000). Since 1980 a massive scale of turtle farming has developed to breed the animals of this genus successfully (Shi *et al.*, 2008), but the wild populations have declined dramatically at the same time. At present, all the members of this genus are listed as endangered in the IUCN Red List. *M. sinensis,* formerly known as *Ocadia reevesii* (Spinks *et al.*, 2004; Feldman and Parham, 2004), is a native freshwater turtle ranging from Taiwan, Hainan and mainland provinces in southeastern China to northern Vietnam (Shi, 2008). The published field data of *M. sinensis* were not available for mainland provinces until now. However, some studies were done in Taiwan, China: Chen and Lue (1998b) reported an intensive study, including population, reproduction and diet; Chen and Lue (1999) reported the dietary differences between sexes, ages and seasons; Chen and Lue (2008) studied the home range and movement; Chen and Lue (2009) studied the population structure, dietary change after human disturbance; and Chen and Lue (2010) provided the data on the population status and distribution in Taiwan.

There is an increasingly wide distribution of *T. s. elegans* found throughout China (Liu *et al.* 2011). Our field studies were conducted from September 2010 to November 2011 at the Gutian Nature Reserve in Guangdong, and from August 2011 to January 2013 along the Wanquan River in Hainan. The studies allow us to understand the food habits of *T. s. elegans* and sympatric *M. sinensis*, and show the adaptation of the invasive *T. s. elegans* and its impact on native species in China.

2. Materials and Methods

The Gutian Nature Reserve (23°06' N, 114°47' E) of Huidong County in Guangdong is designed to protect monsoon evergreen forest. A large number of *T. s. elegans* were released into a stream within the Nature Reserve a few years ago, and they have survived successfully there. Although this Nature Reserve is located in subtropical zone, all turtles still hibernate during winter. Also, a 19.9 ha island in the Wanquan River near Qionghai City (19°15' N, 110°27' E) in Hainan was chosen for this study. This section of the river is actually a big reservoir because of a dam downstream, and the island in this part of the river has a natural lake of 1.9 ha. Contrastingly, this region belongs to tropical monsoon climate, and therefore turtles generally do not hibernate during winter.

Turtles were caught by hand using baited hoop traps. The species, sex, age, length and weight of each collected turtle were recorded. Females are sexually matured at a carapace length (CL) > 160 mm, while males matured at a CL > 100 mm (Gibbons, 1990). Individuals smaller than CL < 100 mm and without male secondary sexual characteristics were designated as juveniles (Chen and Lue, 1998a).

Eighty-four *T. s. elegans* (including 57 females, 25 males and two juveniles) were studied in Guangdong, 138 *T. s. elegans* (90 females, 22 males and 26 juveniles) and 21 *M. sinensis* (nine females, 10 males and two juveniles) were studied in Hainan.

Frequency of occurrence of food items for *T. s. elegans* was obtained from analysis of 59 fecal samples and dissection of 21 stomach samples at Gutian, Guangdong. The quantitative dietary habits were studied in Hainan with stomach flushing technique (Parmenter and Avery, 1990) from 118 newly caught sliders and 17 Chinese stripe-necked turtles, and also through dissection of 20 *T. s. elegans* and four *M. sinensis* that died naturally or drowned in fishermen's traps. As it is difficult to pull the neck of some *M. sinensis* out of their shells to insert a tube into the stomach, anesthetization [tiletamine-zolazepam (Zoletil®) 2.5 mg/kg following the package insert] was used. Stomach contents were identified to the lowest taxon where possible. Most food items were highly fragmented and digested, and the quantity of each item from a stomach sample could be very little. Due to the difficulty in measuring the number and volume of items, we measured them by fresh weight, which could be given to the nearest 0.01 g using an electronic balance.

The items found in less than 1% of samples were disregarded as insignificant and were excluded from subsequent analyses. Frequency of occurrence (F_i) and

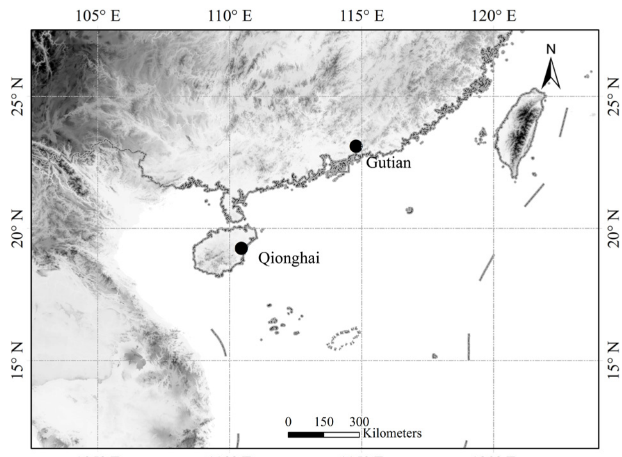

Figure 1 Map of the study areas.

weight percentage (W_i) of each item were recorded, and these data were combined to form an index of relative importance (Bjorndal *et al*., 1997):

$$IRI = \frac{100 F_i W_i}{\sum (F_i W_i)} \quad (1)$$

Levin's (1968) index of niche breadth and Pianka's (1973) index of niche overlap of food resources were estimated. P_i equals to the percentage of *IRIi*,

$$P_i = IRIi/100 \quad (2)$$

$$\text{Levin's index: } B = \frac{1}{\sum p_i^2} \quad (3)$$

$$\text{Standardized Levin's index: } B' = \frac{B-1}{n-1} \quad (4)$$

where *n* means the number of categories of food items.

$$\text{Pianka's index: } O_{jk} = \frac{\sum P_{ij} P_{ik}}{\sqrt{\sum P_{ij}^2 \sum P_{ik}^2}} \quad (5)$$

where P_{ij} means the P_i of species $_j$, and P_{ik} means the P_i of species$_k$.

For a large number of categories of food items, they were combined as animal or vegetative; then their qualitative occurrence in each stomach sample was evaluated as 1, and the absence 0. Chi-square tests among season, sex, age and species were run for animal and plant items on frequency. A Shapiro-Wilk test was used to test the normality of quantitative data of weight percentage of animals and plants consumed, and all the data are abnormality. Nonparametric Mann-Whitney *U*-test and Kruskal-Wallis *H*-test were used for data from two and multiple groups, respectively.

This work was carried out in compliance with the current laws on animal welfare and research in China. Furthermore, statistics were performed in Microsoft Excel 2003 and SPSS 13.0.

3. Results

3.1 Diet of *T. s. elegans* in Guangdong Thirty-eight taxa, 21 plant and 17 animal species, were detected and identified as prey diets. By the order of frequency, Gramineae (four species, 42.5%), Osteichthyes (four species, 36.6%), Athyriaceae (*Callipteris esculenta*, 30.5%), Insecta (six species, 30.5%) and Amaranthaceae (alligator weed *Alternanthera philoxeroides* and *Celosia argentea*, 19.5%) are the most common food diets for *T. s. elegans*, followed by Umbelliferae (*Oenanthe rosthornii* and *Hydrocotyle sibthorpioides*, 4.9%), Acanthaceae (*Hygrophila salicifolia*, 4.9%), Commelinaceae (dayflower *Commelina communi*, 3.7%), Theaceae (*Eurya thunb*, 3.7%), Moraceae (*Ficus variolosa*, 3.7%), Onagraceae (*Ludwigia hyssopifolia*, 3.7), Caesalpiniaceae (*Caesalpinia crista*, 2.4%), Primulaceae (*Lysimachia fortunei*, 2.4%), Cyperaceae (2.4%), lizards (*Sphenomorphus indicus*, 2.4%) and snakes (two species, 2.4%), and then the lowest, Oxalidaceae (*Oxalis corniculata*, 1.2%), Epuisetaceae (*Scorzonera albicaulis*, 1.2%), Polygonaceae (*Polygonum lapathifolium*, 1.2%), Lygodiaceae (*Lygodium scandens*, 1.2%) and Gastropoda (snail *Crown conchs*, 1.2%).

There was a very significant difference (Chi-square test χ^2 = 24.786, *df* = 1, *P* = 0.001) in the frequency ratio between feeding on animal (70.7%) and plant (91.5%) materials using Chi-square test, while no significant difference between males (n = 25) and females (n = 57) in the frequency ratio of animal (χ^2 = 0.764, *df* = 1, *P* = 0.378) or plant food materials (χ^2 = 0.913, *df* = 1, *P* = 0.333). No comparison was conducted between adults and juveniles because of the small juvenile sample size (n = 2).

3.2 Diet of *T. s. elegans* and *M. sinensis* in Hainan Forty prey taxa were obtained from 138 samples of *T. s. elegans*, consisting of 20 animal and 20 plant materials, including native Gastropoda (four snail species, 55.1%), Osteichthyes (fish, 42.0%), Gramineae (three species, 41.3%), Caridea (shrimp *Macrobrachium hainanense*, 13.8%), Brachyura (crabs, 6.5%), apple snail (*Pomacea canaliculata*, 5.8%), unknown plants (5.1%), Insecta (three species, 3.6%), Pontederiaceae (water hyacinth *Eichhornia crassipes*, 3.6%), Pelecypoda (six shell species, 2.9%), Moraceae (*Ficus heterophylla*, 2.2%), slider turtle scutes (2.2%), Commelinaceae (Dayflower *Commelina paludosa*, 1.4%), Mammalia (rodents, 1.4%), Convolvulaceae (water spinach *Ipomoea aquatica*, 1.4%), Onagraceae (*Ludwigia octovalvis*, 1.4%), Unknown animal (1.4%), Aves (birds, 0.7%), Araceae (taro *Colocasia esculenta* and water lettuce *Pistia stratiotes*, 0.7%), Fabaceae (*Pongamia pinnata* and *Pterocarpus indicus*, 0.7%), Amaranthaceae (*Alternanthera philoxeroides* and *A. pungens*), Euphorbiaceae (*Phyllanthus niruri*), Lemnaceae (*Lemna minor*) and Umbelliferae. Some impurities such as stones, hooks, plastic, cloth and paper were also found.

Twenty-one *M. sinensis*, consumed 10 taxa of prey, mainly including Gramineae (57.1%), Convolvulaceae (water spinach, 14.3%), unknown plants (14.3%), and occasionally Caridea (shrimp, 14.3%), native Gastropoda (snails, 9.5%), Osteichthyes (fish, 9.5%), Commelinaceae (dayflower, 9.5%), Amaranthaceae (Alligator weed, 4.8%), apple snail (4.8%) and Aves (birds, 4.8%).

Trachemys s. elegans consumed more animals (92.0%) than plants (52.9%, χ^2 = 52.948, *df* = 1, *P* = 0.000), while *M. sinensis* preferred more plants (100%) than animals (42.1%, χ^2 = 9.867, *df* = 1, *P* = 0.002; Figure 2). Additionally, the Chi-square test between the two species showed significant difference (χ^2 = 32.604, *df* =1, *P* = 0.000).

The weight percentage of animals (79.7%) was dominant in the diet of *T. s. elegans*, whereas plants (87.3%) form the majority for *M. sinensis* (Figure 3). There are significant differences between animal and plant consumption within the diets of *T. s. elegans* (*Z* = −10.930, *P* = 0.000) and *M. sinensis* (*Z* = −5.101, *P* = 0.000), and also between the two species (*Z* = −6.178, *P* = 0.000) by the use of Mann-Whitney *U*-test.

The index of relative importance combines the data of frequency and weight percentage, and implies similar results (Figure 4). The most important items consumed by *T. s. elegans* were native snails (44.6%) and fish (33.1%), while grass made up the majority (81.3%) of the diets of *M. sinensis*.

Standard Levin's index of niche breadth of *T. s. elegans* is 0.1091 and that of *M. sinensis* is 0.0260. Pianka's index of niche overlap between the two species is 0.3048.

3.3 Intraspecific differences in diets of *T. s. elegan*s in Hainan There were 138 samples for *T. s. elegan*s from Hainan consisting of 26 juveniles, 41 sub-adults and 71 adults (90 females and 22 males). Among the females, there were 36 sub-adults and 54 adults, with the latter samples being divided into 30 in the wet season and 24 in the dry season. Of the males, there were five sub-adults and 17 adults.

The Chi-square tests of frequency showed no differences between seasons (χ^2 = 0.523, *df* = 1, *P* = 0.770) within female adults and between female and male adults (χ^2 = 0.829, *df* = 1, *P* = 0.363). Mann-Whitney *U*-tests of weight percentage suggested no difference between seasons (*Z* = −1.289, *P* = 0.198) within female adults and between sexes (*Z* = −0.513, *P* = 0.608) within adults. However, there were significant differences among ages on the frequency (χ^2 = 6.608, *df* = 2, *P* = 0.005) and weight percentage (Kruskal-Wallis *H*-test χ^2 = 2.305, *df* = 2, *P* = 0.000). Juveniles ate more animals (100% in frequency, 91.7% in weight percentage) than sub-adults (92.7%, 84.0%) and adults (88.7%, 72.8%).

4. Discussion

4.1 Diet of *T. s. elegans* Thirty-eight prey items were found from *T. s. elegan*s in Gutian, Guangdong and 40 items in Qionghai, Hainan. Hart (1983) identified 38 taxa of food items from *T. s. elegans* in Louisiana, USA. Eight items (Chen and Lue, 1998a) and 12 items (Chen, 2006) of prey were found from *T. s. elegans* in Taiwan at

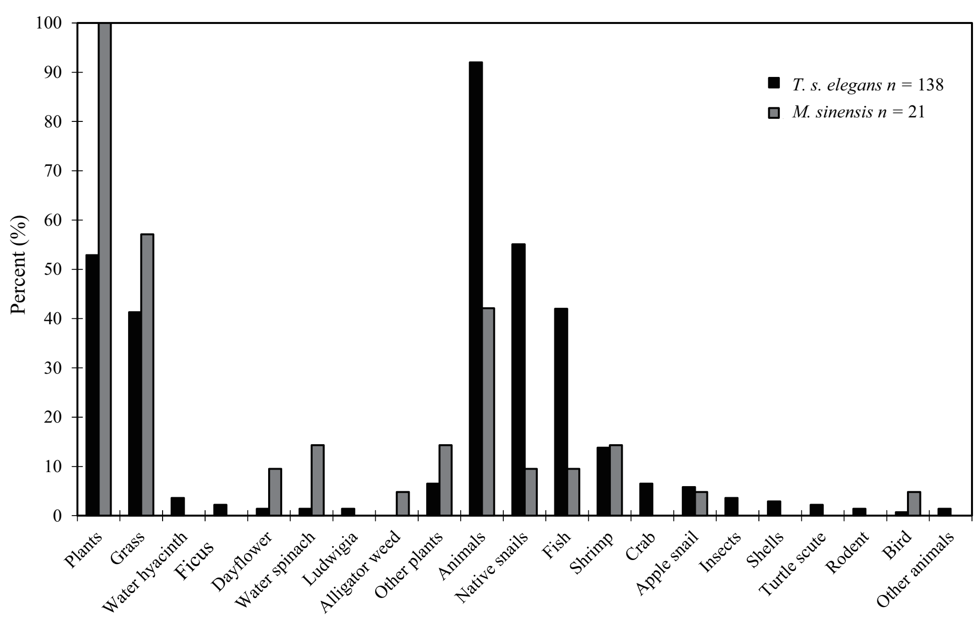

Figure 2 Frequencies of food items of *T. s. elegans* and *M. sinensis*.

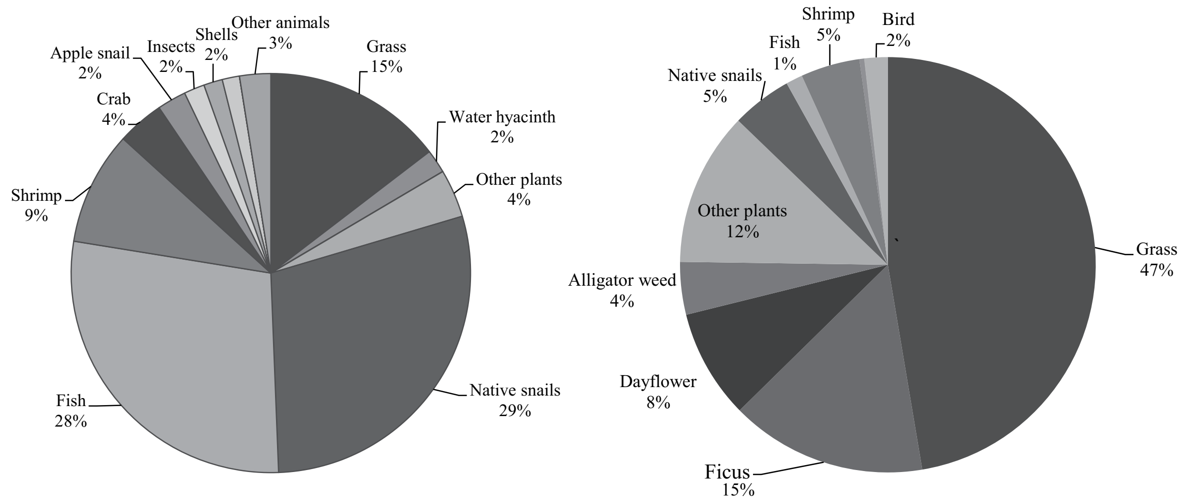

Figure 3 Weight percentages of food items of *T. s. elegans* and *M. sinensis*.

different periods of time. Cadi and Joly (2003) obtained two categories and Prevot-Julliard *et al.* (2007) eight categories of food items from this turtle in France. Lee and Park (2010) described only four food items from the animal in South Korea. Our results are nearly equal to the report from the native range, and much higher in number than other studies in introduced areas, that is, 14 families of plants: Athyriaceae, Amaranthaceae, Umbelliferae, Acanthaceae, Theaceae, Moraceae, Caesalpiniaceae, Primulaceae, Oxalidaceae, Epuisetaceae, Lygodiaceae, Convolvulaceae, Fabaceae, and Euphorbiaceae, and three sorts of animals: apple snail, lizard, rodents, are first reported as prey for *T. s. elegans*.

There is a significant difference between the frequency and weight percentage of animal and plant food items in both Guangdong and Hainan, but more plant items are eaten in Guangdong, while more carnivorous behavior appears in Hainan, which is similar to the results of other studies (Cadi and Joly, 2003; Prevot-Julliard *et al.,* 2007; Chen, 2006; Lee and Park, 2010). It demonstrates Parmenter and Avery (1990)'s description that the red-eared slider is an opportunistic omnivore, consuming a wide variety of invertebrates, vertebrates, and plants in its native range.

No differences are found between different seasons and sexes, but young *T. s. elegans* take more animal material than older ones. Also in its natural home range, young individuals tend to be carnivorous, but adults switch to omnivorous (Hart, 1983). Parmenter and Avery (1990) suppose that the demand for amino acids is probably greater for faster-growing juveniles; small turtles, having less mass, use less total energy than large adults in pursuit of a same animal prey.

The increase in food menu and shift of diet among different ages and areas imply a high adaptability to the new environment, which may lead to its successful invasion.

4.2 Diet of *M. sinensis* Gramineae, mainly reed (*Phragmites karka*), is the most important part (IRI 81.3) of 10 taxa of prey items (n = 21) in Hainan, and 22 taxa were found from *M. sinensis* in northern Taiwan (Chen and Lue, 1999, 2009), which may be due to a relatively larger sample size (n = 136). Nevertheless, two families of plants: Convolvulaceae (water spinach) and Amaranthaceae (alligator weed), and four sorts of animals: shrimp, native snails, apple snail and birds, are first reported for *M. sinensis*.

Our results conclude that native stripe-necked turtles are more herbivorous in Hainan. However, Chen and Lue (1998b, 1999) show that the diet composition is varied by sexes and seasons; females shift from an omnivorous to a herbivorous diet as they are growing, and they consume more plant materials compared to males; animal materials contribute more to cool season diets. Plant materials assume greater importance than they had prior to the habitat disturbances (Chen and Lue, 2009). No intraspecific analysis was conducted in our study due to limited sample size (n = 21), because of the small population size of native *M. sinensis*.

4.3 Interaction between *T. s. elegans* and native species Niche breadth of *T. s. elegans* (0.1091) is wider than that of *M. sinensis* (0.0260), and niche overlap between the two species is 0.3048. These low values show there is a possible vacant niche in nutrition resources, and empty niche hypothesis (Elton, 1958) suggests it contributes to

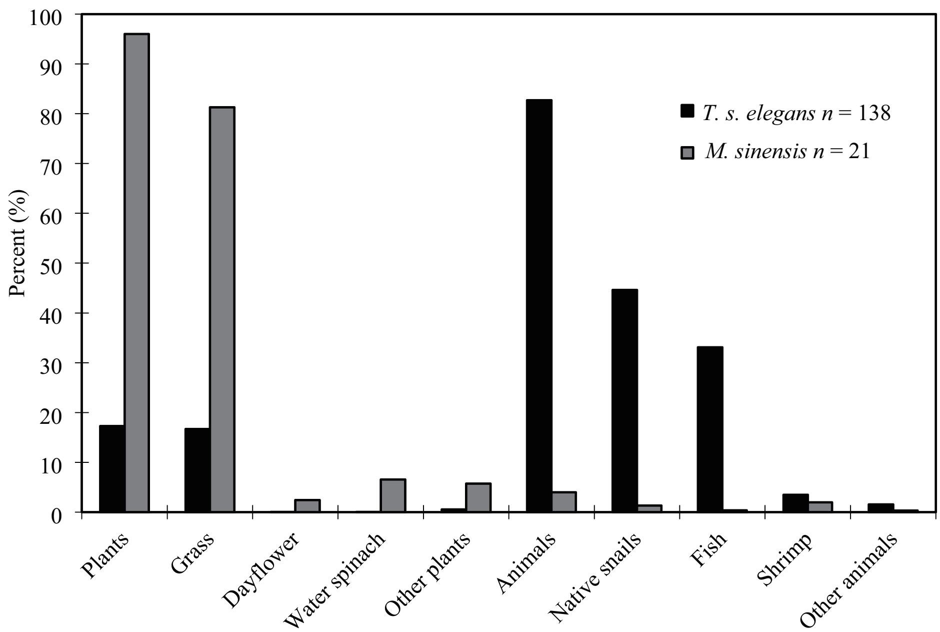

Figure 4 Indexes of relative importance of food items of *T. s. elegans* and *M. sinensis*.

success of invaders. All of the food items consumed by *M. sinensis* could be found in the menu of *T. s. elegans*, and if the feral population of *T. s. elegans* grows rapidly and exceeds the carrying capacity of environment, potential competition may take place with native turtle species.

Although *T. s. elegans* eats some invasive species, such as apple snail and water hyacinth, most of its diet consists of native species. Our study in Hainan shows that native snails are the most important food (IRI 44.6) for *T. s. elegans*, while snail (*Physa acuta*) presents 82.0% in frequency of its diets in Taiwan, China (Chen and Lue, 1998a). Lee and Park (2010) found turtles forage mainly on water snails in South Korea too, but snail (*Crown conchs*) was found only once during our study in Gutian, Guangdong. However, *C. conchs* is distributed abundantly in streams within the Nature Reserve where no *T. s. elegans* has invaded. Interviews with park managers confirm that there were many snails in our study site before *T. s. elegans* was released there.

Additionally, there used to be abundant water spinach and dayflower floating on the water surface of the lake we worked in Qionghai, Hainan in 2010, but they are now all replaced by exotic water hyacinth. *T. s. elegans* may play a negative role in this process, which refers to an associate interaction in invasive mechanism (Lu *et al*., 2010).

Trachemys s. elegans is opportunistic in dietary habit and highly adaptable to new environments where there is a vacant niche in nutrition, and impacts native prey species negatively. It is necessary to further study the invasion mechanism of *T. s. elegans*, so as to provide scientific data for effective control and eradication of this invasive species.

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