Ant Specialization in Diet of the Narrow-mouthed Toad, *Microhyla ornata*, from Amamioshima Island of the Ryukyu Archipelago

TOSHIAKI HIRAI AND MASAFUMI MATSUI*

Graduate School of Human and Environmental Studies, Kyoto University, Sakyo-ku, Kyoto 606-8501 JAPAN

Abstract: *Microhyla ornata* consumed numerous ants, representing 77.1% in number and 44.6% in volume of the diet. The toad took ants in higher proportion than were present in the surrounding environment, and therefore, could be viewed as an ant specialized predator. Ants were the most numerously consumed prey in both spring and summer, while beetles and woodlice were less frequently taken in summer. Females have a larger body and wider mouth than males, and consumed significantly larger prey in maximum size than did males. However, mean prey size, and frequencies of occurrence for all prey taxa did not differ significantly between the sexes. These results suggest that the sexes do not differ in their use of food resources despite their morphological differences.

Key words: *Microhyla ornata*; Ant-specialists; Prey availability; Ryukyu Archipelago; Gape-limited predator

INTRODUCTION

The Anuran assemblage in the Ryukyu Archipelago (excepting Osumi Islands) is unique and more highly diversified than that found in the adjacent mainland of Japan. While 21 anuran species/subspecies occur in mainland Japan, 20 other species are distributed in the Ryukyu Archipelago, and 14 of them are endemic to the archipelago (Maeda and Matsui, 1999).

Quite a few comprehensive taxonomic and biogeographical studies have been made on anurans in the Ryukyu Archipelago (e.g., Matsui, 1994; Ota, 1998), but ecological studies are much more limited, and mostly confined to reproduction (e.g., Utsunomiya, 1980, 1989). A preliminary report by Okochi and Katsuren (1989) is the only information available about diet of anurans on Okinawajima Island.

Microhyla ornata ranges throughout the Ryukyu Archipelago from Amamioshima southward through China to Southeast Asia and India (Frost, 1985), and inhabits various habitats from lowlands to montane regions (Maeda and Matsui, 1999). The toad is presumed to be specialized for eating ants or termites because of its small body and narrow mouth (Maeda and Matsui, 1999). However, detailed quantitative studies on the food habits of this species have not been done so far.

* Corresponding author. Tel: +81–75–753–6846; Fax: +81–75–753–2891.
E-mail address: fumi@zoo.zool.kyoto-u.ac.jp (M. Matsui)

Berry (1965) reported that ants predominated in the diet of two congeneric species, *M. butleri* and *M. heymonsii* from Singapore. Many dendrobatid and bufonid species are also well-known for eating numerous ants, and are called ant specialists because they take ants in higher proportion than are found in the environment (Toft, 1980, 1981).

Toft (1985), in reviewing resource partitioning studies in amphibians and reptiles, considered that food partitioning plays an important role in the organization of adult anuran communities. Therefore, knowledge of food habits of each community member might provide pivotal insights into the factors that are responsible for frog community structures in the Ryukyu Archipelago.

In order to obtain information on prey selection by the narrow-mouthed toad, *M. ornata*, we conducted field work on Amamioshima which is near the northern limits of its range.

MATERIALS AND METHODS

For the diet study, we collected toads in evergreen forests of the outskirts of Naze city on Amamioshima Is. (28°22′ N, 129°31′ E). We made collections at night (2100–2300 h) on 6 April (spring) and 12 July (summer) of 1998. We captured all individuals encountered on the forest floor, and immediately fixed them in 10% buffered formalin to preserve stomach contents with minimum digestion.

In order to estimate prey availability in the habitat of the toads, we sampled leaf litter invertebrates by two different methods. In spring, we set pit-fall traps near the temporal pool where toads were abundant. Fifteen plastic cups (90 mm in diameter and 130 mm in depth) were set in the ground at about 2 m intervals for two nights from 7 to 9 April. A small quantity of ethylene glycol was put into each cup to preserve samples. In summer, at the same time as the collection of toads, we collected four 0.5×0.5 m quadrate samples of leaf litter and brought them to the laboratory. After large or inactive animals were removed from these samples, the remaining ones were extracted by Tullugren's funnel method (Aoki, 1973). These potential prey invertebrates were stored in ethylene glycol for later analyses.

Stomach contents were removed by dissection of toads, and preserved in 10% buffered formalin for later analyses. For each toad, snout-vent length (SVL) and mouth width (MW) were measured with a caliper to the nearest 0.1 mm.

We identified stomach contents and potential prey to the level of class or order except for Hymenoptera, which was classified into Formicidae and non-Formicidae. For holometabolous insects, larvae and adults were separately treated. The occurrence of plant materials or minerals was recorded for each stomach. Details about measurement of stomach contents are given in Hirai and Matsui (1999).

To detect seasonal variation in the diet, we compared the presence or absence of each prey taxon between spring and summer by Fisher's exact probability test. Next, we examined the relationships between prey availability and diet composition by calculating Kendall's rank correlation coefficients (τ). In this analysis, we used only taxa that were commonly found in both potential prey samples and the stomach contents because prey taxa found only in one of these might have large sampling errors. We presumed that the exclusion of these uncommon prey taxa would not affect the result of analyses because the common prey taxa accounted for more than 75% of both diet and prey samples. Moreover, we tested the sexual difference in the diet by comparing the presence or absence of each prey taxon by Fisher's exact probability test. In additition, we quantified dietary overlap between sexes by calculating simple similarity indices (Schoener,

1968):

$$C_{xy} = 1 - 0.5 \Sigma |P_{ix} - P_{iy}|$$

based on proportion of prey taxa (i) in diet of two different sexes (x and y). We calculated both numeric and volumetric overlap in this analysis.

RESULTS

Diet composition

We identified 1234 prey items extracted from 55 stomachs (41 males, 14 females) of 56 individuals captured; the remaining stomach from an immature female was empty. Prey items included five arthropod classes (Arachnida, Crustacea, Diplopoda, Chilopoda, and Insecta), of which Insecta contained eight orders (Table 1). Ants (Formicidae) were consumed by all individual toads with stomach contents, and predominated in the diet, representing 77.1% by number, and 44.6% by volume. The next most frequently consumed prey taxon was beetles (Coleoptera; 67.3%), but they made up only 6.4% by number, and 16.9% by volume. The other prey taxa constituted minute fractions, making up less than 5% by number, and 15% by volume. Plant (vegetable scraps) and mineral materials (pebbles and dirt) occurred in 47.3% and 1.8%, respectively, of the stomachs.

Seasonal variation in diet

The toads appeared to take more prey in spring (Mean ± SE = 26.1 ± 3.9) than in summer (16.5 ± 2.7), but the difference was not significant (U-test, p > 0.05). However, the volume of stomach contents differed seasonally, and almost three times more food was ingested in spring (59.2 ± 8.1 mm³) than in summer (20.8 ± 4.0 mm³) (U-test, p < 0.01).

Ants constituted the bulk of the diet numerically and volumetrically, and their proportions varied little seasonally (Table 2). Among 10 prey taxa commonly consumed in both seasons, all prey taxa except

TABLE 1. Diet composition (in %) of *Microhyla ornata* (1234 prey from 55 individuals, total volume 2448.3 mm³). Abbreviations: F = frequency of occurrence; N = numeric proportion; V = volumetric proportion

Prey taxa	F	N	V
Insecta			
Hymenoptera			
Formicidae	100.0	77.1	44.6
non-Formicidae	5.5	0.2	0.5
Coleoptera	67.3	6.4	16.9
larvae	3.6	0.3	4.1
Diptera	14.6	1.0	0.8
larvae	10.9	1.0	4.4
Lepidoptera	1.8	0.2	0.2
larvae	1.8	<0.1	0.9
Hemiptera	20.0	1.1	3.2
Isoptera	3.6	4.7	1.4
Orthoptera	1.8	<0.1	0.3
Collembola	21.8	1.5	0.2
Arachnida			
Araneae	10.9	0.7	1.1
Pseudoscorpiones	1.8	<0.1	<0.1
Acarina	21.8	2.5	0.5
Crustacea			
Isopoda	20.0	1.3	11.3
Chilopoda	12.7	0.7	2.6
Diplopoda	21.8	1.2	7.1
Plant materials	47.3	—	—
Minerals	1.8	—	—

for ants and wasps (non-formicids) were found more frequently in spring than in summer, but only two prey taxa, beetles and woodlice (Isopoda), differed significantly in fequency of occurrence (Fisher's exact probability test, p < 0.01 for Coleoptera; p < 0.05 for Isopoda). Volumetric contribution by these two prey taxa was great in spring, but it showed striking decrease in summer. By contrast, termites (Isoptera) made up a larger numerical proportion in summer because of two individuals (9.5% in frequency) that contained unusually many termites (Table 2). Frequency of oc-

TABLE 2. Dietary comparison of *Microhyla ornata* between spring (887 prey from 34 individuals, total volume 2012.4 mm³) and summer (347 prey from 21 individuals, total volume 435.9 mm³). See Table 1 for abbreviations.

Prey taxa	F		N		V	
	Spring	Summer	Spring	Summer	Spring	Summer
Insecta						
Hymenoptera						
Formicidae	100.0	100.0	79.8	70.0	45.0	43.1
non-Formicidae	2.9	9.5	0.1	0.6	0.3	1.6
Coleoptera	82.4	42.9	7.7	3.2	18.4	9.5
larvae	0	9.5	0	1.2	0	23.2
Diptera	17.7	9.5	1.1	0.6	0.7	1.0
larvae	17.7	0	1.4	0	5.4	0
Lepidoptera	0	4.8	0	0.6	0	1.0
larvae	2.9	0	0.1	0	1.1	0
Hemiptera	23.5	14.3	0.9	1.4	3.4	2.5
Isoptera	0	9.5	0	16.7	0	7.7
Orthoptera	0	4.8	0	0.3	0	1.7
Collembola	26.5	14.3	1.7	0.9	0.2	0.1
Arachnida						
Araneae	14.7	4.8	0.8	0.3	1.3	<0.1
Pseudoscorpiones	0	4.8	0	0.3	0	<0.1
Acarina	26.5	14.3	2.6	2.3	0.3	1.4
Crustacea						
Isopoda	29.4	4.8	1.6	0.6	12.8	4.0
Chilopoda	20.6	0	1.0	0	3.2	0
Diplopoda	26.5	14.3	1.2	1.2	7.8	3.4
Plant materials	26.5	90.5	—	—	—	—
Minerals	2.9	0	—	—	—	—

currence of plant materials markedly increased from spring (26.5%) to summer (90.5%), and differed significantly between the seasons (Fisher's exact probability test, p<0.01).

Prey selection

A total of 20 potential prey invertebrates were collected when samples in spring and summer were combined (Table 3). Among these, larval caddisflies (Trichoptera), earwigs (Dermaptera), gastropod snails, and earthworms (Oligochaeta) were not found in the toad stomachs. Conversely, moths (Lepidoptera) and their larvae were not

sampled from the surrounding habitat. Specifically in spring, 11 of 14 potential prey invertebrates sampled from the environment were found in diet composition. Ants seemed to be the most readily available prey for toads, and were consumed in much higher proportion than those found in the environment. However, the next most abundant possible prey, collembolans, were consumed much less in proportion by toads. Consequently, there was no significant correlation between prey availability in the habitat and diet composition ($\tau=0.278$, p>0.05). In summer, 12 of 17 potential prey invertebrate taxa were actually found

TABLE 3. Comparison of diet composition of *M. ornata* with prey availability in the environment assessed by pitfall traps in spring and funnel traps in summer.

| | Spring | | | | Summer | | | |
| | Diet | | Environment | | Diet | | Environment | |
Prey taxa	n	%	n	%	n	%	n	%
Formicidae	708	79.8	97	41.6	243	70.0	40	10.6
non-Formicidae	1	0.1	1	0.4	2	0.6	0	0
Coleoptera	68	7.7	10	4.3	11	3.2	4	1.1
larvae	0	0	0	0	4	1.2	15	4.0
Diptera	10	1.1	26	11.2	2	0.6	4	1.1
larvae	12	1.4	1	0.4	0	0	1	0.3
Lepidoptera	0	0	0	0	2	0.6	0	0
larvae	1	0.1	0	0	0	0	0	0
Trichoptera larvae	0	0	0	0	0	0	1	0.3
Hemiptera	8	0.9	2	0.9	5	1.4	2	0.5
Isoptera	0	0	6	2.6	58	16.7	8	2.1
Dermaptera	0	0	0	0	0	0	1	0.3
Orthoptera	0	0	0	0	1	0.3	1	0.3
Collembola	15	1.7	35	15.0	3	0.9	1	0.3
Araneae	7	0.8	17	7.3	1	0.3	2	0.5
Pseudoscorpiones	0	0	1	0.4	1	0.3	0	0
Acarina	23	2.6	3	1.3	8	2.3	161	42.8
Isopoda	14	1.6	11	4.7	2	0.6	35	9.3
Chilopoda	9	1.0	0	0	0	0	1	0.3
Diplopoda	11	1.2	17	7.3	4	1.2	11	2.9
Gastropoda	0	0	6	2.6	0	0	0	0
Oligocheata	0	0	0	0	0	0	88	23.4

in stomachs of toads. As was found in spring, the proportion of ants in the diet was larger than that found in the environment. Instead, mites, the most abundant prey in the environment, were consumed by few toads. We could not detect a significant correlation between prey availability and diet composition ($\tau = 0.381$, $p > 0.05$).

Comparisons between sexes

Females (mean $\pm$ SE = 30.5 ± 0.6 mm, range = $25.6 - 33.0$ mm) were significantly larger in SVL than males (26.3 ± 0.2 mm, $22.1 - 29.6$ mm) (U-test, $p < 0.01$). Females also had a significantly wider mouth (8.3 ± 0.1 mm, $7.5 - 9.3$ mm) than males (7.3 ± 0.1 mm, $6.1 - 8.5$ mm) ($p < 0.01$). Sexual

difference was highly significant in maximum prey size (females: 19.9 ± 4.1 mm; males: 12.0 ± 2.2 mm) ($p < 0.01$), but was not significant in mean (females: 3.0 ± 0.5 mm, males: 1.9 ± 0.2 mm) or minimum prey size (females: 0.6 ± 0.2 mm, males: 0.3 ± 0.04 mm) ($p > 0.05$ for both) due to their large variations. Similarly, neither the number (females: 28.7 ± 8.0, males: 20.3 ± 2.4) nor the volume (females: 66.8 ± 16.8 mm^3, males: 36.9 ± 4.8 mm^3) of stomach contents differed significantly between the sexes ($p > 0.05$ for both).

Diet compositions did not differ markedly between females and males as suggested by high dietary overlap (similarity indices = 0.85 in number and 0.70 in volume:

TABLE 4. Dietary comparison of female (402 prey from 14 individuals, total volume 934.6 mm³) and male (832 prey from 41 individuals, total volume 1513.7 mm³) *Microhyla ornata*. See Table 1 for abbreviations.

Prey taxa	F		N		V	
	Female	Male	Female	Male	Female	Male
Insecta						
Hymenoptera						
Formicidae	100.0	100.0	86.1	72.7	57.8	36.5
non-Formicidae	7.1	4.9	0.3	0.2	0.7	0.5
Coleoptera	57.1	70.7	3.0	8.1	9.3	21.5
larvae	7.1	2.4	0.3	0.4	2.6	5.1
Diptera	7.1	17.1	0.3	1.3	0.9	0.7
larvae	21.4	7.3	2.2	0.4	8.0	2.2
Lepidoptera	0	2.4	0	0.2	0	0.3
larvae	7.1	0	0.3	0	2.4	0
Hemiptera	14.3	22.0	0.8	1.2	1.5	4.3
Isoptera	0	4.9	0	7.0	0	2.2
Orthoptera	0	2.4	0	0.1	0	0.5
Collembola	7.1	26.8	0.5	1.9	<0.1	0.2
Arachnida						
Araneae	21.4	7.3	1.0	0.5	1.7	0.8
Pseudoscorpiones	7.1	0	2.0	0	<0.1	0
Acarina	42.9	14.6	0.3	2.8	0.3	0.6
Crustacea						
Isopoda	14.3	22.0	1.0	1.4	8.4	13.1
Chilopoda	14.3	12.2	0.8	0.7	1.2	3.5
Diplopoda	28.6	19.5	1.5	1.1	5.3	8.2
Plant materials	42.9	53.7	—	—	—	—
Minerals	7.1	0	—	—	—	—

Table 4). Indeed, frequency of occurrence of all prey taxa did not differ significantly between the sexes (Fisher's exact probability test, $p > 0.05$ for all pray taxa). Ants predominated in their diet, both numerically and volumetrically (Table 4).

DISCUSSION

Ants were consumed by all individuals of *M. ornata* studied, and comprised more than 70% of the total prey items. Following Simon and Toft's (1991) definition, *M. ornata* is regarded as an ant specialist because they consumed ants higher in propor-

tion than those available from the environment.

Berry (1965) reported that ants occurred in more than 94.9% of stomachs, and made up 86–87% of the total prey items in the diet of two microhylids, *M. butleri* and *M. heymonsii* from Singapore. Results of our study in *M. ornata*, i.e., ants occurring in all stomachs, and making up 77.1% of total prey items, are consistent with Berry's (1965) observation. Therefore, the food habits of this genus would be characterized by eating numerous ants.

Seasonal variation in diet was conspicuous in beetles and woodlice. In spring,

these prey taxa were consumed more frequently, and made up relatively large proportions by volume. Fewer chances of consuming these prey might have caused a decrease in the amount of food ingested during summer. Instead, plant materials were found more frequently in summer. A ranid frog, *Rana hexadactyla*, has been reported to supplement energy gain by consuming plant materials (Das, 1996), and *M. ornata* might also consume plant materials frequently in summer so as to compensate for reduction of animal food consumption.

Sexual dimorphism in body size and mouth width was observed in *Microhyla ornata*, and both the variables were larger in females than in males. Generally, anurans are gape-limited in predation, and size of consumable prey is regulated by body size or mouth width (e.g., Kramek, 1972; Toft, 1980). Hence, such sexual dimorphism in morphology may help to alleviate potential competitive interactions by partitioning food resources. In fact, females of *Rana cancrivora* with larger body and wider mouth than males were reported to consume larger prey than males (Premo and Atmowidjojo, 1987). In our observations, where maximum prey size was larger in females suggests that consumable prey size in *M. ornata* is also determined by the mouth width. However, the sexes did not differ in mean or minimum prey size. Further, they were similar in frequency of occurrence for all prey taxa. These lines of evidence indicate that food resources were not partitioned between the sexes. High dietary overlap of females and males also seems to support this assumption.

Among anurans occurring in the Ryukyu Archipelago, diet data for four ranid species, *Rana namiyei, R. narina, R. ishikawae,* and *R. holsti* from Okinawajima Island, are available (Okochi and Katsuren, 1989). These four species are relatively large, reaching 55 to 120 mm in SVL, and consume few ants. Therefore, ant specialization in *M. ornata* of less than 30 mm in

SVL might be partially responsible for the coexistence with larger anuran species. Anuran fauna in the subtropical Ryukyu Archipelago is characterized by the presence of many endemic species, and by greater species diversity than in temperate mainland Japan (Matsui, 1996).

In the tropics where species diversity is greater than in temperate and subtropical regions, and anurans have specialized their various ecological attributes (Duellman and Trueb, 1986), diet specialization has been demonstrated to be important in structuring an anuran community (Toft, 1980). Therefore, ant specialization in *M. ornata* might be playing a great role in structuring anuran communities in the Ryukyu Archipelago as well. Further studies based on community ecology are necessary to evaluate the importance of the role of food specialization.

LITERATURE CITED

AOKI, J. 1973. Soil Zoology. Hokuryukan, Tokyo. (in Japanese)

BERRY, P. Y. 1965. The diet of some Singapore Anura (Amphibia). Proc. Zool. Soc. London 144: 163–174.

DAS, I. 1996. Folivory and seasonal changes in diet in *Rana hexadactyla* (Anura: Ranidae). J. Zool. London 238: 785–794.

DUELLMAN, W. E. AND L. TRUEB. 1986. Biology of Amphibians. McGraw-Hill Book Co., New York.

FROST, D. R. (ed.). 1985. Amphibian Species of the World: A Taxonomic and Geographical Reference. Allen Press, Lawrence, Kansas. i–v+732p.

HIRAI, T. AND M. MATSUI. 1999. Feeding habits of the pond frog, *Rana nigromaculata*, inhabiting rice fields in Kyoto, Japan. Copeia 1999(4): 940–947.

KRAMEK, W. C. 1972. Food of the frog *Rana septentrionalis* in New York. Copeia 1972: 390–392.

MAEDA, N. AND M. MATSUI. 1999. Frogs and Toads of Japan. Rev. Ed. Bun-ichi Sogo Shuppan, Tokyo. (in Japanese with English abstract)

MATSUI, M. 1994. A taxonomic study of the *Rana narina* complex, with description of

three new species (Amphibia: Ranidae). Zool. J. Linn. Soc. 111: 385–415.

MATSUI, M. 1996. Natural History of the Amphibia. University of Tokyo Press, Tokyo. (in Japanese)

OKOCHI, I. AND S. KATSUREN. 1989. Food habits in four species of Okinawan frogs. p. 405–412. *In*: M. Matsui, T. Hikida, and R. C. Goris (eds.), Current Herpetology in East Asia. Herpetol. Soc. Jpn., Kyoto.

OTA, H. 1998. Geographic patterns of endemism and speciation in amphibians and reptiles of the Ryukyu Archipelago, Japan, with special reference to their paleogeographical implications. Res. Popul. Ecol. 40: 189–204.

PREMO, D. B. AND A. H. ATMOWIDJOJO. 1987. Dietary patterns of the crab eating frog *Rana cancrivora* in west Java. Herpetologica 43: 1–6.

SCHOENER, T. W. 1968. The *Anolis* lizards of Bimini: resource partitioning in a complex fauna. Ecology 49: 704–726.

SIMON, M. P. AND C. A. TOFT. 1991. Diet specialization in small vertebrates: mite-eating in frogs. Oikos 61: 263–278.

TOFT, C. A. 1980. Feeding ecology of thirteen syntopic species of anurans in a seasonal tropical environment. Oecologia 45: 131–141.

TOFT, C. A. 1981. Feeding ecology of Panamanian litter anurans: patterns in diet and foraging mode. J. Herpetol. 15: 139–144.

TOFT, C. A. 1985. Resource partitioning in amphibians and reptiles. Copeia 1985: 1–21.

UTSUNOMIYA, T. 1980. Reproduction of *Rana ishikawae* on Amamioshima Island. Nippon Herpetol. J. 17: 17–18. (in Japanese)

UTSUNOMIYA, T. 1989. Five endemic frog species of the Ryukyu Archipelago. p. 199–204. *In*: M. Matsui, T. Hikida, and R. C. Goris (eds.), Current Herpetology in East Asia. Herpetol. Soc. Jpn., Kyoto.