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Morphological Characterization and Classification of Anuran Tadpoles in Korea

Park, Daesik[1]*, Seokwan Cheong[2] and Hacheol Sung[2]

[1]*Department of Science Education, Kangwon National University, Chuncheon, Gangwon 200-701, Korea*

[2]*Department of Biology Education, Korea National University of Education, Cheongwon, Chungbuk 363-791, Korea*

ABSTRACT: The tadpoles of 12 Korean anuran species, including *Bombina orientalis, Bufo gargarizans, B. stejnegeri, Hyla japonica, Kaloula borealis, Rana dybowskii, R. huanrenensis, R. coreana, R. nigromaculata, R. chosenica, R. rugosa,* and *R. catesbeiana,* were classified based on their morphological characteristics. We collected eggs or tadpoles of the 12 Korean anuran species from Gangwon, Incheon, Chungcheong, and Gyeonggi districts in 2005 and 2006 breeding seasons. When the tadpoles reached at 27～37 Gosner's developmental stages, we described morphological characteristics of the tadpoles of each anuran species and measured their physical parameters such as total length, body length, and body mass. After that, we chose 12 morphological characteristics to identify each species and to use them as classification keys such as eye location, caudal musculature pattern, spiracle location, oral disc morphology, and labial tooth row formula. In this paper, we presented classification keys, morphological characteristics, and drawings for the tadpoles of 12 anuran species.

Key words: Anuran, Classification, Frog, Morphology, Tadpole

INTRODUCTION

Total 15 anuran species have been registered in South Korea, but two species of them, *Bufo raddei* (Liu et al. 2000) and *Rana emeljanovi* (Yang et al. 2000) are still in debating on their existence in Korea. Thus, it is generally accepted that total 13 anuran species are currently known in South Korea within 5 genera, *Bombina, Bufo, Hyla, Kaloula,* and *Rana*, in 5 families of Discoglossidae, Bufonidae, Hylidae, Microhylidae, and Ranidae (Won 1971, Kang and Yoon 1975, Yang et al. 2001). Yang et al (2001) recently reviewed the distribution, morphological characteristics, variations, ecology, and classification of 13 Korean anuran species.

Description and classification of the tadpoles of Korean anurans were previously done for 11 species of *B. orientalis, B. stejnegeri, K. borealis, H. japonica, R. dybowskii, R, coreana, R. nigromaculata, R. chosenica, R. catesbeiana*, *B. gargarizans* and *R. rugosa* but some descriptions were partial and comparable drawings of the tadpoles were absent (Won 1971, Kang and Yoon 1975). In addition, any descriptions for *R. huanrenensis* were not made yet. Such deficient information about the tadpoles of several Korean anurans makes it impossible to identify tadpoles of a specific anuran species and to produce classification keys for using anuran surveys in the field.

Since anuran larvae, tadpoles, remain in specific aquatic habitats for longer time periods than adults, we can encounter tadpoles more frequently so that well-developed classification keys will be useful tools for anuran survey and for ecology education. For such purposes, we classified the tadpoles of 12 Korean anuran species based on their morphological characteristics and made classification keys. We excluded the Suwon tree frog, *H. suweonensis* for its morphological high similarity to the Korean tree frog, *H. japonica* and for its unknown breeding ecology in the field.

MATERIALS AND METHODS

We collected eggs or tadpoles of 12 Korean anuran species from rice fields, mountain streams, agricultural ponds, and swamps in Chuncheon-shi (*B. orientalis, B. stejnegeri, H. japonica, R. nigromaculata, K. borealis*) and Pyeongchang-gun (*R. dybowskii, R. huanrenensis*) Gangwon-do, Cheongwon-gun (*R. catesbeiana, B. gargarizans*), Chungcheongbuk-do, Ongjin-gun (*R. chosenica*) Incheon, and Yangpeyong-gun (*R. rugosa, R. coreana*) Gyeonggi-do in 2005 and 2006 breeding seasons. We could easily identify eggs of a species based on the species-specific morphological characteristics of egg clumps (Kang and Yoon 1975). Tadpoles of *R. chosenica* had a distinctive golden stripe on the body (Won 1971) and those of *R. catesbeiana* were much bigger than any other species' tadpoles.

Eggs and tadpoles collected in the field were transported to the behavioral ecology laboratory in the Kangwon National University. Tadpoles of each species were separately kept with no more than 20 individuals in an aquarium (32 cm long, 19.5 cm wide, 20 cm high) containing 20 L of aged tap water. Each egg clutch of each

* Corresponding author; Phone: +82-33-250-6793, e-mail: parkda@kangwon.ac.kr

species was also kept in same condition with plenty air supply. We supplied boiled spinaches, cabbages, and crushed chicken eggs as tadpole foods *ad libitum*. We changed half of the water every two days while siphoning out debris and wastes on the bottom of the aquarium. When the tadpoles reached at 27～37 Gosner's developmental stages (Gosner 1960), we anesthetized tadpoles in 0.5% MS 222 for 5 min, measured their physical parameters such as total length, body length, and body mass, determined their morphological characteristics under a dissecting microscope, and sketched tadpole shapes and their oral discs. After that, used tadpoles were sacrificed by overdose in 1.0% MS222 and reserved as specimens in 10% neutral formalin in the laboratory. To determine morphological characteristics of the tadpoles of an anuran species, we used 1～3 tadpoles of each species to exclude individual and developmental variations.

To classify the tadpoles of Korean anurans, we determined 12 morphological characteristics (Fig. 1) with focusing on oral disc morphology based on Altig and McDiarmid (1999); 1) whether complex oral disc is absent or exists, 2) whether eyes form part of the dorsal outline of a tadpole (lateral) or not (dorsal, Fig. 1, ②), 3) location of external opening for exit of water from the opercular chamber: medioventral spiracle near vent (medioventral) or lateral spiracle on left side of body (sinister, Fig. 1, ③), 4) direction of external opening of the cloaca: aperture of vent tube in line with axis of ventral fin (medial) or aperture of vent tube opens to right of axis of ventral fin (dextral, Fig. 1, ④), 5) patterns on caudal musculature (mottled or unicolored, Fig. 1, ⑤), 6) whether oral disc is emarginate (Fig. 1, ⑥) or not, 7) existence of gaps in the marginal papillae (dorsal gap, Fig. 1, ⑦, ventral gap, dorsal-ventral gap, or no gap, complete), 8) existence of the submarginal papillae (Fig. 1, ⑧), 9) relative length of upper supportive jaw cartilages to the lower cartilages: extending well beyond the lower jaw (long, Fig. 1, ⑨), extending definitely beyond the lower jaw (medium), extending slightly beyond the lower jaw (short), 10) marginal shape of the middle parts of keratinized jaw sheaths (not cuspate, cuspate pointedly, cuspate roundly, Fig. 1, ⑩), 11) existence of serrate tooth on the margin of keratinized jaw sheaths (Fig. 1, ⑪), 12) labial tooth row formula: the number of labial tooth rows in both anterior and posterior labia and whether each tooth row has a median gap or not (Fig. 1, ⑫). For example, labial tooth row formula, 4(2-4)/4 [1] of *Rana huanrenensis* means that anterior labium has four tooth rows, the first tooth row is complete, no gap, but the second, third, and fourth rows have median gaps and that posterior labium has 4 tooth rows and the first row only has a median gap. Related tutorial materials for using the classification keys are found at http://www.pwrc.usgs.gov/tadpole/ tutorial.htm.

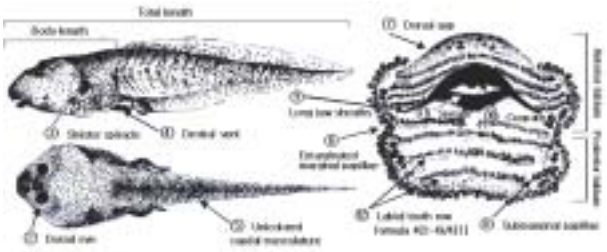

Fig. 1. Tadpole of *Rana huanrenensis*, showing several classification keys used in the study: lateral view (left side, above), dorsal view (left side, below), and oral disc (right side). Hereafter, in all figures, we presented the tadpoles in same size for clarity. The real size of each tadpole appeared in Table 1.

Using a dichotomous strategy, we produced and presented classification keys to the tadpoles of 12 Korean anuran species and described their morphological characteristics of each species with figures. Our key production was focused not on evolutionary relationships among tadpoles of different species but on efficiency that one can use the keys to easily classify tadpoles.

RESULTS

Based on morphological characteristics, we have successfully classified the tadpoles of 12 Korean anuran species. *R. catesbeiana* tadpoles were the biggest among the 12 species (Table 1). *R. nigromaculata, R. rugosa,* and *R. chosenica* tadpoles were relatively bigger

Table 1. Summary of physical parameters of the tadpoles used for final classification

Species \ Parameters	Total length (cm)	Body length (cm)	Depth of caudal musculature (cm)	Tail depth (cm)	Body mass (g)	Gosner's stage
Bombina orientalis	3.50	1.20	0.20	0.70	0.25	32
Bufo gargarizans	3.00	1.20	0.30	0.50	0.20	37
Bufo stejnegeri	2.20	1.00	0.15	0.40	0.05	36
Hyla japonica	2.70	1.10	0.30	0.60	0.50	32
Kaloula borealis	1.08	0.87	0.27	0.28	0.02	27
Rana coreana	1.90	0.70	0.15	0.30	0.05	29
Rana catesbeiana	7.90	2.90	1.10	1.60	4.60	35
Rana chosenica	3.99	1.50	0.55	0.97	0.65	34
Rana dybowskii	3.00	1.20	0.30	0.60	0.50	35
Rana huanrenensis	3.20	1.00	0.40	0.50	0.20	35
Rana nigromaculata	5.65	1.85	0.75	1.17	1.75	36
Rana rugosa	4.38	1.20	0.72	1.07	1.05	36

than tadpoles of other species (Table 1). *K. borealis* tadpoles were the smallest (Table 1). *R. coreana, H. japonica,* and *B. stejnegeri* tadpoles were relatively smaller than tadpoles of other species (Table 1). We summarized physical parameters of the tadpoles used for final classification (Table 1) and classification keys (Table 2) for each species.

Keys to the tadpoles of Korean anuran species

1a. Complex oral disc is absent. ----------*Kaloula borealis*
1b. Complex oral disc exists.----------2
2a. Eyes are lateral. ----------3
2b. Eyes are dorsal. ----------4
3a. Labial tooth row formula is 2(2)/3. ----------*Hyla japonica*
3b. Labial tooth row formula is 1(1)/2. A distinctive golden strip exists on caudal musculature. ----------*Rana chosenica*
4a. Spiracle is medioventral. ----------*Bombina orientalis*
4b. Spiracle is sinister. ----------5
5a. Dorsal-ventral gaps in the marginal papillae. ----------6

Table 2. Summary of 12 morphological characteristics to classify the tadpoles of 12 Korean anuran species

Characteristics / Species	Location of eyes	Location of spiracle	Location of vent	Caudal musculature pattern	Oral disc morphology				Relative length of upper jaw	Jaw morphology (2 characters)	Labial tooth row formula
					Marginal papilla row	Emargination	Gap in marginal papillae	Submarginal papillae			
Bombina orientalis	dorsal	medioventral	medial	mottled	one row	no	complete	none	long	not cuspate, serrate	2/3[1]
Bufo gargarizans	dorsal	sinister	medial	unicolored	one row	yes	dorsal/ventral	yes	long	not cuspate, serrate	2(2)/3
Bufo stejnegeri	dorsal	sinister	medial	mottled	one row	yes	dorsal/ventral	yes	medium	cuspate roundly, serrate	2(2)/3
Hyla japonica	lateral	sinister	dextral	mottled	one row	no	dorsal	yes	medium	cuspate roundly, serrate	2(2)/3
Kaloula borealis	lateral	medioventral	medial	mottled	none	none	none	none	none	none	None
Rana coreana	dorsal	sinister	dextral	mottled	one row	no	dorsal	yes	long	cuspate pointedly, serrate	2(2)/3[1]
Rana catesbeiana	dorsal	sinister	dextral	mottled	one row	yes	dorsal	yes	long	not cuspate, serrate	3(2-3)/3[1]
Rana chosenica	lateral	sinister	medial	mottled	one row	yes	dorsal	yes	medium	cuspate roundly serrate	1(1)/2
Rana dybowskii	dorsal	sinister	dextral	mottled	one row	yes	dorsal	yes	long	not cuspate, serrate	4(2-4)/4[1]
Rana huanrenensis	dorsal	sinister	dextral	unicolored	one row	yes	dorsal	yes	long	cuspate roundly, serrate	4(2-4)/4[1]
Rana nigromaculata	dorsal	sinister	dextral	mottled	one row	yes	dorsal	yes	medium	not cuspate, serrate	2(2)/3[1]
Rana rugosa	dorsal	sinister	dextral	mottled	one row	no	dorsal	yes	medium	cuspate roundly, serrate	1/3[1]

5b. Dorsal gap in the marginal papillae. ----------7
6a. Patterns on caudal musculature are unicolored. ----------
----------*Bufo gargarizans*
6b. Patterns on caudal musculature are mottled.
----------*Bufo stejnegeri*
7a. Labial tooth row formula is 1/3[1]. ----------*Rana rugosa*
7b. Labial tooth row formula is 3(2-3)/3[1].
----------*Rana catesbeiana*
7c. Labial tooth row formula is 4(2-4)/4[1]. ----------8
7d. Labial tooth row formula is 2(2)/3[1]. ----------9
8a. Patterns on caudal musculature are unicolored.
----------*Rana huanrenensis*
8b. Patterns on caudal musculature are mottled.
----------*Rana dybowskii*
9a. Keratinized jaw sheaths are not marginally cuspate.
A distinctive strip exists on the dorsal plate.
----------*Rana nigromaculata*
9b. Keratinized jaw sheaths are cuspate pointedly.
----------*Rana coreana*

Description of the Tadpoles of Korean Anuran Species

1. Tadpoles of *Bombina orientalis* (Fig. 2)

Developmental stage 32, total length 3.50 cm, body length 1.20 cm, body mass 0.25 g. Anterior part of the head is moderately sharp. Head length is about 1.5 times as long as wide. Nostrils are much closer to eyes than to the tip of snout. Tail depth is deeper than body depth at the middle of length of tail. Numerous distinctive short strips are presented on most areas of body and tail.

Eyes are dorsal, spiracle is medioventral, vent is medial, and caudal musculature is mottled. Oral disc is not emarginate, marginal papillae are in single row and complete, no gaps, and submarginal papillae do not exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are not cuspate, but serrate marginally. Anterior labium has completed 2 tooth rows. Posterior labium has 3 tooth rows, and the first row only has a median gap. Labial tooth row formula is 2/3[1]. Distinctively each tooth row is biserial.

Fig. 2. Tadpole of *Bombina orientalis*.

2. Tadpoles of *Bufo gargarizans* (Fig. 3)

Developmental stage 37, total length 3.00 cm, body length 1.20 cm, body mass 0.20 g. Anterior part of the head is wider than posterior part. Head length is about 2 times as long as wide. Tail length is 1.5 times longer than head length. In dorsal view, mouth parts are visible for protrusion.

Eyes are dorsal, spiracle is sinister, vent is medial, and caudal musculature is unicolored. Oral disc is emarginate, marginal papillae are in single row and have dorsal and ventral gaps, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are not cuspate, but serrate marginally. Anterior labium has 2 tooth rows; the second row only has a median gap. Posterior labium has 3 tooth rows, and they are all complete. Labial tooth row formula is 2(2)/3.

3. Tadpoles of *Bufo stejnegeri* (Fig. 4)

Developmental stage 36, total length 2.20 cm, body length 1.00 cm, body mass 0.15 g. Anterior part of the head is wider than posterior part. Head length is about 1.5 times as long as wide. In dorsal view, mouth parts are visible for protrusion.

Eyes are dorsal, spiracle is sinister, vent is medial, and caudal musculature is mottled. Oral disc is emarginate, marginal papillae are in single row and have dorsal and ventral gaps, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend definitely beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate roundly and serrate marginally. Anterior labium has 2 tooth rows; the second row only has a median gap. Posterior labium has 3 tooth rows, and they are all complete. Labial tooth row formula is 2(2)/3.

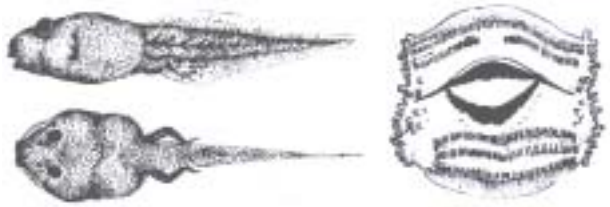

Fig. 3. Tadpole of *Bufo gargarizans*.

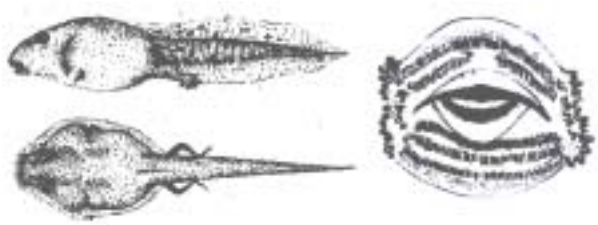

Fig. 4. Tadpole of *Bufo stejnegeri*.

4. Tadpoles of *Hyla japonica* (Fig. 5)

Developmental stage 32, total length 2.70 cm, body length 1.1 cm, body mass 0.50 g. Head shape is oval. Head length is about 1.2 times as long as wide. Tail length is 2 times longer than head length. Caudal musculature is relatively thin.

Eyes are lateral, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is not emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend definitely beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate roundly and serrate marginally. Anterior labium has 2 tooth rows; the second row only has a median gap. Posterior labium has 3 tooth rows, and they are all complete. Labial tooth row formula is 2(2)/3.

5. Tadpoles of *Kaloula borealis* (Fig. 6)

Developmental stage 27, total length 1.08 cm, body length 0.87 cm, body mass 0.02 g. Head shape is somewhat round. Tail length is approximately 1.3 times longer than head length.

Eyes are lateral, spiracle is medioventral, vent is medial, and caudal musculature is mottled. Complex oral disc is absent. Marginal papillae, keratinized supportive jaw cartilages, and labial teeth are absent.

6. Tadpoles of *Rana coreana* (Fig. 7)

Developmental stage 35, total length 1.90 cm, body length 0.70 cm, body mass 0.05 g. Head shape is oval. Anterior part of the head is relatively narrow. Tail length is about 2 times longer than head length. Caudal fins are the deepest at the middle of length of tail. Caudal musculature is relatively thin. Nostrils are closer to the tip of snout than to eyes.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is not emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate pointedly, and serrate marginally. Anterior labium has 2 tooth rows; the first row is only complete. Posterior labium has 3 tooth rows, and the first row only has a median gap. Labial tooth row formula is 2(2)/3[1]. In 1971, Won reported 1/3[1-2] labial tooth row formula of this species, captured in North Korea.

7. Tadpoles of *Rana catesbeiana* (Fig. 8)

Developmental stage 35, total length 7.90 cm, body length 2.90 cm, body mass 4.60 g. Head shape is oval. Head length is 1.3 times as long as wide. Caudal fins are shallow and caudal musculature is relatively thick.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are not cuspate, but serrate marginally. Anterior labium has 3 tooth rows; the first row is only complete. Posterior labium has 3 tooth rows, and the first row only has a median gap. Labial tooth row formula is 3(2-3)/3[1]. In 1971, Won reported 1/3 labial tooth row formula of this species, captured in North Korea.

8. Tadpoles of *Rana chosenica* (Fig. 9)

Developmental stage 34, total length 3.99 cm, body length 1.50

Fig. 5. Tadpole of *Hyla japonica.*

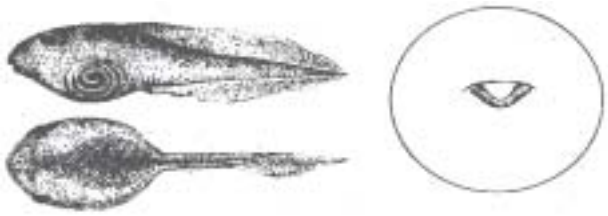

Fig. 6. Tadpole of *Kaloula borealis.*

Fig. 7. Tadpole of *Rana coreana.*

Fig. 8. Tadpole of *Rana catesbeiana.*

cm, body mass 0.65 g. Head shape is oval. Head length is about 1.5 times as long as wide. Anterior part of the head is relatively narrower than posterior part. Tail length is about 2 times longer than head length. A distinctive narrow golden strip exists along the middle of caudal musculature.

Eyes are lateral, spiracle is sinister, vent is medial, and caudal musculature is mottled. Oral disc is emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend definitely beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate roundly and serrate marginally. Anterior labium has 1 tooth row, having a median gap. Posterior labium has completed 2 tooth rows. Labial tooth row formula is 1(1)/2.

9. Tadpoles of *Rana dybowskii* (Fig. 10)

Developmental stage 35, total length 3.00 cm, body length 1.20 cm, body mass 0.50 g. Head shape is depressed oval. Head length is 1.5 times as long as wide. Tail length is about 1.5 times longer than head length. Caudal musculature is relatively thick.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are not cuspate, but serrate marginally. Anterior labium has 4 tooth rows; the first row is only complete. Posterior labium has 4 tooth rows, and the first row only has a median gap. Labial tooth row formula is 4(2-4)/4[1].

10. Tadpoles of *Rana huanrenensis* (Fig. 11)

Developmental stage 35, total length 3.20 cm, body length 1.00 cm, body mass 0.20 g. Anterior part of the head is wider than posterior part. Eyes are somewhat protrusive. Caudal fins are shallow but caudal musculature is relatively thick.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is unicolored. Oral disc is emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend well beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate roundly and serrate marginally. Anterior labium has 4 tooth rows; the first row is only complete. Posterior labium has 4 tooth rows, and the first row only has a median gap. Labial tooth row formula is 4(2-4)/4[1].

11. Tadpoles of *Rana nigromaculata* (Fig. 12)

Developmental stage 36, total length 5.65 cm, body length 1.85 cm, body mass 1.75 g. Head shape is oval. Tail length is over 2 times longer than head length. A distinctive bright stripe exists along the middle of dorsal plate.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend definitely beyond the lower jaw cartilages. Keratinized jaw sheaths are not cuspate but serrate marginally. Anterior labium has 2 tooth rows; the second row only has a median gap. Posterior labium has 3 tooth rows, and the first row only has a median gap. Labial tooth row formula is 2(2)/3[1].

12. Tadpoles of *Rana rugosa* (Fig. 13)

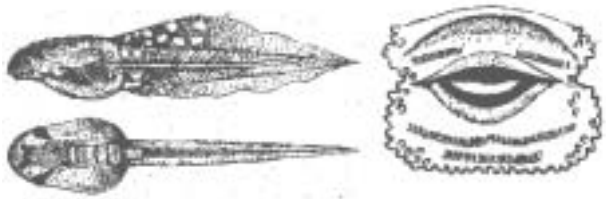

Fig. 9. Tadpole of *Rana chosenica.*

Fig. 10. Tadpole of *Rana dybowskii.*

Fig. 11. Tadpole of *Rana huanrenensis.*

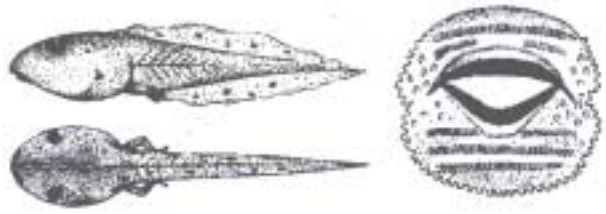

Fig. 12. Tadpole of *Rana nigromaculata.*

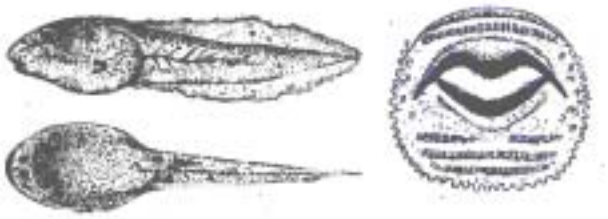

Fig. 13. Tadpole of *Rana rugosa.*

Developmental stage 36, total length 4.38 cm, body length 1.20 cm, body mass 1.05 g. Head shape is oval. Head length is 1.5 times as long as wide. Tail length is about 1.5 times longer than head length. Caudal fins are the deepest at the middle of length of tail.

Eyes are dorsal, spiracle is sinister, vent is dextral, and caudal musculature is mottled. Oral disc is not emarginate, marginal papillae are in single row and have a dorsal gap, and submarginal papillae exist. Keratinized supportive jaw cartilages in the upper jaw extend definitely beyond the lower jaw cartilages. Keratinized jaw sheaths are cuspate roundly and serrate marginally. Anterior labium has completed 1 tooth row. Posterior labium has 3 tooth rows; the first row only has a median gap. Labial tooth row formula is 1/3[1]. In 1971, Won reported 2(1)/3[1] labial tooth row formula of this species, captured in North Korea.

DISCUSSION

We successfully classified the tadpoles of 12 Korean anuran species using seven morphological characteristics out of 12 determined and presented classification keys into the tadpoles of each anuran species.

The tadpoles of *K. borealis* were the easiest to distinguish from other tadpoles because *K. borealis* was the only species that complex oral disc was absent. Orton (1953) also separated microhylidae tadpoles from other tadpole groups as the second type of tadpoles which has simple oral disc without marginal papillae and keratinized jaw cartilages. With a classification key of whether eyes form part of the dorsal outline of a tadpole or not, we could distinguish *H. japonica, R. chosenica*, and *K. borealis* from others, where the all three species have lateral eyes forming part of the dorsal outline of a tadpole. Subsequently with the labial tooth row formula, we further separated *H. japonica* and *R. chosenica* because it showed 2(2)/3 for *H. japonica* and 1(1)/2 for *R. chosenica*. Furthermore, *R. chosenica* uniquely had a distinctive golden strip on caudal musculature. *B. orientalis* was the only species having dorsal eyes, medioventral spiracle, and biserial labial tooth rows so that it was easily distinguished from others. Bufonidae was distinguished from others with three combined characteristics of dorsal eyes, sinister spiracle, and both ventral and dorsal gaps in the marginal papillae. Within the Ranidae, labial tooth row formula, patterns on caudal musculature, and keratinized jaw sheaths morphology were used as important keys to determine the tadpoles of a species. For example, *R. dybowskii* tadpoles had mottled patterns on caudal musculature and their labial tooth row formula was 4(2-4)/4[1]. *R. coreana* tadpoles had pointedly cuspate jaw sheaths and the labial tooth row formula was 2(2)/3[1].

Comparing morphological characteristics previously known of *Bombina* (Boulenger 1892), *Bufo* (McDiarmid and Altig 1990), *Hyla* (Duellman and Trueb 1989), *Kaloula* (Liu 1950, Kirtisinghe 1958), and *Rana* (Hillis and Frost 1985, Scott and Jennings 1985) tadpoles, our findings on tadpole morphologies of Korean anurans were mostly consistent with previous reports (reviewed in Altig and McDiarmid 1999) although there were few exceptions. First, *R. chosenica* tadpoles in *Rana* had lateral eyes despite of the previous knowledge that *Rana* tadpoles have only dorsal eyes. Second, *B. orientalis* tadpoles had medioventral spiracle unlike previously known sinister spiracle. Third, submarginal papillae in the oral disc of *B. orientalis* tadpoles were not confirmed in this study. Finally, variations in the labial tooth formula of *R. coreana, R. catesbeiana, R. rugosa* were detected in this study comparing reports by Won (1971) and Kang and Yoon (1975).

As for relationships between tadpole morphology and ecology, Orton (1953) first suggested six major adaptive tadpole groups of arboreal, surface-feeding, direct development, mountain stream, nektonic, and carnivorous based on spiracle and external oral morphologies. More recently Altig and Johnston (1989) summarized the relationships among developmental modes, morphologies, and habitats of different tadpoles. The tadpoles of Korean anurans can be largely grouped into mountain stream breeders or nektonic, pond breeders. During our study, although we didn't particularly pay attention to the relationships between tadpole morphologies and their habitats, several relationships came up. For example, the tadpoles of *R. dybowskii* and *R. huanrenensis* that breed in mountain streams had more labial tooth rows than other tadpole groups such as *R. chosenica* and *R. nigromaculata* who breed in agricultural fields or temporary ponds. Also, the tadpoles of temporary pond breeders such as *K. borealis* were smaller in their body size than others. Future studies on the relationships between detailed morphological characteristics of tadpoles and ecology should give further understanding tadpole biology in South Korea.

To efficiently classify the tadpoles of Korean anurans using our keys, we suggest that one should first be familiar with basic knowledge of Korean anuran ecology. Based on habitat characteristics and breeding phenology, one could often easily exclude several tadpole species from possible species before actually using the keys

to classify a tadpole species. For example, if you find a tadpole in mountain streams in late July, the tadpole might be of *R. rugosa* because in June and July only *R. nigromaculata*, *R. chosenica*, *R. catesbeiana*, *R. rugosa*, *H. japonica*, and *K. borealis* are being in breeding seasons and only *R. rugosa* breeds in mountain streams. Other species generally breed in agricultural fields, ponds, or temporary ponds.

In conclusion, we hope that our keys to the tadpoles of Korean anurans would be useful for further study of ecomorphological anuran species diversity, for monitoring of Korean anurans in the field, and for ecology education as pedagogical tools.

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