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Abundance and Breeding Migration of the Asian Toad (*Bufo gargarizans*)

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ABSTRACT: We monitored a breeding population of the Asian toad (*Bufo gargarizans*), in the Wonheunge pond at Sannamdong, Chungju, from 5 March to 11 April, 2006 and 14 February to 31 March, 2007 to investigate their movement patterns, breeding population sizes, and physical characteristics. Terrestrial migration to the pond started on 5 March in 2006 and 14 February in 2007. We captured a total of 266 immigrating individuals (213 males, 53 females) in 2006 and 307 (222 males, 85 females) in 2007, and found 50 adults apparently killed by motor vehicles while migrating to the pond in 2007. Emigration from the pond to terrestrial sites started on 15 March 2006 and 5 March 2007. We captured a total of 245 emigrating toads (181 males, 65 females) in 2006 and 99 (92 males, 7 females) in 2007. An additional 10 emigrating adults were found dead on the road. During both the immigration and emigration periods, two peaks in capture frequency appeared for each sex in each breeding season. The immigration peaks corresponded with higher temperatures, while the emigration peaks corresponded with high humidity. Migrating Asian toads showed sexual size dimorphism and a male-biased sex ratio. Body weights and SVL (snout-vent length) of immigrating and emigrating individuals were negatively related with migration dates.

Key words: Asian toad, *Bufo gargarizans*, Migration, Sexual dimorphism

INTRODUCTION

Anthropogenic habitat destruction, modification and fragmentation have been primary factors leading to global declines of amphibian populations (Alford and Richards 1999, Stebbins and Cohen 1995, Dodd and Smith 2003). Habitat destruction not only eliminates populations directly, but also can promote extinction by isolating local populations. Basic ecological and behavioral information is critical for the development of effective conservation strategies for threatened amphibian populations. However, to date, few studies of Korean amphibians have been conducted.

The Asian toad, *Bufo gargarizans*, is widely distributed across East Asia and is common in Korea (Yang et al. 2001). Asian toads are typical 'explosive breeders', visiting breeding ponds, such as the Wonhunge pond, to breed in early spring, and then returning to terrestrial areas to live for the non-breeding season and hibernate during winter. The Asian toad is nocturnal, resting under rocks or in bushes during the daytime and becoming active at sunset (Kang and Yoon 1975). Despite its broad distribution, the Asian toad's reproductive ecology has never been studied in Korea.

Recent development and construction of human facilities (i.e. construction of new buildings and roads, and cutting of hillsides) near the Wonhunge pond has caused great concern about the effects of the loss of habitats and suitable breeding sites on the local toad population. Accordingly, all interested parties, including civilians, government employees, and developers, agreed to attempt to reduce the risk of local extinction and to maintain a healthy breeding toad population by preserving the breeding pond despite the modification of the surrounding landscape, which isolated the pond from nearby terrestrial areas and mountains. Subsequently the interested parties constructed two biological corridors connecting the terrestrial sites and the breeding pond. Ecological and behavioral information about the breeding toad population at Wonhunge and the use of habitat corridors will be critical for the design of appropriate future conservation actions.

Our research goal was to obtain basic ecological and behavioral information about the adult breeding toad population at the Wonhunge pond, including their physical characteristics, breeding population size, and migration patterns. This is the first systematic field study of the breeding ecology of an Asian toad population in Korea and may provide useful information for conservation planning.

MATERIALS AND METHODS

Study Site

The study was conducted from 5 March to 11 April 2006 and

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14 February to 31 March 2007 at the Wonheunge pond (36° 36' 800" N, 127° 27' 971" E; Fig. 1), located in Sannamdong, Cheongju City, Chungbuk. The 5,066.0 m^2 pond is a permanent reservoir surrounded by a steep 14 m high bank with a maximum depth of about 1.5 m. Asian toads have used the pond as a breeding site for many years. However, construction activities in the areas surrounding the pond in 2005 and 2006 isolated the pond completely from terrestrial vegetation in the nearby mountains, which is habitat for toads during the non-breeding season. In an attempt to reduce the impacts of human activities on the toads, two biological corridors were constructed between the pond and the mountains that comprise toad habitat outside of the breeding season. One corridor (230 m long; 5～10m wide) connects the western edge of the pond to the mountains and the other (180 m long; 3～4 m wide) connects the northern edge of the pond to the mountains (Fig. 1). The two corridors were established along the main rainy season waterways to the breeding pond. During the toad's immigration period, we often sprayed water on the dry corridors.

Enclosure Construction and Survey

To capture adult toads entering or exiting the pond, we constructed two drift fences before the seasonal migration in 2006 (Fig. 1). The 800 m outer fence was set up along the path between the pond and the mountains. The 300 m inner fence was placed just outside of the pond. We buried 13 pitfall traps (diameter 30 cm; depth 45 cm) at about 50 m intervals along the outer fence and eight traps at about 35 m intervals along the inner one. In 2007, we added two more traps on both sides of the water flow. The

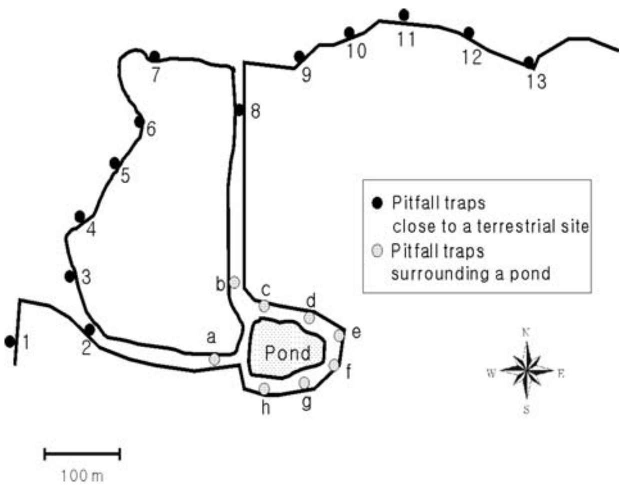

Fig. 1. Map of Wonheunge pond showing the drift fences leading migrating Asian toads (*Bufo gargarizans*) to the biological corridors and the pitfall traps used to capture the toads. Traps 2a and 8b are located in the biological corridors. Areas enclosed in the drift fences have been modified for human use.

fence was made of green Formax (60 cm height) and gray wire gauze with 0.5 cm mesh, and was buried about 10 cm below the ground surface to prevent toads from passing under the fence. The fence was supported by 1.2 m metal stakes.

Groups of 2～5 observers, including researchers and >40 civilians and members of the Peace Federation for Wonhunge Life, conducted daily surveys throughout the study period. We checked the pitfall traps twice per day (10:00～12:00 AM and 2:00～4:00 PM) and sometimes a third time (6:00～8:00 PM). Adult toads captured in the traps of the outer fence were considered to be immigrants into the area while toads captured in the traps of the inner fence were considered to be emigrants leaving the area. For each toad captured, we recorded the capture date, time, location, and sex, and measured the toad's SVL (snout-vent length; to the nearest 0.1 mm) using vernier calipers and body mass (to the nearest 0.1 g) using an electronic field balance (Dae-Hyun Science Co., Seoul, model CB-200). Only three people measured SVL to increase the reliability of the collected data. The sex of each toad was determined based on the presence or absence of the nuptial pad. After measuring the toads, we released them on the opposite side of the fence. We directly transferred some immigrant toads into the breeding pond and emigrant toads to the near mountain areas for their safety on hot dry days.

We obtained weather information such as mean daily temperature, humidity and precipitation for the study period from the Chungju Weather Station, which is located about 3.5 km southeast of the study site.

Analysis

We examined variation in toad physical characteristics between years using one-way ANOVA after testing the data for significant deviations from normality (One-sample Kolmogorov-Smirnov test, $P>0.05$). To evaluate the relationship between physical characteristics, weather conditions and dates arriving or leaving the breeding pond, we calculated the means for physical characteristics of toads captured on each day and then used the non-parametric Spearman's rank test (Zar 1999). Numerical data in the text are presented as mean ± SD. Data were analyzed using SPSS statistical software (v.11.5; SPSS 2002).

RESULTS

Immigration Patterns of Adult Asian Toads

In 2006, a total of 266 adult immigrants [53 (19.9%) females and 213 (80.1%) males] were caught between 5 and 12 March (Fig. 2A). Two peaks in capture rates for immigrants occurred in early (day 5 for females, 6 for males) and mid-March (day 10) (Fig. 2A).

The mean number of immigrants on a given day for both female and male toads was significantly correlated with average air temperature (females, r_s = 0.759, n = 12, p = 0.004; males, r_s = 0.659, n = 12, p = 0.02; Fig. 2B). However, neither humidity nor rain was significantly correlated with the mean number of immigrants.

In 2007, a total of 307 adult immigrants [85 (27.7%) females and 222 (72.3%) males] were captured between 14 February and 7 March. Fifty additional toads were killed on the road by motor vehicles during the immigration period. As in 2006, there were two immigration peaks, the first in late February (day 26 for males, 27 for females) and the second in early (day 3) March (Fig. 2D). Again, the mean number of immigrants was highly correlated with the daily average air temperature (females, r_s = 0.703, n = 21, p< 0.001; males, r_s = 0.660, n = 21, p = 0.001; Fig. 2E), and neither humidity nor rain was significantly correlated with the mean number of immigrants.

Emigration Patterns of Adult Asian Toads

In 2006, the first emigration of a toad occurred on 15 March, and 69 emigrating females (including an additional 16 females that might hibernate around the breeding pond) and 181 emigrating males (85.0% of immigrated males) were caught in the traps before 11 April. Two emigration peaks occurred for both sexes: the first one on 16 March for females and 23 March for males; the second on 2 April for both sexes (Fig. 3A). The mean daily number of immigrants was significantly correlated with average humidity (r_s = 0.501, n = 28, p = 0.008; Fig. 3B).

In 2007, the first emigration of a toad occurred on 5 March. Between 5 and 31 March, we caught only seven females (0.08 % of the number of female immigrants) in the traps, a sample that was too small to permit further examination of patterns of emigration by females for that year. During the same period, 92 emigrating males (41.4 % of the number of male immigrants) were captured. Two

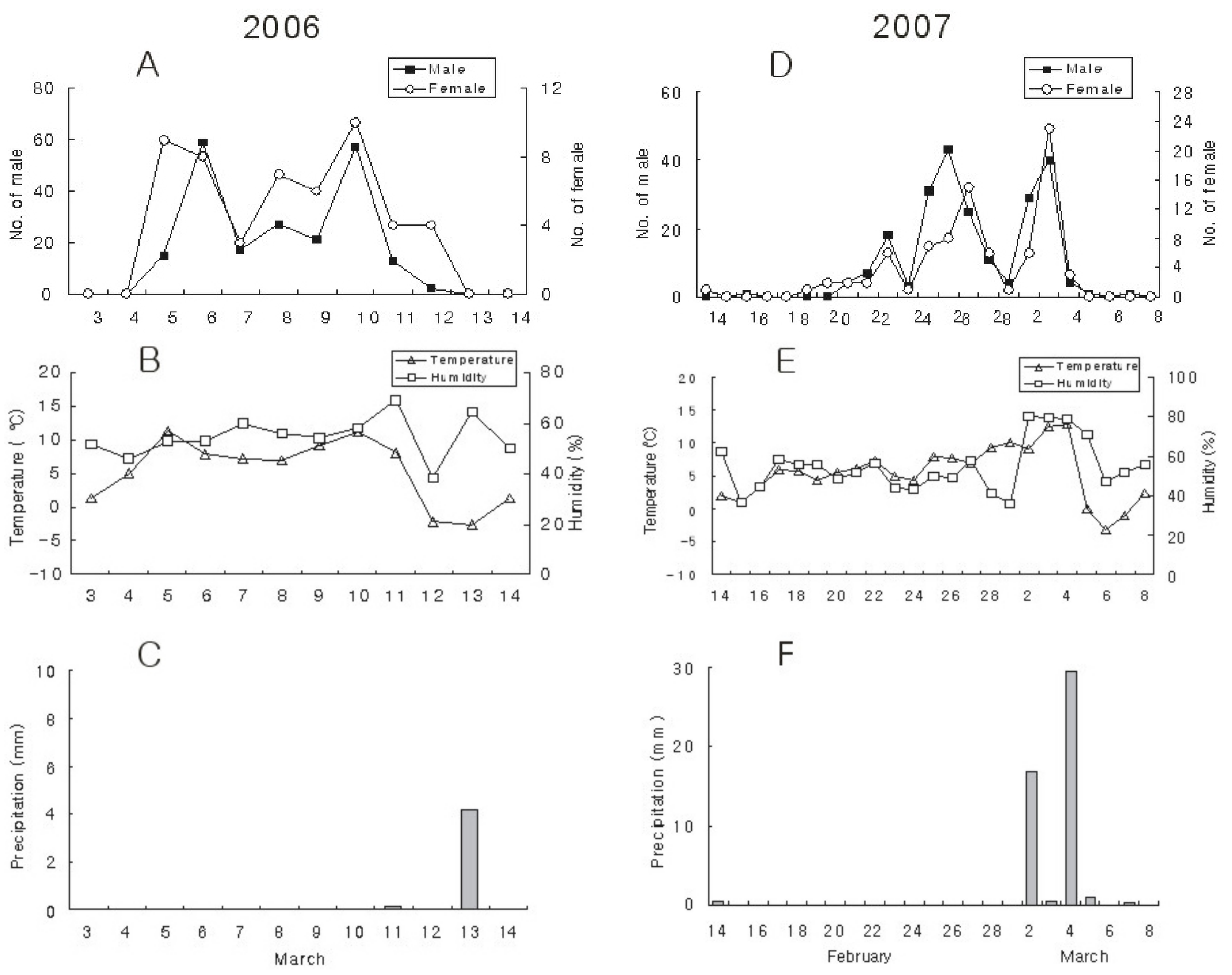

Fig. 2. Number of Asian toads captured while immigrating to the breeding pond (A, D) in relation to changes in environmental variables (air temperature and humidity B, E; daily precipitation C, F) over the study period.

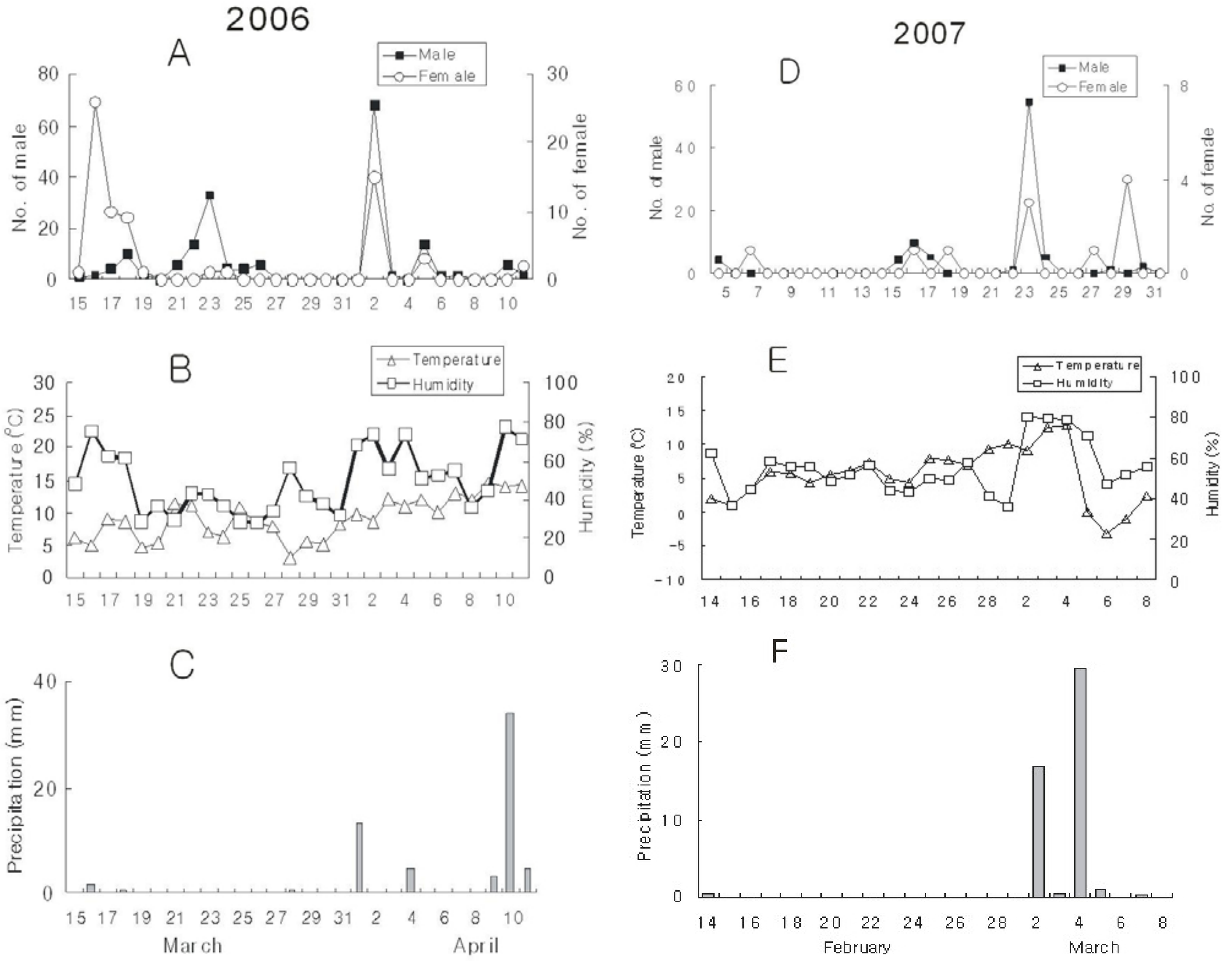

Fig. 3. Number of Asian toads captured while emigrating from the breeding pond to the terrestrial habitat (A, D) in relation to changes in environmental variables (air temperature and humidity B, E; daily precipitation C, F) over the study period.

emigration peaks were observed, on 17 and 23 March (Fig. 3D). The mean daily number of emigrants was significantly correlated with the average humidity (r_s = 0.481, n = 18, p = 0.043; Fig. 3E).

Seasonal Changes in Physical Characteristics

Females captured in the traps were much larger than males (Table 1). The ratio of immigrant female SVL to male SVL was 1.36 in 2006 and 1.34 in 2007, and that of emigrant female SVL to male SVL was 1.31 in 2006. The SVL of immigrating females was larger than that of emigrating females in 2006, but the SVL of immigrating males was not different from that of emigrating males in 2006 or 2007. Immigrants were significantly heavier than emigrants for both females and males in 2006, and males in 2007 (Table 1). Body mass was significantly negatively correlated with emigration dates for both sexes for both years, and immigration dates for males in 2007 (Table 2). SVL of immigrating and

Table 1. Comparisons of physical parameters between immigrating and emigrating adult Asian toads

Variable	Immigration (Sample size)	Emigration (Sample size)	One-way ANOVA F
(A) In 2006			
Male SVL	79.96 ± 6.36(181)	78.75 ± 5.29 (79)	2.207
Female SVL	108.73 ± 7.79(36)	102.87 ± 7.73 (47)	11.632**
Male weight	57.19 ± 11.04(181)	58.86 ± 16.33 (207)	4.865*
Female weight	146.42 ± 33.95(36)	130.46 ± 31.95 (47)	4.814*
(B) In 2007			
Male SVL	77.40 ± 6.64(207)	76.71 ± 6.15 (85)	0.695
Male Weight	58.86 ± 16.33(207)	51.52 ± 9.47 (85)	15.059***

*p<0.05, **p<0.01, ***p<0.001.

Table 2. Spearman rank correlations between toad physical parameters and date variables

Date variables	Physical parameters	
	SVL	Weight
(A) In 2006		
Male immigration dates (*n* = 7)	−0.321	0.025
Male emigration dates (*n* = 10)	−0.200	−0.673*
Female immigration dates (*n* = 7)	−0.250	−0.571
Female emigration dates (*n* = 10)	−0.250	−0.679*
(B) In 2007		
Male immigration dates (*n* = 12)	−0.259	−0.622*
Male emigration dates (*n* = 9)	−0.333	−0.810*
Female immigration dates (*n* = 12)	−0.336	−0.664*

*$p<0.05$.

emigrating toads were also negatively related with migration dates, but these results were not statistically significant.

DISCUSSION

The present results provide basic information about the breeding ecology of the Asian toad. The timing of immigration peaks for toads was related to daily air temperature, while the timing of emigration peaks was related to the humidity. Both immigration and emigration occurred earlier in 2007 than in 2006, which might result from the 6.5℃ difference in mean temperatures in February between years (2007 was warmer than 2006). In some anuran species, the timing of breeding migration is closely related with rainfall (Gibbons and Bennett 1974, Okuno 1985, Richter and Seigel 2002). Higher rainfall may decrease migration-related mortality from desiccation. However, the drier skin of the Asian toads and the fact that most Asian toads live in various terrestrial habitat types during the non-breeding period suggest that they might be more tolerant to dry conditions than other anuran species (Hillman 1980, Burggren and Vitalis 2005). Thus, it is unsurprising that rainfall does not appear to be the main factor affecting migration patterns of adult toads. Rather, temperatures may have a stronger effect on migration activity because lower temperatures reduce the toads' physical capacity for activity.

The number of adult toads immigrating to the pond increased to 357 in 2007 from 266 in 2006, but the number of immigrants in 2007 was still much lower than the approximately 500 adults counted by civilian volunteers in 2005. The low return rate of the toads to the breeding pond may be due to one of three possibilities (Richter and Seigel 2002): 1) the toads may be using alternative breeding sites, 2) the toads may not attempt to reproduce every year, and 3) there may be low survival rates in the local population. However, no other breeding pond is known in this study area, although some pairs may breed in paddy rice fields. Similarly, while some *Bufo* species are known to reproduce biennially (Bragg 1940), the total toad numbers were low in both 2006 and 2007. The most likely explanation for the reduced rate of return to the pond is therefore that modification of terrestrial habitats as a result of human construction activities has affected survivorship and the movement patterns of adult toads. Changes in the landscape have been shown to affect reproductive dynamics and movement patterns of individuals of many anuran species (Gibbs 1998, Mazerolle 2001, Marsh and Thenham 2001, Neckel-Oliveira 2004). However, more information about non-breeding habitats, survival rates, travel distances, and reproductive activities of marked individuals will be required to determine the actual cause(s) of the low number of breeding immigrants for this population.

Males in the study population were smaller than females, with a ratio of female SVL to male SVL of 1.31～1.36. Such sexual size dimorphism is consistent with the results of previous studies (Shine 1979, Fukuyama and Kusano 1989). Sexual dimorphism in anurans results from the combined effects of natural and sexual selection (Lande and Arnold 1983, Ryan 1985, Arak 1988). Most anuran males prefer to mate with larger females due to their high fecundity (Arntzen 1999, Castellano et al. 2004). In this population, the operational sex ratio was male-biased at 2.61～4.02 males/females, which may lead to intense male-male competition for more fecund large females.

The larger males and females at this site arrived at and left the breeding pond earlier than smaller individuals. Larger males and females may be more successful because they are more attractive to the opposite sex (Howard and Young 1998). In addition, greater size may increase male and female reproductive success because larger adults may have more stored energy, which may in turn permit higher reproductive effort (i.e. ability to stay in amplexus until egg-laying; Eggert and Guyétant 2003). Indeed, a positive relationship between fecundity and body size has been observed in many anuran species (Duellman and Trueb 1986, Halliday and Verrell 1988, Kuhn 1994, Castellano et al. 2004). Thus, larger males and females may be able to obtain higher quality mates as well as displaying higher fecundity.

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