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Habitat Use and Home Range of the Endangered Gold-Spotted Pond Frog (*Rana chosenica*)

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Because of their complex life styles, amphibians and reptiles living in wetlands require both aquatic and terrestrial buffer zones in their protected conservation areas. Due to steep declines in wild populations, the gold-spotted pond frog (*Rana chosenica*) is listed as vulnerable by the IUCN. However, lack of data about its movements and use of habitat prevents effective conservation planning. To determine the habitat use and home range of this species, we radio-tracked 44 adult frogs for 37 days between 10 July and 4 Nov. 2007 to observe three different populations in the breeding season, non-breeding season, and late fall. The gold-spotted pond frog was very sedentary; its daily average movement was 9.8 m. Frogs stayed close to breeding ponds (within 6.6 m), and did not leave damp areas surrounding these ponds, except for dormancy migration to terrestrial sites such as dried crop fields. The average distance of dormancy migration of seven frogs from the edge of their breeding ponds was 32.0 m. The average size of an individual's home range was 713.8 m^2 (0.07 ha). The year-round population home range, which accounts for the home ranges of a population of frogs, was determined for two populations to be 8,765.0 m^2 (0.88 ha) and 3,700.9 m^2 (0.37 ha). Our results showed that to conserve this endangered species, appropriately sized wetlands and extended terrestrial buffer areas surrounding the wetlands (at least 1.33 ha, diameter 130 m) should be protected.

Key words: gold-spotted pond frog, *Rana chosenica*, radiotelemetry, home range, dormancy

INTRODUCTION

Wetlands are continuously decreasing in size due to the extension of farmlands and urban areas (Holland et al., 1995; Brinson and Malvárez, 2002). This decrease contributes to the loss of animal species diversity, including the loss of semi-aquatic amphibians and reptiles (Knutson et al., 1999; Snodgrass et al., 2000; Gibbs, 2000). Considering the continuous worldwide decline of amphibian populations (Houlahan et al., 2000; McCallum, 2007) and the ecological importance of wetlands, many countries have established various laws to protect wetlands. Traditionally, wetland protection efforts have focused on protecting bodies of fresh water and the surrounding small terrestrial areas in order to conserve animals living in the wetlands, and ensure that they have access to fresh water (Phillips, 1989).

Recently, several studies have suggested that protected wetland areas created to conserve amphibians and reptiles should include more extended terrestrial buffer areas to account for the semi-aquatic animals' use of terrestrial habitat during the non-breeding season and dormancy period (Semlitsch, 2000; Fellers and Kleeman, 2007). Because there is high pressure to develop wetlands for human use in many countries, results from spatial ecological studies are critical for determining the appropriate sizes of protected areas to conserve semi-aquatic amphibians and reptiles. Relatively few studies have addressed the complex life styles of these animals (Burke and Gibbons, 1995; Joyal et al., 2001; Porej et al., 2004; Goates et al., 2007), and results for various semi-aquatic species are still lacking. In particular, there are few spatial ecological studies of Asian anurans (Kusano et al., 1995). In Korea, a law to protect wetlands was established in 1999 (#5866; MEK, 1999), but the areas protected under the law do not include terrestrial buffer zones. In addition, most small agricultural wetlands are not under protection by the law. To date, no studies examining the importance of terrestrial buffer zones near wetlands to conserve semi-aquatic wetland amphibians have been conducted in Korea.

The gold-spotted pond frog (*Rana chosenica*) has distinctive gold stripes on the dorsal plate, so the frog is easily discriminated from other frogs (Sung et al., 2007). The frogs inhabit small agricultural wetlands along the west coast of

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the Korean peninsula. They breed from early June to late July and lay eggs in clumps among water plants in breeding ponds or waterways of wetlands (Lee, 2004; Sung et al., 2007). Due to the loss and fragmentation of small agricultural wetlands in Korea, the number and size of wild gold-spotted pond frog populations are decreasing. To conserve this species, the Ministry of Environment of Korea has listed it as an endangered category II species since 2005 (#7167; MEK, 2005). The species has also been listed as vulnerable in the IUCN since 2004 (Matsui, 2004). However, the lack of data on the spatial ecology of the species, for example the size of their home range and the locations of their dormancy sites, prevents effective conservation planning.

In this study, we determined the habitat use, dormancy sites, and home range of the endangered gold-spotted pond frog by radio tracking 44 adult frogs in agricultural wetlands during the breeding season, non-breeding season, and late fall period.

MATERIALS AND METHODS

Study sites

Two of the populations in our study inhabited wetlands located in Oongjin, Incheon, South Korea. One population inhabited an agricultural wetland (Fig. 1A), and the other an area that had previously been a reservoir, but had been allowed to dry considerably (Fig. 1B). The third population in our study was located in an agricultural wetland (Fig. 1C) in Cheongwon, Chungbuk, South Korea. At Oongjin, studies were conducted during the breeding season, non-breeding season, and late fall. At Cheongwon, a study was conducted only in the late fall.

The agricultural wetlands (50 m long × 80 m wide) at Oongjin consist of agricultural swamp fields; these had not been farmed for the previous five years (Fig. 1A). The swamp fields contain a pond (5.5 m wide × 0.8 m deep) and two waterways (41.2 m long × 1.5 m wide × 0.9 m deep; 30.4 m long × 4.5 m wide × 0.8 m deep) that are regularly used as breeding sites by the gold-spotted pond frog (Cheong et al., 2007). Rice paddies and dried crop fields adjoin the wetlands. Pine forests surround the areas at a distance of roughly 40–100 m from the edge of the breeding pond. Within the breeding pond and waterways, water plants such as cattails (*Typha orientalis*) and reeds (*Phragmites communis*) cover more than 90% of the water surface. Within the damp swamp areas (water depth about 5–10 cm) surrounding the breeding pond and waterways, cattails (*Typha orientalis*) and plants in the families Polygonaceae, Gramineae, and Cyperaceae cover entire areas.

In the abandoned reservoir site (227 m long × 98 m wide) at Oongjin, the gold-spotted pond frog uses as breeding sites a swamp pond (80 m long × 6 m wide × 1.2 m deep) in the reservoir area and a waterway (60 m long × 4 m wide × 1.2 m deep) that is separated from the reservoir by banks 10 m wide (Fig. 1B). The swamp pond covers about 3.6% of the total reservoir area, and the rest consists of damp areas with water depths of less than 10 cm. Cattails and reeds cover about 50% of the water surface in the swamp pond, and plants in the families Polygonaceae, Gramineae, and Cyperaceae cover whole sections of the damp areas. Fifteen meters west of the swamp pond, there is an artificially constructed fishing pond (160 m long × 30 m wide) that is not used for fishing. The artificial fishing pond and rice paddies flank the waterway used by the frogs to breed. Water plants such as cattails, reeds, and water chestnuts (*Trapa japonica*) cover more than 90% of the water

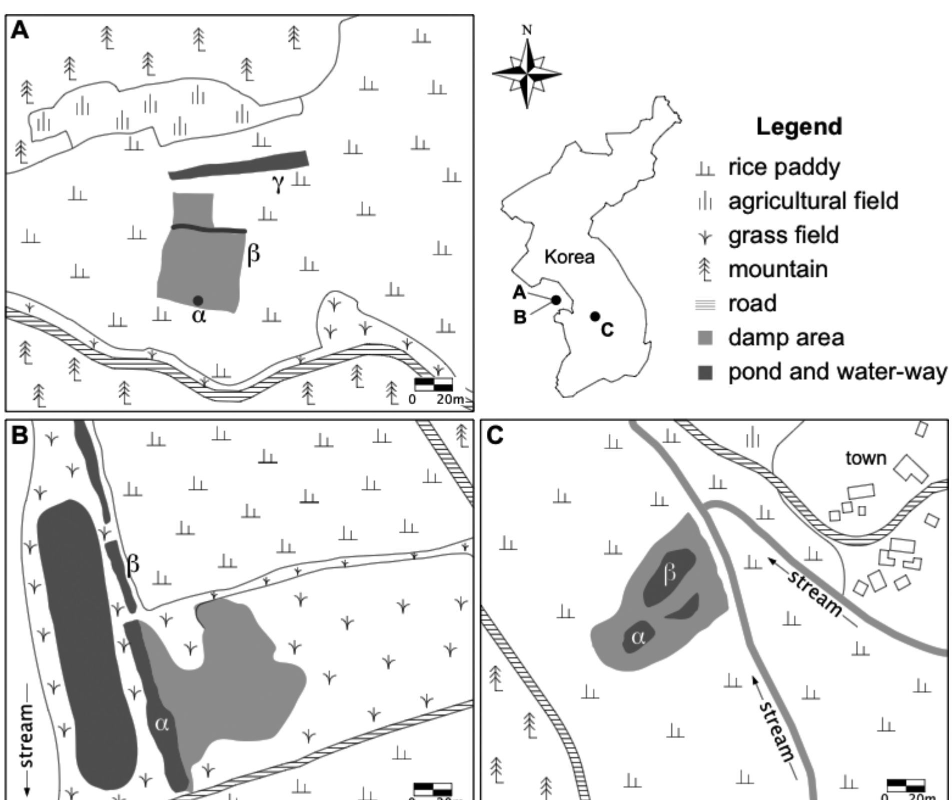

Fig. 1. Study sites where we radio tracked gold-spotted pond frogs. **(A)** Agricultural wetlands and **(B)** an abandoned reservoir at Oongjin in Incheon. **(C)** Agricultural wetlands at Cheongwon in Chungbuk, Korea. α, β, γ indicate ponds and waterways that were used as breeding sites by the study populations.

surface of the waterway. A second waterway (70 m long × 5 m wide) lies next to the first waterway from the reservoir, and holds water only temporarily during rains (Fig. 1B).

The agricultural wetlands (89 m long × 49 m wide) at Cheongwon also consist of agricultural swamps; these had not been farmed for the previous five years (Fig. 1C). Cattails and plants in the families Polygonaceae, Gramineae, and Cyperaceae cover the whole swamp area. Three breeding ponds (27 m long × 14 m wide × 1 m deep; 20 m long × 11 m wide × 0.7 m deep; 20 m wide × 6.7 m long × 0.7 m deep) are in the center of the wetlands (Fig. 1C), surrounded by intermittently dry areas that become wet during the rainy season. Outside the wetlands are the adjoining dried terrestrial crop fields and rice paddies. Oak forests are located 50 meters west of the wetlands (Fig. 1C).

Radio tracking was conducted separately over the following three time periods between 10 July and 4 Nov. 2007: the breeding season (10–18 July), the non-breeding season (31 Aug–8 Sept.), and the late fall (17 Oct.–4 Nov.). This study was approved by the Ministry of Environment of Korea. All amphibian handling processes followed the guidelines of the The American Society of Ichthyologists and Herpetologists (ASIH, 2004).

Radiotelemetry

We used waterproof transmitters (Model BD-2N, average battery life 10 days; Holohil Systems, Canada) to follow the movements of gold-spotted pond frogs. We first glued each transmitter onto a semi-elastic plastic belt using gauze and epoxy (0.57±0.04 g for each transmitter prepared; n=44). We fastened the belt around the waist of each frog (Weick et al., 2005) and then adjusted the diameter of the belt to the waist size of each individual frog by lengthening the belt using two dull forceps until it loosely fitted the frog. Every two or three days, we captured each frog that carried a transmitter by hand or by using a hand net in order to determine whether the belt had caused any problems. Well-fitted belts did not cause any problems in most frogs. At the beginning of the study, the belts caused some skin bruises on the dorsal and ventral skins of four frogs. For these frogs, we terminated radio tracking and applied Phobidon (Dongin Medicine, Korea) to the bruised skin for two to three days to prevent viral and fungal infections. We kept these frogs in individual shoe boxes (30 cm long × 17 cm wide × 15 cm deep), and after their skin had healed, released them at the locations where they were originally caught.

We determined the location of each individual twice daily, between 0800 and 1000 and between 1500 and 1700, using a TRX-1000 receiver and a hand-held three-element Yagi antenna. If we could not visually detect a frog, we determined its approximate location by applying close triangulation (<30 cm). Before tracking a frog, we recorded air temperature and humidity using an electronic thermo- and hygrometer (Model # RS-232, Center, Taiwan). We measured the water temperature to the nearest 0.01 using a mercury thermometer. Precipitation data on each study day were obtained from the nearest meteorological stations at Incheon (21.8 Km away) for the Oongjin site and at Cheongju (9.2 Km away) for the Cheongwon site.

To record the locations of each frog tracked, we first made a sketch of the study area and measured to the nearest 1 cm the size of each breeding pond, reservoir, waterway, and rice paddy using a 50 m measuring tape. We also used these features as local landmarks. When we located a frog, we recorded its location as an x- and y-axis distance from a known landmark. We measured the shortest straight distance between the current location and the previously determined location to determine how far the frogs moved daily. We also used 5-m and 50-m measuring tapes to measure the distance between a frog's location and the edge of its breeding pond to determine how often the frogs used water vs. terrestrial habitats, and how far the frogs moved away from the ponds. During the breeding and non-breeding seasons, we captured all frogs in the breeding ponds or waterways, and considered the body of water where the frog was captured to be its breeding pond. During the late fall, several frogs were captured outside breeding ponds or waterways. For those frogs, we considered the nearest pond to be their breeding pond. Since most frogs moved relatively short distances each day, we did not use GPS to record their locations. We flagged the confirmed location of a frog to facilitate the next measurement.

We judged that a frog had selected its dormancy site when the frog's whole body was submerged under the ground surface and the frog remained at the site without changing location for more than three continuous days. In our rearing facility, most frogs in this condition continued dormancy (personal observation). Following this criterion for dormancy, we determined the dormancy location of seven frogs. After a frog started dormancy, we recorded its daily movement as 0 m in order to calculate the daily mean movement for the population. The distance of a dormancy migration for a frog was defined as the distance between the dormancy location and the edge of the frog's breeding pond.

Data analysis

For the analysis, we included data points for a day only if the location of the frog could be determined during the two times of the day we measured. We compiled the movement and distance data to calculate the average daily movement of each individual frog, as well as the average distance of frog movements for each day. The daily individual movement of a frog was the sum of its morning and afternoon movements. To calculate average daily individual movement, we divided the total movements made by a frog over a study period by the number of days in the study period. To obtain the distance of average frog movements for a given day, we first summed the movement of all frogs on a given day and divided by the number of frogs. We compiled the distances between the location of a frog and the edge of the frog's breeding pond using the same procedures as described for the movement data. If the distance was positive, it meant that a frog moved out from the breeding pond. The distance data for frog number 15 in the agricultural wetlands during the late fall were lost.

Home ranges were determined for 36 frogs that were radio-tracked for more than two days; these consist of 13 frogs during the breeding season, eight during the non-breeding season, and 15 during late fall (23 females, 13 males). We excluded three frogs that were radio-tracked for just one day. We also excluded five frogs from the Cheongwon population because we were only able to obtain daily movement data during the late fall for this population, and we were only able to determine the dormancy sites of two of the frogs.

To calculate the size of the frogs' home range, we first marked all locations of each frog on a digital map (1:5000, National Geographic Information Institute in the Ministry of Construction and Transportation of Korea) by carefully comparing the frog's location data to local landmarks on the map. After that, the size of the home range of each frog was determined using the adaptive kernel method (95%; Worton, 1989) in the Animal Movement program (v. 2.0, Hooge et al., 1999) operated in ArcView (v. 3.2, Environmental Systems Research Institute). Previous studies have shown that the kernel method determines animals' home ranges better than the minimum convex polygon method (Nilsen et al., 2007). In addition, we determined the year-round population home range of the two study populations at Oongjin, using data from 12 frogs belonging to the first population and 24 frogs belonging to the second. These were data obtained during the breeding and non-breeding seasons and late fall period.

Since most movement and distance data did not show a normal distribution (Kolmogorov-Smirnov, $P<0.05$), we applied a non-parametric method to determine significance. A Spearman correlation analysis was used to determine the correlation between the daily average movement and parameters such as distance, air and water temperature, humidity, and precipitation. To compare the distance moved between rainy and non-rainy days, we used the Mann-Whitney U test. Body weight changes before and after radio tracking were compared by the Wilcoxon signed rank test. To determine whether average daily individual movement and average individual distance from the edge of the breeding ponds were different between the breeding season, non-breeding season, and late fall, we applied the Kruskal-Wallis ANOVA test and conducted a post-hoc test to determine if the difference was significant (Siegel and Castellan, 1988). To compare movement and distance data between males and females, we applied the Mann-Whitney U test. We described the migration distance for dormancy for seven frogs.

The log-transformed home range data matched assumptions for parametric analysis (Kolmogorov-Smirnov, $P>0.05$), so we used a one-way ANOVA test to determine whether the size of home ranges was significantly different between the breeding season, non-breeding season, and late fall. The difference between home ranges of males and females was tested by using an independent sample *t*-test. Relationships between the length of tracking days and the home range size, body weight, and SVL (snout-vent length) of frogs were analyzed by the Pearson correlation test. We used SPSSPC (v. 14.0) to analyze all data, and the significance was determined at $P=0.05$ with two tails. The data are presented as the mean±SD.

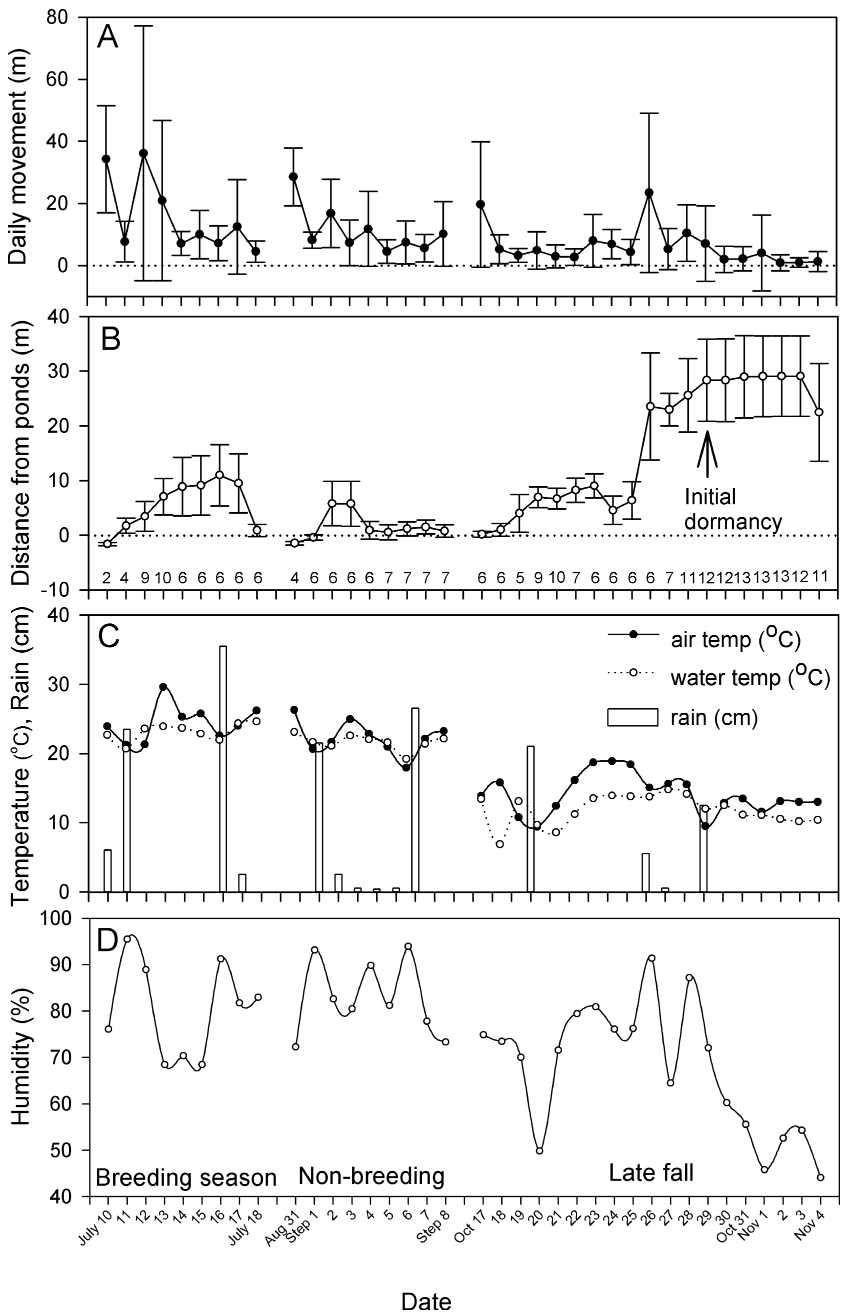

Fig. 2. **(A)** Daily average movements and **(B)** distances from breeding ponds of gold-spotted pond frogs, and **(C, D)** local climate conditions between 10 July and 4 Nov. 2007. Radio tracking was done on separate occasions during the breeding season, non-breeding season, and late fall; a dormancy migration period was included. Numbers in (B) indicate the sample size on each day.

RESULTS

Of the 44 total frogs followed, 16 (females=11, males=5) were followed during the breeding season, 8 (females=5, males=3) during the non-breeding season, and 16 (females=10, males=6) during the late fall. The mean body weight of the tracked frogs was 14.5±6.9 g (6.8–36.7 g, n=44) and the mean SVL was 5.0±0.7 cm (3.9–6.5 cm, n=44). Percentile weight of the attached transmitters relative to the body weight of the frogs was 4.81±2.06% (1.50–8.82%, n=44). After tracking, the body weight did not significantly change (Wilcoxon signed rank test, Z=–0.81, n=27, P=0.419). The body weight of 13 frogs increased (1.8±1.7 g, n=13), 12 decreased (1.3±2.2 g, n=12), and two did not change. Oviposition by a female occurred during the breeding season study.

Over 37 days, we located frogs on 562 instances and each of the 44 animals was sighted between two and 32 times (12.77±8.20, n=44) during a mean of 6.39±4.10 days (1–16 days, n=44, total=281 days). Out of the 562 total localizations, direct visual localization was made in 446 cases (79.36%). Most indirect localizations were made during late fall (91 cases out of 116) because during this period, some adults were submerged under the muddy water and did not come up to the water surface. The rest (25) of the indirect localizations were made during the breeding season (9) and the non-breeding season (16).

Daily average movement of frogs was positively correlated with the air (r=0.445, P=0.006, n=37) and water (r=0.489, P=0.002, n=37) temperatures and the humidity (r=0.368, P=0.025, n=37). The daily mean distance from the edge of breeding ponds was negatively correlated with the air (r=–0.588, P<0.01, n=37) and water (r=–0.549, P<0.01, n=37) temperatures, and to the humidity (r=–0.557, P<0.01, n=37) (Fig. 2). Although the amount of precipitation was not significantly correlated with either the daily average movement (r=–0.068, P=0.691, n=37) or the mean distance from the edge of the breeding ponds (r=–0.196, P=0.244, n=37), frogs moved more on rainy days (11.3±8.5 m, n=14) than on non-rainy days (8.5±9.2 m, n=23, Mann-Whitney U test, U=98.00, N_1=23, N_2=14, P=0.049).

The average daily individual movement was different between the breeding season, non-breeding season, and late fall (Kruskal-Wallis test, $H_{44,\,2}$=15.75, P<0.01) (Table 1, Fig. 3A, B). In particular, during the breeding season, frogs moved more than they did during late fall (post-hoc test, P<0.05). Other comparisons were not significant (post-hoc test, P>0.05). The difference in average daily individual movement between males and females was not significant (Mann-Whitney U test, P=0.709) (Table 1).

In the analysis of mean daily individual distance from the edge of breeding ponds, 10 individuals out of 16 were more often located inside breeding ponds than outside during the breeding season, five out of eight exhibited this characteristic during the non-breeding season, and five out of 14 during the late fall. The difference in the mean daily individual distance from the edge of breeding ponds was not significant between the breeding season, non-breeding season, and late fall (Kruskal-Wallis test, P=0.084) (Table 1). The difference between males and females was also not significant (Mann-Whitney U test, P=0.560) (Table 1).

We determined the dormancy sites of seven out of 12 frogs tracked during the late fall. Until the batteries of the transmitters ran out, two frogs stayed in a breeding pond and three frogs in damp swamp areas. The first dormancy was observed on 28 Oct. in the agricultural wetlands at Oongjin. Four frogs started dormancy on 29 Oct., and two frogs on 1 Nov. (Figs. 2A, 3C). Out of seven frogs that started dormancy, three chose dormancy sites in dried rice paddies covered with debris from the rice harvests, one in a dried terrestrial crop field, and the other three in the banks of rice and terrestrial crop fields. The mean migration distance for dormancy from the edge of the breeding ponds was 32.0±23.4 m (median=44.3 m, 3.4–81.9 m, n=7) (Fig. 3C).

The mean individual home range size of 36 individuals radio-tracked for more than two days was 713.8±1,607.4 m^2 (median=240.7, 3.8–9,549.3 m^2) (Table 1). Home range size did not correlate with the body weight (P=0.742) and SVL (P=0.945) of the frogs or the length of tracking days (P=0.492), and was not different between the breeding season, non-breeding season, and late fall ($F_{2,33}$=1.721, P=0.195) (Table 1), or between males and females (t=0.233, df=34, P=0.817) (Table 1). The size of the year-round pop-

Table 1. Summary of results showing daily average movement, daily average distance from breeding ponds, and the size of home ranges of gold spotted-pond frogs radio-tracked during the breeding season, non-breeding season, and late fall, including a dormancy migration period in 2007. Data presented as the mean±SD (median, range).

	Parameters	Average daily individual movement (m)	Average daily Individual distance from ponds (m)	Individual home range (m^2)
Seasons	Breeding	15.2±8.4 (14.9, 2.9–30.1)	3.7±11.8 (–0.8, –3.6–45.0)	1258.2±2529.3 (543.4, 9.9–9549.3)
	Non-breeding	10.4±4.9 (10.9, 3.7–16.6)	1.4±4.1 (–1.0, –1.5–8.5)	322.0±357.5 (213.1, 71.6–1164.7)
	Late fall	5.3±3.7 (4.0, 1.1–13.3)	12.8±17.3 (3.1, –2.2–47.0)	450.9±689.1 (114.7, 3.8–2126.1)
	Total	9.8±7.4 (8.0, 1.1–30.1)	6.6±13.8 (–0.4, –3.6–47.0)	713.8±1607.4 (240.7, 3.8–9549.3)
Sex	Male	9.5±8.0 (7.7, 1.5–30.1)	4.0±6.4 (0.9, –2.0–16.6)	1057.5±2577.4 (330.4, 3.8–9549.3)
	Female	10.0±7.2 (8.4, 1.1–26.5)	12.8±17.3 (–0.5, –2.2–47.0)	519.5±614.7 (192.9, 7.2–2126.1)

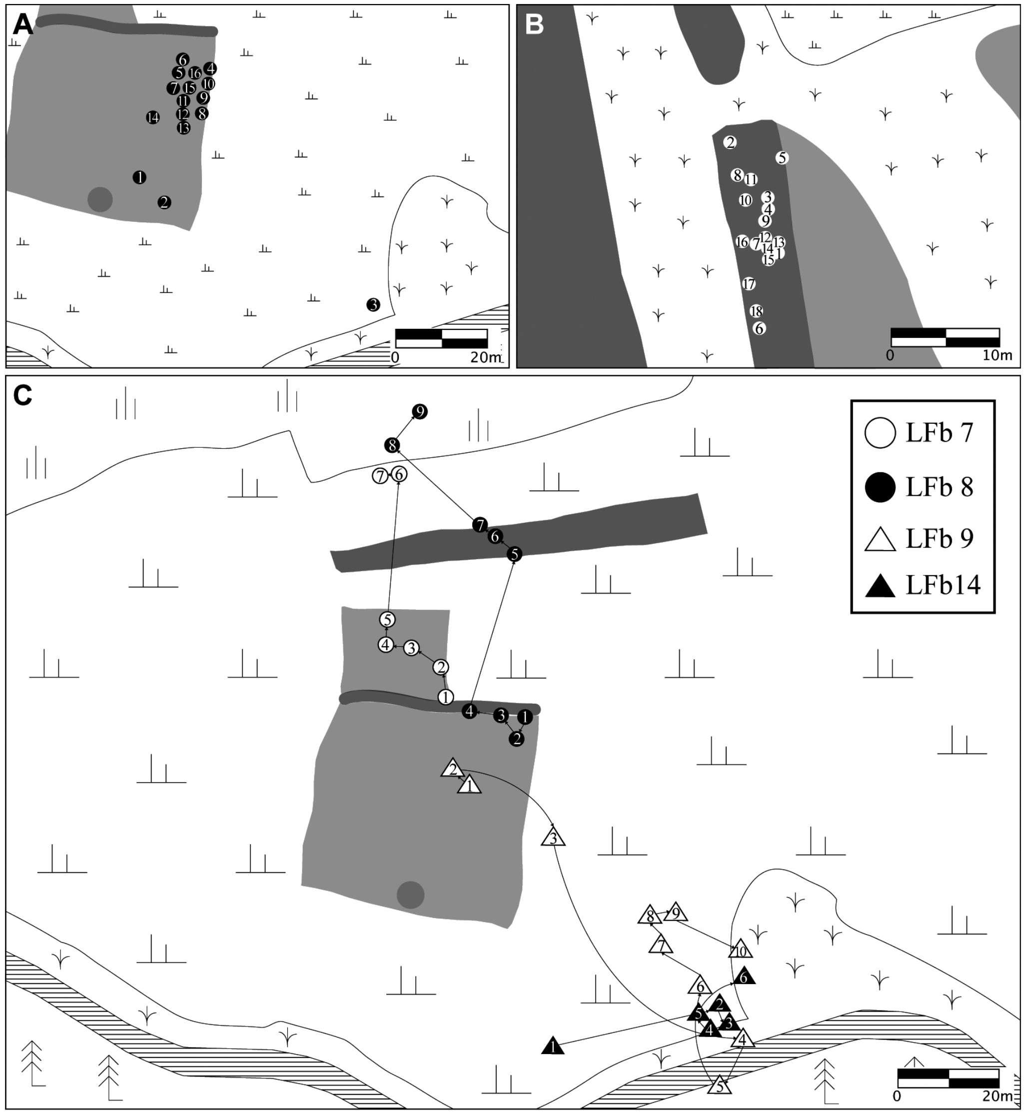

Fig. 3. Representative daily movements and dormancy migrations of gold-spotted pond frogs. **(A)** Movements of female Bbα9 during the breeding season in the agricultural wetlands. **(B)** Movements of male NBaα3 during the non-breeding season in the abandoned reservoir. **(C)** Dormancy migration of four frogs in the agricultural wetlands at Oongjin. Numbers in the figures indicate movement order of the frog over the radio-tracking period. Light shading, damp areas; dark shading, pond and waterways.

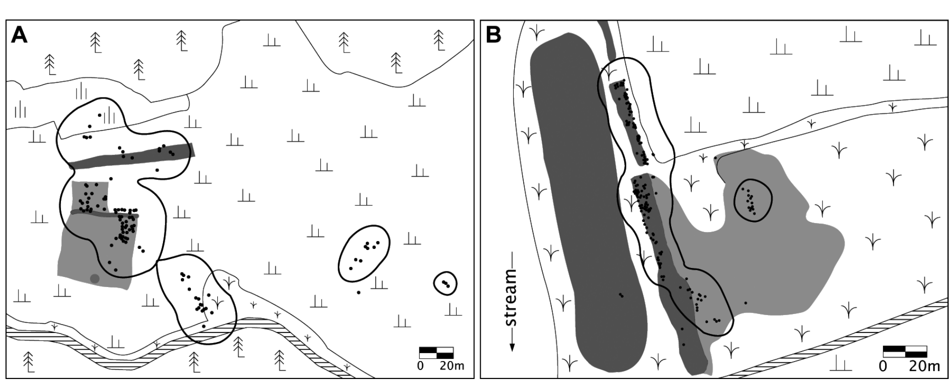

Fig. 4. Year-round population home range of the gold-spotted pond frog in two study populations at Oongjin. The home range was calculated by the adaptive kernel method (95%). Home ranges of **(A)** 12 frogs in the agricultural wetlands and **(B)** 24 frogs in the abandoned reservoir at Oongjin in Incheon between 10 July and 4 Nov. 2007, a period spanning the breeding season, non-breeding season, and late fall, and also including a dormancy migration period. Each black dot indicates the determined position of each frog during the study period. Light shading, damp areas; dark shading, pond and waterways.

ulation home range, which accounts for the home ranges for all of the frogs in a population, was obtained from the two populations at Oongjin. In the agricultural wetlands, the size of the year-round population home range was 8,765.0 m^2 (~0.88 ha, n=12) (Fig. 4A), and at the abandoned reservoir was 3,700.9 m^2 (~0.37 ha, n=24) (Fig. 4B).

DISCUSSION

Our results reveal several important aspects of the spatial ecology of the gold-spotted pond frog: 1) the frogs live a sedentary life style with little daily movement, 2) they prefer to live close to water, even during the non-breeding season, and 3) the terrestrial dormancy sites of at least some adults are close to breeding ponds. To our knowledge, this is the first study of an Asian anuran species that determines a year-round population home range.

Our radio-tracking data provide some important information on the movements of and use of habitat by the gold-spotted pond frog. The small weight of the transmitters relative to the frogs' body weight (<5%) in this study should not have affected their normal activities (Richards et al., 1994; Weick et al., 2005; Blomquist and Hunter, 2007). In the agricultural wetlands at Oongjin, one amplexed female oviposited eggs and one male moved 132 m overnight while wearing transmitters during the breeding season. Although two frogs were eaten, the predation rate was not high. In this study, the colored belt used to attach transmitters might have increased predation rates, however, the belts were necessary because they were very useful for finding and discriminating between frogs in muddy water. Based on previous observations that gold-spotted pond frogs were sedentary in wetland habitats (Sung et al., 2007), we tried to increase the sample size within the limited study period allowed by transmitter battery life (~10 days) rather than to follow an individual over a long period by replacing expired transmitters (Baldwin et al., 2006; Fellers and Kleeman, 2007).

As in most anuran species whose movements depend on weather conditions (Bulger et al., 2003; Penman et al., 2006), the daily movement of the gold-spotted pond frogs was related to air and water temperature and humidity. Increased temperature and humidity increased their movements, but they stayed within their breeding ponds as did summer breeding *R. lessonae* (Sinsch, 1984; Holenweg and Reyer, 2000). Gold-spotted pond frogs moved more on rainy days than on non-rainy days, as is well documented for many anuran species (Baldwin et al. 2006; Fellers and Kleeman, 2007). During our study, the longest daily movement of a frog occurred during a rainy night.

Throughout the year, except for the dormancy migration period, gold-spotted pond frogs were highly sedentary as compared to the *Rana* species previously studied (Driscoll, 1997; Semlitsch and Bodie, 2003), and stayed mostly within 7 m from the edge of breeding ponds. Daily average movement ranged from 5–15 m in different seasons. Such a small daily movement has been reported in other species, including *Geocrinia alba*, *G. vitellina* (Driscoll, 1997), and *Dendrobates variegata* (Donnelly, 1989). *Rana draytonii* moved a daily 0 or 150 m median distance (Fellers and Kleeman, 2007). *Rana sylvastica* moved about 60 m (Regosin et al., 2003; Baldwin et al., 2006), and *R. pipiens* moved about 160 m per day (Dole, 1965). During the late fall, gold-spotted pond frogs moved even less, only about 5 m per day. It is not clear from this study whether such small movements were to save energy for winter dormancy (Lamoureux et al., 2002) or were due to low temperature, which corresponded to a reduction in their movements (Sinsch, 1984; Penman et al., 2006). Considering that the areas surrounding breeding ponds are all damp areas with a water depth of about 10 cm, gold-spotted pond frogs rarely leave water bodies throughout the year, except for winter dormancy.

Unlike many species in the genus *Rana*, most gold-spotted pond frogs stayed continuously in breeding ponds or near damp areas during the non-breeding season. Most species of *Rana* leave their breeding sites and move to feeding areas, due to high feeding competition and increased predation risks at breeding sites (Bull and Hayes, 2001). For example, *R. sylvatica* (Regosin et al., 2005; Rittenhouse and Semlitsch, 2007) and *R. lessonae* leave the breeding sites and move to wet mountain areas or stream shore areas. Although *R. catesbeiana* does not leave the breeding sites, it increases movements to outside the breeding sites (Ingram and Raney, 1943; Matthieu et al., 2007). *Rana draytonii* travels repeatedly towards territorial areas during rainy periods, and some frogs completely leave the breeding areas (Bulger et al., 2003; Fellers and Kleeman, 2007). The finding that the frogs we studied stay in breeding ponds during the non-breeding season implies not only that the frogs are closely attached to the water body, but also that they can obtain sufficient prey in the area. This interpretation is supported by our results from a test that determined the frogs' preference for different feeding sites (Eom et al., 2007). In that study, we found that adult gold-spotted pond frogs obtained the most prey on the water surface or at the edge of an experimental pond.

Our study of dormancy sites first showed that at least some gold-spotted pond frogs lie dormant in terrestrial areas, such as dried crop fields and rice paddies. The distance between breeding ponds and dormancy sites was small, about 32 m. This is the shortest distance yet reported for a *Rana* species. Several *Rana* species, such as *R. lessonae* (98.5 m) and *R. sylvatica* (65 m) (Holenweg and Reyer, 2000; Regosin et al., 2005; Rittenhouse and Semlitsch, 2007), move relatively short distances. Most anurans can lie dormant both in water and in terrestrial areas depending on environmental conditions (Pinder et al., 1992; Stewart et al., 2004). Species in the genus *Rana* generally lie dormant in the water, where dissolved oxygen is abundant (Pinder et al., 1992). However, most adults of *R. sylvatica* and *R. lessonae* lie dormant in terrestrial areas (Holenweg and Reyer, 2000; Baldwin et al., 2006) because they can cope with low temperature, but cannot tolerate water anoxia (Tattersall and Boutilier, 1997). In this study, all seven frogs for which dormancy sites were determined chose dormancy sites in terrestrial areas. No frogs that we began radio tracking outside breeding ponds entered the breeding ponds. In addition, in our rearing facility, all subadult and adult frogs lied dormant in terrestrial areas (personal observation). These results suggest that most gold-spotted pond frogs lie dormant in terrestrial areas. However, we cannot completely exclude ponds as dormancy sites, because due to the short battery life of the transmitter, we could not determine the dormancy sites of the frogs that stayed in the breeding ponds. We considered these two cases as lost (Appendix 1). One more case of a lost signal occurred in waterways during the late fall and another in a pond during the breeding season. At Oongjin, although pine forests are located close to breeding ponds, no frogs lay dormant in the forests. This result implies that if there are appropriate terrestrial dormancy sites nearby, gold-spotted pond frogs might migrate only short distances, similarly to *R. draytonii* (Fellers and Kleeman, 2007). Many wild populations of the gold-spotted pond frog are in the middle of agricultural fields (Sung et al., 2007). The closest forests are often located several hundred meters away from breeding ponds, suggesting that frogs in these populations lie dormant in dried crop fields. During dormancy migration, most gold-spotted pond frogs moved directly from breeding ponds to nearby dormancy sites. A similar direct pattern of movement was reported for *R. draytonii* (Bulger et al., 2003), which moved relatively short distances for dormancy.

The year-round population home range of the gold-spotted pond frog was small, approximately 8,765.0 m^2 (~0.88 ha) and 3,700.9 m^2 (~0.37 ha) in two populations. To date, the year-round population home range has been determined only in a few anuran species (Matthews and Pope, 1999; Fellers and Kleeman, 2007). In most species, since frogs migrate during the non-breeding season, home ranges during the breeding season, non-breeding season, and dormancy period have been calculated separately (Matthews and Pope, 1999). The calculated size of the year-round population home range of the gold-spotted pond frog is the smallest known among *Rana* species (Driscoll, 1997; Dodd and Cade, 1998; Semlitsch and Bodie, 2003). We should also consider in future studies whether populations of the gold-spotted pond frog show characteristics of forming metapopulations, as do many frog species (Sjögren, 1991; Driscoll, 1997; Marsh and Trenham, 2001), with some exceptions (Smith and Green, 2005). If so, we need to determine the colonization and re-colonization routes among subpopulations and should include corridors and potential subpopulations within protected areas in order to conserve the gold-spotted pond frog.

Many studies have shown that in order to conserve semi-aquatic animals that have complex life cycles, their core habitats of wetlands and the extended terrestrial buffer zones surrounding the wetlands need to be protected (Burke and Gibbons, 1995; Matthews and Pope, 1999; Joyal et al., 2001; Goates et al., 2007). After analyzing existing spatial ecology data for more than 32 amphibian species and 33 reptilian species, Semlitsch and Boide (2003) suggested that about 164 m of core habitat range (~8.5 ha) needs to be protected in order to conserve a species. In Korea, a law for wetland conservation currently protects 10 wetlands that total ~4.6 ha (MEK, 1999). The protected wetland areas are very limited, and most protected areas do not include terrestrial buffer zones surrounding the wetlands.

In this study, we showed that the endangered gold-spotted pond frog is very sedentary in wetland habitats, and rarely leaves the areas surrounding the breeding ponds even during the non-breeding season. However, the frog chooses dormancy sites in nearby terrestrial areas, resulting in a relatively small year-round population home range. These results suggest that in order to conserve this endangered *Rana* species, appropriately sized wetlands and extended terrestrial buffer areas surrounding the wetlands (at least ~1.33 ha, diameter 130 m) should be protected by law. Furthermore, if the gold-spotted pond frog forms metapopulations, the protected areas to conserve the species should be further extended.

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Appendix I. Summary of gold-spotted pond frogs radio-tracked in three different wild populations during the breeding season, non-breeding season, and late fall, including a dormancy migration period in 2007. In frog ID, B, NB, and LF indicate breeding season, non-breeding season, and late fall, respectively; a, b, and c indicate different study populations (abandoned reservoir and agricultural wetland populations at Oongjin, and agricultural wetland population at Cheongwon, respectively). α, β, γ indicate the ponds and waterways that were used as breeding sites (see Fig. 1). Weights 1 and 2 indicate the body weights of frogs before and after radio tracking. Positive values of the farthest distance from ponds indicate that frogs stayed more outside than within ponds. Home ranges were calculated by the adaptive kernel method (95%). Dates tracked are the days we obtained data twice for analysis. Fates of tracked frogs: lost signal in ponds (LS), slipped belt (SB), transmitter removed (RE), transmitter removed due to bad condition of animal (BC), death with no sign of predation (D), and predation (PR).

Frog ID	Sex	Body weight 1 (g)	SVL	Body weight 2 (g)	Dates tracked	Average daily movent (m)	Minimum daily movment (m)	Maximum daily movement (m)	Average daily distance from ponds (m)	Fartest distance from ponds (m)	Home range (m^2)	Fate	Dormancy starting
Baα1	m	16.8	5.5	·	7/10–7/10	22.1	22.1	22.1	–2.0	–1.6	·	sb	
Baα2	f	12.2	5.4	15.8	7/10–7/14	24.9	9.4	46.4	–1.4	–0.4	1067.9	bc	
Baα3	f	12.6	5.1	10.2	7/12–7/13	14.6	11.4	17.7	–1.2	–0.9	543.4	bc	
Baα4	f	10.9	5.1	11.0	7/12–7/13	14.4	7.9	20.9	4.7	12.8	1018.5	bc	
Baα5	f	11.1	4.7	12.1	7/12–7/13	26.5	12.3	40.7	–3.6	–2.3	1266.4	ls	
Baβ6	f	10.5	4.6	10.3	7/12–7/14	7.6	2.6	14.2	–1.9	–0.4	28.6	bc	
Bbβ7	f	11.8	4.5	10.8	7/11–7/14	4.8	2.0	7.3	0.1	1.4	192.9	d	
Bbβ8	m	6.8	3.9	·	7/11–7/13	7.7	1.5	19.5	10.4	17.6	396.1	pr	
Bbα9	m	6.8	4.1	6.8	7/11–7/18	15.7	1.0	68.9	11.3	42.0	991.2	re	
Bbγ10	m	6.8	4.2	·	7/11–7/18	30.1	4.5	132.1	2.4	11.2	9549.3	re	
Baβ11	f	21.2	5.9	21.6	7/13–7/18	20.0	2.1	91.2	45.0	47.4	844.8	re	
Baβ12	f	12.3	4.8	11.7	7/16–7/18	2.9	1.0	5.7	–0.9	–0.1	9.9	re	
Baα13	f	11.9	5.0	·	7/15–7/15	21.1	21.1	21.1	–1.6	–0.8	·	sb	
Bbα14	f	8.5	4.5	·	7/15–7/15	15.2	15.2	15.2	–0.3	–0.2	·	sb	
Baα15	m	7.2	4.2	7.0	7/16–7/18	12.0	6.4	17.5	–1.2	0.1	437.0	re	
Baβ16	f	11.6	4.6	10.7	7/16–7/18	3.8	1.3	6.0	–0.7	0.1	10.6	re	
NBaβ1	m	10.5	4.5	·	8/31–9/1	16.5	11.7	21.4	–1.1	0.0	412.6	sb	
NBaα2	f	21.8	6.0	24.0	8/31–9/8	15.6	4.3	42.1	–1.2	0.1	267.6	re	
NBaα3	f	27.6	6.2	28.0	8/31–9/8	13.3	4.6	29.3	–1.5	–0.6	142.3	re	
NBaα4	f	25.6	6.1	25.1	8/31–9/8	8.8	3.1	23.4	–1.4	–0.7	237.9	re	
NBaβ5	m	10.9	4.7	11.6	9/1–9/8	13.0	0.7	35.1	7.3	33.6	1164.7	re	
NBbβ6	f	11.9	4.8	12.4	9/1–9/8	3.7	0.0	9.5	8.5	12.4	71.6	re	
NBbβ7	f	22.0	5.8	22.0	9/2–9/8	5.7	2.0	16.7	1.6	7.0	90.7	re	
NBaβ8	m	11.6	4.7	10.4	9/5–9/8	6.4	2.6	16.7	–0.9	0.0	188.3	re	
LFaβ1	m	11.4	4.5	10.9	10/17–10/21	4.3	1.4	12.8	–1.2	–0.8	17.6	re	
LFaα2	m	10.3	4.5	10.0	10/17–10/23	9.1	0.0	20.1	12.6	14.9	243.5	re	
LFaα3	m	7.9	4.2	11.5	10/17–10/21	5.9	0.0	11.0	3.0	5.4	330.4	d	
LFaα4	f	36.7	6.5	38.0	10/17–10/23	12.0	0.0	59.0	3.1	7.8	114.7	re	
LFaβ5	f	24.6	6.2	25.5	10/17–10/21	1.1	0.6	2.1	–0.6	–0.3	7.2	re	
LFbβ6	m	6.8	4.0	·	10/20–10/22	1.5	0.0	2.8	16.6	17.3	47.2	re	
LFaβ7	f	17.3	5.5	23.1	10/17–10/18	8.4	2.4	14.3	–2.2	–1.5	769.5	pr	
LFbβ8	f	23.4	5.6	15.5	10/20–11/4	4.7	0.0	32.6	28.5	44.3	2126.1	re	10/29–
LFbβ9	f	14.9	5.2	18.0	10/20–11/4	7.1	0.0	40.5	32.9	58.2	1765.4	re	10/28–
LFbβ10	f	17.6	5.3	·	10/20–11/3	9.2	0.0	62.2	40.4	81.9	9.0	re	10/29–
LFaβ11	f	22.6	5.7	22.2	10/21–11/4	3.7	0.4	15.0	0.3	3.4	174.0	re	10/31–
LFaβ12	m	8.1	4.3	·	10/24–11/4	2.5	0.0	11.0	–0.5	1.0	3.8	ls	
LFaβ13	m	7.6	4.1	·	10/24–11/4	1.7	0.3	6.6	–0.6	–0.2	3.8	ls	
LFbα14	f	22.8	5.4	·	10/31–11/4	3.2	0.0	10.7	47.0	47.0	31.7	re	11/1–
LFbβ15	f	16.2	5.0	·	10/30–11/4	13.3	0.7	44.5			1119.9	ls	
LFcβ16	m	7.9	4.0	·	10/28–11/4	3.1	0.0	20.4			·	re	
LFcα17	m	10.1	4.2	·	10/28–11/4	8.4	0.0	42.1			·	re	
LFcβ18	m	10.4	4.4	·	10/28–11/4	1.8	0.0	13.1			·	re	10/28–
LFcα19	f	21.3	5.4	·	10/28–11/4	1.7	0.0	10.7			·	re	
LFcβ20	f	20.2	5.5	·	10/29–11/2	3.5	0.0	17.4			·	re	10/29–