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ORIGINAL ARTICLE

Changes in Habitat Use by Female Japanese Pipistrelles (*Pipistrellus abramus*) during Different Stages of Reproduction Revealed by Radio Telemetry

Chul Un Chung[1)*], Sung Chul Kim[1)], Young Shin Jeon[1,2)], Sang Hoon Han[3)]

[1)]*Department of Life Science, Dongguk University, Gyeongju 38066, Korea*
[2)]*Korea National Park, Gyeongju 38127, Korea*
[3)]*National Institute of Biological Resources, Incheon 22689, Korea*

Abstract

We analyzed how foraging area use changed in female *Pipistrellus abramus* during the breeding season. Radio tracking was used to follow 12 female *P. abramus* in Gyeongju City, from 2013 to 2015. We followed three bats in each of four stages of reproduction: early pregnancy, late pregnancy, lactation, and post-lactation. Our data showed that the usable area of a foraging site and the area that was actually used by bats in that site were different, and foraging site use also differed according to stage of reproduction. The bats used arable land the most, with use rates of 57%, 40.4%, and 73.2% during early pregnancy, late pregnancy, and lactation, respectively. Bats in a post-lactation state did not use arable areas at all and instead foraged over bodies of water 90% of the time. There was no difference in the use of each foraging environment between bats in early pregnancy and late pregnancy. However, bats in late pregnancy and those that were lactating did use arable land to different extents, and bats that were lactating and those that were post-lactation also used arable land and bodies of water to different extents.

Key words : Foraging, Habitat preference, *Pipistrellus abramus*, Radio tracking

1)1. Introduction

Habitat loss, which can cause a decrease in animal populations, can result from changes in land use (Mackie and Racey, 2007). The suitability of habitat for bats in particular is strongly affected by changes in landscape use. Because the primary roosting sites for bats are mainly located in areas that humans also use, they can be affected by disturbances from human activity (Russo et al., 2002).

In Europe, habitat loss and changes in land use caused by increased agricultural activity and pesticide use are considered to be major causes of the decline in bat populations since the 1940s (Davidson-Watts and Jones, 2006). Thus, land use by humans may affect the characteristics of the environment that make it a suitable resting area for bats (Lumsden et al., 2002). It is critical to obtain accurate information about the condition of bat habitat in order to protect and manage this habitat for

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[*]**Corresponding author**: Chul Un Chung, Department of Life Science, Dongguk University, Gyeongju 38066, Korea
Phone : +82-54-770-2514
E-mail : batman424@naver.com

bats (Davidson-Watts and Jones, 2006).

Several studies have explored the habitat preferences and behavior of bats (Walsh and Harris, 1996; Zukal and Rehak, 2006). Bat foraging habitat includes forest (Rachwald, 1992; Walsh and Harris, 1996), agricultural areas, streets with lights (Catto et al., 1996), and bodies of water, including reservoirs, rivers, canals, and lakes (Walsh and Harris, 1996; Zukal and Rehak, 2006).

A total of 23 species of bats inhabit South Korea (Han et al., 2011). Among them, *Pipistrellus abramus* is easily seen, because it uses human-made structures rather than caves or forests as roosting sites during the day or night (Funakoshi and Uchida, 1978). *P. abramus* is widely distributed through eastern South Asia and has spread to Siberia, Japan, Korea, eastern China, and Taiwan from northern Vietnam, Burma, and India (Koopman, 1993; Simmons, 2005). In Korea, however, due to rapid industrialization and environmental change, the habitat and population of this species have declined. Environmental changes in urban redevelopment projects, such as urban development, building maintenance, and roof maintenance, have the most direct effects on bats.

In Europe, the genus *Pipistrellus* serves as an indicator species for the health of the environment and for biological diversity (Davidson-Watts et al., 2006). However, in East Asia, *P. abramus* was studied only in China (Huang and Huang, 1982), Japan (Funakoshi and Uchida, 1978; Uchida et al., 1988), and Taiwan (Lee and Lee, 2005) in studies that focused on feeding and reproduction. Their use of foraging areas has not been studied in East Asia, including Korea.

Pipistrelles forage in various landscapes, such as the edge of forests (Schnitzler et al., 2003), above water (Racey et al., 1998), and around street lights (Blake et al., 1994). Rapid urbanization and environmental change in Korea are responsible for the decline of various landscapes used as foraging areas. Little research has been carried out on habitat protection for *P. abramus* and there are no data to support a protection strategy plan. Therefore, the purpose of the present study is to report the data needed to protect and manage foraging areas for *P. abramus* by understanding the patterns of foraging area use during the reproductive period, when energy requirements for *P. abramus* peak.

2. Materials and Methods

2.1. Study site

The research was carried out in a colony of *P. abramus* in North Gyeongsang Province, Gyeongju, from May 2013 to August 2015. The study site contains many concrete tunnel structures where bats have lived for many years, including the parturition, lactation, and hibernation stages of their life cycle.

The study area is approximately 20 km from the center of Gyeongju City and includes rivers, streams, forests, villages, arable lands, and small roads. Each habitat type is clearly demarcated. The arable land is closest to the *P. abramus* colony and is the site of rice cultivation from spring until autumn. The next closest habitat is a small village built of old bricks and slab structures and containing street lights. The forest area is a natural broad-leaved forest containing less than 10% coniferous trees. Rivers adjacent to the roost range in width from 3 m to 10 m and contain riparian plants. The rivers flow into a large body of water, Hyeongsan river, which is more than 100 m wide.

All surveys were carried out in the same roost to enable an accurate comparison, and there were no environmental changes to the surrounding habitats during the survey period.

2.2. Capture and selection of bats

A total of 12 adult female *P. abramus* were used.

Bats emerged from their day roost after sunset and were captured using a hand net. We used three adult bats representing each stage of reproduction: early pregnancy, late pregnancy, lactation, and post-lactation.

Bats in early pregnancy were selected from among those trapped in March that weighed less than 8 g. Survey results have shown that *P. abramus* in the survey area give birth in early July. Therefore, bats in late pregnancy were selected from among those captured after mid-June that weighed at least 10 g. Bats in lactation were selected from those captured in early July which had specific visible features, such as weight and pacifiers, indicating lactation (Owen et al., 2003). Field research indicated that the bats born each year were capable of free flight by the end of July. Therefore, bats in the post-lactation stage were selected from among those captured in August.

2.3. Radio tracking methods

The captured bats were fitted with small radio transmitters weighing 0.38 g (LTM Single Stage Radio Transmitter), about 4.4% of the bat's body weight on average (range: 2.8%-6.1%). We trimmed the fur from a small surface in the scapulae and attached a transmitter using a medical bond. The transmitter was attached for an average of 6.9 days.

In order to find the location of the bats, an R2000 ATS receiver (Advanced Telemetry System, Inc., Isanti, MN), a three-element Yagi antenna, and vehicle antennas (roof-mounted antennas and an Omni-directional whip antenna) were used together. Triangulation methods (Bontadina et al., 2002) and continuous tracking methods (Davidson-Watts et al., 2006) were used to track their location.

Tracking was carried out from the time that a bat with a transmitter left the roost after sunset until the time that it returned to the original roost before sunrise. If the bat flew continually in the same type of environment, we recorded the specific location and the environment type. If the bat traveled between foraging sites and its exact location could not be identified, we recorded its positions on the map using triangulation data.

A data point was recorded once every 5 min if possible. If the bat's location was unknown and 5 min had elapsed since recording the last position, we located the bat and restarted our record of its position every 5 min. When bats returned to the day roost during the night to digest and excrete food or flew to a resting location under a bridge, the time that they spent on these non-foraging activities was not recorded. We used a bat detector (Pettersson Elektronki AB, model D-240) as a supplementary method to check bats' movements and use of foraging areas.

Our preliminary research revealed the main foraging areas of *P. abramus* in the study area. We recognize that if the bats move to a remote area, it may be impossible to know their location and foraging area. Therefore, each bat in the study was followed by at least nine researchers in order to minimize the risk of missing location data.

2.4. Data analysis and habitat classification

All the collected locations were analyzed by landscape type using ArcGIS 9.3.1 (ESRI, Inc.). Typically, landscape types can be analyzed using a land cover map, but the landscape of a small area may change rapidly. Therefore, we analyzed satellite maps overlapped with digital maps (NSIC, 1:25000) to determine the most accurate land use. To ensure the accuracy of our completed map, we referred to our own field research. The area was calculated by converting the land into a polygon format using ArcTool for classification and rate estimates for land use.

Bats forage in a variety of environments, depending on conditions. However, the research area is a very simple set of landscapes and each type of

Table 1. The four dominant habitat categories in the present study

Habitat type	Description	Proportion of habitat within bats' range	
		400 m	2,400 m
Arable (A)	Rice paddy field	54.7%	30.0%
Bodies of Water (BW)	Running water (rivers and streams), standing water, and plants that were immediately adjacent to riparian habitats	12.3%	13.4%
Woodland (W)	Deciduous woodland and coniferous woodland (80% or more broadleaf trees and 10% or less conifers)	10.0%	41.2%
Suburban (S)	Low-density residential housing, including tracks, paths, roads, and streetlights, typically classified as a normal suburban area	23.0%	15.4%

landscape is clearly isolated from others. Therefore, it was not difficult to identify in which areas each bat was foraging.

Bats remain foraging in a specific area when insect density is high (Rautenbach et al., 1996; Kalcounis et al., 1999). The amount of time that bats stay in a specific habitat has a positive relationship with foraging activity (Kusch et al., 2004). Therefore, in the present study, the range for a foraging area was defined as the 50% Kernel Home Range (KHR) that is classified as the core area among the collected location data.

Habitats used as foraging area by *P. abramus* were divided into arable land, bodies of water, woodland area, and suburban area (Fig. 1). Some types of habitat, such as grassland adjacent to water, bush, and roads around the village, do not clearly fall within any of the habitat types. These areas were classified the same way as the most adjacent habitat.

During early pregnancy, late pregnancy, and lactation, bats flew no more than 400 m from the day roost. Therefore, our analysis used a radius of 400 m as the range, and each type of environment was classified as a percentage of the total area within the range of a 400 m radius. Arable land composed 54.7% of this area, water 12.3%, woodland 10.0%, and suburban land 23.0%. The bats that flew the farthest to forage were in the post-lactation stage, and they flew a maximum of 2400 m from the day roost. Arable land composed 30.0% of this larger area, water 13.4%, woodland 41.2%, and suburban land 15.4% (Table 1).

All statistical analyses were carried out using SPSS Ver. 18.0 (SPSS, Chicago, IL, USA). We used one-way analysis of variance (ANOVA) to compare the selection of foraging habitat in each reproduction stage, and we compared the change in the rate of utilization of each habitat type in relation to reproduction stage via t-test. In all statistical tests, significance was set at $p < 0.05$.

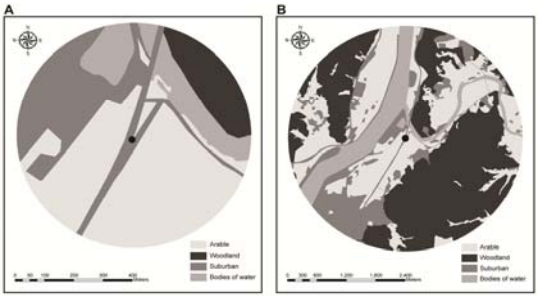

Fig. 1. Map of the study site at Gyeongju City where tagged bats were recorded. (A) A radius of 400 meters around the day roost of bats in early pregnancy, late pregnancy, and lactation; (B) A radius of 2,400 meters around the roost of bats in post-lactation. The full circle indicates the day roost.

3. Results and Discussion

Our radio tracking data showed that there was a difference between the amount of habitat that was available and the amount of actual foraging activity that occurred there (Fig. 2). The usage pattern of foraging sites differed according to reproductive stage (Fig. 3).

In early pregnancy, arable land was the most preferred habitat type (57.02%), followed by suburban area (26.32%) and bodies of water (16.67%). Woodland was not used by bats in early pregnancy. In late pregnancy, arable land remained the most preferred habitat (40.43%), and suburban area was the least used (8.51%) (Fig. 2 and 3).

During the lactation stage, the arable area was again the most preferred, and the rate of use was quite high, 73.15% ($p < 0.01$). Meanwhile, bats that were lactating did not appear to use the suburban area. During the post-lactation stage, bats foraged mostly over water (about 90%) and did not use the arable area at all (Fig. 2 and 3).

Our comparison of reproduction stages revealed no significant change between early pregnancy and late pregnancy in the use of all types of foraging areas (Table 2). However, bats in late pregnancy and those in lactation showed a clear difference in their use of arable land ($p < 0.05$), and no significant difference in their use of other types of habitat. Bats that were lactating and post-lactation bats differed in their use of arable land and water bodies ($p < 0.01$), but no significant difference was found in their use of woodland or suburban areas (Table 2).

During the reproductive period, the foraging activities of female bats are affected by various factors, including the density of insects, energy demands, the need to nurse, and so on (Winkelmann et al., 2000). We carried out radio tracking of 12 bats in order to understand the changes in females' choice of foraging area during the reproduction period.

Analysis of fecal pellets has revealed that *P. abramus* eats various types of prey (Lee and Lee, 2005). Therefore, bats may use various foraging areas within their range. However, the present study showed that the bats alter their foraging activities depending on their stage of reproduction: bats in early, late pregnancy, lactation, and post-lactation stages chose significantly different foraging habitats.

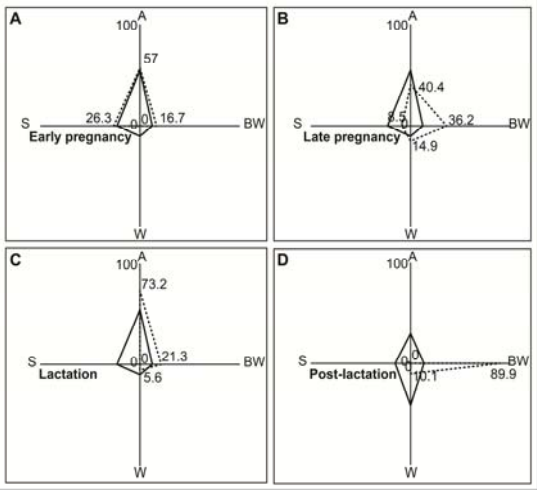

Fig. 2. Utilization rate of foraging habitats by bats in different stages of reproduction. The proportion of available habitat in shown by a solid line; the actual use of each habitat is shown by dotted line. Values in the figure are actual use of each habitat. Habitat abbreviations and proportion of each available are shown in Table 1.

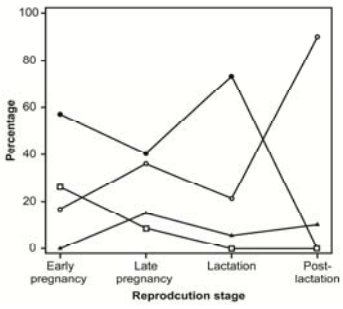

Fig. 3. Selection of type of foraging habitats by *Pipistrellus abramus* in different stages of reproduction (● Arable, ○ Bodies of water, ▲ Woodland, □ Suburban).

Table 2. Correlations between foraging habitats used during each reproduction stage. *t*-test was used to compare the use rate of each type of habitat

Reproduction stages compared	Arable	Bodies of water	Woodland	Suburban
Early pregnancy vs. late pregnancy	n.s.	n.s.	n.s.	n.s.
Late pregnancy vs. lactation	*	n.s.	n.s.	n.s.
Lactation vs. post-lactation	**	**	n.s.	n.s.

Significant effect (* $p < 0.05$, ** $p < 0.01$), n.s., not significant

In early pregnancy, bats preferentially foraged in arable areas, followed by suburban areas and then bodies of water. They did not forage in woodland areas. The arable areas that were the most commonly used in early pregnancy (57.02%) are located only a short distance from the day roost of the bats. This arable land, which is used to grow rice, is similar to a body of water habitat because the rice fields are flooded in May, when planting begins. If water habitats are defined to include flooded rice fields as well as bodies of water, bats used these habitats to forage more than 70% of the time.

Although pipistrelles will feed in a variety of environments, they appeared to prefer water-based habitats due to the high density of aquatic insects (Walsh and Harris, 1996; Vaughan et al., 1997; Davidson-Watts et al., 2006; Zukal and Rehak, 2006). In a habitat preference study of *P. abramus*, a species that is similar to *P. pipistrellus* and *P. pygmaeus*, water-related habitats appeared to be preferred over other habitats (Davidson-Watts et al., 2006). The arable lands were thus appealing both because of their proximity to the roost and because they were similar to a body of water. Although the forest area occupied about 10% of the area within the bats' range, they engaged in no foraging activity there. Insect density is evidently higher in water habitats, including arable land, and in suburban habitat consisting of old houses and street lights. *P. abramus* use human-made constructions like the brick and slab buildings in the suburban area as a major habitat, and they forage around street lights because the lights attract many insects (Zukal and Rehak, 2006). This suburban area was located adjacent to the rice fields so it was also fairly close to the roost.

During late pregnancy, bats used for all four types of habitats and there was no significant change in the choice of foraging areas between early and late pregnancy stages. Bats still used the arable area the most, around 40% of the time. However, compared with bats in early pregnancy, those in late pregnancy used bodies of water slightly more often, around 36% of the time. The rice field remains as full of water in June as it was in May. Therefore, about 76% of the total area in the bats' range may be considered water habitat, including the arable land and the rivers.

In a previous study on the food source of *P. abramus*, Funakoshi and Uchida(1978) reported that bats in Japan preyed on four orders of insects, and Yang(1996) reported that they used six different types of food resources in China. A more recent study reported that the bats fed on 12 orders of insects (Lee and Lee, 2005) and typically preferred the six orders Coleoptera, Diptera, Hymenoptera, Trichoptera, Lepidoptera, and Hemiptera.

The water habitats, including arable areas, were likely favored by the bats because many types of insects live in vegetation near water or around water. In contrast, the forest areas were not used at all until late pregnancy and were used only 15% of the time in late pregnancy. The insects classified as typical food

sources for bats by Lee and Lee(2005) usually occur around rice paddy fields and bodies of water, but some insects, such as members of Coleoptera, Lepidoptera, and Hemiptera, also occur in forest areas.

Our comparison between habitat use in lactation and late pregnancy showed a difference in the use of arable areas ($p < 0.05$). Arable land composed 54.7% of the area in the bats' foraging range, but lactating bats used it at a disproportionately high rate, up to 73.15%. The use rates of bodies of water and woodland by lactating bats were 21.30% and 5.56%, respectively, and they did not use suburban areas at all. However, if we consider arable areas to be bodies of water, the use rate of arable land and water habitat together by lactating bats exceeded 94%, although arable land and bodies of water composed only 67% of the total area.

Similar to other insectivorous mammals, bats consumed a large number of prey during the breeding period, including pregnancy and lactation (Rydell, 1992). Females must consume enough energy to achieve pregnancy and support their offspring's development during pregnancy and lactation (Dietz and Kalko, 2007). The highest insect density is found in the habitat of water bodies (Walsh and Harris, 1996), and this area provides a large number of potential prey (Davidson-Watts and Jones, 2006).

In the temperate-climate zone of Korea in July, daily temperatures are typically rising and populations of aquatic insect larvae and insects that live in vegetation around water are peaking. Thus, water habitats, including flooded rice fields, are frequently used as foraging areas by bats.

Another reason for the higher use of arable areas during the lactation period is related to female flight characteristics during this reproductive stage. A previous study reported that the choice of foraging area is limited during the lactation period; females did not travel far to forage and tended to feed close to the colony (Vaughan et al., 1997). In another study on the foraging activities of *P. pipistrellus* during the breeding period, females flew the shortest distance to forage during the lactation period (Davidson-Watts and Jones, 2006). During lactation, females need to return to their young waiting in the roost (Swift, 1980; Maier, 1992). Therefore, we conclude that they preferred the arable area because it is the closest location to the roost and supports high populations of insects due to its flooded nature.

The females in the post-lactation stage showed the most notable change in their choice of foraging area, compared with females of the other stages of reproduction, especially compared with lactating females. The use rate of the arable area and bodies of water significantly differed between females who were lactating and in the post-lactation stage ($p < 0.01$). Although bodies of water occupied only about 13.4% of the total foraging area, their use rate increased from 21.30% to about 90% in post-lactating females, who spent the remaining 10% of their foraging time in the forest. Meanwhile, arable land, which was used most often by bats in previous reproductive stages, occupied about 30% of the total area but was not used by post-lactating bats at all, nor was the suburban area.

Insectivorous bats rarely use only one habitat type, and they usually choose from among several types of habitat depending on the type of food resources that are available (Kusch et al., 2004; Zukal and Rehak, 2006). However, our data revealed that post-lactating bats used one type of habitat (bodies of water) more often than bats of other reproductive stages.

The habitat that was furthest from the roost, 2400 m from the colony, was bodies of water. The choice of foraging areas during post-lactation appears to be related to the physiological condition of females and environmental characteristics of rice fields in August. During this reproductive stage, females are not under physiological stress related to providing for their

young. They can also forage the entire night, without coming back to their roosts during the night. In addition, foraging at a faraway site enables these bats to avoid competing with young bats that were just born that year. As reported by a previous study, bats used a specific foraging area in order to avoid competition for food between colonies or similar species of bats (Robinson and Stebbings, 1997). We believe that long-distance foraging by females is one of their strategies to avoid competing with young bats that are just starting to forage for themselves and can only fly short distances. Although bats that were tracked using radio telemetry did not use arable land, the young bats born that year used the arable land frequently.

Another reason that mature females may use the bodies of water to forage is the condition of the rice fields in August after the end of the lactation period. At this time, the rice crop has completed its main growth period and is close to harvest. Therefore, each rice plant is close to its maximum size and the water in the rice fields is very shallow. The surface of the water is completely obscured from the bats by the rice plants, including their seeds and leaves. Therefore, the arable land does not display the same characteristics as a body of water at this time.

Russ and Montgomery(2002) classified more than 20 types of habitats used by bats in Northern Ireland, and Glendell and Vaughan(2002) classified 16 habitat categories used by bats in the UK. Safi et al.(2007) divided bat habitat use into five categories (river, lake, open landscape, forest, and urban areas) in order to understand the typical home range and use of foraging sites of parti-colored bats. Although monitoring with telemetry can provide useful information, the technique is limited, because insectivorous bats are typically small in size. In addition, the transmitter used in the present study has a short life and can only report limited data on the behaviors of bats (Davidson-Watts and Jones, 2006).

Female bats used the most efficient strategy to gain the necessary weight during pregnancy and to nourish their young during lactation. Our data showed a clear difference in the foraging areas used by *P. abramus* during different stages of reproduction, spanning early pregnancy to the post-lactation period. Our results can explain the pattern of habitat use of *P. abramus* inhabiting the suburbs of Korea. They also reveal that arable land and bodies of water used intensively by *P. abramus* should be maintained and managed in order to protect the bats.

In order to conserve a species, it is necessary to understand its ecology. Although the ecology of *P. abramus* has been studied in some regions of East Asia, few studies of this species have been conducted in Korea. Therefore, we must maintain and improve the quality of habitats required by bats and decrease negative disturbances to their habitats. Additional research on their preferred foraging areas will help guide conservation of bats.

4. Conclusion

P. abramus, one of the 23 species of bats living in Korea, are most widely seen in downtown areas and suburban districts. However, due to recent environ -mental changes caused by rapid industrialization, including forest development, reduction of arable lands, and river improvement work, habitat for *P. abramus* is decreasing. Our analysis of the foraging area use pattern by 12 female *P. abramus* showed clear differences depending on the state of reproduction. Arable lands were preferred most during early pregnancy, late pregnancy, and lactation, while bodies of waters were preferred most during post-lactation. There was no difference in the foraging area use pattern during early pregnancy and late pregnancy. However, there were differences in the availability of arable lands during late pregnancy and lactation, and there were also differences in the

availability of both arable and riparian lands during lactation and post-lactation. The results indicate that *P. abramus* change their foraging areas depending on their state of reproduction. Arable lands and water bodies should be preferentially maintained for the protection of *P. abramus*.

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