The Current Distribution and Habitat Preferences of Hibernating *Myotis formosus* in Korea

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**ABSTRACT:** We monitored 38 hibernation sites of *Myotis formosus* in South Korea and recorded the number of bats occupying each site and assessed the micro-climate at the sites during four winters from 2005 to 2009. The mean rock temperature of the bat roosting sites was 13.2±1.4°C and the mean body temperature of the hibernating bats was 13.3±1.3°C. The number of hibernating bats was negatively related to the size of the entrance and positively related to the minimum ambient temperature and humidity in the site interior. More bats hibernated in roosts with smaller entrances and higher minimum ambient temperatures, and more bats selected sites presenting a narrow temperature range. This study showed that the internal environments of hibernacula of *M. formosus* were highly stable despite dramatic variation in the external environment.

**Key words:** Hibernacula, Hibernation, *Myotis formosus*, Temperature, Thermal preference

**INTRODUCTION**

Bats roost in various type of shelters and the majority of species depend on structures that offer suitable conditions for roosting during the winter when the weather is cold and fluctuates dramatically (Kunz 1982, Kunz and Lumsden 2003). The choice of roosting sites is of vital importance for bats, because their survival is dependent on the protection from environmental extremes and predators that suitable roosts offer (Kunz 1982, Tidemann and Flavel 1987). Roost selection by bats therefore has implications for their life-histories, and the selection of appropriate roosting sites is vital for both survival and reproduction (Kunz 1982, Tuttle and Stevenson 1982).

Underground sites, both natural (e.g., caves) and artificial (e.g., mines and fortifications), are crucial for the survival of many bat species worldwide (Dalquest and Walton 1970, Hutson et al. 2001, Kunz and Lumsden 2003). Although caves and man-made underground structures provide ideal roosts for many bat species, little research has been carried out on cave-dwelling bats. A better understanding of the factors affecting roosting site selection and habitat use patterns is necessary for bat conservation planning.

Defining the status of a species is crucial for prioritizing conservation actions, but appropriate data are often difficult to collect. Therefore, it is difficult to establish the conservation status of many species accurately. Many bat species tend to be relatively faithful to specific roosting sites for hibernation (McNab 1974, Humphries et al. 2002). The current distribution of the species should reflect optimal environmental conditions (Krebs 2001) because each bat species selects sites displaying the optimal thermal conditions to allow them to survive long periods of torpor with minimum energy expenditure. Structural and environmental factors can influence the availability of roosting sites and the extent of site fidelity by bats. Therefore, a better understand of factors affecting roost selection by bats is necessary for developing useful conservation strategies (Crampton and Barclay 1998). However, to date little is known about roosting site selection by bats (Vonhoff 1996, Vonhoff and Barclay 1996, Kalcounis and Brigham 1998, Rabe et al. 1998).

The cooper-winged bat (**Myotis formosus**) is a medium-sized (11~13 g) vesperilionid bat, with a broad geographic range across. In Korea, it is designated as a Class I endangered species by the Ministry of Environment and a natural monument (No. 452) by the Cultural Heritage Administration, respectively. Since the first record of hibernacula in Korea used by considerable numbers of *M. formosus* was made in Hampyeong, Jeollanamdo in 1999, information about the distribution of its winter roosting sites has been reported sporadically by local researchers and residents. Regrettably, however, sufficient ecological information is not yet available to permit the implementation of effective conservation of *M. formosus* to prevent local extinction of the species. Indeed, basic questions about its population size and ecology remain to be answered.

The main aims of this study were: (1) to describe the current status and distribution of the species *M. formosus* at underground...
sites in Korea during the winter and (2) to investigate the species’ thermal preferences and habitat requirements to propose a conservation action plan.

METHODS

We visited 260 underground sites, such as abandoned mines and caves, throughout peninsular South Korea during the hibernation season in four years from December 2005 to February 2009. Of the 226 winter roost sites that were used as roosting sites by cave-dwelling bats, 38 sites were used by hibernating *M. formosus*. Each of these 38 sites was visited at least twice during the study period.

The species and number of hibernating bats were recorded for each site. When hibernating bats were found, we measured the body temperature of the hibernating bats and the temperature of the rock surface where bats were hanging with an infrared light thermometer (ST80, Raytek, USA). We also examined the physical structure of the 38 *M. formosus* hibernacula, taking the following measurements: area of entrance, number of entrances, total length of passages, and the maximal width and maximal height of passages, and recording the presence or absence of standing water. We also measured the ambient temperature and humidity within a hibernaculum with a Testo 605-H1 (Testo, Germany).

For four major hibernacula (those containing more than twenty bats) of *M. formosus*, the annual fluctuation in temperature and humidity was measured. To monitor the internal temperature, we used 24 dataloggers (Testo 171, Testo, Germany; Thermo Recorder TR-52, T&D, Japan; EL-USB-2 Temp/RH, Lasca Electronics Ltd, England) in 2007. Six dataloggers were installed at three points (in the entrance and in the middle and end of the main passage) within each hibernaculum. For the external temperature, Mokpo data from the Korea Meteorological Administration were used. Our methods for monitoring and counting bats are in accordance with the guidelines for recommended methodologies to be used for the monitoring of bat species in Europe (Jones and McLeish 2004). No bats awoke as a result of disturbance during the study.

To evaluate major factors affecting the habitat preferences of *M. formosus*, we examined the relationships between the number of bats and habitat characteristics of the 38 hibernacula. The variables reflecting the physical structure of the hibernacula and environmental measures did not follow a normal distribution (Shapiro-Wilk tests). Therefore, non-parametric Spearman’s rank correlations were used for the analyses. All statistical analyses were performed on SPSS software (v.11.5) following the guidelines of Zar (1999).

We also evaluated the ability of four major hibernacula to buffer the internal environment against changes in the external environment, using an index of temperature variability (Tuttle and Kennedy 2002): 

\[ V = \frac{\text{T}_{\text{max-roost}} - \text{T}_{\text{min-roost}}}{\text{T}_{\text{max-surface}} - \text{T}_{\text{min-surface}}} \]

where \( T \) represents the maximum or minimum temperature recorded at the roost or outside the hibernaculum, as indicated by the subscripts. A small value of \( V \) indicates a stable internal environment that varies little with changing external conditions and a large value of \( V \) indicates a less stable internal environment.

RESULTS

The Current Distribution of *Myotis formosus* in Korea

Winter roosting sites of *M. formosus* were distributed all over the country. A total of 338 hibernating bats were found in 38 caves in seven provinces (Table 1): four sites in Gangwon, two in Gyeonggi, two in Gyeongbuk, fifteen in Jeonnam, one in Jeonbuk, three in Chungnam and eleven in Chungbuk. Fourteen of these sites were only used by *M. formosus* whereas the other 24 sites were shared with other bat species, including *Rhinolophus ferrumequinum*, *Miniopterus schreibersii*, *Myotis daubentonii*, *Myotis ictinokovi*, *Murina leucogaster* and *Plecotus auritus*.

*M. formosus* hibernated in both natural caves (6 sites) and abandoned mines (32 sites) in mountains. Most individuals (331 individuals, 97.9%) were found in abandoned mines, with only a few bats (7 individuals, 2.1%) hibernating in caves. Only seven sites had more than 10 bats. Though the sites were widely distributed, most of the bats that we found were in Jeonnam province (222 individuals, 65.7%), followed by Chungbuk (70 bats, 20.7%), Chungnam (15 bats, 4.4%), Gangwon (12 bats, 3.6%), Gyeongggi (12 bats, 3.6%), Gyeongbuk (5 bats, 1.5%), and Jeonbuk (2 bats, 0.6%).

The Thermal Preferences of *Myotis formosus*

Our measurements of the rock temperature and the body temperature of bats hibernating in the 38 hibernacula in midwinter (December–February) are shown in Table 2. The mean body temperature of hibernating bats was 13.3 ± 1.3°C and ranged from 10.2 to 16.8°C. The rock temperature also ranged from 9.8 to 16.8°C and averaged 10.2°C (± 1.3°C SD). Body temperature was strongly related with rock temperature (Spearman’s rank correlation, \( r_s = 0.994, p < 0.001 \)). The narrow range of body temperatures of hibernating bats found in this study suggests that *M. formosus* has distinct thermal preferences for their hibernation sites.

The Characteristics of Hibernacula of *Myotis formosus*

Table 3 shows the relationships between the number of hibernating bats and the physical and environmental characteristics of the 38 hibernacula. The number of bats hibernating in each site was related negatively to the area of the entrance (Spearman’s rank corre-