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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 at. The mean rock temperature of the bat roosting sites was 13.2 ± 1.4℃ and the mean body temperature of the hibernating bats was 13.3 ± 1.3℃. 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) vespertilionid 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

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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 were 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): $V = (T_{max\text{-}roost} - T_{min\text{-}roost}) / (T_{max\text{-}surface} - T_{min\text{-}surface})$, 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 Joennam, 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 schriebersii*, *Myotis daubentonii*, *Myotis ikonokovi*, *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%), Gyeonggi (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℃ and ranged from 10.2 to 16.8℃. The rock temperature also ranged from 9.8 to 16.8℃ and averaged 10.2℃ (± 1.3℃ 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-

Table 1. Description of 38 sites used by *M. formosus* during four winters from 2006 to 2009 in South Korea

Province	Site	Type	Peak counts (Year)
Gangwon	Boogui	Abandoned mine	6 (Mar 2008)
	Seongae	Cave	2 (Mar 2008)
	Yongho	Abandoned mine	3 (Dec 2008)
	Kangcheon	Cave	1 (Feb 2006)
Gyoenggi	Sandpyeong	Abandoned mine	10 (Feb 2009)
	Sajeong2	Abandoned mine	2 (Dec 2007)
Gyeongbuk	Hogye	Abandoned mine	3 (Dec 2008)
	Youngduk	Abandoned mine	2 (Jan 2007)
Joennam	Koryeong	Abandoned mine	6 (Feb 2008)
	Lisung	Abandoned mine	4 (Mar 2006)
	Kangjeong 1	Abandoned mine	16 (Feb 2008)
	Jindallae	Abandoned mine	3 (Feb 2006)
	Jobi	Abandoned mine	27 (Feb 2008)
	Deungdae	Abandoned mine	1 (Feb 2007)
	Duckyang 1	Abandoned mine	2 (Feb 2007)
	Jeongchang L	Abandoned mine	7 (Feb 2008)
	Gogul	Abandoned mine	22 (Feb 2006)
	Jeongchang	Abandoned mine	59 (Feb 2006)
	Seoho	Abandoned mine	8 (Feb 2006)
	Yeonam	Abandoned mine	57 (Feb 2008)
	Myodong	Abandoned mine	2 (Feb 2008)
	Jucjang	Abandoned mine	7 (Mar 2009)
	Hwasun	Cave	1 (Mar 2007)
Jeonbuk	Songlim	Artificial structure	2 (Feb 2008)
Chungnam	Songgeunle	Abandoned mine	8 (Feb 2009)
	Dongsan	Abandoned mine	5 (Feb 2007)
	Sunggeo	Abandoned mine	2 (Feb 2007)
Chungbuk	Gunang	Cave	1 (Feb 2008)
	Geumsung	Abandoned mine	40 (Mar 2009)
	Daemyeong	Abandoned mine	2 (Feb 2008)
	Northwall 1	Cave	1 (Feb 2008)
	Gwangjuri	Cave	2 (Feb 2008)
	Shinchaen	Abandoned mine	2 (Feb 2008)
	Soekoji 1	Abandoned mine	4 (Feb 2007)
	Soekoji 2	Abandoned mine	4 (Feb 2007)
	Noeun	Abandoned mine	2 (Mar 2008)
	Seapori	Abandoned mine	11 (Mar 2008)
	Yangji	Abandoned mine	1 (Feb 2008)
	38 sites		338 individuals

Table 2. Body temperature of hibernating *Myotis formosus* and rock temperature at hibernation sites

	Mean ± SD	Range	CV (%)
Body temperature ($N = 265$)	13.3 ± 1.3	10.2～16.8	10.0
Rock temperature ($N = 265$)	13.2 ± 1.4	9.8～16.8	10.2

Coefficient of variation (CV) = (SD/mean)*100.

Table 3. Spearman's correlations between the number of bats and habitat characteristics in 38 hibernacula of *Myotis formosus* in Korea

	Mean ± SD	r_s	Sig.
Area of entrance (m^2)	2.6 ± 2.1	−0.391	$p < 0.05$
Number of entrance	1.1 ± 0.2	−0.011	NS
Total length of passages (m)	212.2 ± 249.8	−0.130	NS
Maximum width of the passage (m)	2.4 ± 1.6	−0.294	NS
Maximum height of the passage (m)	2.7 ± 1.8	−0.192	NS
Minimum ambient temperature (℃)	8.4 ± 3.1	0.612	$p < 0.001$
Maximum ambient temperature (℃)	13.5 ± 0.9	0.032	NS
Humidity (%)	91.5 ± 6.1	0.461	$p < 0.01$

lation, $r_s = -0.391$, $p < 0.05$) and positively related to the minimal ambient temperature ($r_s = 0.612$, $p < 0.001$) and humidity ($r_s = 0.461$, $p < 0.01$). Thus, more bats hibernated in roosts with smaller entrances and higher minimum ambient temperatures. More bats were also found at sites presenting a narrow range of ambient temperatures ($r_s = -0.411$, $p < 0.01$), and these sites were used only by *M. formosus* (Fig. 1).

The four major hibernacula in Jeonnam province provided a higher temperature and a more humid environment during the hibernation period than other sites (Table 4). In these sites, the low indices of temperature variability (V = 0.00～0.04) indicate that the internal environments were highly stable against changes in the external environment.

DISCUSSION

We assume that the characteristics of roosts that are used tend to reflect the roosting preferences of the species, because the best

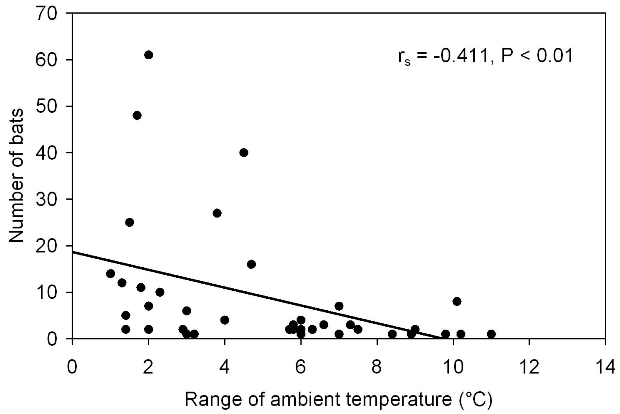

Fig. 1. Number of hibernating bats in relation to the range of inner ambient temperatures in 38 hibernacula of *Myotis formosus* in Korea.

indicators of roost requirements are descriptions of roosts used by stable colonies (Tidemann and Flavel 1987, O'Donnell 2000, Kunz and Lumsden 2003). Therefore, it stands to reason that the characteristics of bat roosting sites reflect the thermal preferences of the species and thus their ecological requirements for the hibernation period. This study showed that *M. formosus* had a preference for sites with a narrow temperature range and relatively high temperatures during the hibernation period (Table 2) and for hibernacula with stable inner ambient temperatures (Table 4). This suggests that *M. formosus* is highly sensitive to temperature conditions in the winter roosting site.

In this study, the mean temperature recorded inside most occupied roosts ranged from 12℃ to 15℃, which may be the critical temperature zone for *M. formosus* (Geirser 2004). Thermal factors are important for roosting bats because they are able to expend minimal energy by matching their body temperature to that of their environment (McNab 1974, Thomas et al. 1990, Webb et al. 1996, Speakman and Thomas 2003, Boyles et al. 2007). *M. formosus* may minimize their energy expenditure across the hibernation period by selecting appropriate hibernation sites.

Of the structural characteristics examined, only the size of the entrance and two microclimate variables (temperature and humidity) were significantly related to the number of bats (Table 3). The temperature profiles documented for major winter roosting sites (Table 4) probably reflect the ideal hibernating conditions for *Myotis formosus*. The size of entrance may be related to the microclimate, which may explain why the size of the entrance was an important factor affecting the selection of hibernacula by *M. formosus* (Kim et al. 2004, Kim 2005). The environmental conditions in the four major hibernacula indicated very stable roost microclimates, well buffered from external temperature fluctuations, where bats would not be forced to move to avoid potentially lethal temperature extremes (Thomas et al. 1990, Richter et al. 1993, Tuttle and Kennedy 2002, Speakman and Thomas 2003).

Management Implications

In general, protection of only one roost type is not adequate for protection of a bat species, and temporal variation in roost selection must be considered for when setting conservation goals (Fenton 1997, Pierson 1998). Conservation of preferred roost sites is essential to maintain existing populations. Therefore, conservation plans for *M. formosus* should focus on the management of winter rooting sites in areas with high probabilities of occurrence. This study emphasizes the need for recognition of potential bat habitats so that effective conservation management programs can be put into place before the bats become seriously endangered. Across the range of *M. formosus* in Korea, caves and mines that serve as winter roosting sites must provide thermal stability in the right temperature range (12～15℃) to permit successful hibernation. These sites must therefore store sufficient warm air to meet the bats' hibernation needs and buffer the internal environment to minimize the risk of temperature fluctuations (Thomas et al. 1990, Humphreir et al. 2003,

Table 4. Ambient temperature and humidity from December 2007 to February 2008 as measured in the roosting position within four major hibernacula of *Myotis formosus* in Korea

Hibernaculum	Temperature (℃)		Humidity (%)		V value[1]
	Mean ± SD	Range	Mean ± SD	Range	
Jeongchang	12.5 ± 0.20	11.8～12.7	100 ± 0.00	0	0.04
Gogul	12.8 ± 0.16	12.4～13.0	99.3 ± 0.86	98～100	0.02
Yeonam	12.0 ± 0.08	11.9～12.3	97.7 ± 0.28	97～100	0.02
Jobi	15.0 ± 0.00	0	99.5 ± 0.60	97～98	0.00

[1] Index of temperature variability (V): a small value indicates a stable internal environment that varies little with changing external conditions and a large value indicates a less stable, more variable, internal environment.

Speakman and Thomas 2003). Protection of caves and mines with these characteristics and restoration of features promoting appropriate temperatures in altered sites are essential for habitat recovery of *M. formosus*.

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