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Reproductive Ecology and Human-Caused Mortality in the Japanese Mamushi Snake (Gloydius blomhoffii) on the Northernmost Main Island of Japan

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ABSTRACT.—Japanese Mamushi (Gloydius blomhoffii) has long been exploited for its medicinal value. We studied this snake’s reproductive ecology on Hokkaido and assessed its vulnerability. We marked 299 individuals from 1999–2002 and kept 29 pregnant females in captivity until parturition. Pregnant females aggregated at gestation sites during summer and fall until just before parturition. Behavior suggestive of mating seasons was evident mostly in August and September. As expected, there was an apparent sex difference in body size in adults but not in neonates: females were larger than males. Consistent with previous reports, both neonates and adults were larger in Hokkaido than in southern Japan. The smallest pregnant female measured 44.8 cm in SVL, which was larger than values reported from southern regions. Offspring sex ratio was statistically equal: 88 males to 105 females. Litter size averaged 6.6 offspring. Longer females tended to produce larger litters and longer neonates. The proportion of pregnant to non-pregnant females, coupled with mark–recapture data, suggested that Mamushi females skip one or more years between reproductive bouts. Relative litter mass (RCM) was large (83% on average), and postpartum body condition was lower, especially so in females with larger RCM. Direct human-caused mortality was highest for pregnant females (70.2%), followed by non-pregnant females and then males. High adult mortality, particularly of pregnant females, raises a concern about population persistence, because Mamushi exhibit a slow life history. The tendency of pregnant females to aggregate at predictable locations further makes Mamushi populations vulnerable to human killing and exploitation.

There no longer seems any doubt that snake numbers in nature are dropping rapidly (Reading et al., 2010), and these declines are of increasing conservation concern (Mullin and Seigel, 2009). The causes of these declines are poorly understood but likely involve multiple factors linked to human activities. In many parts of the world, significant habitat loss is involved in population declines of snake, as for so many other species today (Dodd 1987, 1993). Over use of wild snake populations is also involved. Reasons range from economic (e.g., marketing of skins) to recreational (e.g., rattlesnake roundups) to medicinal (Shine et al., 1999; Fitzgerald and Painter 2000; Zhou and Jiang, 2004; Alves and Pereira Filho 2007; Brooks et al., 2010). Furthermore, unlike most taxa, snakes are also impacted by seemingly irrational killing by humans (Sasaki et al., 2008).

Information on reproductive biology has a strong practical application in conservation and management of wildlife. Data on reproductive output and associated life-history characteristics (e.g., the number of offspring, age or size at maturity, and reproductive frequency) help to assess populations’ trajectories and infer something about their future viability (Seigel and Sheil, 1999). Knowledge of the spatial locations in which reproductive events (e.g., aggregation during gestation) take place is also important to protect and manage such critical habitats and to maintain or facilitate reproductive success (Shine and Bonnet, 2009). Although an expansive literature exists on reproductive biology of snakes (Seigel and Ford, 1987), most studies are limited to species from North America, Europe, and Australia. Furthermore, although considerable intraspecific variation in reproductive and ecological characteristics exists within snakes (Pearson et al., 2002; Shine, 2003; Ji and Wang 2005), most species remain unstudied in this regard. Lack of population-specific information can result in ineffective conservation efforts.

Japanese Mamushi (Gloydius blomhoffii) are Asian pitvipers that are endemic to the Japanese archipelago (Toriba, 1996; Hikida, 2002). The Mamushi is one of the most geographically widespread snakes in Japan, occurring on all four major islands of Japan, Kyushu, Shikoku, Honshu, and Hokkaido (in order south to north), as well as other small islets. Nevertheless, Mamushi appear to be declining or already extirpated in many places and have become a species of conservation concern in some prefectures (e.g., Tochigi Prefecture, 2005). As for so many species over the world, significant habitat loss seems to be involved (Sasaki et al., 2005). However, habitat loss is not the only cause of declines and extirpations. Mamushi, like other Gloydius species in Asia, have long been hunted for their nutritional and medicinal value (Goris, cited in Gloyd and Conant, 1990; Conant, 1992). In addition, Mamushi are also impacted by malicious, indiscriminate, or seemingly irrational killing in more recent years (Sasaki et al., 2009, 2010). This raises a concern about population persistence because Mamushi do not become sexually mature until at least three years of age and have a low frequency of reproduction (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999), characteristics of species that are imperiled when adult mortality rates are greatly increased (Seigel and Sheil, 1999; Row et al., 2007). Our knowledge of reproductive biology of Mamushi is based largely on the population of the southern island of Kyushu (approximately 31°N), which is located in the southernmost geographic range of Mamushi (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). Therefore, our first objective here is to document reproductive characteristics of Mamushi in the northern range of this species on Hokkaido (approximately 41°N) and compare them to available information from other regions. We also describe habitat and spatial locations where parturition and gestation take place, which have not been described previously. We have previously documented a direct human-caused mortality from one of the populations of our study area (Sasaki et al., 2009). Using data collected from a much larger study area, we assess vulnerability of Mamushi populations to human predation pressure by characterizing
human-caused mortality with respect to life stage, sex, and female reproductive status.

**Materials and Methods**

**Study Area.**—We studied several Mamushi populations in a rural region of southwestern Hokkaido (approximately 41°N), the northernmost main island of Japan. Because of potential risks of attracting commercial harvesting, the exact location of the study area and the specific study sites (N = 24) are not published. The study area was situated about 30 km along the coastline and extended inland about 18 km. The area is mountainous and hilly, containing many valleys. Most field surveys were conducted at elevations <200 m. About two-thirds of the study populations were located on or around three widely separated floodplains and several attenuated strips of level land bordering rivers. These bottomland areas were largely anthropogenic landscapes, including agricultural fields and residential areas, with reduced forest cover. The remaining study populations were situated in more remote areas, and a large portion of the area was covered by forests, including forest plantations (for the spatial distribution of the major study sites [i.e., sites with at least 10 individuals], see Sasaki et al. [2009]). The sites have an average of 229 frost-free days per year, from 9 April to 13 November (based on averages from years 1971–2000, Japan Meteorological Agency).

**Data Collection.**—In each of four years (16 June to 30 July 1999; 2 July to 4 August 2000; 13 August to 12 October 2001; 28 May to 30 July 2002), we conducted field searches mostly during daylight hours and used snake tongs to capture Mamushi. A total of 299 snakes were captured. We recorded snout–vent length (SVL), body mass (BM), sex, and female reproductive status and then released subjects at sites of capture. We measured SVL with a squeeze box (Quinn and Jones, 1974) and determined the mass of snakes with an electronic scale to the nearest 0.1 g. Sex was determined by probing for hemipenes. Female reproductive status was assessed by ventral palpation to determine the presence of enlarged follicles or embryos. To ensure our ability to detect enlarged follicles or embryos by palpation, radiographs of a few females were taken at the Kawamata Animal Hospital in Hakodate. Reproductive status of females caught earlier in the season was confirmed with certainty when they were recaptured later in the season (mid- to late stages of pregnancy) or immediately postpartum. To mark individuals, we implanted passive integrated transponder (PIT) tags (AVID Identification Systems, Norco, CA) or clipped ventral scales for long-term identification and painted numbers on the dorsum with nail polish for short-term recognition. We determined mating season based on the presence or absence of the following behavior in the field: copulation, courtship, accompaniment (male and female located within 0.3 m of one another), mating aggregation, and male–male combat.

In 2001 and 2002, we kept 29 wild-caught pregnant females in individual cages (40 × 25-cm plastic cages with mesh tops) until parturition (mean ± 1 SD = 25 ± 17 days). They were kept in a laboratory with windows and held at 25–26°C (at the warmest part in the cages) during the day (0900–1700 h with heat lamps) and 19–20°C at night (1700–0900 h without heat lamps). These daytime temperatures allowed females to achieve the ranges of body temperatures observed in natural conditions. Water and shelter were provided at all times. Every week, we provided locally collected mice or frogs (although none were consumed). Immediately after parturition, we determined the mass of the females and sexed, measured, and determined the mass of the neonates. We included only live young for determination of litter size and mass. Additional data on litter size were obtained from three pregnant females: one killed by traffic; one observed giving birth in the wild; and one killed by a local resident.

To determine the pattern of direct human-caused mortality, we recorded life stage (neonate: SVL ≤ 23 cm, juvenile: SVL 24–39 cm, and adult: SVL ≥ 40 cm), sex, and female reproductive condition of killed snakes that we encountered in the field, as well as snakes that were processed into “snake jerky” or “snake whisky” by local people for noncommercial consumption. However, many of these processed snakes were in such condition that sexing or measuring was not possible.

**Data Analysis.**—Relative litter mass (RCM, Seigel and Fitch, 1984) was calculated as the mass lost at parturition divided by the mother’s post-partum mass. We estimated body condition (BC) as the standardized residual score derived from a general linear regression of natural log-transformed BM against natural log-transformed SVL (Secor and Nagy, 2003). Data from all populations and years and sites were pooled for analyses because of small sample sizes. We have documented body size (SVL) differences previously among our major populations with respect to differential hunting pressures (Sasaki et al., 2009). In the present analysis, we pooled those data and included other datasets not used previously. Statistical analyses were conducted using t-tests, ANOVA, linear regression, logistic regression, and Chi-squared tests, with significance level set at α = 0.05. Data were transformed using natural log when necessary. Averages are reported ± 1 standard error unless otherwise noted. We used total body lengths, instead of SVL, for geographic comparisons because of availability. We performed all statistical analyses using R version 2.13.0 (R Development Core Team, 2011).

**Results**

Gestation Sites.—Several gestation sites were identified during the course of the study. Gestation sites are small areas where pregnant females, often in groups, reside for several weeks before parturition. All gestation sites received sunlight much of the day, contained abundant shelters, and generally had interspersed herbaceous vegetation or woody debris. Places most commonly used as gestation sites included piles of large rocks or woody debris on the dry riverbed, piles of large rocks in abandoned mines or other disturbed sites, and gabions and partially fallen rock walls along riverbanks, roadsides, or ditches. Some known gestation sites were clustered together, as close as 10 m from one another, and others were widely separated, more than a kilometer apart. The average number of pregnant females observed together at censuses of known aggregation sites averaged 6.6, ranging from 1 to 18. The number of pregnant females observed at gestation sites peaked from August to mid-September.

Mating Season.—Mamushi are known to mate in August and September in Kyushu, the southernmost range of Mamushi (Isogawa and Kato, 1995; Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). Our observations in Hokkaido also suggest that mating occurs during this period. Although we failed to observe copulation, we noted behavior that might be associated with mating seasons (Table 1), all of which took place in August and September (with one late July exception). First, one marked male was consecutively found with the same marked non-pregnant female (20 August and 20 September) or
Table 1. Observed behavior potentially associated with mating seasons in Gloydius blomhoffii on Hokkaido, Japan, 1999–2002. All years are combined. Accompaniment refers to a behavioral observation in which a male and a female are located within 0.3 m of one another. Male aggregation refers to a behavioral observation in which two or more males are located together, with their bodies touching.

<table>
<thead>
<tr>
<th>Date</th>
<th>Accompaniment</th>
<th>Male aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 July</td>
<td>3♂ with 2♀</td>
<td>–</td>
</tr>
<tr>
<td>14 August</td>
<td>2♂ with 1♀; 1♂ with 1♀</td>
<td>–</td>
</tr>
<tr>
<td>15 August</td>
<td>1♂ with 1♀</td>
<td>–</td>
</tr>
<tr>
<td>20 August</td>
<td>1♂ with 1♀</td>
<td>2♂</td>
</tr>
<tr>
<td>28 August</td>
<td>–</td>
<td>3♂</td>
</tr>
<tr>
<td>31 August</td>
<td>–</td>
<td>4♂</td>
</tr>
<tr>
<td>1 September</td>
<td>–</td>
<td>2♂</td>
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<tr>
<td>2 September</td>
<td>–</td>
<td>4♂</td>
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<td>3 September</td>
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<tr>
<td>14 September</td>
<td>1♂ with 1♀</td>
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<td>20 September</td>
<td>1♂ with 1♀</td>
<td>–</td>
</tr>
<tr>
<td>23 September</td>
<td>1♂ with 1♀</td>
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</tbody>
</table>

*The same male and female.

at the same location where this female had been recently (28 August and 19 September). Second, 10 males were found within 0.3 m of a female during late July to late September (and one of these on two different days a month apart), all at gestation sites. Third, we found male aggregations. At each of these 6 aggregations, 2 to 4 males were found with their bodies touching each other. All but one of the male aggregations was found in the close vicinity of gestation sites (the exception being 60 m away). No reports of male–male combat have been made in G. blomhoffii, and we likewise observed no agonistic interactions among males.

Parturition.—Parturition in both the field and captivity took place from late summer to fall, ranging from 12 September to 24 October (25th, 50th, and 75th percentiles were 27 September, 4 October, and 18 October, respectively). The last pregnant females found in the field in a given year (N = 2) occurred on 3 October, and each gave birth on 3 and 24 October in captivity. The timing of parturition seems to be later than that in southern regions (Moriguchi, 2007). Because litter size varies considerably among mothers and also with food availability (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999), available data do not allow geographic comparisons.

Litter size averaged 6.6 ± 0.37 offspring in the Hokkaido Mamushi (Table 2). No clear geographic trend was apparent in litter size (Table 2). The largest litter size (13) from wild-caught Mamushi was observed in central Honshu (Fukada, 1962) and on Teuri Island, just off the coast of northern Hokkaido (Moriguchi, 2007). Because litter size varies considerably among mothers and also with food availability (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999), available data do not allow geographic comparisons.

Positive correlations between maternal body size and litter and offspring characteristics typically observed within snakes (Seigel and Ford, 1987) were also evident in our study. Litter size from our Hokkaido populations was weakly, but significantly, positively correlated with maternal SVL (r² = 0.18, F₁,₂₈ = 6.16, P = 0.019; Fig. 1a). Larger (in SVL) females tended to produce larger (in SVL) neonates (r² = 0.15, F₁,₂₄ = 4.34, P = 0.048; Fig. 1b). Mamushi produced large litters relative to maternal mass (RCM, 0.83 ± 0.07, range = 0.40–1.50, N = 19). Females after parturition had lower BC than females in nonreproductive years (t₂₉₀ = 7.52, P < 0.001). Females with larger RCM were especially thinner (i.e., lower BC) after parturition (F₁,₁₇ = 7.503, P = 0.014).

Reproductive Frequency.—The proportion of females pregnant in 1999, 2000, 2001, and 2002 was 0.27 (4 of 15), 0.40 (6 of 15), 0.39 (33 of 85), and 0.59 (66 of 112), respectively. Our figures were consistent with the values reported for the Kyushu population (0.24–0.54). Our short-term recapture data indicated that at least some females are nonreproductive for at least two years. Of 12 females that we captured in both 2001 and 2002, 6 were pregnant in only one of the years (one was pregnant in 2001, and the other in 2002), and 6 were not pregnant in either year.

In Kyushu Mamushi, the proportion of reproductive females tends to increase with body length (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). This was also the case for our Hokkaido populations (Table 3). A logistic regression analysis showed a statistically significant relationship (Hosmer-Lemeshow test: χ² = 6.87, df = 8, P = 0.550, null deviance-residual deviance = 16.88, df = 1, P < 0.001).

Hunting and Intentional Killing.—We located 102 snakes that were hunted or killed intentionally by humans. All of these snakes were adult. Of those, we were able to assess sex and female reproductive status of 47 individuals: 33 (70.2%) were pregnant, 11 (23.4%) were not pregnant, and 3 (6.4%) were males.
These differences were statistically significant ($\chi^2 = 54.03$, df = 2, $P < 0.0001$).

**Discussion**

This study provides basic information on reproduction in Mamushi on southwestern Hokkaido and compares our data to populations studied previously from southern regions of Japan. We also provide previously undocumented information on Mamushi reproductive biology (e.g., gestation and parturition sites). Aggregation of pregnant females has been reported in several snake species (Graves and Duvall, 1993), including a close relative of Mamushi, the genus *Agkistrodon* (e.g., Wharton, 1966; Smith et al., 2009). We are unaware of formal reports of aggregations of pregnant Mamushi. Local people from central Honshu noted Mamushi aggregations (Fukada, 1962), although the author did not verify the presence of pregnant females in these aggregations. Pregnant females during gestation form aggregations as a result of mutual attraction to preferred habitat features or attraction to reproductively similar conspecifics (Graves and Duvall, 1995). Although we did not investigate causes of such aggregations, our observations that a number of pregnant females were found alone during gestation support the notion of attraction to habitat features (but do not reject attraction to conspecifics). Gestation sites share some common features, most notably, open areas with abundant shelters and sparse vegetation. Such features may be important for effective and safe behavioral thermoregulation (Graves and Duvall, 1995).

Many of our results from Hokkaido were consistent with those reported for Mamushi from southern regions: (1) body sizes do not differ between sexes at birth, but there is an apparent sex difference in body size in adults (females are larger than males); (2) the mating season occurs from August to September; (3) sex ratio at birth is about equal; (4) parturition occurs from late summer to fall; (5) Mamushi exhibit delayed maturation; and (6) Mamushi may skip one or more years between reproductive bouts. The sex difference in body size of adults (result 1 above) appears to be attributable to a difference in growth rates after sexual maturity. In a captive-rearing experiment on Kyushu Mamushi, females continued to grow, whereas males slowed down their growth after sexual maturity (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999).

Our study also provides relatively large amounts of data that support a generally recognized geographic trend: Hokkaido Mamushi are larger than southern counterparts (Moriguchi and Takenaka, 1984; Ota and Nakagawa, 1985). No data are available to determine whether this apparent sex difference in adult body size reflects adaptation or results from differences in size-specific mortality or longevity.

![Figure 1](image_url)  
*Fig. 1.* Relationship (a) between female snout–vent length (SVL) and litter size and (b) between female (SVL) and mean neonate SVL as assessed by linear regressions.
Mating has been confirmed in August and September in an outside enclosure in Kyushu, the southernmost range of Mamushi (Isogawa and Kato, 1995; Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). Although our behavioral observations support an August and September mating season on Hokkaido, the presence of spring mating cannot be discounted because our field study did not begin early enough in the season to observe spring matings. We noted one rarely documented phenomenon, the aggregation of males. In the Midget Faded Rattlesnake (*Crotalus oreganus concolor*) in Wyoming, male aggregation was associated with ecdysis (Parker and Anderson, 2007). In our study populations, however, the occurrence of ecdysis was not apparent in aggregating males. Although what causes male aggregations is not known in Mamushi, the occurrence of aggregation during our estimated mating season and in the close vicinity of gestation sites of females suggests a mating function.

The timing of parturition on Hokkaido seems to be later than that in southern regions. This could result from slowed gestation processes attributable to a later onset and shorter duration of the growing season and the cooler climate on Hokkaido. However, this also could be simply attributable to insufficient sample sizes in the central Honshu population (N = 17; Fukada, 1992) and our Hokkaido populations. Regardless of a geographic difference or lack thereof, the timing of parturition exhibited on Hokkaido may pose a challenge for postpartum females because they may not have an opportunity to feed prior to hibernation. We observed four postpartum females in late October who apparently had not recently fed, as judged from their notably emaciated appearance. Two radio-tagged postpartum females also did not feed at least until the end of our field surveys (28 October). We confirmed the death of these two females during the winter following parturition; however, their deaths could have been caused by the negative impacts of the radiotags.

Size and age of organisms determines the onset of reproductive maturity in snakes (Byars et al., 2010), including Mamushi (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). The smallest pregnant female found in our study was larger than the smallest reported in southern regions. It is speculated that it requires at least 3–4 years in nature to attain these body sizes recorded in the Kyushu and central Honshu populations (Fukada, 1992; Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999). Mamushi on Hokkaido may grow slower than southern counterparts because of a shorter growing season, based on preliminary data from Kyushu (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999), central Honshu (Fukada, 1972), and Hokkaido (Sasaki et al., 2007). If growth rates of Hokkaido Mamushi are indeed slower than (or even similar to) those in Kyushu and central Honshu, Hokkaido Mamushi may take longer to attain maturity.

Many snakes in temperate regions do not reproduce every year (Aldridge and Duvall, 2002). Our figures on the proportion of females pregnant (range = 0.27–0.59) and pregnancy status of the same females caught in consecutive years suggest a biennial or triennial cycle, which is consistent with the presumed pattern in the Kyushu population. Strengthening this conclusion is the fact that our estimates of the proportion of females pregnant are likely to be overestimates because pregnant females were easier to find because of their predictable occurrence at gestation sites. As observed in several snake species (Shine, 1986; Macartney and Gregory, 1988; Bonnet et al., 2000), including Mamushi on Kyushu (Yomeishu Seizo Co., Ltd. Central Research Laboratories, 1999), the proportion of reproductive females increased with increasing body length in Hokkaido Mamushi. This information, along with data on size structure, can provide insight into the proportion of reproductive females in a population of concern.

High current reproductive investment may compromise survival (Stearns, 1992) and, therefore, the chance that females will reproduce again. High mortality of reproductive females is evident in other viviparous species (e.g., *Vipera berus*, Madsen and Shine, 1993; *Vipera aspis*, Bonnet et al., 2002). Although we do not have direct measures of postpartum mortality rates, RCM and postpartum body condition may predict the probability of a female’s postpartum survival (Madsen and Shine, 1993). Relative litter mass exhibited by Mamushi on Hokkaido was remarkably large (83% on average) compared to other snake species of comparable size (Seigel and Fitch, 1984; Sun et al., 2002). As expected from such a high investment, female Mamushi were greatly emaciated after parturition, especially those with larger RCM. Moreover, low to no feeding opportunity before hibernation following late parturition may further compromise survival. Relatively low recapture rates of pregnant females in our study (only one pregnant female was recaptured, whereas 11 non-pregnant ones were recaptured) may be a result of low survival rates of postpartum females. However, such differences in recapture rates may also arise from differences in catchability attributable to differential habitat use.

Conservation Implications.—Mamushi on Hokkaido are not a species of conservation concern at the national level. Nonetheless, our observations and those of local residents at our study area suggest that many local populations are small, declining, or have been extirpated (Sasaki et al., 2009). In the Tokachi region of Hokkaido, several local extirpations have been reported (Sato, 1990, 1993).

High adult mortality caused by direct human predation raises a concern for the capacity of Mamushi populations to recover or persist. Mamushi, especially on Hokkaido, exhibit biological characteristics of species that are prone to population decline and extirpation when adult mortality rates increase: small litters, delayed maturation, and infrequent reproduction (MacArthur and Wilson, 1967; Reed and Shine, 2002; Webb et al., 2002). Furthermore, the tendency of pregnant females to congregate at gestation sites makes pregnant females particularly vulnerable to human predation. Species that form aggregations have been found to be associated with increased extinction risk in birds (Reed, 1999). Moreover, with the biased take of pregnant females, recruitment of young into the population is curtailed. Furthermore, high adult mortality can cause rapid evolution in a way that could affect population persistence negatively (Darimont et al., 2009). We have previously documented that the strong selective force exerted...
by human predation on Mamushi is likely to have caused rapid evolution of multiple traits (body size, vertebral number, life-history traits, and antipredator behavior) that would normally be disadvantageous under natural conditions and, therefore, could potentially lower population fitness (Sasaki et al., 2009).

We consider the protection of gestation sites to be a key component of Mamushi conservation on Hokkaido (and any other regions where pregnant females form aggregations). First, the protection of gestation sites would automatically protect a key component of a population, pregnant females. Second, gestation sites are probably an essential microhabitat that allows successful reproduction, probably by offering favorable microclimate and perhaps proximity to parturition sites. Finally, successful reproduction, probably by offering favorable micro-habitat, is an essential component of a population, pregnant females. Second, gestation sites are probably an essential microhabitat that allows successful reproduction, probably by offering favorable microclimate and perhaps proximity to parturition sites. Finally, successful reproduction, probably by offering favorable micro-habitat, is an essential component of a population, pregnant females. Hence, we suspect that most gestation sites occur at lower elevations, based on observations by local people who often visit higher elevations for fishing or mushroom hunting.

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LITERATURE CITED


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