Infestation and Seasonal Fluctuation of Gamasid Mites (Parasitiformes: Gamasida) on Indochinese Forest Rat, *Rattus andamanensis* (Rodentia: Muridae) in Southern Yunnan of China

**Abstract:** A 12-month consecutive investigation was made at Jingha village in southern Yunnan of China from April 2016 to March 2017, the present paper studied the infestation and seasonal fluctuation of gamasid mites on the Indochinese forest rat, *Rattus andamanensis*, the most dominant species of rodent at the investigated site. The temperature and rainfall are two key factors that influence the seasonal fluctuation of the mites.

**Keywords:** Acari; mite; ectoparasite; rodent; *Rattus*; small mammal

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**Simple Summary:** Gamasid mites are a large group of arthropods and some of them are ectoparasites on the body surface of rodents and some other small mammals. Some species of ectoparasitic gamasid mites are associated with the transmission of some zoonotic diseases such as rickettsialpox and hemorrhagic fever with renal syndrome (HFRS). Based on a 12-month consecutive investigation at Jingha village in southern Yunnan of China from April 2016 to March 2017, the present paper studied the infestation and seasonal fluctuation of gamasid mites on the Indochinese forest rat, *Rattus andamanensis*, the most dominant species of rodent at the investigated site. The temperature and rainfall are two key factors that influence the seasonal fluctuation of the mites.

**Abstract:** A 12-month consecutive investigation was made at Jingha village in southern Yunnan of southwest China from April 2016 to March 2017. A total of 2053 Indochinese forest rats (*Rattus andamanensis* Blyth, 1860) were captured and examined, which account for 84.69% (2053/2424) of all the animal hosts (rodents and other small mammals) at the investigation site. And 39.82% (13,531/33,980) of gamasid mites were identified from the body surface of *R. andamanensis* and they belong to 41 species, 10 genera, 3 subfamilies and 2 families. Of the 41 species of gamasid mites identified from *R. andamanensis*, *Laelaps nuttalli* Hirst, 1915 and *Laelaps echidninus* Berlese, 1887 were the most dominant with 70.63% and 20.67% of constituent ratios respectively. In monthly fluctuations of all the gamasid mites on *R. andamanensis*, the constituent ratio (*C*) and overall infestation mean abundance (*MA*) of the mites in 12 months showed two obvious peaks in January (winter season) and June (summer season). However, the two dominant mite species, *L. nuttalli* and *L. echidninus*, showed different patterns of seasonal fluctuations. *Laelaps nuttalli* occurred throughout the year, and its *C* and *MA* showed two prominent peaks in winter season (December and January) and summer season (June), which belongs to the summer-winter type of seasonal fluctuation. *Laelaps echidninus* also occurred on *R. andamanensis* throughout the year, but its *C* and *MA* showed only one peak in winter season (December and January), which belongs to the winter type of seasonal fluctuation. A negative correlation existed between two climatic factors (temperature and rainfall) and the infestations (*C*, prevalence *P* and *MA*) of two dominant mite species (*L. nuttalli* and *L. echidninus*) on *R. andamanensis* (*p < 0.05*). Temperature and rainfall are considered to be two key factors that influence the seasonal fluctuations of the mites on the studied rat species.

**Keywords:** Acari; mite; ectoparasite; rodent; *Rattus*; small mammal
1. Introduction

Gamasid mites are a large group of arthropods with different ecological behaviors and they belong to the order Gamasida (or Mesostigmata) of the superorder Parasitiformes in the subclass Acari and the class Arachnoidea in zoological taxonomy [1,2]. The majority of gamasid mites are free living creatures and they can be found in the top soil, various humus and litter, animals nests, some stored goods or even on some plants [3,4]. Some gamasid mites are ectoparasites and they are often found on the body surface of rodents and some other small mammals [5,6]. The ectoparasitic gamasid mites can directly sting the human body and cause dermatitis, and some of them can be the vector or potential vector of some zoonotic diseases (zoonoses), such as rickettsialpox and hemorrhagic fever with renal syndrome (HFRS) [7,8]. Rodents and some other small mammals (insectivores and tree shrews) are the most important hosts of ectoparasitic gamasid mites [9–12].

As an important species of rodent, the Indochinese forest rat, Rattus andamanensis Blyth, 1860 has been documented in some regions of China, Vietnam, Laos, Cambodia, Thailand, central and northern Myanmar, northeastern India, Bhutan, eastern Nepal and Bangladesh [13]. In China, R. andamanensis is known to be mainly distributed in some regions of southern and southwestern China, such as Tibet, Guizhou, Hainan, Guangdong and Hong Kong [14]. A consecutive 12-month investigation for ectoparasitic gamasid mites was made at Jingha village (a localized site) in southern Yunnan of southwest China from April 2016 to March 2017, and Rattus andamanensis was found to be the most dominant species of small mammal hosts at the village. Based on the investigation data, the present paper analyzed the infestation and seasonal fluctuation of gamasid mites on R. andamanensis for the first time.

2. Materials and Methods

2.1. Field Investigation

From April 2016 to March 2017, a consecutive 12-month field investigation was made at Jingha village, Jinghong county, Xishuangbanna prefecture in the south of Yunnan province (21°50′ N, 100°52′ E, 500–700 m a.s.l., Figure 1). Each month’s investigation lasted 15–20 days. Jingha village is a typical valley and flatland area near the coast of the Lancang River, a river from the northwest to the south in Yunnan province [15,16]. The village is a rubber planting area with lots of rubber woodlands dotted with some banana fields, farmlands, bush areas and broad-leaved forests. The meteorological data was from the online resources provided by the local weather forecasting department [17].

Figure 1. The locality of the field investigation site, Jingha village, Jinghong county, Xishuangbanna prefecture in the south of Yunnan province, China.
2.2. Collection and Identification of Gamasid Mites and Their Hosts

At the investigation site (Jingha village), the animal hosts of gamasid mites, rodents, and some other small mammals, were mainly captured with mousetraps (18 × 12 × 9 cm³, Guixi Mousetrap Apparatus Factory, Guixi, Jiangxi, China) every month. The mousetraps were set in the former evening and checked in the next morning. Each captured animal host was separately put in a white cloth bag and then brought to the field laboratory where the host was anesthetized with ether. Over a large white tray, the gamasid mites on the body surface of every host were collected with the help of a magnifier and the collected mites from each host were separately preserved in an Eppendorf tube containing 70% ethanol solution. After the mite collection, every animal host was identified to species according to its morphological features such as body size, body shape, body color and other measurements [13,14,18–21]. The identified R. andamanensis rats, together with the gamasid mites collected from the rats, were used as the target of the present paper. In the laboratory, the preserved gamasid mites were slide-mounted with Hoyer’s liquid which contains glycerin, the clearing reagent. The slide-mounted mite specimens were dried at 50 °C for about one week in an electric drying oven (DHG-9240A, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China) through which the mounted mite specimens were gradually dehydrated and hyalinized. After dehydration and hyalinization, the mounted mite specimens were identified to species under the microscope (Nikon DS–RI2, Nikon Corporation, Japan) with the help of relevant taxonomic literature including taxonomic monographs and identification keys [22–26]. The capture of animal hosts was officially approved by the local administration department of wildlife affairs. The ethical approval code or the permitted number was DLDXLL2020-1104. The representative specimens of gamasid mites and their animal hosts were deposited in the Institute of Pathogens and Vectors, Dali University, Dali, China.

2.3. Statistical Analysis

The constituent ratio (Cr), prevalence (PM), mean abundance (MA) and mean intensity (MI) were used to calculate the infestation of R. andamanensis with gamasid mites, in which Cr represents the percentage of a certain species of gamasid mite in all the mites, PM the percentage of the infested rat hosts with gamasid mites in all the rat hosts, MA the average number of gamasid mites per captured rat host and MI the average number of gamasid mites per infested rat host [7,27–29]. The richness index (S), Shannon-Wiener’s diversity index (H′), Pielou’s evenness (E) and Simpson’s dominance index (D) were used to calculate the community structure of the gamasid mite community on the rat R. andamanensis [27,30].

\[
Cr = \frac{N_i}{N} \times 100\%; \quad PM = \left( \frac{H_m}{H} \right) \times 100\%; \quad MA = \frac{N_i}{H}; \quad MI = \frac{N_i}{H_m};
\]

\[
S = \sum S_i; \quad H' = -\sum_{i=1}^{S} \left( \frac{N_i}{N} \right) \ln \left( \frac{N_i}{N} \right); \quad E = \frac{H'}{\ln S}; \quad D = \sum_{i=1}^{S} \left( \frac{N_i}{N} \right)^2
\]

In the above formulas, \(N_i\) represents the individuals of gamasid mite species \(i\). \(N\) the total individuals of all the gamasid mites. \(H\) represents the total number of the rat hosts (R. andamanensis), \(H_m\) the number of infested hosts by gamasid mite \(m\). \(S_i\) stands for gamasid mite species \(i\) in the gamasid mite community.

The correlation was analyzed between the seasonal fluctuation of dominant gamasid mites and the fluctuation of climatic factors and the significance level was at 0.05 (\(\alpha = 0.05\)). Pearson correlation coefficient is calculated when the data conform to the normal distribution, and Spearman rank correlation coefficient is calculated when the data do not conform to the normal distribution.
3. Results

3.1. Collection of Gamasid Mites and Their Hosts

From the consecutive 12 months’ field investigation at Jingha village in southern Yunnan of China between April 2016 and March 2017, a total of 2,424 small mammal hosts were captured and they were identified into 15 species, 10 genera and 5 families under four orders, Rodentia, Erinaceomorpha, Soricomorpha and Scandentia. Of the identified 15 species of hosts, the abundance of *R. andamanensis* rats accounted for 84.69% (2053 rat individuals captured), which is the most dominant animal host at the investigation site, Jingha village. From the body surface of *R. andamanensis*, 13,662 gamasid mites were collected. The majority of the collected mites (13,531; 99.04%) were identified into 41 species, 10 genera, 3 subfamilies and 2 families (Table 1), and the remaining 131 mites have not been identified due to their body damage or ambiguous morphology.

### Table 1. Systematic list of gamasid mites from the body surface of Indochinese forest rats (*Rattus andamanensis*) at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Taxa                        | N  | Taxa                        | N  | Taxa                        | N  | Taxa                        | N  |
|-----------------------------|----|-----------------------------|----|-----------------------------|----|-----------------------------|----|
| Family Lealapidae           | 13,530 | L. jettmari Vitzthum, 1930  | 1  | Genus Cosmolaelaps C. gerulue Ma, 1995 | 6  | Subfamily Haemogamasinae | 11 |
| Subfamily Lealapinae        | 13,410 | L. extremi Zachvatkin, 1948 | 3  | Genus Eucoelaples Ma, 1995  | 6  | Genus Eucoelaples  | 9  |
| Genus Laelaps               | 13,337 | A. singularis Wang et Li, 1965 | 4  | Genus Hypoaspis Ma, 1981  | 109 | E. jiulinensis Wen, 1976 | 2  |
| L. nuttalli Hirst, 1915     | 9557  | Genus Tricholaelaps H. concinni Teng, 1982 | 15 | Genus Hypoaspis  | 109 |
| L. liui Wang et Li, 1965    | 104   | T. myonysognathus H. aculeifer Canestrini, 1884 | 15 | E. subtabularis Yang et Gu, 1986 | 1  |
| L. guizhouensis Gu et Wang, 1981 | 34  | L. chin Wang et Li, 1965  | 29  | H. petauristae Gu et Wang, 1980 | 1  | O. bacoti Hirst, 1913 | 1  |
| L. echidinus Berlese, 1887  | 2797  | H. glasgowi Ewing, 1925  | 1  | H. petauristae Gu et Wang, 1980 | 1  | O. bacoti Hirst, 1913 | 1  |
| L. turkestanicus Lange, 1955 | 216  | H. linteyini Samsinak, 1964 | 1  | H. petauristae Gu et Wang, 1980 | 1  | O. bacoti Hirst, 1913 | 1  |
| L. traubi Domrov, 1962      | 219   | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. fukienensis Wang, 1963   | 110   | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. algericus Hirst, 1925    | 84    | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. cheni Li, 1965           | 116   | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. jinghaensis sp.nov       | 22    | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. chin Wang et Li, 1965    | 29    | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |
| L. clethronomus Lange, 1955 | 45    | H. petauristae Gu et Wang, 1980 | 15 | E. substabularis Yang et Gu, 1986 | 1  |

3.2. Community Structure and Overall Infestations of Gamasid Mites on *Rattus andamanensis*

The community indices of gamasid mites on *Rattus andamanensis* fluctuated irregularly from month to month. The richness index (S) was the highest in January and the lowest in October, Shannon-Wiener’s diversity index (H) was the highest in September and the lowest in October, Pielou’s evenness (E) was the highest in September and the lowest in May, and Simpson dominance index (D) was the highest in October and the lowest in January (Table 2, Figure 2). The constituent ratio (Cr) and overall mean abundance (MA) of gamasid mites showed two obvious peaks in January (winter season) and June (summer season) (Table 3, Figures 3 and 4).
Table 2. Monthly fluctuation of community indices of gamasid mites on *Rattus andamanensis* at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Years and Months | Community Structure of Gamasid Mites |
|------------------|-------------------------------------|
|                  | Years | Months | S      | \(H^*\) | E | D |
| 2017             | 1     | 16     | 1.098  | 0.396   | 0.396 |
|                  | 2     | 14     | 1.053  | 0.399   | 0.428 |
|                  | 3     | 13     | 0.891  | 0.347   | 0.485 |
| 2016             | 4     | 12     | 1.053  | 0.424   | 0.504 |
|                  | 5     | 15     | 0.451  | 0.166   | 0.818 |
|                  | 6     | 8      | 0.751  | 0.361   | 0.665 |
|                  | 7     | 8      | 1.032  | 0.496   | 0.498 |
|                  | 8     | 10     | 0.901  | 0.391   | 0.564 |
|                  | 9     | 9      | 1.165  | 0.530   | 0.456 |
|                  | 10    | 6      | 0.340  | 0.190   | 0.839 |
|                  | 11    | 11     | 0.647  | 0.270   | 0.681 |
|                  | 12    | 12     | 0.770  | 0.310   | 0.518 |
| Total            | 41    |        | 1.013  | 0.273   | 0.542 |

Annotation: The field investigation at Jingha village was made between April 2016 and March 2017, which forms a consecutive process from January to December.

Figure 2. Monthly and seasonal fluctuation of community indices of gamasid mites on *Rattus andamanensis* at Jingha village in southern Yunnan of China (April 2016–March 2017).

Table 3. Monthly fluctuation of overall infestations of *Rattus andamanensis* with gamasid mites at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Months | Host (R. andamanensis) | Mites | Host Infestation |
|--------|------------------------|-------|------------------|
|        | N                      | \(C_r\) (%) | No. of Mites | \(C_r\) (%) | \(P_M\) (%) | MA | MI |
| 1      | 182                    | 8.87  | 2165            | 16.00       | 80.77       | 11.90 | 14.73 |
| 2      | 167                    | 8.13  | 1160            | 8.57        | 73.05       | 6.95  | 9.51  |
| 3      | 182                    | 8.87  | 1074            | 7.94        | 83.52       | 5.90  | 7.07  |
| 4      | 168                    | 8.18  | 720             | 5.32        | 51.79       | 4.29  | 8.28  |
| 5      | 184                    | 8.96  | 1304            | 9.64        | 68.48       | 7.09  | 10.35 |
| 6      | 150                    | 7.31  | 1570            | 11.60       | 63.33       | 10.47 | 16.53 |
| 7      | 152                    | 7.40  | 549             | 4.06        | 40.13       | 3.61  | 9.00  |
| 8      | 151                    | 7.36  | 738             | 5.45        | 59.60       | 4.89  | 8.20  |
| 9      | 141                    | 6.87  | 748             | 5.53        | 69.50       | 5.30  | 7.63  |
| 10     | 190                    | 9.25  | 678             | 5.01        | 54.21       | 3.57  | 6.58  |
| 11     | 197                    | 9.60  | 1237            | 9.14        | 71.57       | 6.28  | 8.77  |
| 12     | 189                    | 9.21  | 1588            | 11.74       | 77.25       | 8.40  | 10.88 |
| Total  | 2053                   | 100.00| 13,351          | 100.00      | 66.63       | 6.59  | 9.89  |
3.3. Dominant Species of Gamasid Mites and Their Seasonal Fluctuations

The constituent ratios ($C_r$) of *Laelaps nuttalli* ($C_r = 70.63\%$) and *L. echidninus* ($C_r = 20.67\%$) were the highest and they were the dominant species of gamasid mites on the studied rat species. In comparison with other species of gamasid mites, two dominant mite species showed relatively high prevalence ($P_M$), mean abundance ($MA$) and mean intensity ($MI$) (Table 4). The monthly fluctuations of infestations of *R. andamanensis* with two dominant gamasid mite species were summarized in Tables 5 and 6.
Table 4. Constituent ratios and infestations of two dominant species of gamasid mites (*Laelaps nuttalli* and *Laelaps echidninus*) on the rat host *Rattus andamanensis* at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Dominant Mite Species | Mites Host Infestation |
|-----------------------|------------------------|
|                       | N  | C_r (%) | P_M (%) | MA  | MI  |
| *L. nuttalli*         | 9557| 70.63   | 57.04   | 4.66 | 8.16 |
| *L. echidninus*       | 2797| 20.67   | 33.07   | 1.36 | 4.12 |
| Total                 | 12,699| 91.30   |          |      |     |

Table 5. Monthly fluctuations of constituent ratios and infestations of the gamasid mite *Laelaps nuttalli* on the rat host *Rattus andamanensis* at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Months | Examined Hosts | Infested Hosts | No. of Mites | C_r (%) | P_M (%) | MA  | MI  |
|--------|----------------|----------------|--------------|---------|---------|-----|-----|
| 1      | 182            | 127            | 1366         | 14.29   | 69.78   | 7.51| 10.76|
| 2      | 167            | 96             | 609          | 6.37    | 57.49   | 3.65| 6.34 |
| 3      | 182            | 112            | 637          | 6.67    | 61.54   | 3.50| 5.69 |
| 4      | 168            | 71             | 493          | 5.16    | 42.26   | 2.93| 6.94 |
| 5      | 184            | 116            | 1176         | 12.31   | 63.04   | 6.39| 10.14|
| 6      | 150            | 84             | 1269         | 13.28   | 56.00   | 8.46| 15.11|
| 7      | 152            | 44             | 372          | 3.89    | 28.95   | 2.45| 8.45 |
| 8      | 151            | 72             | 541          | 5.66    | 47.68   | 3.58| 7.51 |
| 9      | 141            | 82             | 481          | 5.03    | 58.16   | 3.41| 5.87 |
| 10     | 190            | 95             | 619          | 6.48    | 50.00   | 3.26| 6.52 |
| 11     | 197            | 137            | 1004         | 10.51   | 69.54   | 5.10| 7.33 |
| 12     | 189            | 135            | 990          | 10.36   | 71.43   | 5.24| 7.33 |
| Total  | 2053           | 1171           | 9557         | 14.29   | 69.78   | 7.51| 10.76|

Table 6. Monthly fluctuations of constituent ratios and infestations of the gamasid mite *Laelaps echidninus* on the rat host *Rattus andamanensis* at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Months | Examined Hosts | Infested Hosts | No. of Mites | C_r (%) | P_M (%) | MA  | MI  |
|--------|----------------|----------------|--------------|---------|---------|-----|-----|
| 1      | 182            | 95             | 517          | 18.48   | 52.20   | 2.84| 5.44|
| 2      | 167            | 83             | 449          | 16.05   | 49.70   | 2.69| 5.41|
| 3      | 182            | 106            | 392          | 14.02   | 58.24   | 2.15| 3.70|
| 4      | 168            | 28             | 67           | 2.40    | 16.67   | 0.40| 2.39|
| 5      | 184            | 30             | 86           | 3.07    | 16.30   | 0.47| 2.87|
| 6      | 150            | 30             | 141          | 5.04    | 20.00   | 0.94| 4.70|
| 7      | 152            | 30             | 95           | 3.40    | 19.74   | 0.63| 3.17|
| 8      | 151            | 42             | 104          | 3.72    | 27.81   | 0.69| 2.48|
| 9      | 141            | 51             | 143          | 5.11    | 36.17   | 1.01| 2.80|
| 10     | 190            | 27             | 52           | 1.86    | 14.21   | 0.27| 1.93|
| 11     | 197            | 61             | 181          | 6.47    | 30.96   | 0.92| 2.97|
| 12     | 189            | 96             | 570          | 20.38   | 50.79   | 3.02| 5.94|
| Total  | 2053           | 679            | 2797         | 100.00  | 33.07   | 1.36| 4.12|

*Laelaps nuttalli* occurred on the body surface of *R. andamanensis* throughout the year and its constituent ratio (*C_r*) and mean abundance (*MA*) showed prominent peaks in winter season (December and January) and summer season (June) (Table 5, Figures 5 and 6). *Laelaps echidninus* also occurred on *R. andamanensis* throughout the year and its *C_r* and *MA* showed prominent peaks in winter season (December and January) (Table 6, Figures 7 and 8).
Figure 5. Monthly and seasonal fluctuations of constituent ratio ($C_r$), prevalence ($P_M$) of the gamasid mite *Laelaps nuttalli* on the rat host *Rattus andamanensis* at Jingha, southern Yunnan of China (April 2016–March 2017).

Figure 6. Monthly fluctuations of mean abundance ($MA$) and mean intensity ($MI$) of the gamasid mite *Laelaps nuttalli* on the rat host *Rattus andamanensis* at Jingha, southern Yunnan of China (April 2016–March 2017).
Figure 7. Monthly and seasonal fluctuations of constituent ratio ($C_r$), prevalence ($P_M$) of the gamasid mite *Laelaps echidninus* on the rat host *Rattus andamanensis* at Jingha, southern Yunnan of China (April 2016–March 2017).

Figure 8. Monthly fluctuations of mean abundance ($MA$) and mean intensity ($MI$) of the gamasid mite *Laelaps echidninus* on the rat host *Rattus andamanensis* at Jingha, southern Yunnan of China (April 2016–March 2017).

3.4. Relationship between the Seasonal Fluctuation of Dominant Gamasid Mites and the Fluctuation of Climatic Factors

According to the meteorological data at the investigation site from April 2016 to March 2017, a correlation analysis was made between monthly climatic factors (temperature, rainfall and humidity) and monthly infestation indices ($C_r$, $P_M$, $MA$ and $MI$) of gamasid mites on the rat host *R. andamanensis* using R statistical software (R version 3.5.3) [17]. The results showed that the rainfall was negatively correlated with the constituent ratio ($C_r$) and prevalence ($P_M$) of *L. echidninus* ($r = −0.5874$ for $C_r$ and $r = −0.6224$ for $P_M$, $p < 0.05$). The average temperature was negatively correlated with the prevalence ($P_M$) of *L. nuttalli* ($r = −0.6922$, $p < 0.05$). The temperature was negatively correlated with the constituent ratio ($C_r$), prevalence ($P_M$) and mean abundance ($MA$) of *L. echidninus* ($p < 0.05$). The correlation
coefficient between the humidity and infestations of two dominant mite species, however, was of no statistical significance (Table 7).

Table 7. Pearson correlation between two dominant species of gamasid mites and climatic factors (total rainfall, average temperature and average humidity) at Jingha village in southern Yunnan of China (April 2016–March 2017).

| Species of Gamasid Mites | Infestation Indices | Pearson Correlation, $r$ ($p$) | Average Temperature ($^\circ$C) | Average Humidity (%) |
|--------------------------|---------------------|---------------------------------|---------------------------------|----------------------|
| L. nuttalli               | $C_r$               | 0.0946 (0.77)                  | −0.2698 (0.3963)               | 0.1023 (0.7517)      |
|                          | $PM$                | −0.5441 (0.0674)               | −0.6922 (0.0126) *             | −0.0211 (0.948)      |
|                          | $MA$                | 0.035 (0.9212)                 | −0.3627 (0.2466)               | 0.1761 (0.5841)      |
|                          | $MI$                | 0.3706 (0.2367)                | 0.1761 (0.5841)                | 0.2747 (0.3876)      |
| L. echidninus            | $Cr$                | −0.5874 (0.0488) *             | −0.6373 (0.0258) *             | −0.1408 (0.6624)     |
|                          | $PM$                | −0.6224 (0.0348) *             | −0.6444 (0.0237) *             | −0.1408 (0.6624)     |
|                          | $MA$                | −0.5734 (0.0555)               | −0.6549 (0.0208) *             | −0.0845 (0.794)      |
|                          | $MI$                | −0.3279 (0.2981)               | −0.3591 (0.2516)               | −0.2113 (0.5098)     |

Annotation: The figures in the Table represent the coefficients of Pearson’s correlation ($r$), and the figures in the brackets stand for the probability of significance ($p$). The “*” represents statistically significant (double tail, $\alpha = 0.05$).

4. Discussion

Rattus andamanensis was first named by Blyth in 1860, which was originally named Mus (Leggada) andamanensis Blyth (1860), and it was once described as a subspecies of Rattus rattus in some later literature [31]. Ellerman even thought that R. andamanensis was a synonym of Rattus rattus brunneusculus [32]. In some later literature, however, R. r. brunneusculus was described as an independent species, R. brunneusculus (the southeast Asian house rat) which was thought to be different from R. andamanensis [33]. Nowadays, much evidence supports that R. andamanensis is an independent species of rodent with a few confused synonyms such as Mus buralus, Mus flebilis, Epimys rattus klunensis, Epimys rattus kraensis, Rattus rattus koratensis, Rattus rattus hainanicus, Rattus confucians yaoshanensis, Rattus rattus holchu, Rattus remotus, Rattus rattus brunneusculus and Rattus sikkimensis [13,14,19,32,34–39]. In some literature published by Chinese scholars, however, R. andamanensis was often confused with Rattus rattus sladeni, Rattus sladeni, Rattus brunneusculus and Rattus brunneusculus sladeni [18,21,27,33,40–43].

Previously, Lv et al. reported the infestation and seasonal fluctuation of chigger mites at Jingha village of southern Yunnan, the same localized area with the present paper. Influenced by the above-mentioned confusion, the Indochinese forest rats (R. andamanensis) were incorrectly identified as the southeast Asian house rats (R. brunneusculus) in this report [44]. After Lv et al.’s publication, we reexamined the rat specimens repeatedly and found that they are actually Indochinese forest rats (R. andamanensis), and the southeast Asian house rat (R. brunneusculus) was misused in the above-mentioned paper [44]. Therefore, here we use the correct name (R. andamanensis) instead of the previously misused identification.

The results of the present study showed that the captured R. andamanensis rats accounted for 84.69% (2053/2424) of all the 15 species of animal hosts at the investigation site (Jingha village in southern Yunnan of China), which were the most dominant host species at the village. The abundant R. andamanensis rats may be associated with the special habitat of the investigation site. As a typical wild rodent species, R. andamanensis often lives in various wild habitats such as forests, bush areas, and farmlands [14,19]. The investigation site, Jingha village, is a rubber planting area with lots of rubber woodlands dotted with some banana fields, farmlands, bush areas and broad-leaved forests, and this kind of wild habitat seems to be suitable for the survival and reproduction of R. andamanensis.

Similar to other species of rodents, R. andamanensis is an important host for some ectoparasites such as chigger mites, gamasid mites, fleas and sucking lice [31]. The identified 41 species of gamasid mites from such a single rodent species (R. andamanensis) at such a confined local area (Jingha village) even exceed the total number of gamasid mite species
reported in other provinces or local regions of China. According to previous reports, 8
gamasid mite species were reported in Taiwan, 11 species in Dezhou of Shandong province,
13 species in Sandu’ao Island of Fujian province and 13 species in the northeastern border of
China (four cities together) [45–48]. The number of Gamasida species in the present study
also exceeds the number of gamasid mite species in some reports from other countries.
For example, 8 species were recorded in Kuala Lumpur and the states of Selangor and
Negeri Sembilan, and 10 species at Ulu Muda Forest Reserve, in Kedah of Malaysia [49,50].
The abundant species of gamasid mites on R. andamanensis at Jingha village reflect a high
species richness and species diversity of the mites on a single rodent species at a localized
area. The result suggests that R. andamanensis in southern Yunnan of China has a high
potential to harbor lots of gamasid mite species.

As two dominant species of gamasid mites found on the studied rat host, L. nuttalli
\( (C_r = 70.63\%) \) and L. echidninus \( (C_r = 20.67\%) \) had a relatively high prevalence \( (P_M) \), mean
abundance \( (MA) \) and mean intensity \( (MI) \) (Table 4). Laelaps nuttalli and L. echidninus are
two common species of gamasid mites found on the body surface of many animal hosts
and the hosts’ nests with low host specificity. Some previous studies showed that L. nuttalli
and L. echidninus often occurred on the body surface of some rat species in the genus
Rattus simultaneously and they were often the dominant species of gamasid mites [51–53].
The result of the present study is consistent with the previous studies, and it implies that
L. nuttalli and L. echidninus may have some preference to Rattus rats [51–53]. As the world-
distributed species of gamasid mites, L. nuttalli and L. echidninus are widely distributed in
Asia, Europe, America, Africa, Australia, and other parts of the world [1,46,47,49–51,54–60],
and they often co-exist on the same species of hosts in the same geographical regions [61–68].
From north to south, L. nuttalli and L. echidninus have been recorded in many parts of
China such as Heilongjiang, Jilin, Jiangsu, Hunan, Hubei, Guangdong, Guangxi, Fujian,
Hainan, Sichuan, Chongqing, Guizhou, Yunnan, Taiwan, and Hong Kong, etc. To date,
L. nuttalli and L. echidninus have been found on the body surface of more than 30 host
species which involves rodents, insectivores, pikas and tree shrews, and some rat species
of the genus Rattus, e.g., R. tanezumi Temminck, 1844, R. norvegicus Berkenhout, 1769,
R. nitidus Hodgson, 1845, R. losea Swinhoe, 1871 and R. andamanensis, are the most common
hosts [2,6,8,69,70]. Laelaps nuttalli and L. echidninus can invade human beings to cause skin
irritation and dermatitis [71]. Moreover, L. echidninus is suspected of being associated with
some zoonoses such as Q fever, rickettsialpox and pseudotuberculosis, etc., for the related
pathogens were once isolated from it [72]. The frequent occurrence of L. echidninus with
a high constituent ratio on some Rattus rats including R. andamanensis may have some
potential significance of preserving or transmitting the causative agents of some zoonotic
diseases.

The present paper described the seasonal fluctuations of L. nuttalli and L. echidninus on
R. andamanensis for the first time. The two principal mite group showed different patterns
of seasonal fluctuations. Laelaps nuttalli mites occurred throughout the year, and
its constituent ratio \( (C_r) \) and mean abundance \( (MA) \) showed two prominent peaks in winter
season (December and January) and summer season (June), which belongs to the summer-
winter type of seasonal fluctuation (Figures 5 and 6). Laelaps echidninus mites also occurred
throughout the year, but its \( C_r \) and \( MA \) showed only one peak in winter season (December
and January), which belongs to the winter type of seasonal fluctuation (Figures 7 and 8).
The seasonal fluctuations of L. nuttalli and L. echidninus on R. andamanensis in southern
Yunnan of China seem to be different from those of the same mite species on some other
rat hosts and in some other geographical regions. In the border areas of northeast China,
the seasonal fluctuations of L. nuttalli on R. norvegicus rats showed two peaks in May and
October [46]. In Taiwan, the highest seasonal peak of L. nuttalli and L. echidninus on R. lossa
rats was in autumn [48]. In Argentina, L. echidninus had the highest infestation frequency
on R. norvegicus in spring [58]. The above results suggest that the seasonal fluctuations
of L. nuttalli and L. echidninus may vary with different species of hosts and different
geographical regions. At present, it is difficult to explain why \( L. \) nuttalli and \( L. \) echidinus showed different seasonal fluctuation patterns, and further studies are needed.

The previous reports demonstrated that temperature and rainfall are two key factors which influence the seasonal fluctuation of chigger mites [44]. In the present study, a negative correlation existed between two climatic factors (temperature and rainfall) and the infestations (\( C_r \), \( P_M \) and \( MA \)) of two dominant mite species (\( L. \) nuttalli and \( L. \) echidinus) on \( R. \) andamanensis rats (\( p < 0.05 \)), which suggests that temperature and rainfall are two key factors that influence the seasonal fluctuations of the gamasid mites, \( L. \) nuttalli and \( L. \) echidinus. However, we cannot speculate how the temperature and rainfall influence the seasonal fluctuations of \( L. \) nuttalli and \( L. \) echidinus and their dynamic variations, and more studies are still needed in the future.

5. Conclusions

The Indochinese forest rat (\( R. \) andamanensis) in southern Yunnan of China has a high potential to harbor a lot of gamasid mite species. \( Laelaps \) nuttalli and \( L. \) echidinus are the dominant species of Gamasida on \( R. \) andamanensis and they have different patterns of seasonal fluctuations. The seasonal fluctuation of \( L. \) nuttalli belongs to the summer-winter type, and that of \( L. \) echidinus belongs to the winter type. Temperature and rainfall (precipitation) are two key factors which influence the seasonal fluctuation of gamasid mites.

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