Original Article

Species Abundance Distribution of Ectoparasites on Norway rats (*Rattus norvegicus*) from a Localized Area in Southwest China

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Abstract

Background: The species of ectoparasites that live on a specific host in a geographical region form an ectoparasite community. Species abundance distributions describe the number of individuals observed for each different species that is encountered within a community. Based on properties of the species abundance distribution, the expected total number of species present in the community can be estimated.

Methods: Preston's lognormal distribution model was used to fit the expected species abundance distribution curve. Using the expected species abundance distribution curve, we estimated the total number of expected parasite species present and the amount of species that were likely missed by our sampling in the field.

Results: In total, 8040 ectoparasites (fleas, sucking lice, gamasid mites and chigger mites) were collected from 431 Norway rats (*Rattus norvegicus*) from a localized area in southwest China. These ectoparasites were identified to be 47 species from 26 genera in 10 families. The majority of ectoparasite species were chigger mites (family Trombiculidae) while the majority of individuals were sucking lice in the family Polyplacidae. The expected species abundance distribution curve demonstrated the classic pattern that the majority of ectoparasite species were rare and that there were a few common species. The total expected number of ectoparasite species on *R. norvegicus* was estimated to be 85 species, and 38 species were likely missed by our sampling in the field.

Conclusions: Norway rats harbor a large suite of ectoparasites. Future field investigations should sample large numbers of host individuals to assess ectoparasite populations.

Keywords: Ectoparasite, Species abundance distribution, Expected species estimation, Norway rat, *Rattus norvegicus*

Introduction

The Norway rat (also called the brown rat), *Rattus norvegicus* (Berkenhout 1976), is a dominant rodent species in residential areas and farmlands in many places throughout the world. In addition to destroying crops, the Norway rat is also an important reservoir host of many zoonoses (Yu and Xu 1988, Huang et al. 1995). Norway rats harbor a suite of ectoparasites including fleas and sucking lice as well as chigger and gamasid mites that act as important vectors for zoonoses and vector-borne diseases. Specifically, fleas are known to be vectors of the plague, murine typhus (endemic typhus), and fleaborne spotted fever. Sucking lice (for example the human louse, *Pediculus humanus*) are vectors of epidemic typhus, epidemic relapsing fever, and trench fever. Gamasid mites may play a potential role in transmitting hemorrhagic fever with renal syndrome (HFRS, also called epidemic hemorrhagic fever, EHF) and chigger mites are the vectors of scrub typhus, or tsutsugamushi disease (Deng et al. 1993, Li et al. 1997, Jin 1999, Song 1999, Brouqui and Raoult 2006, Wang and Ye 2006, Wu 2007, Bitama et al. 2010).

The species of ectoparasites that live on a specific host in a geographical region form

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an ectoparasite community. Species abundance distributions describe how the abundance of a species changes over space. By using the species abundance distributions of ectoparasites sampled in the field, the expected number of species in a community can be estimated (Guo 1999). It is often necessary to use this estimation procedure because it is impossible to collect all species that are present at all sites within a geographical region (Guo 1999).

The species abundance distributions of ectoparasitic gamasid and chigger mites living on small mammals including rodents have been quantified over a large geographical region in Yunnan Province of China (Guo 1999, Guo et al. 2006).

This paper examines the species abundance distributions of ectoparasites (fleas, sucking lice, gamasid mites and chigger mites) on Norway rats (*R. norvegicus*) in the area surrounding Erhai Lake, in Dali Prefecture of Yunnan Province, southwest China. In addition to quantifying the species abundance distribution of these ectoparasites, the present study also aims to estimate how many ectoparasite species Norway rats (a single rodent species) harbor in this small area (only about 450 km^2).

Materials and Methods

Collection and identification of Norway rats and ectoparasites

The study site included the area surrounding Erhai Lake of Dali (100005′E-100017′E, 25036′N-25058′N). The total study area covered approximately 450 km^2 at an altitude of approximately 1976 m. Norway rats were captured using mouse traps (Guixi Mousetrap Apparatus Factory, Guixi, Jiangxi, China) at three sampling sites (Xiaguan, Wase and Xizhou) in 2003 and 2004. Mouse traps were set in residential areas (houses, barns, stables, etc.) and farmlands (paddy fields, corn fields and other crop lands) in the evening and then checked the following morning. Trapped rats were placed in cloth bags and brought to the laboratory. All the rats were identified according to their morphological features (Huang et al. 1995, Kia et al. 2009, Huang et al. 2013). At the laboratory, ectoparasites were collected and preserved in vials containing 70% ethanol (Kia et al. 2009, Zuo and Guo 2011, Zuo et al. 2011, Huang et al. 2013, Zhan et al. 2013). Chigger mites were mainly collected from the auricles and external auditory canals of the host ears using a curette and a lancet (Li et al. 1997, Guo et al. 2006). All the ectoparasites were dehydrated, made them transparent, mounted on glass slides, and identified to species under microscopes (Deng et al. 1993, Li et al. 1997, Jin 1999, Wu 2007, Kia et al. 2009, Huang et al. 2013). Voucher ectoparasite species, together with specimens of rats are deposited in the specimen repository at the Institute of Pathogens and Vectors, Dali University.

Basic statistical analysis

We calculated the constituent ratios (Cr), as well as the prevalence (P), mean abundance (MA) and mean intensity (MI) of each ectoparasite species (Ritzi and Whitaker 2003, Storm and Ritzi 2008, Huang et al. 2013, Zhan et al. 2013).

Description of species abundance distribution

Species abundance distributions describe the number of individuals observed for each different species that is encountered within a community. We examined the species abundance distribution using the methodology provided in Preston 1948. In a semi-logarithmic rectangular coordinate system, the X-axis indicating the ectoparasite individuals was marked with log intervals based on $\log_3 M$ (Table 4 in "Results") and the Y-axis was an arithmetic scale, indicating the ectoparasite species. Preston’s lognormal distribution model was used to fit the expected species abundance distribution curve (Preston 1948, Greig-Smith 1983, Baltanas 1992, Guo 1999, Guo et al. 2006) using the following equation. $\hat{S}(R) = S_0 e^{-[a(R-R_0)]^2}$

Where $\hat{S}(R)$ is the expected number of species within the R-th log interval, R_0 is the modal log interval (the log interval with the most species), S_0 is the number of species within the R_0 log interval (the modal log interval). The value of α (spread constant) was determined by calculating the coefficient of determination (R^2) using the following formula (Ni 1990, Guo et al. 2006).

$$R^2 = 1 - \frac{\sum_{R=0}^{m}[S(R) - \hat{S}(R)]^2}{\sum_{R=0}^{m}[S(R) - \bar{S}(R)]^2},$$

$$\bar{S}(R) = \frac{1}{m}\sum_{R=0}^{m} S(R)$$

Where S(R) is the observed number of ectoparasite species in R-th log interval, m is the number of log intervals, and $\hat{S}(R)$ and R are the same as presented above.

Total expected species estimation

Based on the species abundance distribution, the expected number of ectoparasite species (S_T) and the number of ectoparasite species likely missed in the field sampling (S_M) were approximated following Preston (1948) (see also Greig-Smith 1983, Baltanas 1992, Guo 1999) using the following formulas.

$S_T = (S_0\sqrt{\text{®}})/a$, $S_M = S_T - S_A$

S_A represents the observed number of ectoparasite species collected in the field.

Results

Ectoparasites present on Norway rats

In total, 8040 ectoparasites (fleas, sucking lice, gamasid mites and chigger mites) were collected from 431 Norway rats in a localized area (the area surrounding Erhai Lake of Dali), Yunnan Province, southwest China. The collected ectoparasites were identified as comprising 47 different species from 26 genera in 10 families. Of these ectoparasites, 857 fleas were identified to be 6 species from 6 genera in 3 families, 4307 sucking lice were identified to be 2 species from 2 genera in 2 families, 2531 gamasid mites were identified to be 16 species from 10 genera in 4 families, and 345 chigger mites were identified to be 23 species from 8 genera in 1 family (Table 1). In total, 71.2 % of the rats were infested by ectoparasites with a mean abundance of 18.7 parasites/per examined host and a mean intensity of 26.2 parasites/per infested host. Of the 4 ectoparasite taxa (fleas, sucking lice, chigger mites and gamasid mites), the majority of ectoparasite species were chigger mites, which accounted for 48.9 % of the ectoparasite species diversity. The majority of ectoparasite individuals, however, were sucking lice, which accounted for 53.6 % of the total number of parasite individuals (Table 2). Overall, we collected a suite of potential zoonoses vectors, including 5 species of fleas that are potential vectors of the plague and murine typhus, 6 species of gamasid mites that are potential vectors of HFRS, and 5 species of chigger mites that are potential vectors of scrub typhus (Table 1).

Species abundance distribution of ectoparasites

From Norway rats (a single rodent species) in the area surrounding Erhai Lake of Dali, the collected individuals of ectoparasites were greatly different among 47 different species of the parasites. Most ectoparasite species were rare with few individuals collected and only a few parasite species were really common with abundant individuals on the rat. Table 3 showed the relationship between the individuals and species of

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ectoparasites on Norway rats (*R. norvegicus*).

The species abundance distribution of ectoparasites on Norway rats was fitted by Preston's lognormal distribution model (R^2= 0.80). The expected curve (theoretical curve) of the species abundance distribution showed a gradually descending tendency from the rare parasite species to the dominant parasite species. The expected curve of the species abundance distribution indicated that the majority of the parasite species were rare and that fewer species were abundant (Table 4, Fig. 1). The equation of the expected curve equation (theoretical curve equation) was $\hat{S}(R) = 13e^{-(0.27R)^2}$ (S_0 = 13, R_0 = 0, α = 0.27).

Total expected species estimation of ectoparasites

Based on $S_T = (S_0\sqrt{®})/a$ and $S_M = S_T - S_A$ (Preston's method), the total expected species of ectoparasites on *R. norvegicus* was estimated to be 85 species. This calculation suggests that 38 species of ectoparasites were missed by our sampling.

Table 1. Collection details of ectoparasite species, grouped by families, collected from Norway rats (*Rattus norvegicus*) in the area surrounding Erhai Lake of Dali, Yunnan Province, southwest China

Taxonomic taxa of ectoparasites	Collected species and individuals
1. Fleas	
Pulicidae	*Xenopsylla cheopis** (90)
Leptopsyllidae	*Leptopsylla segnis** (182), *Frontopsylla spadix** (190), *Paradoxopsyllus custodis** (359)
Ceratophyllidae	*Monopsyllus anisus** (35), *Macrostylophora euteles* (1)
2. Sucking lice	
Hoplopleuridae	*Hoplopleura pacifica* (118)
Polyplacidae	*Polyplax spinulosa* (4,189)
3. Gamasid mites	
Laelapidae	*Laelaps echidninus** (380), *L. nuttalli* (823), *L. xingyiensis* (4), *L. guizhouensis* (3), *L. algericus* (1), *L. chini* (1), *L. turkestanicus** (1), *Haemolaelaps (Androlaelaps) casalis** (1), *Androlaelaps singularis* (6), *Hypoaspis pavlovskii* (4), *Haemogamasus pontiger** (5), *Eulaelaps stabularis* (1), *Echinonyssus (Hirstionyssus) sunci** (61)
Macronyssidae	*Ornithonyssus bacoti** (1226)
Aceocejidae	*Proctolaelaps pygmaeus* (13)
Parasitidae	Parasitidae sp. (unidentified genus and species) (1)
4. Chigger mites	
Trombiculidae	*Leptotrombidium rusticum* (3), *L. shuqui* (21), *L. bambicola* (1), *L. shanghaense* (1), *L. insulare** (6), *L. scutellare** (5), *L. jinmai* (3), *L. sinicum* (12), *L. yui**(10), *L. kitasatoi* (1), *L. bengbuense* (48), *L. taishanicum* (2), *L. akamushi** (36), *Leptotrombidium* sp.(25), *Ascoschoengastia indica** (2), *A. rattinorvegici* (127), *A. Leechi* (1), *Helenicula simena* (24), *Walchia Koi* (5), *Herpetacarus hastoclavus* (7); *Trombiculindus yunnanus* (1), *Gahrliepia madun* (3), *Cheladonta micheneri* (1)

Annotation: (1) The species marked "*" are potential vectors of the plague, murine typhus (endemic typhus), hemorrhagic fever with renal syndrome (HFRS; also called epidemic hemorrhagic fever, EHF in China) and scrub typhus (tsutsugamushi disease). (2) The numbers given in brackets reflect the number of individuals collected for each ectoparasite species.

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Table 2. The constituent ratios (Cr), prevalence (P), mean abundance (MA) and mean intensity (MI) of the 4 taxa of ectoparasites on Norway rats (*Rattus norvegicus*) in the area surrounding Erhai Lake of Dali, Yunnan Province, southwest China

Ectoparasite taxa	Species and constituent ratios (Cr)		Parasite individuals and constituent ratios (Cr)		Infestation prevalence (P)		Mean abundance (MA)	Mean intensity (MI)
	Species	Cr (%)	Individuals	Cr (%)	Infested rats	*P* (%)	MA	MI
Fleas	6	12.8	857	10.7	143	33.2	1.9	5.9
Sucking lice	2	4.3	4307	53.6	127	29.5	9.9	33.9
Gamasid mites	16	34.0	2531	31.5	190	44.1	5.9	13.3
Chigger mites	23	48.9	345	4.3	32	7.4	0.8	10.8
All insects (fleas and sucking lice)	8	17.0	5164	64.2	221	51.3	11.9	23.4
All mites (chigger and gamasid mites)	39	82.9	2879	35.8	207	48.0	6.7	13.9
Total ectoparasites	47	100.0	8040	100.0	307	71.2	18.7	26.2

Table 3. The relationship between the individuals and species of ectoparasites on Norway rats (*Rattus norvegicus*) in the area surrounding Erhai Lake of Dali, Yunnan Province, southwest China

Number of individuals	Number of ectoparasite species	Number of individuals	Number of ectoparasite species	Number of individuals	Number of ectoparasite species	Number of individuals	Number of ectoparasite species
1	13	**10**	1	**36**	1	**190**	1
2	2	**12**	1	**48**	1	**359**	1
3	4	**13**	1	**61**	1	**380**	1
4	2	**21**	1	**90**	1	**823**	1
5	3	**24**	1	**118**	1	**1226**	1
6	2	**25**	1	**127**	1	**4189**	1
7	1	**35**	1	**182**	1		

Table 4. The statistical parameters for fitting the expected curve of species abundance distribution of ectoparasites on Norway rats (*Rattus norvegicus*) in the area surrounding Erhai Lake of Dali, Yunnan Province, southwest China

Log intervals (R)	Individual ranges in each log interval (I)	Midpoint values of each individual range (M)	Observed parasite species	Expected parasite species
0	1	1	13	13.00
1	2–4	3	8	12.09
2	5–13	9	9	9.71
3	14–40	27	5	6.75
4	41–121	81	4	4.05
5	122–364	243	4	2.10
6	365–1093	729	2	0.94
7	1094–3280	2187	1	0.37
8	3281–9841	6561	1	0.12

Annotation: M is the midpoint of I, $3^R = M$, $\log_3 M = R$. $\alpha = 0.27$, $R^2 = 0.80$.

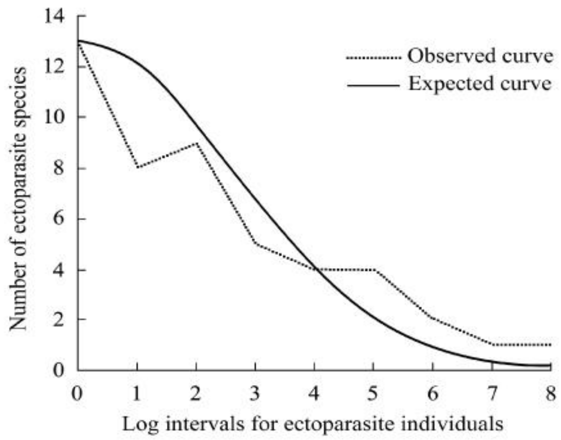

Fig. 1. The species abundance distribution of ectoparasites on Norway rats (*Rattus norvegicus*) fitted by Preston's lognormal distribution model with the expected curve equation of $\hat{S}(R) = 13e^{-(0.27R)^2}$ (S_0 = 13, R_0 = 0, α = 0.27, R^2 = 0.80

Discussion

Infestation of ectoparasites on Norway rats

Ectoparasites are parasites that live on the skin or body surface of their hosts, and include a variety of taxonomic taxa, including fleas, sucking lice, chewing lice, batflies, ticks, chigger mites, gamasid mites, itch mites (mange mites, scabies mites), demodex mites (vermiform mites, follicle mites), feather mites, fur mites (cheyletiellid mites) and even some occasional arthropods that are parasitic on skin (e.g. some maggots) (Wilson and Durden 2003, Changbunjong et al. 2010, Zhan et al. 2013). This paper examined 4 taxa (fleas, sucking lice, gamasid mites and chigger mites), which are the majority of ectoparasites on rodents and other small mammals (Pan and Deng 1980, Deng et al. 1993, Li et al. 1997, Jin 1999, Wu 2007, Zuo and Guo 2011, Zuo et al. 2011, Huang et al. 2013, Zhan et al. 2013).

In the present study, the sample size of 431 host animals of a single species in a localized area was larger than some previous studies which have included multiple species sampled over much wider geographical range (Bengston et al. 1986, Oguge et al. 2009, Paramasvaran et al. 2009, Changbunjong et al. 2010). From this large host sample we collected 47 species of ectoparasites. This number also exceeded the numbers observed in some previous studies using smaller sample sizes (Luyon and Salibay 2007, Kia et al. 2009, Oguge et al. 2009, Paramasvaran et al. 2009, Changbunjong et al. 2010). For example, from 14 species and 204 individuals of rodents and shrews in Malaysia, 20 species of ectoparasites were collected and included 5 taxa (Paramasvaran et al. 2009). Another survey documented 6 species of ectoparasites present on 56 individuals of 4 species of rodents in Philippines (Luyon and Salibay 2007). The present study showed that Norway rats had high and diverse infestations of ectoparasites. The large host sample (431 rats) increased the probability of detecting additional uncommon ectoparasite species. Therefore, a large host sample is strongly recommended in future field investigations. In addition, the larvae of chigger mites are often present on the auricles and external auditory canals of the host ears (Li et al. 1997, Guo et al. 2006), and they are too small to be seen by the naked eye. In our collection, both ears of each rat were carefully inspected and this allowed us to find many chigger mite species (23 species). These may have been overlooked in some previous investigations.

Of the 4 taxa of ectoparasites we found on the Norway rat, the majority of species were chigger mites, while the majority of individuals were sucking lice (Table 2). Many species of chigger mites infesting such a single host species (*R. norvegicus*) imply that the Norway rat seems to have a great potential to harbor many chigger species. In contrast, only two species of sucking lice with numerous individuals in the sample were collected from the rat and this reveals that the Norway rat may be a suitable host for these sucking lice.

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Some transmitting vectors (or potential transmitting vectors) of zoonoses were found from the Norway rat (Table 1). Of these vectors, the flea *Xenopsylla cheopis* is a important transmitting vector of the plague and murine typhus in Yunnan of China (Wu 2007, Zuo and Guo 2011), and it increases the transmission risk of the zoonoses between rodents and human beings.

Species abundance distribution and total expected species estimation

The Preston's lognormal distribution model is an established method to fit the species abundance distribution, which aims to illustrate the relationship between species and individuals in a given community (Preston 1948, Greig-Smith 1983, Baltanas 1992, Guo 1999). The expected curve (theoretical curve) of species abundance distribution for the ectoparasites on *R. norvegicus* showed a gradually descending tendency, and this revealed that most parasite species were rare with very few individuals in the sample, but few dominant species were abundant with numerous individuals in the sample. Based on the expected curve, the total expected number of ectoparasite species on the rats was estimated to be 85 species. Hence, about 38 parasite species might have been missed in our investigation.

In ecology, it is important to estimate the expected total species in a given community because some species are too rare to be found in a limited sample (Guo 1999). Besides Preston's method $S_T = (S_0\sqrt{\text{®}})/a$, some other methods (e.g. Chao1 method) can also be used to estimate the total expected species number (Chao 1984, Bunge et al. 1993, Cowell 2009). As a simple nonparametric estimator, Chao1 formula is described as $S_T = S_A + \left(A^2/2B\right)$, where S_T = the estimate of the total number of species, S_A= the observed number of species, A = the number of rare species with one individual in the sample and B = the number of rare species with two individuals in the sample. When Chao1 method was used in the present study, the total expected parasite species (S_T) was estimated to be 89 species (S_A= 47, A= 13 and B= 2 in Table 3) and the number of species missed was about 42 species, which was more than the number of species estimated by the Preston's method (38 species).

Conclusion

This result indicates that at least 38 species of ectoparasites might have been missed in our investigation. Although we captured 431 rats, this number was sufficient to collect only about half the species of ectoparasites present. This further emphasizes the necessity of collecting large samples of host individuals to adequately assess their ectoparasite populations.

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