June 2019

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EAP Tropical Biology and Conservation Program, Spring 2019
7 June 2019

ABSTRACT

Bats are commonly affected by parasites known as bat flies in the families Nycteribiidae and Streblidae. It is important to understand bat flies and their effects on bat populations due to their ubiquity. Differences in roosting behaviors, led me to believe that female bats would carry more bat flies than males. I investigated the difference in bat fly abundance between the sexes in a variety of species in Monteverde included in the genera *Carollia* (n = 9), *Sturnira* (n = 5), *Lonchorhina* (n = 1), *Micronycteris* (n = 1), *Artibeus* (n = 6), *Glossophaga* (n = 1), *Desmodus* (n = 1), *Platyrrhinus* (n = 1), and *Myotis* (n = 19) for a total of 44 bats. In order to investigate the effect of the presence of bat flies on overall health, I chose to focus on two indicators of health. This included different body temperatures collected from the underarm, belly, membrane, and forearm along with the effect on the presence of holes and scars in the wing membrane as this is where the bat flies are commonly found. No significant difference in the average abundances of bat flies between sexes was found (males = 0.70 ± 1.06, females = 0.86 ± 1.49). My findings do not support the idea that females carry more bat flies compared to males. No significant correlation was found between having bat flies and holes or scars; as well as between the abundance of bat flies and body temperatures. I did not find evidence that the presence of bat flies has an effect on these health parameters.

Murciélagos machos y hembras tienen un número similar de moscas

RESUMEN

Los murciélagos comúnmente son afectados por parásitos conocidos como “moscas de murciélagos”, que son dípteros de las familias Nycteribiidae y Streblidae. Es importante entender a estas moscas y sus efectos en las poblaciones de murciélagos debido a su ubicuidad. Las diferencias de comportamiento de los murciélagos en cuanto a los sitios donde se resguardan, me hicieron pensar que murciélagos hembras podrían llevar más cantidad de moscas que los murciélagos machos. Yo investigué la diferencia en abundancia de las moscas de murciélagos entre ambos sexos en una variedad de especies que capturé en Monteverde, incluidos los géneros *Carollia* (n=9), *Sturnira* (n=5), *Lonchorhina* (n=1), *Micronycteris* (n=1), *Artibeus* (n=6), *Glossophaga* (n=1), *Desmodus* (n=1), *Platyrrhinus* (n=1), and *Myotis* (n=19) para un total de 44 individuos. Para investigar los efectos de la ocurrencia de las moscas en la salud general de los murciélagos, consideré dos indicadores de su salud. Incluyendo las temperaturas debajo de un brazo, de el abdomen, de la membrana del ala y del antebrazo, así como también la cantidad de huecos y de cicatrices en las alas, que es donde comúnmente se encuentran las moscas. No encontré diferencia significativa en la abundancia media de las moscas entre ambos sexos (machos $x = 0.70 \pm 1.06$, hembras $x = 0.86 \pm 1.49$). Mis hallazgos no apoyan la idea de que las hembras lleven más moscas en comparación con los machos. No hubo correlación entre la cantidad de moscas y la cantidad de huecos, tampoco con la cantidad de cicatrices, ni entre la abundancia de moscas y las temperaturas registradas. No encontré evidencia de que la presencia de las moscas en los murciélagos tuviera efecto en estos parámetros de salud.

Bats are the second most abundant order of mammals in the world, making up more than half of the amount of species of mammals found in Costa Rica. They stand out among other orders of mammals due to the high proportion of species that are social and exhibit very complex and variable social behaviors-- including their diet, their roosting behaviors and their occupancy of different niches (Kerth 2008). Bats serve as important hosts for many ectoparasites including several groups of flies, mites and ticks. (Wenzel et al. 1966). The most common ectoparasite in bats are the bat flies, which are blood-sucking pupiparous flies that are obligate parasites of bats. Bat flies are part of the order Diptera and the family Nycteribiidae; or the close relative family Streblidae; meaning that all bat flies cannot be categorized into one family (Wenzel et al. 1966). Patterson et al. (1998) reported that 153 species of Strebilidae are found in the Western. Hemisphere on different species of bats; whereas only 37 species of Nycteribiidae are found.

The very common social behaviors of bats provide an easy mechanism for bat flies to spread within a colony. “In most species, females form so-called maternity colonies to rear their young communally, whereas males are solitary, form groups of their own, or join female groups” (Kerth 2008). Female colonies have been studied with great detail. However, the formations of male colonies have not been studied very much possibly due to the lesser frequency of them; or the lack of knowledge as to why males would form colonies. It has been hypothesized that the formation of male colonies relates to information-transfer, which would not require as much time in physical contact with each other compared to the behaviors of female colonies (Levin et al. 2013). This difference between general lifestyles of male and female bats could potentially lead to a difference in abundance of bat flies between sexes.

Bat flies feed on blood and live at the expense of the host, meaning that the host’s general health may be at risk. Parasites can many times transmit infections and diseases which can indirectly affect a number of host functions due to trade-offs in the allocation of resources. This can often be seen by changes in immune responses such as increased antibody production and fevers (Devevey et al. 2008). This concept has not been deeply studied in bats so it would be interesting to see how these aspects of bat ecology connect. In this study, I addressed the question: Is the abundance of bat flies on bats correlated with the sex and overall health of the bat?

MATERIALS AND METHODS

To begin the study and capture bats we set mist nets during the period of May 7th to May 29th. These mist nets were first set in a location near the San Gerardo Field Station in the Children's Eternal Rainforest. The mist nets were opened at night following sunset. While the mist nets were opened, I moved away from the nets, coming back to check for bats in intervals of 15 minutes. If a bat was present, I removed the bat from the net with the help of Federico and placed it in a cloth bag. After removal of all of the bats from the net from that time interval, I measured the mass of each bag with the bat inside. Then, working with one bat at a time, I identified the sex of the bat and determined if there are any scars or holes in the membrane of the wing. I then inspected the bat's fur and wings looking for bat flies. I removed all of the bat flies that I found on each bat and stored them in small labeled vials for later identification. After the bat fly removal, I measured the forearm of the bat, as this is an important characteristic that is indicative of species. I then determined the species of the bat. Next, I measured the temperature of the bat's wing membrane, belly and forearm using an EXTECH Instruments IR Thermometer and the underarm temperature using a Microlife MT 19E1 Digital Flexible Tip Thermometer. I cut off a small section of hair on the bat's shoulder to use as an indicator of a previous capture. This process was repeated in two more locations near the Monteverde Institute in the Crandell Memorial Reserve and on Frank Joyce's property in Bajo del Tigre. The bat was then released, and the mass of the empty bag was recorded to determine the mass of the bat. This process was done for each bat captured during the 15-minute intervals.

Following the collection of data, analysis was conducted to determine the significance of trends and differences in my findings. T-tests were conducted to determine the significance of the difference in the average number of bat flies between male and female bats for all species and for *Myotis pilosatibialis*. In addition to this, chi-squared tests were used to determine the association between having bat flies and having holes and scars.

RESULTS

In this study, we captured 44 bats; including 21 females and 23 males. All of the captured bats were of the genera *Carollia* (n = 9), *Sturnira* (n = 5), *Lonchorhina* (n = 1), *Micronycteris* (n = 1), *Artibeus* (n = 6), *Glossophaga* (n = 1), *Desmodus* (n = 1), *Platyrrhinus* (n = 1), and *Myotis* (n = 19). Bat fly abundance was recorded for each of these 44 individuals. Bat flies were found on 17 individuals (9 males and 8 females) in the *Carollia*, *Sturnira*, *Artibeus*, *Glossophaga*, *Desmodus*, and *Myotis* genera.

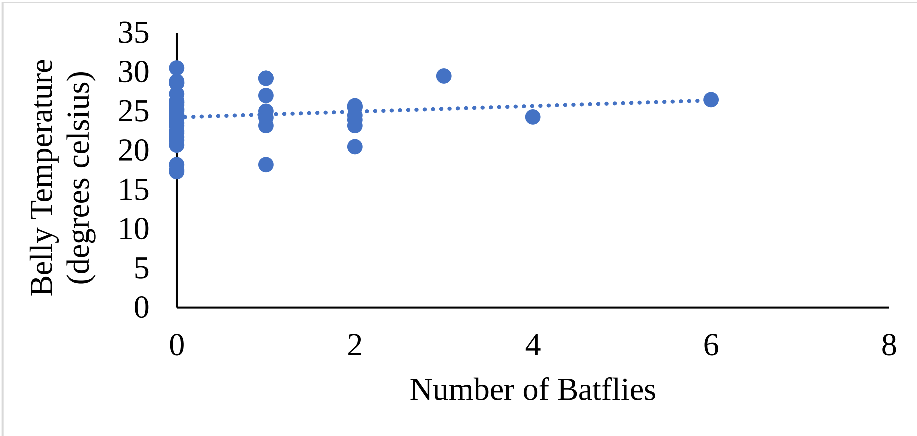

Figure 1. Belly temperatures for all bat captures with varying number of bat flies. These values were collected using a laser thermometer to find the surface temperature of the ventral side of the bat. There is not a significant correlation between the number of bat flies and belly temperatures ($R^2 = 0.0229$).

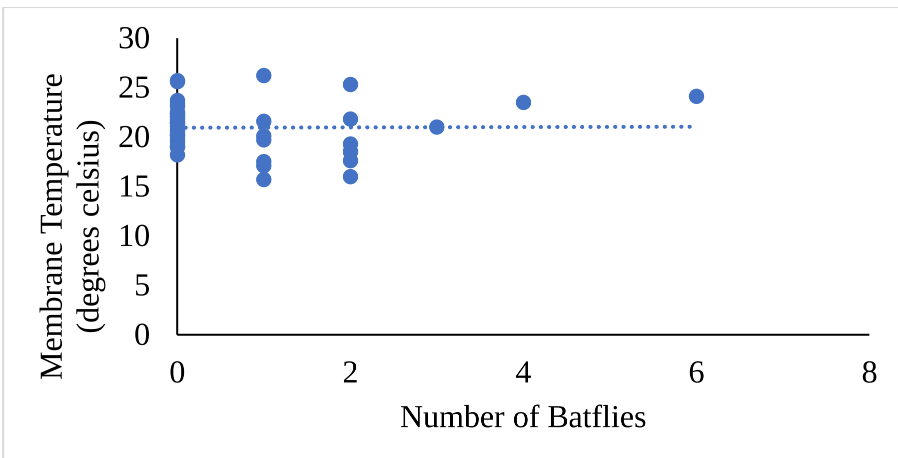

Figure 2. Wing membrane temperatures for all bat captures with varying number of bat flies. These values were collected using a laser thermometer to find the surface temperature of the wing membrane of the bats. There is not a significant correlation between the number of bat flies and wing membrane temperatures ($R^2 = 0.0006$).

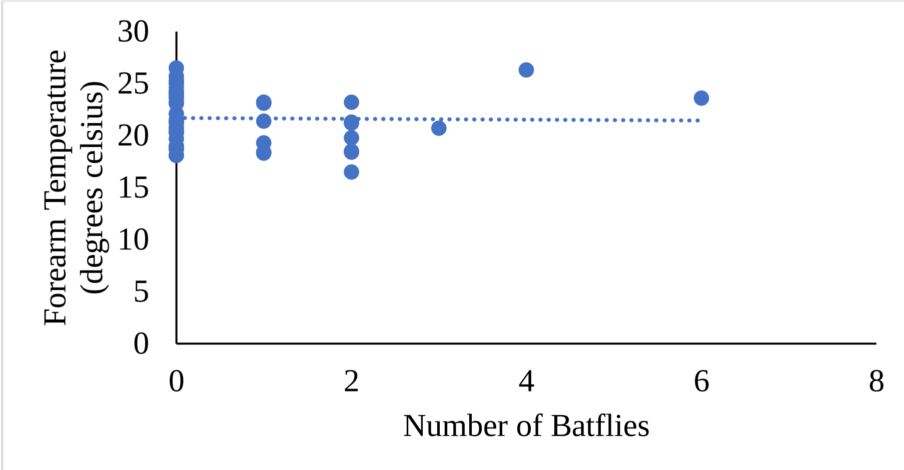

Figure 3. Forearm temperatures for all bat captures with varying number of bat flies. These values were collected using a laser thermometer to find the surface temperature of the forearm of the bats. There is not a significant correlation between the number of bat flies and forearm temperatures ($R^2 = 0.001$).

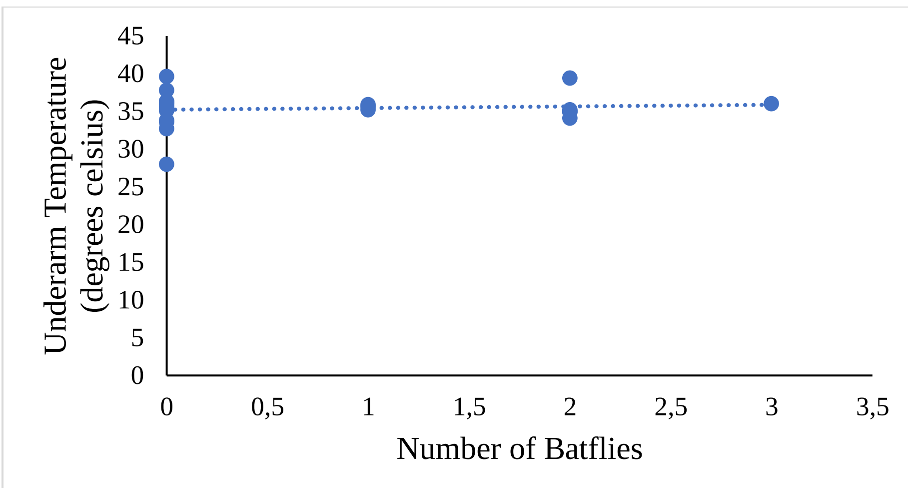

Figure 4. Underarm temperatures for all bat capture with varying number of bat flies. These values were collected using a digital thermometer to find the temperature of the underarm of the bats. There is not a significant correlation between the number of bat flies and underarm temperatures ($R^2 = 0.0646$).

For all of the types of temperatures taken of each of the bats including belly, membrane, forearm, and underarm, there is no correlation between the number of bat flies and temperature as seen by the R^2 values of each of the previous graphs.

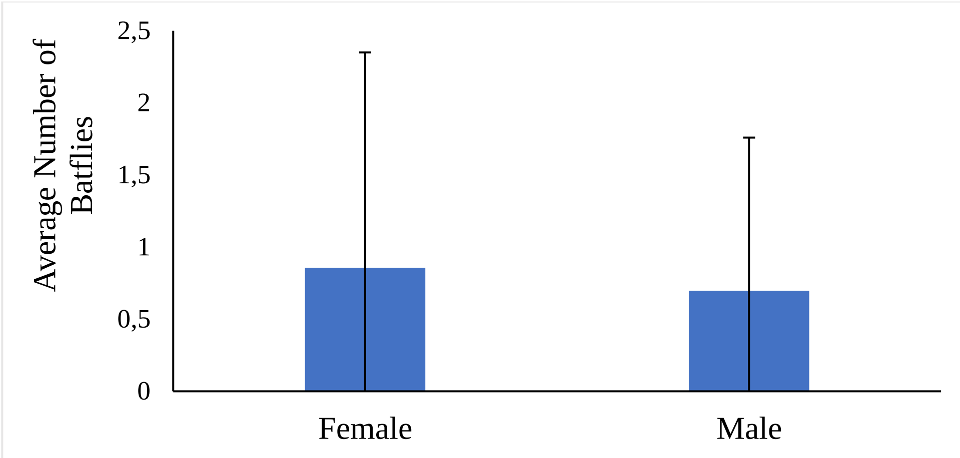

Figure 5. The average number of bat flies in the different sexes for all of the bat species collected. There is not a significant difference between the average number of bat flies in male and female bats of all collected species.

Overall, females were found to carry a greater number of bat flies compared to males ($\overline{x}_{female} = 0.857$, $\overline{x}_{male} = 0.696$). There is no significant difference in the average abundance of bat flies between the sexes ($t = 0.41$, $df = 36$, $P = 0.68$). The error bars in Fig. 5 overlap greatly indicating the wide range of numbers of bat flies for both male and female bats.

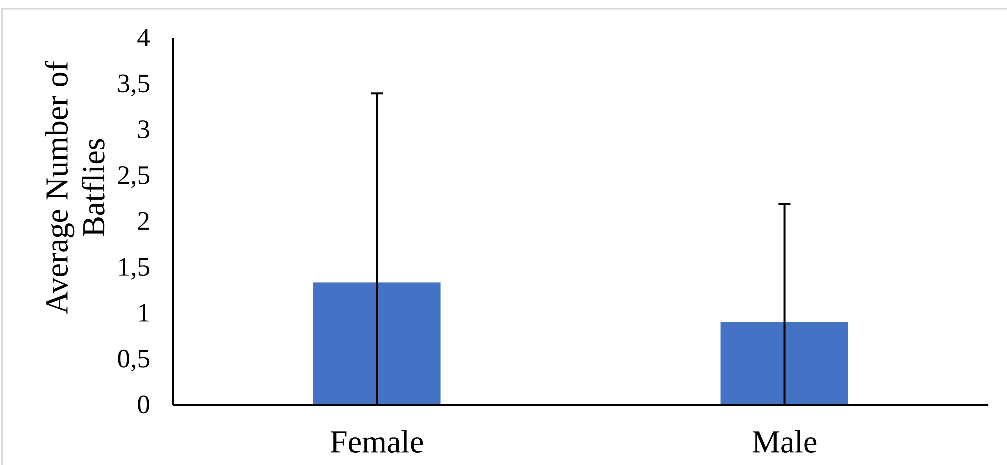

Figure 6. The average number of bat flies in the different sexes for the *Myotis pilosatibialis* species. There is not a significant difference between the average number of bat flies in male and female bats of this species.

A similar result came from the analysis of the difference in the average number of bat flies between males and females of the *Myotis pilosatibialis* species. I decided to analyze this relationship in a specific species to keep more variables constant to better isolate the relationship between the sex of the bat and the number of bat flies. There is no significant difference in the number of bat flies between sexes ($t = 0.54$, $df = 36$, $P = 0.60$). Again, the error bars in Fig. 6 overlap greatly indicating the wide range of numbers of bat flies for both male and female bats of this species.

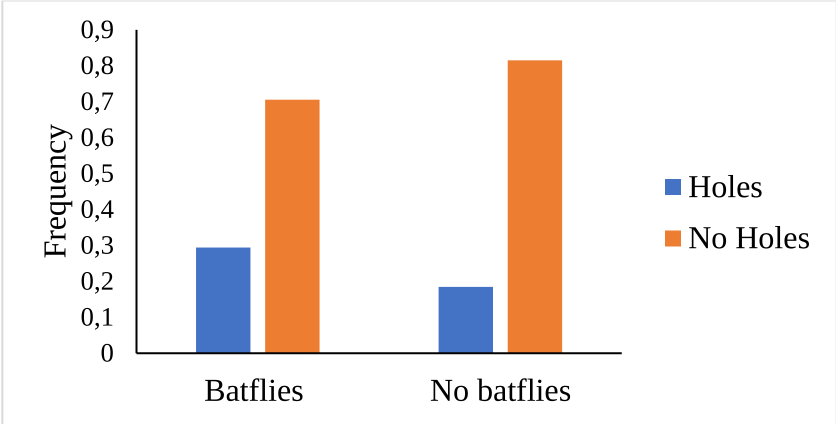

Figure 7. The frequency of holes in the wing membrane of bats in the presence of bat flies versus the absence of bat flies. There is no significant difference in the frequency of holes in the wings under these different conditions.

Generally, there were more bats without holes in the wing membrane (n = 34) than ones with holes (n = 10). Although bats with bat flies had a higher frequency of having holes than the ones without bat flies, I found that there is not a significant association between having bat flies and holes ($\chi^2 = 0.50$, df = 1, P = 0.48).

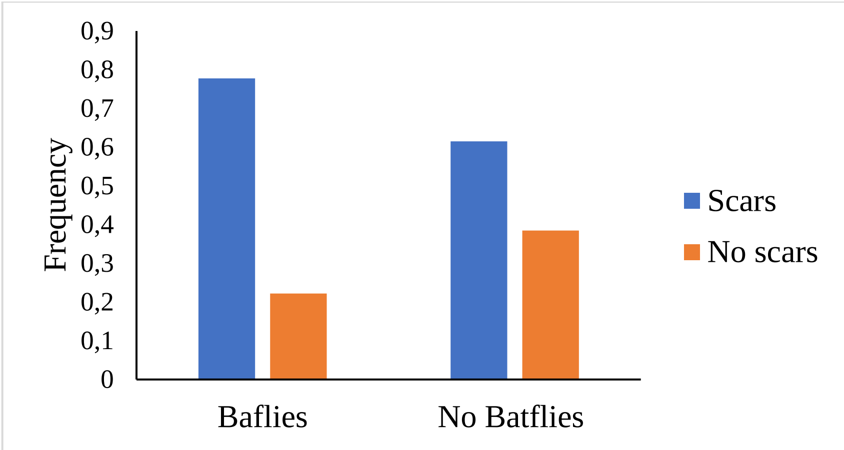

Figure 8. The frequency of scars in the wing membrane of bats in the presence of bat flies versus the absence of bat flies. There is no significant difference in the frequency of scars in the wings under these different conditions.

Contrary to the presence of holes in the wings, there were more bats with scars on their wings (n = 30) compared to ones without scars (n = 14). Again, although bats with bat flies had a higher frequency of having scars than the ones without bat flies, through a chi-squared test, I found that there is not a significant association between having bat flies and scars ($\chi^2 = 0.164$, df = 1, P = 0.28).

DISCUSSION

Ultimately, the average number of bat flies are not significantly different between male and female bats and there are no significant correlations between different temperatures of the bat and number of bat flies. In addition to this, there was no significant association between the presence of bat flies and holes or scars in the wing membrane.

Based on knowledge about the differences in roosting and general social behaviors of male and female bats, one could predict that females would have more bat flies than males. Generally, females are more commonly found in colonies whereas males are much more solitary and less social (Carter et al. 2015). Although this generalization about differences in behavior can be made, many bat species exhibit “cryptic” lifestyles which are difficult to study in the field, leading bats to be very underrepresented as compared to other social mammals in the field of behavioral ecology (Kerth 2008). Although there are no significant differences between the number of bat flies found on male and female bats across all species in this study and the specific species of *Myotis pilosatibialis*, there may be other factors of bat behavior that are understudied that lead to this unexpected similarity. Sex and age are factors that are thought to play a role in selecting habitat due to differences in physiological or behavioral imperatives which leads to the complexity of group compositions (Angell et al. 2013). The complexities of roosting behaviors may serve as an explanation for the similar abundances of bat flies in both males and females. Although females appear to normally exclude males from their nursery colonies, for some species in changing habitats, males are present in these colonies. The presence of males in these colonies provides thermoregulatory benefits which can outweigh the cons of having males in the colony. This mixed composition also allows opportunities for increased breeding success (Angell et al. 2013). During this investigation, the temperature in Monteverde was starting to decrease and precipitation increased entering the rainy season. These climatic factors may have caused this type of change in roosting behaviors for the bats in this study leading to a greater probability of spreading bat flies between male and female bats since bat fly pupae develop on the walls of the roosts before colonizing the host (Dick et al. 2007).

Social behaviors of bats are very species specific and are difficult to generalize into one description. Due to this it is difficult to pin point mechanisms of bat fly transfer among individuals across all species. Reproduction is an important factor to consider when assessing the interaction between male and female bats. Despite this, species of bats in Costa Rica tend to reproduce during the spring months (Tschapka 2005). This study included 8 pregnant females and 7 females that were nursing. The fact that this data was collected during a time in which males and females were in more contact with one another for the purposes of reproduction could serve as an explanation for the lack of difference in bat fly abundances as mating is a probable mechanism for the transfer of bat flies between individuals.

Some males, however, roost with groups of females in harems year-round and may therefore experience the same parasite dynamics as females (Frank et al. 2016). Bat flies lay eggs that develop on the walls of roosts, providing an easy mechanism for finding hosts. Therefore, bats that use roosts and employ more protected roosting behaviors have more parasites (Dick et al. 2007). Seasonal roosting behavior or species-specific roosting behavior could potentially serve as explanations for my results.

Environmental factors may have affected the temperatures measured from the bat. Upon removal of the bats from the mist nets, the bats were kept in cloth bags until they were ready to be processed. The differing time in which each bat was in the bag with reduced physical activity could have led to variable decreases in their body temperatures leading to the wide range of body temperatures collected.

Bat flies are obligate parasites living at the expense of their host, the bat; because of this I predicted that with an increasing number of bat flies, the overall health of the bat would decrease exhibiting an increase in temperature, and an increase in holes and scars in the wing membranes. The indicators of health used in this investigation did not show any significant correlation with the number of bat flies found on the bats. Of course, overall health has many factors and cannot be determined with just two types of observations. Although bat flies exhibit a variety of morphological adaptations, which suits them for the two physical substrates offered to them by their bat hosts, the fur and the flight membranes, they do not seem to have a direct physical effect on these parts based on observations (Dick et al. 2006).

Although an increased abundance of bat flies did not have a negative effect on different body temperatures and the presence of holes and scars in the wing membranes of bats, this does not mean they are not being affected by them at all. The possibilities of future investigations of such affects are endless despite the convoluted behaviors of bats.

ACKNOWLEDGEMENTS

I would like to thank Federico Chinchilla who took on the role as my primary advisor. Without him I would not have been able to do this project and learn how to properly handle bats. I would also like to thank Ana Moreland who was my fieldwork partner, and although we had different projects, we worked together to process the bats in a timely fashion. Additionally, I would like to thank Frank Joyce, the Monteverde Institute, and the San Gerardo field station in the Children's Eternal Rainforest for providing me with a space to set mist nets. Lastly, I would like to thank Richard LaVal for his time in discussing my project and his expertise in the study of bats.

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Appendix A

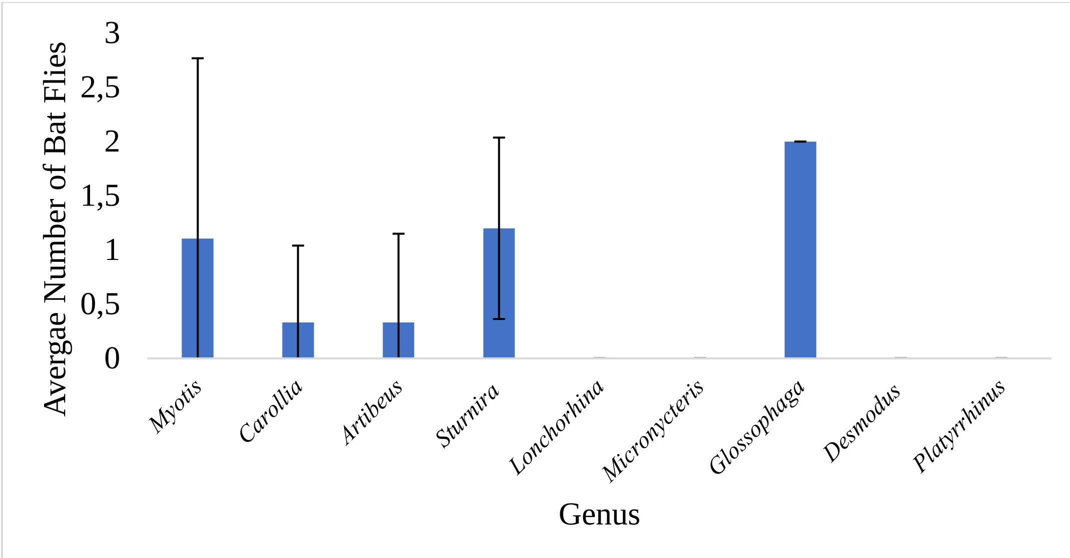

Figure 9. Average number of bat flies in each of the genera of the bats that were captured.

Appendix B

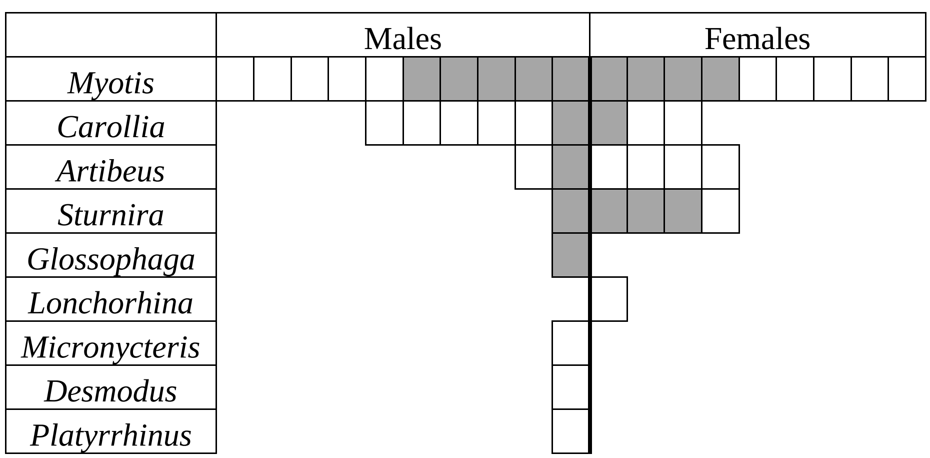

Figure 10. Proportions of individuals with bat flies by genus. Grey boxes indicate “loaded” individuals with bat flies and white boxes indicate “clean” individuals without bat flies.

Appendix C

Table 1. Species of bat flies found on each bat.

Bat #	Species of bat	Sex	Number of Bat flies	Species of bat fly
1	Hairy Tibia Myotis	Female	7	*Mastoptera minuta*
3	Hairy Tibia Myotis	Male	2	*Mastoptera minuta*
6	Sturnira mordax	Female	2	*Strebla Weidemann*
9	Hairy Tibia Myotis	Male	4	*Mastoptera minuta*
11	Sturnira	Male	1	*Trichobioides perspicillatus*
12	Sturnira	Female	1	*Megistopoda Maccquart*
13	Carollia sowelli	Female	1	*Synthesiostrebla Townsend*
19	Sturnira hondurensis	Female	2	*Megistopoda Maccquart*
20	Hairy Tibia Myotis	Male	1	*Mastoptera minuta*
27	Hairy Tibia Myotis	Male	1	*Mastoptera minuta*
29	Hairy Tibia Myotis	Female	2	*Mastoptera minuta*
32	Carollia	Male	2	*Synthesiostrebla Townsend*
34	Hairy Tibia Myotis	Male	3	*Mastoptera minuta*
38	Hairy Tibia Myotis	Female	1	*Mastoptera minuta*
40	Hairy Tibia Myotis	Male	2	*Mastoptera minuta*

Appendix D

Table 2. Raw Data: Observations from each bat caught.

Bat	Species	Sex	Mass with B	Forearm Len	Temp Armpi	Temp Belly	Temp Memb	Temp Forear	Batflies	Mass of Bag	Mass of Bat	Holes	Scars	Screaming
1	Hairy Tibia Myotis	Female	48	38	--	26.5	24.1	23.6	6	40	8	No	No	--
2	Hairy Tibia Myotis	Female	50.5	38	--	30.5	22.3	23.6	0	43	7.5	No	Yes	--
3	Hairy Tibia Myotis	Male	49	36	--	29.2	26.2	23.2	1	44	5	No	No	--
4	Hairy Tibia Myotis	Female	50	38	--	28.6	23.7	25.7	0	43.5	6.5	No	No	--
5	Sword Leaf Nose (*Lonchorhina aurita)*	Female	47	51	--	28.8	23.3	23.8	0	23	24	Yes	Yes	--
6	Yellow shoulder *(Sturnia mordax)*	Female	55	46	--	25.7	19.3	21.3	2	21	34	Yes	No	--
7	Hairy Tibia Myotis	Male	26.5	33	--	26.3	22.5	23.1	0	20.5	6	No	No	--
8	Short tail fruit bat (*Carollia perscpicillata)*	Male	43	42	--	23.5	21.7	26.5	0	24	19	Yes	Yes	--
9	Hairy Tibia Myotis	Male	50	35	--	24.3	23.5	26.3	4	45	5	No	Yes	--
10	Hairy Tibia Myotis	Male	50	35	--	27.2	20.5	23.1	0	43.5	6.5	No	No	--
11	Yellow shoulder	Male	57.5	41	--	29.2	20.1	23.2	1	36	21.5	Yes	Yes	--
12	Yellow shoulder (*Sturnia hondurensis*)	Female	66	44	--	25	19.7	23.1	1	45.5	20.5	No	No	No
13	Short tail fruit bat (*Carollia sowelli*)	Female	48	40	--	27	15.7	18.3	1	25	23	Yes	Yes	Yes
14	Short tail fruit bat (Carollia sowelli)	Male	62	40	--	24.3	21.1	24.2	0	45	17	No	Yes	--
15	Short tail fruit bat (Carollia nicaragueisis)	Female	46.5	44	--	25.3	19.1	25	0	23.75	22.75	Yes	Yes	--
16	Micronycteris schmidtorum	Male	30	35	--	24	20.7	24	0	22	8	No	Yes	
17	Hairy Tibia Myotis	Female	48	35	--	24.5	22.3	20.3	0	41.5	7.5	No	Yes	No
18	Artibeus tortecos	Female	61	42	35.8	28.6	25.6	20.3	0	42	19	Yes	Yes	No
19	Yellow shoulder (Sturnia hondurensis)	Female	64	44	35.2	25.6	25.3	21.2	2	44	20	No	Yes	--
20	Hairy Tibia Myotis	Male	48	37	35.6	24.2	21.6	21.4	1	43.5	4.5	No	Yes	Yes
21	Hairy Tibia Myotis	Female	47.5	36.5	35.2	24.3	20.2	21.3	0	41.5	6	No	No	Yes
22	Artibeus tortecos	Female	61	41	35.3	25.8	19.5	22.1	0	44.5	16.5	No	No	No
23	Short tail fruit bat (Carollia perscpicillata)	Male	61	40	36.3	22.5	19	20.8	0	42	19	No	Yes	No
24	Short tail fruit bat (Carollia perscpicillata)	Male	60	43	36.2	23.2	23.1	18.1	0	42	18	Yes	No	--
25	Hairy Tibia Myotis	Male	50	35	36.1	26.1	21.4	18.7	0	43.5	6.5	No	No	--
26	Artibeus tortecos	Female	60	42	35.6	26.1	21.4	18.7	0	43.5	16.5	No	Yes	No
27	Hairy Tibia Myotis	Male	50	36	35.9	23.2	17.1	18.4	1	43.5	6.5	No	Yes	--
28	Hairy Tibia Myotis	Male	45.5	36.5	28	22.2	25.7	24.2	0	40	5.5	No	No	--
29	Hairy Tibia Myotis	Female	48	36	34.1	20.5	21.8	23.2	2	41	7	No	Yes	
30	Short tail fruit bat (Carollia sowelli)	Female	65	41	36.2	24.6	21.5	21.2	0	46	19	No	Yes	No
31	Yellow shoulder (Sturnia hondurensis)	Female	67.5	43	33.6	20.7	22.5	18.1	0	44.5	23	No	Yes	No
32	Short tail fruit bat (Carollia sowelli)	Male	59	40	35	25.5	18.5	18.4	2	42	17	No	Yes	
33	Hairy Tibia Myotis	Female	48	36	35.2	21.7	20.2	23.2	0	41.5	6.5	No	No	Yes
34	Hairy Tibia Myotis	Female	47.5	36	36	29.5	21	20.7	3	42	5.5	Yes	Yes	Yes
35	Hairy Tibia Myotis	Male	46	35	35.1	17.3	22	19	0	43	3	No	Yes	Yes
36	Glossophaga soricina	Male	54.5	37	34.9	23.2	17.6	18.5	2	43.5	11	No	Yes	No
37	Short tail fruit bat (Carollia sowelli)	Male	63.5	43	37.8	25	20.1	21.5	0	43.5	20	No	No	No
38	Hairy Tibia Myotis	Female	50	37	35.2	18.2	17.5	19.3	1	44	6	No	Yes	Yes
39	Artibeus tortecos	Female	61	41	33.8	17.5	18.2	24.6	0	44	17	No	Yes	No
40	Hairy Tibia Myotis	Male	48	37	35	23.9	18.5	19.8	2	41	7	No	Yes	Yes
41	Vampire (Desmodus rotundus)	Male	86	60	39.6	25.2	22	25.3	0	45	41	No	Yes	Yes
42	Artibeus tortecos	Male	62	44	39.4	24.5	16	16.5	2	44	18	Yes	Yes	No
43	Platyrrhinus helleri	Male	60	38	32.7	21.3	19.7	20.5	0	44	16	No	Yes	Yes
44	Artibeus tortecos	Male	60	41	36.3	18.2	19	19.7	0	46	14	No	Yes	No