Distribution of *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus*

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Introduction

Siphonaptera, otherwise known as fleas, are an order of small external parasites that obtain nutrients by consuming blood from their host. With approximately 2,500 species, flea distribution extends to every continent, including Antarctica, and they can be found in habitats ranging from tropical rainforest to arctic tundra (Whiting 2008). This expansive range results from each species evolving a narrow range of tolerance for temperature and humidity. However, despite a narrow tolerance range, most adult fleas are not limited by microclimates. The seasonal and geographic distribution of fleas is primarily determined by larvae development's specific requirements (Hastriter 2009). The second stage of the flea life cycle, larvae, are typically not parasitic and most often develop off-host (Krasnov 2007). During this stage, the larvae, which are worm-like, blind, and legless, are exceedingly susceptible to life-ending conditions. After three molts, the larvae become pupae and spin into cocoons, where their appendages will begin to develop. The emergence of adults from these cocoons requires specific stimuli dependent on the species, such as temperature, vibration, or pressure (Hastriter 2009). As adults, fleas become permeant satellites of their hosts, alternating their time between periods on the host and periods in the host's burrow/nest (Krasnov 2007). As adults, a series of morphological adaptions allows fleas to attach and remain on their hosts. Laterally compressed bodies enable them to move through their host's fur or feathers. Strong claws and setae enable them to anchor themselves to their host's skin and prevent being dislodged. Their mouthparts have been modified for piercing skin and sucking. And despite not possessing wings, fleas have extremely strong hind legs adapted for jumping (Hastriter 2009). These strong legs allow individuals to jump from host to host or return to their original host after a period in the nest. Much of fleas' distribution and dispersal opportunities depend on what host species they reside on. Despite their strong hind legs, a flea's small size makes traveling great distances difficult, if not impossible, under their own power. Thus, in order for fleas to colonize new locations or new hosts, they must be carried there by another species. As such, a flea's habitat patch is their host, rather than their geographic location, with parasitic individuals distributed across host individuals who provide a place for living, foraging, and mating (Krasnov 2004). Thus, a flea's distribution can be expected to be influenced by the host's habitat and mode of transportation. Based on this information, two hypotheses were investigated. The first hypothesis is that fleas found on flying hosts will have a greater distribution than fleas found on non-flying hosts. Many bird and bat species have yearly migratory patterns that result in them traveling great distances between their summer and winter locations. Meanwhile, non-flying organisms, like rodents and deer, do not migrate great distances and therefore occupy smaller ranges than their flying counterparts. The second hypothesis is that the genus *Rhinolophopsylla* will have greater overall distribution than the genera *Rhopalopsyllus* and *Rhynchopsyllus* because *Rhinolophopsylla* contains more species within its genus. Because fleas have narrow tolerance ranges where their larvae can survive, the increased number of species within *Rhinolophopsylla* will allow the genus to cover a larger range of temperature and humidity than the two genera with fewer species.

Methods

The sample data of fleas was provided by the Chicago Field Museum in the form of specimen images that had been donated to the institution for research purposes. For each image, the collection location was imputed into a pre-formatted excel document also provided by the Field Museum. After recording the collection spots for every specimen, each location was run through GEOLocate to determine the latitude and longitude. Next, all the latitude and longitude sets were mapped onto the globe using ArcGIS mapping software (Fig. 1). Finally, distribution models were created using MaxEnt analysis software to determine where conditions would be suitable for species (Fig. 2-6). The original sample size consisted of 119 total specimen images; however, 7 images were excluded because they did not have a collection location and therefore could not be mapped. The functional sample size consisted of 112 specimen images which were then broken down either by host type (flying or non-flying) or by genus (Rhinolophopsylla, Rhopalopsyllus, and Rhynchopsyllus) to be mapped in MaxEnt. When broken down by variable 1, host type, the sample size consisted of 36 flying hosts and 76 non-flying hosts. When broken down by variable 2, genus, the sample size consisted of 30 Rhinolophopsylla, 76 Rhopalopsyllus, and 6 Rhynchopsyllus. These sample sizes were further cut down by the MaxEnt software as specimens with the same latitude and longitude were only counted once within each variable map. Additionally, when creating the MaxEnt models, the environmental variables of bio_5, 5b, 6, 7, 8, 16, and 17 had to be omitted in each of the models because configuration errors prevented the production of useable maps.

Results

Figure 1. ArcGIS map displaying specimen collection latitudes and longitudes of *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus* fleas.

On the ArcGIS map shown in Figure 1, each point represents the latitude and longitude of at least one flea specimen. Locations with multiple specimens collected at the same latitude and longitude show up as a single point. This map's boundaries are separated by province, and the majority of the data points occur within Central/South America and the Middle East. The MaxEnt models displayed in Figures 2, 3, 4, 5, and 6 predict the probability that fleas of a given variable may survive around the globe. Areas of warmer color have a higher predicted probability because their conditions are more suitable. Meanwhile, areas of cooler color have a lower predicted probability that conditions are suitable. The scale to the right of each map associates each possible color with a given probability; areas of red have a probability of 1, and areas of dark blue regions have a probability of 0.

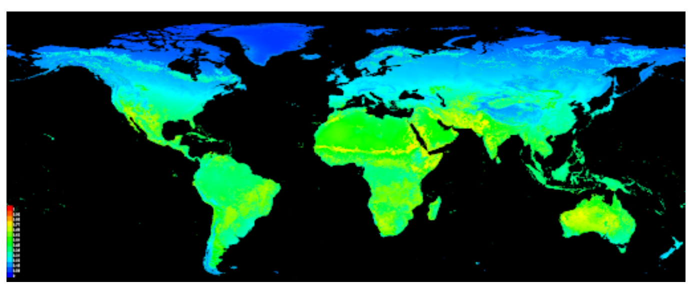

Figure 2. MaxEnt distribution model predicting suitable condition for Rhinolophopsylla, Rhopalopsyllus, and Rhynchopsyllus fleas with flying hosts.

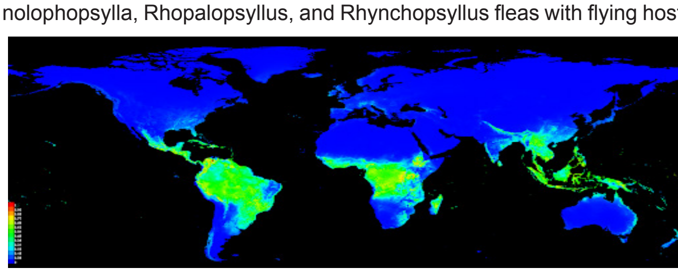

Figure 3. MaxEnt distribution model predicting suitable condition for Rhinolophopsylla, Rhopalopsyllus, and Rhynchopsyllus fleas with non-flying hosts.

As shown above, in Figure 2, *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus* fleas with flying hosts have the possibility of encountering suitable conditions across much of the world. Most of North/South America, Australia, and Asia are colored lime-green, indicating approximately a .54 probability that those locations would have conditions suitable for fleas based on the sample data. Meanwhile, in Figure 3, a much smaller amount of the globe is colored lime-green, with only a portion of South America, Africa, and Southeast Asia having a .54 probability of suitable conditions for *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus* with non-flying hosts.

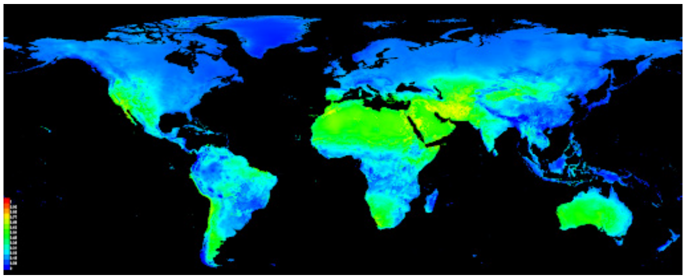

Figure 4. MaxEnt distribution model predicting suitable condition for *Rhinolophopsylla* fleas.

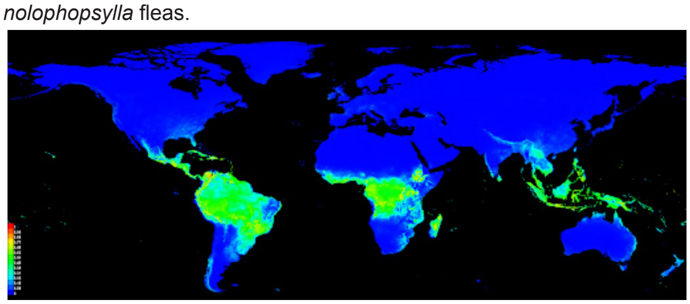

Figure 5. MaxEnt distribution model predicting suitable condition for *Rhopalopsyllus* fleas.

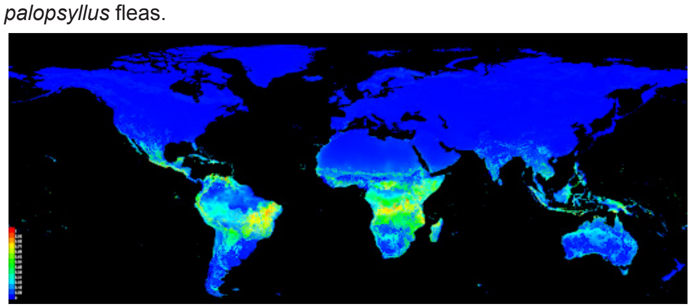

Figure 6. MaxEnt distribution model predicting suitable condition for Rhynchopsyllus fleas.

Figure 4 exhibits that the *Rhinolophopsylla* genus, which contained 9 species, has the possibility to occupy vast amounts of Africa, Australia, and the Middle East, as well as some stretches of land in North/South America and Asia. Meanwhile, in Figure 5, the genus *Rhopalopsyllus*, with 3 species, was only shown to have a smaller possible range than *Rhinolophopsylla* but a larger possible range than *Rhynchopsyllus*. This genera's possible range is restricted to tropical rainforest areas of South America, Africa, and Southeast Asia. Finally, in Figure 6, the genus *Rhynchopsyllus*, which has 1 species, is shown to possess the smallest potential range of genera, occupying smaller amounts of the tropical rainforest found in South America, Africa, and Southeast Asia than *Rhopalopsyllus* does.

Discussion

The greatest number of endemic flea genera are found in the Neotropical, Afro-Tropical, and Australian regions, with each region having greater than 50 percent of flea genera endemic. However, when looking at the Palearctic and Nearctic regions, the percentage of endemic species drops to below 45 percent endemic (Medvedev 1996). This distribution of endemic flea populations displays a similar pattern to the predictions given by MaxEnt in Figure 2-6. Throughout all the Figures, the two consistencies are that Neotropical, Afro-Tropical, and Australian regions are typically shaded lime-green, while the Palearctic and Nearctic regions are mostly shaded dark blue, which means that the Neotropical, Afro-Tropical, and Australian regions have a good chance of having suitable conditions to support flea life, while the Palearctic and Nearctic regions have almost no chance of having suitable conditions to support flea life. In general, it has been found that fleas survive better and develop faster under high ambient temperatures. This trend can explain the increased species richness and abundance of fleas in locations characterized by higher temperatures and lower altitudes, such as those found in the Neotropical, Afro-Tropical, and Australian regions (Linardi 2012). Overall, fleas depend on their hosts for almost everything. Their hosts' bodies provide food, shelter, and a place to reproduce, while their hosts' nests provide housing for their eggs. Due to this, generally, mammals with vast home ranges that do not inhabit dens almost always lack fleas of their own. Whereas hosts with nests exhibit more specific flea fauna than their non-nesting counterparts (Whiting 2007). Many non-flying hosts for *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus* fleas are mammals that do not exhibit strong nesting behaviors. As such, it can be expected that fleas found on these non-nesting, non-flying mammals will have a smaller distribution than their flying, nesting counterparts because they lack a consistently protected place to lay eggs. This also contributes to fleas with flying hosts having a greater distribution because their hosts will nest in not one but two locations as they migrate with seasonal changes - Figures 2 and 3 display possible flea distribution that matches these restrictions, with fleas with flying hosts displaying a much larger distribution in Figure 2 than fleas with non-flying hosts does in Figure 3. Increasing specialization can be interpreted as an increase in the number of recognized habitats rather than reduced niche breadth within a habitat, thus defining habitats by how species use them (Krasnov 2004). Therefore, a flea genus could be considered more specialized than another if it contains more species that utilize a greater number of host species. Normally, when considering highly specialized species, one would assume that they have smaller ranges than their generalist counterparts. However, fleas are parasites and as such much exists on another organism to survive. Thus, fleas can either live on a specialized host with a small range or a generalist host with a wide range. With this in mind, flea genera with a greater number of species would have a better chance of being distributed farther than flea genera with a smaller number of species. In Figure 4, the *Rhinolophopsylla* genus, which contains 9 species, has the greatest possible distribution of the three genera evaluated covering vast amounts of land on every continent except Antarctica. Meanwhile, in Figure 6, the *Rhynchopsyllus* genus, which contained only 1 species, had the smallest distribution of the three genera. Overall, there was not much previous research about *Rhinolophopsylla*, *Rhopalopsyllus*, and *Rhynchopsyllus* fleas as much of the literature focused on human fleas, otherwise known as Pulex fleas. Additionally, more data mapping and specimen collecting should be done to increase our knowledge about other non-human fleas. This is important as fleas are often vectors of disease and common household pests, so expanding our knowledge on where these species and genera are located could help prevent infections and infestations in the future.