# Survey of Ectoparasites Collected from Norway Rats (*Rattus norvegicus*) in Homeless Camps in the City of Oakland, California

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**ABSTRACT:** The City of Oakland is the largest city within Alameda County, the 8th largest city in California, and the 45th largest in the United States. Due to various socioeconomic factors, the number of homeless encampments within Oakland has been increasing over the past few years. A recently completed survey showed that there has been a 47.45% increase in the number of homeless living within the city limits. Approximately 4,071 people are now living in various encampments around the city, primarily concentrated underneath freeway/infrastructure overpasses and on adjoining lands. Surveillance by our staff found that several of these encampments also had active Norway rat populations as indicated by active burrows within and adjacent to the camps, as well as resident reports. Beginning in the fall of 2017, District biologists began live-trapping at a few of the larger encampments to try and ascertain the composition and load of ectoparasites on corresponding Norway rat populations. We specifically looked at flea abundance and species composition, as they are vectors of diseases, such as Murine typhus (*Rickettsia typhi*), flea-borne typhus (*Rickettsia felis*), and plague (*Yersinia pestis*). We trapped at four different camps in Oakland over a nine-month period and found that the flea, mite, and louse abundance, along with species composition, varied between the camps. To date, we have yet to determine the causes of these differences, but fleas tested at two of the four camps have come back as positive for *R. felis*. We are continuing to trap at these camps and are expanding our trapping program to include additional camps in an effort to determine what variables affect the ectoparasite composition on Norway rat populations within the City of Oakland.

**KEY WORDS:** cat flea, *Ctenocephalides felis*, ectoparasite, homeless, Norway rat, Oriental rat flea, *Rattus norvegicus, Xenopsylla cheopis*

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## INTRODUCTION

Alameda County is the 7th most populous county in the state of California, with over 1.5 million people (CDF 2019). The City of Oakland is the largest of 15 cities that comprise Alameda County, and it serves as an economic center for the county. Oakland is also the 8th largest city in California and the 45th largest city in the United States. Alameda County Vector Control Services District ('District' or 'Alameda County VCD') operates under the county's Department of Environmental Health. The mission of the District is to prevent the spread of vector-borne diseases, injury, and discomfort to the residents of the District by controlling insects, rodents, and other vectors and eliminating causal environmental conditions through education and integrated pest management practices.

The number of homeless encampments in Oakland has increased considerably in the past two years. A biennial count of homeless released in May 2019 found a 43% increase in the number of homeless people living within Alameda County. Currently, approximately 4,071 people are living in encampments throughout Oakland, mostly concentrated underneath freeway overpasses/ transportation infrastructure and on adjoining lands (Alameda County 2019) (e.g., Figure 1, Figure 2). Due to the ongoing homeless situation in the County, and the length of time that the encampments have been present in some locations, it came to the attention of the District that

**Figure 1. A homeless encampment in the City of Oakland, California.**

**Figure 2. E 12th and 23rd Street encampment in Oakland, California. This encampment was closed in 2018.**

Norway rat (*Rattus norvegicus*) numbers were increasing within the encampments and that the populations now appeared to be established and breeding. These observations coincided with reports of rat sightings by residents of the encampments, surrounding businesses, and members of the public.

The Norway rat was introduced to North America along the eastern seaboard around 1775 from sailing ships (Bourne 1998). Originally from China (Nowak and Walker 1991), it has become a worldwide pest and is most strongly associated with urban ecosystems. Norway rats are adapted to temperate climates and are well suited for cohabitation with people (Feng and Himsworth 2014). They can commonly be found living inside structures, feeding on refuse and discarded food. Norway rats are extensive burrowers and are normally found associated with sewer systems and other below ground infrastructure. However, as infrastructure within cities start to deteriorate, the rats have the ability to come above ground and establish new populations. This often occurs when there are breaks in the main sewer lines and lateral pipes coming from residences (Margulis 1977). Within Oakland, the District works with the Public Works Department to identify breaks in the sewer system so they can be repaired quickly and prevent rodents from coming above ground and establishing new populations.

Firth et al. (2014) suggested that "urban Norway rats may be an important source of zoonotic pathogens". Coupled with high levels of fecundity, fast growth rates, and high population densities (Firth et al. 2014), ongoing monitoring of Norway rat populations is warranted. Norway rats are known reservoirs of several human pathogens, including *Bartonella* spp., Seoul virus, and *Leptospira interrogans* (Easterbrook et al. 2007, Gundi et al. 2012, Himsworth et al. 2013, Feng and Himsworth 2014).

Historically, Norway rats have been found to harbor varying species of fleas, lice, and mites in North America (Pratt and Good 1954). In 2018 and 2019, there was an outbreak of flea-borne typhus (*Rickettsia typhi*) in Los Angeles County and Orange County, CA. In Los Angeles County, there were 111 confirmed cases of *R. typhi* between 2018 and 2019 and an additional 37 human cases reported in Orange County, CA, during the same period (CDPH 2020). The majority of cases in Los Angeles County occurred in and around downtown Los Angeles and were associated with the homeless population located in the urban center of the city (CDPH, pers. commun. 2019). In Alameda County, we currently have similar conditions in Oakland associated with the homeless encampments that are found in Los Angeles. Oakland has the largest homeless population in the Bay Area, and it is concentrated in the urban center of the city.

The urban transmission cycle for Murine typhus involves the Norway rat and two main flea species: the cat flea (*Ctenocephalides felis*) and the Oriental rat flea (*Xenopsylla cheopis*). Disease transmission occurs when a flea leaves its rodent host and then bites a human. Brown and Macaluso (2016) document a sylvatic transmission cycle for flea-borne typhus that involves opossums (*Didelphis virginiana*), feral cats (*Felis catus*), and cat fleas. Opossums and feral cats are common in Oakland, and it is possible that both the sylvatic and urban transmission cycle may be present within the County.

Beginning in early 2018, District biologists began live-trapping Norway rats at several homeless encampments in Oakland to ascertain ectoparasite diversity and abundance on corresponding Norway rat populations. Because fleas are the primary vectors of flea-borne typhus and plague (*Yersinia pestis*) (Azad 1990, Krueger et al. 2016), District biologists focused on determining flea abundance and species composition. Here, we report our findings from a two-year survey of Norway rats from four different encampments in Oakland, in which we measured flea, mite, and lice abundance and diversity over time.

## METHODS

Within the City of Oakland, four homeless encampments with ongoing Norway rat activity were identified. Trapping took place at the following encampment sites: 1) Wood Street (2221 Wood Street), 2) Northgate: (Northgate Ave. and 27$^{th}$ Street), 3) East 12$^{th}$ and 23$^{rd}$ Avenue, and 4) High Street/Home Depot (4000 Alameda Avenue) (Figure 3). Beginning in early 2018 through late 2019, District staff placed Pro Rat Tomahawk Live Traps (Hazelhurst, WI) at the sites. Traps were baited with a combination of canned mackerel (1-2 grams) and peanut butter (approximately 1 teaspoon). Traps were placed in the late afternoon, 14:00 to 16:30, and the following criteria were used to determine the best areas for trap placement: presence of fresh Norway rat droppings; active burrows (indicated by the burrow entrance being clean, smooth, and free of cobwebs/debris); rat "runs" evident through neighboring vegetation/debris; and residents of the camps directing us to where they saw the heaviest level of rat activity. After traps were set, they were covered with debris found nearby (i.e., discarded clothing, cardboard, blankets, etc.); this was done to mask any potential new odors present on the trap that would induce trap shyness by the rats (Figure 4). Traps were left out overnight and picked up the following morning between 09:00-11:00. During January 2018 to May 2018, trapping events were limited to only one night. Trapping was standardized from June 2018-2019, and 20 live-traps were deployed for three consecutive nights, or until 30 rats were trapped per location, whichever came first.

Live rats were brought back to the Alameda County VCD laboratory and euthanized using $CO_2$ according to protocols outlined by the American Veterinary Medical Association (2020). Euthanized rats were bagged individually and sprayed with PT® P.I.® (BASF Corp., Triangle Park, NC), a pyrethrin insecticide, to kill any ectoparasites. The treated rats were left for at least one hour prior to combing to ensure that all ectoparasites were dead. Rats were combed for ectoparasites using a fine bristle brush (Scotch Brite/3M, St. Paul, MN). Any ectoparasites collected were placed in 95% ethanol (ETOH) and set aside for identification. Ectoparasites were identified using the following taxonomic keys: fleas (Hubbard 1947), lice (Price and Graham 1997), and mites (Pratt and Stojanovich 1961).

In order to determine if the abundance and diversity of ectoparasites associated with the Norway rats changed over time, we trapped at the Wood Street and High Street/ Home Depot encampments approximately every three


**Figure 3. The four homeless encampments where we trapped Norway rats in the City of Oakland, California.**

**Figure 4. A live trap placed at the homeless encampment next to an active burrow and covered with clothing. Traps are covered with clothing/material found at the camp to mask new odors and reduce trap shyness.**

months during 2019. During the initial trapping events in 2018, we mainly focused on looking at the composition of flea species present on Norway rats and their overall abundance (i.e., flea index; Table 1). We expanded the study to include lice and mite species composition and diversity in all subsequent trapping events in 2019. We used the flea index to calculate the average number of flea per rat (fleas/# rats combed) (Gage 1999).

Both the Northgate and E 12th and 23rd Street encampments were cleared out by the City of Oakland at the end of 2018 and the residents moved into housing. Due to this, the District conducted suppression activities to prevent the rats from scattering into the surrounding neighborhoods. Active trapping at these two locations was stopped due to the encampments no longer being in existence.

## RESULTS

### *2018 Results*

The composition and abundance of ectoparasites changed over time for each encampment sampled (Figure 3). We trapped at the E 12th and 23rd St. encampment in August 2018, and we collected 179 fleas from 32 Norway rats, with a flea index = 5.6 (Table 1). Two species of fleas were collected: the cat flea (*Ctenocephalides felis*) and the Oriental rat flea (*Xenopsylla cheopis*). A total of 48 fleas from 43 Norway rats, with a flea index = 1.12, were

**Table 1. Total number of fleas collected from Norway rats trapped at 3 different homeless encampments in Oakland, California during 2018.**

| Encampment | Collection Date | Total # Rats Trapped | Total # Fleas | Flea Index |
|---|---|---|---|---|
| High Street | 05/01/18 | 13 | 0 | 0 |
| High Street | 11/07/18 | 25 | 24 | 0.9 |
| E12th and 23rd St | 08/15/18 | 32 | 179 | 5.6 |
| Northgate | 06/05/18 | 43 | 48 | 1.12 |

**Table 2. Diversity of ectoparasites collected from Norway rats trapped at homeless encampments in Oakland, California, from 2018-2019.**

| Encampment | Year | Flea | Lice | Mites |
|---|---|---|---|---|
| Northgate | 2018 | *Nosopsyllus fasciatus* | * | *Ornithonyssus bacoti* Laelapidae |
| East 12th and 23rd Street | 2018 | *Xenopsylla cheopis* *Ctenocephalides felis* | * | * |
| Wood Street | 2018 | *Xenopsylla cheopis* *Ctenocephalides felis* *Leptopsylla* segnis | * | * |
| Wood Street | 2019 | *Ctenocephalides felis* | Polyplacidae | Laelapidae |
| High Street/ Home Depot | 2018 | *Nosopsyllus fasciatus* *Xenopsylla cheopis* *Ctenocephalides felis* | Polyplacidae | * |
| High Street/ Home Depot | 2019 | *Nosopsyllus fasciatus* *Ctenocephalides felis* | Polyplacidae | Laelapidae |

*We were focused mainly on flea diversity in 2018. We did not survey lice and mite diversity until 2019.

**Table 3. Abundance of ectoparasites collected during 2019 from Norway rats at the High Street/Home Depot homeless encampment in Oakland, California.**

| Encampment | Date | Total # Rats Trapped | Total # Fleas | Flea Index | Total # Lice | Ave # Lice/ rat | Total # Mites | Ave # Mites/ rat | Rats with No Ectos |
|---|---|---|---|---|---|---|---|---|---|
| High Street/ Home Depot | 04/19/19* | 23 | 1 | 0.04 | 606 | 10.22** | 46 | 2 | 9 |
| High Street/ Home Depot | 08/09/19 | 41 | 13 | 0.32 | 50 | 1.22 | 128 | 3.12 | 15 |
| High Street/ Home Depot | 10/29/19* | 25 | 0 | 0 | 49 | 2.7 | 9 | 0.5 | 11 |
| High Street/ Home Depot | 12/04/19 | 30 | 1 | 0.03 | 114 | 3.8 | 45 | 1.5 | 5 |

* Traps deployed for 3 consecutive nights, but less than 30 rats were trapped.
** 371 lice were removed from one rat. This outlier was removed and the average number of lice/rat determined for N=22

collected from the Northgate encampment (Table 1) and comprised only one species: the northern rat flea (*Nosopsyllus fasciatus*) (Table 2). We did not look at lice and mite abundance on the rats collected from these two encampments.

We trapped at High Street/Home Depot in May 2018, and no fleas were recovered from any of the rats that were trapped (N = 13). The second collection in November (N = 25) at the same encampment saw an increase in the number of fleas collected, with a flea index = 0.9 per Norway rat (Table 1). The total number of lice per rat for these two trapping events was not quantified for each rat collected, however two rats trapped in May 2018 had over 200 lice/rat. The number of lice per rat dropped significantly to less than 20 lice/rat in November 2018. Mites were not collected during these two trapping events.

At the Wood Street encampment, trapping occurred three times in 2018 (January, February, and August). Three species of fleas were collected: *Leptopsylla segnis*, *C. felis*, and *X. cheopis*. The flea index did not noticeably differ between trapping events in January (flea index = 1.17) and August 2018 (flea index = 0.92). However, no fleas were collected from the rats trapped in February 2018 (flea index = 0). The number of mites collected per rat over the three trapping events was not consistent (i.e., January = 0 mites/rat, February average mite/rat = 1.30, August average mite/rat = 9). No lice were collected during the 2018 trapping events.

### *2019 Results*

After standardizing our trapping protocol in 2019, we found the ectoparasite abundance collected from Norway rats trapped at the High Street/Home Depot encampment changed over time (Table 3, Figure 5, Figure 6). The ectoparasite abundance collected from the Norway rats trapped at the Wood Street encampment also varied over

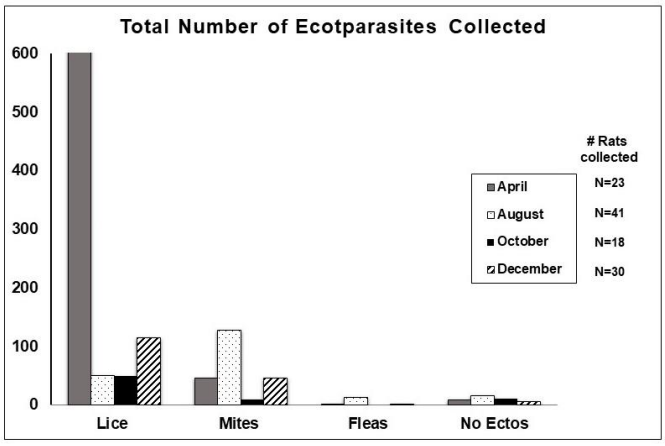


**Figure 5. Total number of ectoparasites collected at the High Street/Home Depot encampment in Oakland, CA, in 2019. "No Ectos" is the number of rats with no ectoparasites collected.**

**Table 4. Abundance of ectoparasites collected during 2018-2019 from Norway rats at the Wood Street homeless encampment in Oakland, California.**

| Encampment | Date | Total # Rats Trapped | Total # Fleas | Flea Index | Total # Lice | Ave # Lice/ rat | Total # Mites | Ave # Mites/ rat | Rats with No Ectos |
|---|---|---|---|---|---|---|---|---|---|
| Wood Street | 01/12/18* | 6 | 7 | 1.17 | N/A | N/A | 0 | 0 | N/A |
| Wood Street | 02/6/18* | 13 | 0 | 0 | N/A | N/A | 17 | 1.30 | N/A |
| Wood Street | 08/28/18* | 13 | 12 | 0.92 | N/A | N/A | 117 | 9 | N/A |
| Wood Street | 05/02/19 | 22 | 0 | 0 | 984 | 0.82*** | 77 | 3.5 | 5 |
| Wood Street | 10/29/19* | 20 | 1 | 0.05 | 11 | 0.55 | 24 | 1.2 | 8 |
| Wood Street | 12/19/19** | 42 | 0 | 0 | 416 | 9.9 | 137 | 3.26 | 3 |

*Single trapping event = 20 traps deployed for 1 night only
** Traps were only deployed for two nights, trapping was interrupted.
*** 966 lice were removed from one rat. This outlier was removed and the average number of lice/rat determined for N=21.

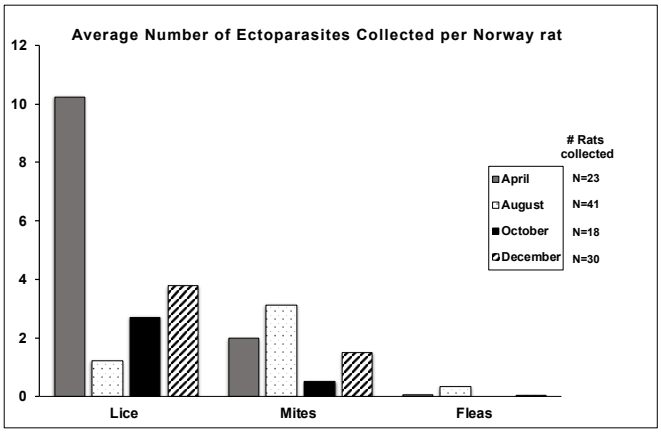


**Figure 6. Average number of ectoparasites collected per Norway rat at the High Street/Home Depot encampment in Oakland, CA, in 2019.**

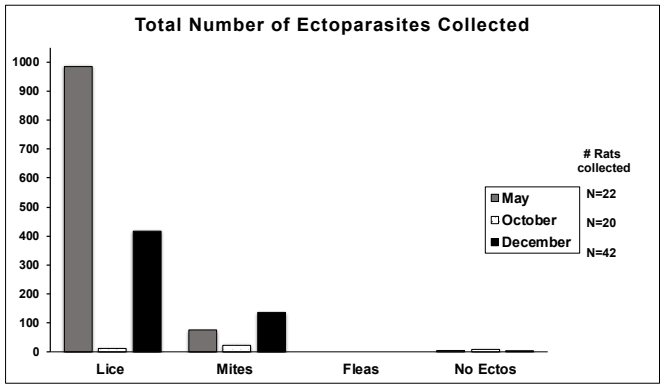


**Figure 7. Total number of ectoparasites collected at the Wood Street encampment in Oakland, CA, in 2019. "No Ectos" is the number of rats with no ectoparasites collected.**

time (Table 4, Figure 7, Figure 8). In 2019, two flea species were collected: *N. fasciatus* and *C. felis* (Table 4). We collected 371 lice from one Norway rat trapped in April 2019. We collected only 1 flea (*C. felis*) in all of 2019 (Table 4).

## DISCUSSION

Norway rats were trapped from four different homeless encampments within the City of Oakland over approximately a two-year period. We looked at flea abundance and diversity associated with Norway rats in the encampments during 2018 and found that the composition of flea species changed between encampments, and even within the same encampment, (High Street/Home Depot) during that time. There were four flea species living on the rats in the encampments in 2018: *N. fasciatus, X. cheopis, C. felis,* and *L. segnis*, but the diversity decreased to just two species, *N. fasciatus* and *C. felis* in 2019. Only one flea species (*C. felis*) at Wood Street in 2019 was collected, while in the previous year three different species were detected: *X. cheopis*, *C. felis*, and *L. segnis*. The High Street/Home Depot encampment employed the assistance of a mobile veterinarian that would come by on a routine basis and treat the dogs in the encampments for fleas. Whether this contributed to the change in diversity of flea species in the encampment is unknown. The Wood Street encampment also had dogs, but as far as we know, a vet never came out to treat dogs at this encampment.

We standardized our trapping protocol in 2019, deploying 20 live-traps per night for a maximum of three

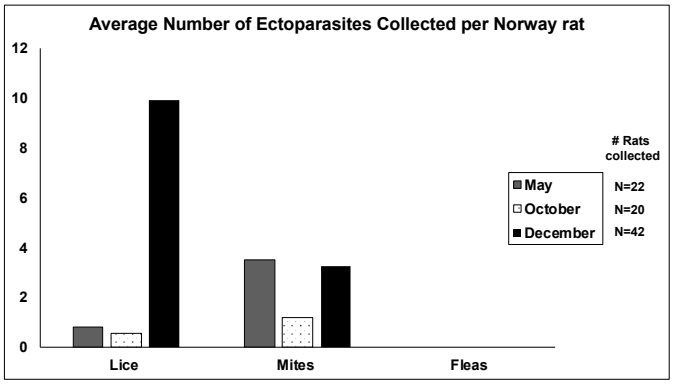


**Figure 8. Average number of ectoparasites collected at the Wood Street encampment in Oakland, CA, in 2019.**

nights. Trapping was concluded when we either trapped 30 rats/trapping event or trapped for three consecutive nights, whichever came first. Trapping could not be run for more than three consecutive nights per trapping event due to time constraints of the staff. Due to this limitation, not all trapping events resulted in N = 30 rats. While some trapping events resulted in more than this, most were less. Statistics were not conducted because the samples sizes were not comparable within an encampment or across different encampments for 2019.

In 2019 we expanded our study to include changes in lice and mite abundance and species diversity within, and between, the different encampments. We found that the flea, lice, and mite abundance changed over the course of the year, and while there was similarity between the Wood Street and High Street/Home Depot encampments, we cannot make any conclusive statements as to the cause. Each encampment is different from the other in terms of number of residents living there, the number and types of pets they have, the amount of debris/garage located within and around the camp, and the ratio of dirt:concrete on which the camp resides, among other potential factors. Whether all of these variables, or none, have any bearing on the abundance or species composition of ectoparasites associated with Norway rats within the camps is unknown.

One rat from each encampment had a high louse load in the spring [Wood Street in May (N = 371 lice) and High Street/Home Depot in April (N = 966)]. However, this was limited to one Norway rat trapped at each location, and the other never averaged over 10 lice per rat throughout the year. The rats trapped in the summer and early fall showed no change in average number of lice per rat between the two trapping events at either encampment. However, rats trapped in December from High Street/Home Depot and Wood Street did have an increased louse load over the previous survey conducted in the fall. Since we currently only have one full year of data, we cannot conclude at present whether this indicates the "normal" pattern of lice abundance on Norway rats in Oakland. We also saw that the number of mites per rat increased in May in both the High Street/Home Depot and Wood Street encampments, but what factors may have contributed to this difference is unclear. There was no apparent pattern in the number of mites per rat collected when successive trapping events were compared over the course of the year.

It is unknown whether this variability in ectoparasite abundance and diversity is linked to normal changes that are seasonal in nature (i.e., weather) or if other factors such as soil composition, type of ground vegetation, microclimate variations (i.e., conditions in the burrows), or contact with animals are influencing ectoparasite species composition and abundance (Krasnov et al. 1997, Gage 1999, Heeb 2000, Stanko and Miklisová 2002). Each encampment is several miles from each other, and we believe these are distinct populations of Norway rats with little to no migration between encampments.

## CONCLUSION

Norway rat control within the encampments is difficult, and routine trapping, while useful from a disease surveillance standpoint, is not a cost-effective means of rodent control within the camps. When rodent populations appear to be skyrocketing within an encampment, we conduct burrow baiting with Contrac pellets (Bell Labs, Madison, WI) to control populations. This can be labor intensive and requires coordination with encampment residents. We return 3-4 days post-baiting to pick up any carcasses. We also coordinate with City of Oakland and their Homeless Task Force, which coordinates city services at the various encampments. We try to time our efforts with when the city performs a garbage pick-up/closing down an of encampment so that we can do a last round of live-trapping or rats for disease surveillance. Once the trapping is completed, we will conduct suppression activities by baiting the burrows in order to prevent the rats from scattering into the surrounding neighborhoods. To date, this coordination with the city has worked well as the rats could be hungry from having their normal food sources removed (i.e., garbage and food waste from the camp residents) and so may readily consume the bait in the burrows.

More research is needed to determine what constitutes an "average" ectoparasite load on Norway rats associated with homeless encampments in the City of Oakland, and what factors may be contributing to the differences seen. By monitoring the changes in ectoparasite diversity and abundance, in conjunction with disease testing, we hope to be able to detect any potential disease outbreaks before they spread to one of the most vulnerable populations currently residing in Alameda County.

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