# Environmental Influences on Resource Collection Behavior on the UC Berkeley *Sciurus niger* Population

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## ABSTRACT

Fox squirrels (*Sciurus niger*) are prevalent on the UC Berkeley campus. Optimal foraging theory states that these squirrels will maximize their net energy input per unit time. To explore what factors affect this decision I investigated how the local environment affects the behavior of these squirrels via focal sampling and Geographic Information Systems (GIS). I examined the effects of local human density, proximity to food sources, and ratio of land-types to how often squirrels sought anthropogenic food sources as opposed to food typically found in their natural diet. I found that my metrics did not predict when how often squirrels scavenged. The biggest factor in squirrel scavenging was having a person directly feed the squirrel. This factor accounted for 78% of squirrel scavenging, and 23% of squirrel food consumption in my observations. This data does support optimal foraging theory, however not in the way I had anticipated. Although my metrics were invalidated this study could inform management decisions to decrease wildlife scavenging in urban environments. It is more effective for management to campaign the public to not feed wildlife than to prevent or restrict wildlife access to garbage according to my data.

## KEYWORDS

optimal foraging theory, scavenging, foraging, fox squirrel, anthropogenic

# INTRODUCTION

Urbanization has a broad influence on the environment. This is especially true where urbanization meets and mixes with nature, known as the wildland-urban interface. This interface encompasses 9.4% of the Continental US, or 38.5% of all housing units (Radeloff et al. 2005). It is known for its negative effects such as habitat loss, fragmentation, and decreasing species richness (Radeloff et al. 2005). Not all species are impacted negatively by the spread of the wildland-urban interface, however. Altered habitats favor disturbance-adapted species, and create niches in the ecosystem into which they can expand. Clumping of resources and the addition of new resources and habitats allows many small mammals to thrive in urbanized areas. For example, the fox squirrel (*Sciurus niger*) has been found to have larger population sizes in areas that are more heavily urbanized because of a decrease in predation and an increase of suitable nest areas (Bowers and Breland 1996). However the same factors that enable them to thrive in urban areas also lead to environments that promote the expansion of parasite ranges and infestation rates in small mammals (Friggens and Beier 2010). Decreased predation and increased resource clumping allow these mammals to live longer and in higher densities, which aides in parasite spread. Parasite loads double when resources are clumped because the animals scavenge much closer to one another (Wright and Gompper 2005). As *S. niger* are more prone to scavenge in urban areas (Bowers and Breland 1996), they are potential vectors for parasites and diseases. *S. niger* are known to transmit over thirty species of parasites (Graham and Uhrich 1943). This includes granulocytic anaplasmosis, a potentially fatal disease to humans and animals, which is transferred via ticks (Nieto and Foley 2008), and the West Nile virus, which may use *S. niger* as an amplifying host (Platt et al. 2008). As the wildland-urban interface expands there may be a greater risk of parasites and diseases carried by small mammals affecting human populations. In order to evaluate how small mammals may contribute to disease spread we must first gain a better understanding of how they utilize their resources in urban areas.

Whether *S. niger* choose to scavenge (seek food from human sources) or to forage (seek food from non-human sources) is likely determined by the principles of 'Optimal Foraging Theory'. Optimal Foraging Theory states that organisms seek to maximize their energy intake while minimizing the time and energy used to do so (Emlen 1966, MacArthur and Pianka 1966). *S. niger* has been found to follow this theory in its natural (non-urbanized) habitat. For example, a study of pinecone consumption by *S. niger* sought to determine if their foraging behavior followed prey value or patch value models closest. The study found that the squirrels followed neither model; they sought neither the largest cones, nor the trees with the highest cone density. Instead, they chose trees with the overall greatest food-energy value, determined by an optimum combination of cone size and cone density within a given tree. (Steele and Weigl 1992). How *S. niger* chooses to balance between scavenging from humans and foraging naturally is also likely determined by which method provides the most energy. A previous study found that *S. niger* scavenged approximately twice as often in "developed" areas containing human constructions compared to undeveloped areas without roads and buildings (Bowers and Breland 1996). Because anthropogenic food sources available to scavengers also tend to be clumped (e.g. trashcans) squirrel feeding decisions will also likely affect how clumped the squirrels are, and thereby affect the parasite concentration amongst them.

Optimal foraging theory is influenced by many factors. These include distribution of prey (patch value), prey characteristics (prey value), predation risk, and resource depletion (Steele and Weigl 1992). In this study 'distribution of prey' is the availability and density of human-sourced food compared to non-human food, areas with more people have a higher density of human-sourced food. 'Prey characteristics' is the energy supply in food sources, anthropogenic foods typically contain more energy per item than what a squirrel would forage for itself. Resource depletion is important because squirrels remove a finite number of supplies from non-human sources, while human sourced food is in constant supply. While all of these factors influence the decision to forage or scavenge it is not known how squirrels weigh these factors in comparison to each other and against threats in the anthropogenic environment such as cats, dogs, people, vehicles, etc… The strength of these factors will be influenced by how developed an area is. Comparing squirrel behavior to the local environment will allow the relative influence of these factors to be examined.

This study seeks to examine how squirrel feeding behavior is related to the local environment. I will determine if there is a stronger statistical association between squirrel scavenging behavior and the development of an area, number of food sources near an individual, or the number of people near an individual. By taking samples from UC Berkeley I will get subjects from both developed areas, with a large density of people at the site, and non-developed areas with less trafficked terrain. This allows for a wide spread of local environment matchups to be made. I will examine how the proportion of scavenging to foraging behaviors in fox squirrels relates to: 1. land use within 10m, 25m, and 50m of the subject; 2. average number of people within 25m of the subject; and 3. number of trashcans within 10m, 25m, and 50m of the subject. I will compare all of these metrics to the percent of scavenging done by the individuals that I track. I hypothesize that urbanization will have a stronger statistical significance to squirrel scavenging than human density or trashcan proximity.

## METHODS

### Study species

The fox squirrel, *S. niger*, was introduced around 1904 in Southern California from the Mississippi Valley and has since spread into Northern California (King 2004). Though *S. niger* historically inhabited the interface between deciduous forest and prairie they are now common in urban and suburban areas (King et al. 2010). They are communal nesters and have litter sizes of 2-3 individuals. Their density depends on habitat quality and fluctuates widely between 5/$km^2$ to 510/$km^2$ (Edwards et al. 2003). *S. niger* has replaced the gray squirrel (*Sciurus carolinensis*) in Berkeley and the Berkeley Hills. It subsists on nuts, berries and insects in a natural environment. However cohabitating with humans allows the fox squirrel to also diet on anthropogenic food sources, acquiring discarded food and handouts from the human population.

### Study area — UC Berkeley

The University of California, Berkeley campus in Berkeley, CA contains a mixture of urban and park-like terrains and roughly 104 buildings across ≈ 1 $km^2$. Nearly all of these are used on a regular basis for classes, while there are a few storage structures as well. There are around five parking areas on campus, half of which are below ground. It has a eucalyptus grove, a stream, and deciduous and evergreen trees throughout its terrain. The campus has 35,000 students enrolled. Foot traffic on campus is heaviest when classes get out between 9AM and 5PM. Students prefer walkways compared to grass areas when walking through campus because the grass is watered daily. Students avoid the wet ground and mud.

*Determining study site*

This location was chosen so I could compare a gradient of relatively high human-use factors to areas with fewer human-use factors. I broke the area into ≈ 30, 35,000m$^2$ quadrats; which were each sub-divided into 4, 9,000m$^2$ grids. This was done so that I could search a large grid easily by parsing the smaller grids systematically. I sampled quadrats with replacement using a random number generator to prevent selection bias.

**Study execution**

I used a replicable method for every subject I recorded data for. In order to gather data I travelled to the center of my randomly selected quadrat and looked for a subject there. I sampled the first subject I found, and recorded the number of other squirrels in the area. If no subjects were found I would count the number of people in the grid and record this. I would repeat this process in the next sub-grid clockwise within the larger grid. This process continued until either a subject was found or the larger grid was parsed. Upon determining my target subject, I began recording its scavenging and foraging occurrences and used an atomic clock to record the start of my 30-minute observation period. I also recorded the number of people 25m around the squirrel at the start, midpoint, and end of the observation period. I did this over three time periods to increase the accuracy of my human density average around my study subject. I did this 25m from the subject because I did not have enough time to do this at all three distance measurements while observing the subject, so I chose the middle metric. In addition to my behavior measurements I also recorded the time, date, location of subject within the quadrat, and the path the subject took during the 30-minute period. In the event that the subject was lost another subject would be found, restarting the process.

**Behavioral measurements**

I recorded each instance of scavenging (acquiring food from human sources) and foraging (acquiring food from natural sources) to quantify squirrel behavior. For a squirrel to have acquired food it must successfully obtain a food source, searching was not counted. Using focal observation methods (focusing on one subject and recording its behavior for a time period) I noted each occurrence of a behavior regardless of how long each action took. I chose to examine instances of actions rather than a by-time analysis because movement could not be differentiated between the intention to scavenge and intention to forage. I also took note of human interactions with my study subjects. I recorded when humans directly interacted with my subject by touching or feeding them. I also recorded indirect interactions. Indirect interactions were classified by human presence that was not direct, but still altered behavior. This includes frightening the squirrels, or otherwise disrupting their action; taunting or tempting the squirrels with food; and distracting them from their action.

### Data analysis

I analyzed the relative rates of scavenging and foraging against human-use factors to determine if there was a correlation between the two. The human-use factors I considered were: 1) Percentage of developed vs. undeveloped land around the subject, and 2) Number of people around the subject, and 3) Number of trashcans around the subject. These metrics were considered within 10m, 25m, and 50m of the subject using ArgGIS, expect for number of people which was only measured at 25m. I used regression analysis and ANOVA to determine if my metrics predict the percentage of scavenging done by an individual with statistical significance.

## RESULTS

Of the UC Berkeley campus study area that I used for sampling 96% of it was developed. Across the UC Berkeley campus there are ≈400 trashcans. Only 13% of my squirrel grid searches netted a subject to observe. Of these observations 30% of the food consumed was due to scavenging, 78% of this scavenging was from direct feeding leaving 6% of squirrel food consumption due to squirrels seeking dropped or discarded anthropogenic foods.

### Statistical analysis

I used linear regression to determine how well each metric predicts the percent of food consumption attributable to scavenging. I also used ANVOA to compute the p-values. This data can be found in table 1.

**Table 1. $R^2$ and p values of study metrics relating to percent food scavenged.** Statistics calculated using StatPlus, a statistics program for Mac Excel 2011.

| | # Trashcans | | | % Developed | | | # People |
|---|---|---|---|---|---|---|---|
| | 10m | 25m | 50m | 10m | 25m | 50m | 25m |
| Regression $R^2$ Value | 0.05953 | 0.25442 | 0.00395 | 0.02509 | 0.00231 | 0.0012 | 0.00163 |
| ANOVA p-value | 0.49694 | 0.13709 | 0.8631 | 0.66205 | 0.89509 | 0.92437 | 0.91184 |

## DISCUSSION

The objective of this study was to determine how fox squirrel scavenging behavior is predicted by various metrics. However none of my metrics predicted scavenging behavior. None of my p-values approached $p < 0.05$. Neither the percentage of developed land within 10m, 15m, or 25m, the number of trashcans within 10m, 15m, or 25m, or the number of people within 25m of the subject had a discernable influence on how often squirrels chose to scavenge. Though unanticipated, this finding is explainable with my data.

### Direct interactions

I had originally anticipated human interactions with squirrels to create outliers in my data, data that would otherwise have a clear trend showing my metrics predicted the percentage of scavenging done. Instead I found that my metrics do not have any influence over scavenging behavior. However my data clearly shows that direct feeding by people is the primary contributor to squirrel scavenging. Of my scavenging occurrences 78% of them were due to direct feeding. This is because squirrels net the most anthropogenic resources not from anthropogenic areas, but from the people themselves.

Elements of this idea are supported by Wojcik's study with bees (2012). I found scavenging was best predicted by someone handing out food, or 'a high-density food source'. Squirrels sought out these high-density food sources regardless of what metrics it fell into. Likewise Wojcik's bees travelled to locations with the highest resource density regardless of how populated or urbanized the area was. They were optimally foraging at the highest resource patches available. For UC Berkeley squirrels optimal foraging theory seems to dictate that unless someone is handing out food, it is more efficient to forage. When someone began to hand out food, it would attract all of the nearby squirrels. Every time someone was feeding my subject there were other squirrels also being fed.

**Parasitism**

While Wright and Gompper used dumpsters and trashcans as their anthropogenic food sources to show parasite loads double when animals scavenge (2005), the same idea is applicable my study. Although the squirrels I observed did not scavenge from trashcans or other food sources, they still clumped around people who were distributing food. This provides the same risk of doubling parasite loads and increasing parasite spread. In fact the proximity to people who are feeding the squirrels makes this risk more dangerous to the human population. In my observations I saw squirrels climb onto the belongings of, and get within inches of people. There were a few cases in which squirrels climbed onto students too. This condition is worse for parasite spread than if animals were merely clumped amongst themselves. Because feeding squirrels on campus has become a normalized activity there is an increased risk of parasite spread to the human population.

**Optimal foraging theory**

Though my metrics did not predict the behavior of UC Berkeley squirrels in any significant way the underlying ideas behind my hypothesis are still valid. It is established that even micrometer-sized animals alter their behavior in order to maximize their net energy intake (Kiørboe 2013), it would be surprising if squirrels behaved differently. My study suggests that scavenging directly from people is the most energetically efficient way to scavenge. This behavior is unique to squirrels because they are particularly endearing to the student body. However, if people were to stop directly feeding squirrels it is likely that squirrels would begin to scavenge from indirect anthropogenic food sources, rather than abandon them all together. There are several studies involving different bird species that show animals in anthropogenic environments are prone to scavenge from anthropogenic food sources (Brousseau 1996, Fleisher 2003, and Kristan 2004). The difference between these birds and the squirrels of my study is that squirrels are generally recognized as cute, and therefore people are drawn to feed them. Whereas gulls and ravens are typically seen as pests by people. This is the factor that separates the indirect scavenging of birds from the direct feeding of squirrels.

**Limitations**

The chief limitation for my study is that I examined a species that is prone to being directly fed by people. It is likely that my metrics are applicable in cases where it is not optimal for the study species to seek direct human feeding. However despite contradicting the hypothesis of my study, I still found interesting information regarding *S. niger*.

**Future directions**

Moving onward from this study, future research could be done on another squirrel population, however this time on a population that was not receiving direct handouts from people. It would be interesting to see how squirrel scavenging behavior changes when they are no longer receiving food directly from humans. It is likely that they would fall in line with other animal populations and begin scavenging from trash and other sources. It would be interesting to compare scavenging behavior between a fed squirrel population, an unfed squirrel population, and another species in the same areas.

**Broader implications**

My study suggests the importance of curbing human feeding of wild populations. If humans are feeding wild populations it is futile to try and restrict access to trash containers and other food sources. This result can inform park management on the importance of distributing educational materials to not feed wildlife. Not only does feeding wildlife increase the risk of parasite spread between animals, but it also increases the risk of parasite spread to people. When humans are actively feeding wildlife it brings the people into the same proximity to the animals that allows parasite loads to double between animals.

**Conclusion**

Although this study missed its original goal to produce metrics that could be used to estimate squirrel scavenging behavior, it did reveal information about squirrel scavenging behavior. This information can be used in further studies to learn more about wildlife scavenging behavior in anthropogenic environments. It can also be used to inform wildlife management decisions.

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