

# COMPARISON OF THE THERMOREGULATORY BEHAVIORS AND HABITAT PREFERENCES OF TWO CRYPTIC SKINK SPECIES (*EMOIA IMPAR* AND *EMOIA CYANURA*) IN MOOREA, FRENCH POLYNESIA

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**Abstract.** Climate change and human land use are changing thermal ranges around the world. To investigate the effects of changing thermal ranges, this study looked at two cryptic species of skink, *Emoia impar* and *Emoia cyanura*, in Moorea, French Polynesia, which are suggested to act as a thermal specialist and a thermal generalist, respectively. This study sought to analyze differences between the two species in terms of preferences for thermal, sunlight, and substrate heterogeneity. Analysis of the behaviors of both species was also conducted. No statistically significant preferences for certain thermal ranges, sunlight distributions, or substrates were found. Furthermore, a lack of statistically significant differences between preferences and behaviors of the two species were found, indicating that the *E. impar* and *E. cyanura* do not act as thermal specialists or generalists in the study site. The results of this study suggest that climate change and land use may affect the two species similarly.

**Key words:** *skinks; Emoia; habitat preference; behavior; thermoregulation; thermal range, thermal heterogeneity; French Polynesia; climate change; human land use*

## INTRODUCTION

Human-induced environmental change such as human land use and climate change are altering habitats globally. Climate change is an increasingly alarming issue that is not only changing temperatures all over the world, but affecting the distribution of those temperatures (Walther et. al 2002). Human land use such as the clearing of forests exacerbates issues arising with changing thermal ranges by destroying habitats, often resulting in more thermally homogenous areas. Both land use and climate change stand as the two biggest threats to biodiversity today, changing habitats and further pushing organisms to their limits of survival (Bellard et. al 2012). Furthermore, forests, as houses of extensive biodiversity, are among the worlds most modified ecosystems, shaped by both human and climatic disturbances (Hansen et. al 2001). As a result of such human led environmental change, animals are constantly faced with altered or lost habitats and so, must adapt to the changing environment to survive.

Reptiles, ectothermic organisms that align their body temperatures closely to the ambient temperature of the environment (Huey and Slatkin 1976, Grant and Dunham 1988), are profoundly affected by temperature and habitat changes that climate change and anthropogenic activity create. Due to their

thermal sensitivity, reptiles are often among the first organisms to feel the effects of environmental changes (Huey et. al 2012). The study of reptiles can give insight to how organisms may be affected by thermal changes in their habitats.

As reptiles do not rely much on internal processes to thermoregulate, they often thermoregulate behaviorally, physically moving to thermally different areas to change their internal temperatures (Sunday et. al 2014). Through such thermoregulation, reptiles can keep their bodies at their preferred temperature ( $T_{pref}$ ) or even their optimal temperature ( $T_{opt}$ ), the temperature at which their bodily functions and physiological performance are maximized (Angilletta et. al 2002). However, such thermoregulatory behavior such as sunning, burrowing, and shuttling have costs in terms of locomotion, exposure to predation, and other interspecies and intraspecies interactions (Huey and Slatkin 1976, Grant and Dunham 1988, Adolph 1990, Buckley et. al 2015). Thus, we assume that when a reptile engages in a thermoregulatory behavior, it is because the physiological benefits of being at a certain temperature outweigh the physiological and ecological costs (Huey and Slatkin 1976). The resulting temperature is the balance between seeking  $T_{opt}$  and the various ecological constraints a habitat may present (Huey et. al

1987). Due to this understanding of reptilian thermoregulation and behavior, reptiles provide a good model for monitoring temperature changes and their associated physiological and behavioral effects on organisms affected by climate change and continued human interference with natural habitats (Huey et. al 1987).

As with other ecological constraints over evolutionary time, reptiles may be selected to be thermal specialists or thermal generalists. It is suggested that this deviation in thermoregulatory strategies is a result of species partitioning into more homogenous or more heterogeneous habitats (Kassen 2002). Thermal specialists tend to inhabit areas with low thermal variance, allowing them to concentrate their thermal breadth within narrow values. In contrast, thermal generalists often live in more thermally variable habitats that select for organisms that can be active at a wide range of temperatures (Gilchrist 1995). The ecological constraints these strategies introduce are believed to be offset by the benefits these strategies may provide which can include increased resource allocation and decreases in energetic cost (Angilletta et. al 2003). Both thermoregulatory strategies have different costs and benefits and allow for species that live in the same areas so partition resources accordingly.

*Emoia impar* and *Emoia cyanura* are two sympatric, cryptic skink species on the island of Moorea, French Polynesia. The two species can be distinguished from one another by tail color, presence of mid-dorsal scales, and presence of a parietal eye (Ullrich 2013, McElroy 2014). Since their recognition as different species, many studies have looked at how these two species differ and interact. Previous studies have found that *E. impar* prefers closed canopy habitats while *E. cyanura* prefers more open spaces. Furthermore, studies have found that the two species have different preferred temperatures, somewhat accounting for the niche partitioning between the species. Additionally, studies suggest that *E. impar* acts as a thermal generalist, while *E. cyanura* acts as a thermal specialist (McElroy 2007).

The present study looked to see if *E. impar* acts as a thermal specialist and if *E. cyanura* acts as a thermal generalist in the forest on Moorea, and if those qualities affect how they partition their habitat in terms of thermal and substrate heterogeneity. More specifically, the present study hypothesized that *E. cyanura*, the species thought to act as a thermal

generalist, would prefer more heterogeneous areas that would allow it to better engage in thermoregulatory behaviors. The goal was to investigate the thermoregulatory behaviors of both species in the field to gain insight into how these organisms use their habitats and how they may behave differently in habitats changed by climate change and human activity in terms of habitat heterogeneity.

## METHODS

### *Study site*

All research was conducted on the island of Moorea, French Polynesia. Field observations were conducted in the tropical forest on the UC Gump Station property (Fig. 1) and all observations occurred between daylight hours of 0700 and 1700 in order to observe all daylight hours. This site was chosen as it contains a human created cement walkway that cuts through the dense forest, allowing for study of human impacted areas and more natural areas.

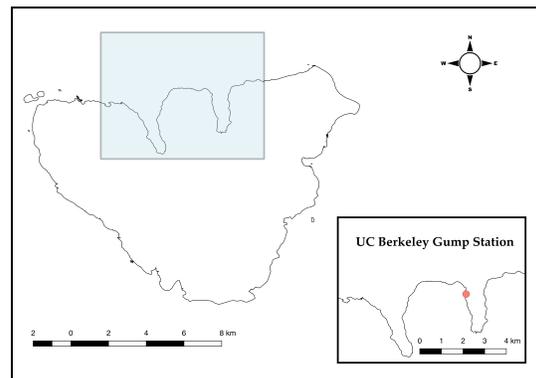


Fig. 1. Map of UC Berkeley Gump Station, courtesy of the Geospatial Innovation Facility, University of California, Berkeley.

This research focused on two species of skinks: *E. impar* and *E. cyanura*. The two species were distinguished by tail coloration and the presence of mid-dorsal scale fusion and parietal eyes (Bruna et. al 1995). Temperature readings throughout the study were taken using an infrared laser thermometer (Extech Instruments, Mini InfraRed Thermometer with Laser Pointer, Model 42500).

### *Density and Habitat Survey*

Skink density of both species in the forest on UC Gump Station was measured through transects. Transects extended from 7 meters inside the walkway gate and upwards to 127 meters away from the gate, encapsulating ~120 m of the adjacent forest. Along this 120 meter transect extending along the side of the forest, perpendicular transects were spaced every 15 meters to minimize disturbing the skinks in the nearby areas. Furthermore, the perpendicular transects extended 10 meters into the forest, allowing for the survey to cover a gradient of habitat from more human impacted into the dense forest. The width of the transect included 1 meter on each side of the transect tape, for a total area of ~20 m<sup>2</sup> surveyed at each perpendicular transect. Within this survey area, the light environment was characterized as 100% sun, 100% shade, mostly sun (i.e., >80% sun), mostly shade (i.e., >80% shade), or mixed. Mixed refers to a transect of any other proportion of sun and shade. At each transect, the number of each species of skinks was counted and their locations along were noted. At each location of the transect where at least once skink was found, a .65 meter by .65 meter quadrat was placed. At each quadrat, percents of shade, sun, and of each substrate were noted. Substrates included soil, leaf litter, wood, rock, coconut, palm frond, and green plant. The thermal range of each quadrat was measured by measuring the thermal minimum and maximum with a temperature gun. Finally, the distance of each quadrat from the walkway was recorded. Transects were repeated 9 times, including at 0700, 0900, 1100, 1300, and 1500, and on both sunny and shady days. Surveys over the course of the day and on sunny and shady days allowed measurements under different light and thermal conditions.

### *Behavioral observations*

Behavioral observations were conducted within the daylight hours of 0700 and 1500 within the same area as the forest transects. The habitat was surveyed by walking along the 120 m transect on both sides, looking for skinks both by eye and with binoculars. Once a skink was spotted in the habitat, their species was noted using the same distinguishable characteristics as used when conducting the transects. Behaviors were recorded during a two minute period. The

skinks were extremely cautious, and so two minutes allowed for adequate observation of behaviors without raising suspicion and scaring the skink. Behaviors recorded included sunning, resting in the shade, moving between areas, interspecies interactions, and intraspecies interactions. To be classified as sunning or resting, the behavior had to occur for at least 5 seconds to ensure that the behavior was intentional and not an act in passing of another action.

### *Substrate testing*

The various substrates that the skinks were found on during the forest transects were measured for heating and cooling rates. These included soil, leaf litter, wood, rock, coconut, palm frond, and green plant. Each substrate was measured for initial temperature and then was placed in direct sunlight for 10 minutes. With the temperature gun, substrate temperature was measured every two minutes. At the end of 10 minutes, the substrate was then moved under the shade, and temperature was again recorded every two minutes for 10 minutes.

### *Statistical analysis*

All statistical tests were performed with RStudio (Version 1.0.153, 2009-2017 RStudio, Inc.) The relationship between number of skinks found and percentage of shade was analyzed through regression. The relationship between skink presence and thermal range was also analyzed with regression. Analysis of variance (ANOVA) tests were used to analyze differences in thermal and substrate preferences (two-way ANOVAs) between the species, as well as behavioral differences and distance from the walkway (one-way ANOVAs) between the species.

## RESULTS

### *Sunlight heterogeneity*

The regression testing the relationship of number of skinks by percentage of shade suggested that the skinks have no preference for a certain percentage of shade ( $R^2 = 0.005552$ ,  $p > 0.05$ ). The two-way ANOVA results indicated that there was no statistically significant difference of preference between *E. impar* and *E. cyanura* ( $F_{1, 8} = 1.6964$ ,  $p > 0.05$ ). Both results are illustrated in Fig. 2.

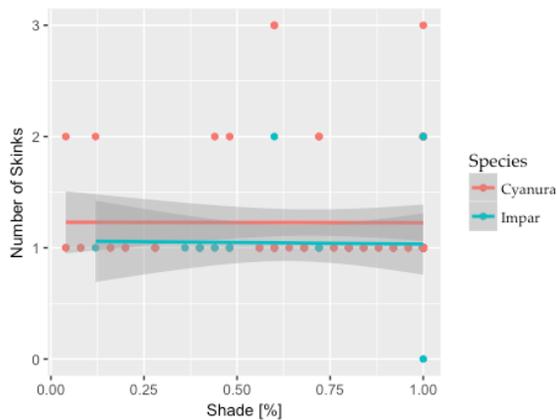


Fig. 2. Scatter plot of number of both skink species by percentage of shade.

However, the average number of skinks was highest in “Mixed” transects (Fig. 3). Furthermore, no skinks were found in transects that were 100% sunny.

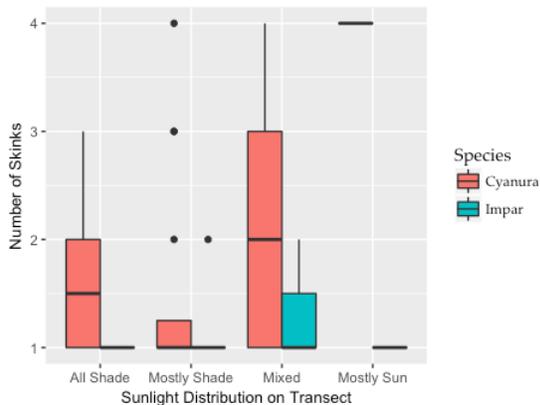


Fig. 3. Average number of skinks of *E. cyanura* (red) and *E. impar* (blue) found per type of transect distinguished by percentage of shade.

#### Thermal preferences

The regression test relating the number of skinks to an increasing thermal range showed no statistically significant preference for any particular thermal range ( $R^2 = 0.006067$ ,  $p > 0.05$ ). The results of the one-way ANOVA showed no statistically significant difference between species ( $F_{1, 38} = 1.271$ ,  $p > 0.05$ ) in preference for a specific thermal range (Fig. 4).

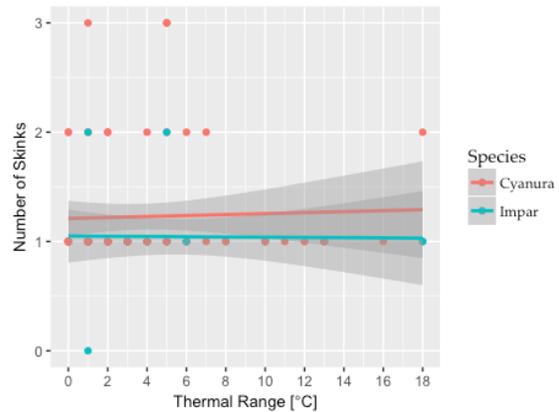


Fig. 4. Scatter plot of number of both skink species by thermal range [°C].

Furthermore, another ANOVA was used to analyze if the two skink species preferred different average temperatures (Fig. 5), and no statistically significant difference in thermal preference between *E. impar* and *E. cyanura* was found ( $F_{1, 38} = 1.2805$ ,  $p > 0.05$ ).

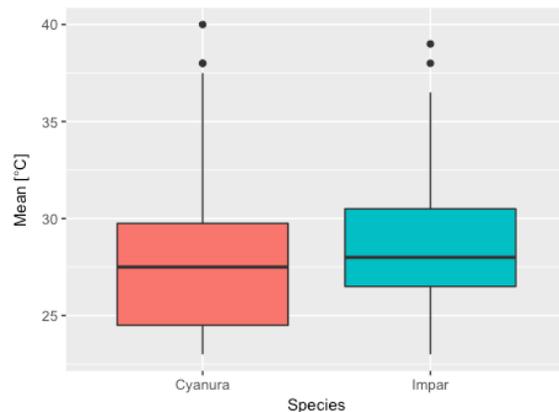


Fig. 5. Average temperatures [°C] *E. cyanura* (left) and *E. impar* (right) where found in forest transects.

#### Substrate Heterogeneity

Data regarding substrate composition of locations of the skinks in the forest transects was analyzed through a one-way ANOVA, seeing if the different species had different substrate preferences. There was no significant difference in skink preference for soil ( $F_{1, 38} = 1.32$ ,  $p > 0.05$ ), leaf litter ( $F_{1, 38} = 0.017$ ,  $p > 0.05$ ),

wood ( $F_{1,98} = 1.186$ ,  $p > 0.05$ ), rock ( $F_{1,98} = 0.143$ ,  $p > 0.05$ ), coconut ( $F_{1,98} = 2.054$ ,  $p > 0.05$ ), palm frond ( $F_{1,98} = 0.034$ ,  $p > 0.05$ ), or green plants ( $F_{1,98} = 0.387$ ,  $p > 0.05$ ).

#### Distance from walkway

Skink density per species from the walkway into the forest was plotted (Fig. 6 and Fig. 7). Both figures show an aversion to the walkway. The shortest distance a skink was found from the walkway was 2.11 m. On average, *E. impar* was 6.072609 meters away from the walkway, *E. cyanura* 5.176933 m away. The one-way ANOVA tests showed this to be a statistically significant difference between the species ( $F_{1,98} = 4.5599$ ,  $p \leq 0.05$ ).

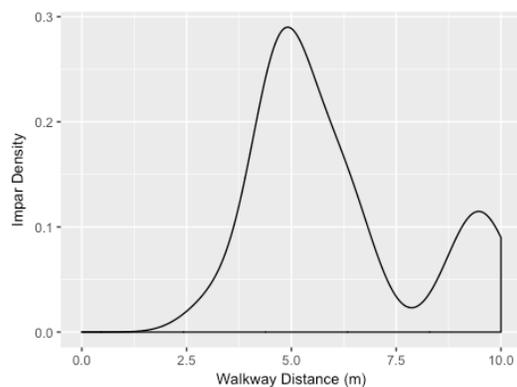


Fig. 6. Density of *E. Impar* plotted by distance (m) from the walkway.

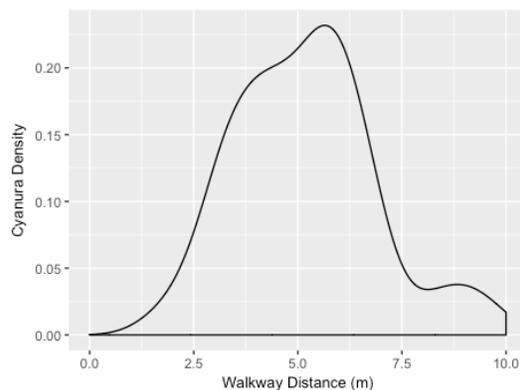


Fig. 7. Density of *E. Cyanura* plotted by distance (m) from the walkway.

#### Behavioral analysis

Results from the analysis of the behavioral data showed no significant difference between the two species for sunning ( $F_{1,98} = 0.001$ ,  $p > 0.05$ ), resting in the shade ( $F_{1,98} = 0.005$ ,  $p > 0.05$ ), or for moving between areas ( $F_{1,98} = 0.025$ ,  $p > 0.05$ ). However, significant differences were shown for sunning ( $F_{1,98} = 17.176$ ,  $p \leq 0.001$ ) and resting in the shade ( $F_{1,98} = 19.861$ ,  $p \leq 0.001$ ) for all skinks on sunny days compared to shady days. There was no significant difference in the skinks moving between areas on sunny compared to shady days ( $F_{1,98} = 2.886$ ,  $p > 0.05$ ). No interspecies or intraspecies interactions were observed. Furthermore, skinks were observed to be sunning on only leaf litter, rock, and wood substrates.

#### Thermal properties of substrates

The heating and cooling rates of all of the substrates the skinks were found on (Fig. 8) showed leaf litter, palm frond, and coconut, and green plant to be the most thermally responsive substrates, heating and cooling rapidly. In contrast, soil, rock, and wood lost heat at more gradual rates than the other substrates.

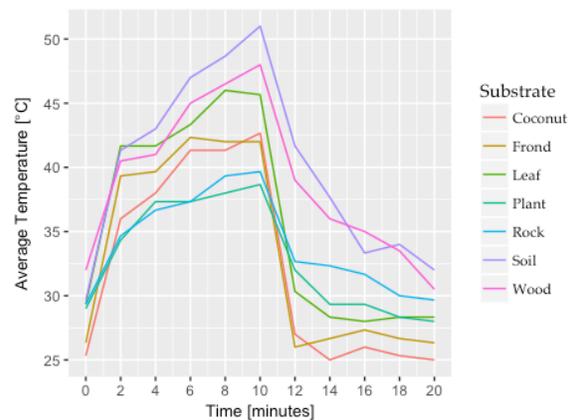


Fig. 8. Heating and cooling rates of the substrates skinks were found on in the forest

## DISCUSSION

#### Sunlight heterogeneity

The regression test for number of skinks by percentage of shade showed no statistically significant preference for a certain percentage

of shade, suggesting that the skinks have no preference for sunlight heterogeneity. Additionally, the ANOVA that showed no statistically significant difference between the species for shade preference indicates that both species acted similarly within this study. However the box plot (Fig. ???), shows that on average, more skinks were found in areas of mixed sunlight than any other distribution of sunlight. Additionally, the complete absence of skinks in areas that were completely sunny suggests that there is still a trend of skinks found in areas with sunlight heterogeneity rather than areas without. While no statistic significance was found in skink preference for sunlight heterogeneity, Figure ??? still shows visible trend of skinks choosing areas of mixed sunlight. The lack of statistical significance in the tests may be due to a small sample size.

#### *Thermal preferences*

No preference for a certain thermal range was found for either species of skink, meaning that there is both no thermal range preference and no difference between the species. This result indicated that though previous literature has suggested that *E. impar* acts as a thermal specialist and *E. cyanura* acts as a thermal generalist (McElroy 2007), they do not partition their habitat by thermal range the way a thermal generalist species and thermal specialist species would be predicted to. This finding could be the result of a small sample size. Alternatively, it may also be a result of the two species not acting as a thermal generalist and a thermal specialist under the specific ecological constraints of the habitat this study looked at.

#### *Substrate Heterogeneity*

Similar to the thermal range and sunlight heterogeneity results, the substrate heterogeneity tests indicate that the two skink species have no differences in substrate preference. This result further suggests that the two species share space in their habitat and that *E. cyanura* does not seek more habitat heterogeneity than *E. impar* does.

#### *Distance from walkway*

The data and statistical tests regarding skink presence in relation to distance from the walkway showed that all skinks stayed at least 2.11 m from the walkway, and that *E. impar*

and *E. cyanura* averaged a distance away from the walkway of 6.072609 m and 5.176933 m respectively. The statistically significant difference in these distances between species may be due to a larger population of *E. cyanura* in the forest on UC Gump Station, as no preference for thermal, sunlight, or substrate homogeneity or heterogeneity between species was evident from the data and analysis. Alternatively, these distances may indicate less of an aversion to the walkway as a homogenous environment, but rather a reflection of the skinks avoiding a high-traffic human area.

#### *Behavioral analysis*

Analysis of the behavioral data suggests that the two species behave similarly to one another, exhibiting similar proportions of time spent engaging in thermoregulatory behaviors such as sunning. However, there were statistically significant differences in skink behavior depending on sunlight conditions. Skinks of both species displayed markedly larger proportions of time sunning on sunny days than on shady days, and prominently more time resting in the shade on shady days than on sunny days. Time spent moving between areas showed no statistically significant difference between days of different sunlight conditions. Such results could mean that *E. impar* and *E. cyanura* behavior and activity could be affected with changing weather conditions affecting the numbers of shady and sunny days.

#### *Thermal properties of substrates*

The thermal properties of the substrates the skinks were found on may help to greatly explain skink thermoregulatory behavior. During behavioral observations, skinks were often seen running into patches of sunlight, often on soil, leaf litter, rock, and wood. Soil and leaf litter likely attract the skinks when sunlight appears, as these substrates were among the most responsive substrates to heating by sunlight. Such sunning on soil and leaf litter upon emergence of sunlight was observed during the behavioral survey. Rock and wood are likely attractive substrates due to their greater heat retention compared to the other substrates tested. This is consistent with observations of the skinks often choosing to bask on rock and wood, especially during times when the sun would come and go. Basking on rock or wood allowed the skink to

continue raising its body temperature for minutes after the substrate had been exposed to sunlight. Thus, the thermal properties of the substrates the skinks were found on provide a strong explanation for *Emoia* substrate choices.

### Conclusion

Overall, it was found that *E. impar* and *E. cyanura* do not act as skinks with differing thermoregulatory strategies in the forest of the UC Gump Station, indicating that climate change and land use may affect both species similarly. This was shown in the lack of statistically significant differences between the two species in terms of thermal, sunlight, and substrate preferences. The two species were also shown to deviate from the predicted thermal specialist and generalist models in their similar behavioral patterns. It is then suggested that the two skink species do not act as a thermal generalist and specialist in this habitat, and do not partition this habitat based on habitat heterogeneity. The two species may have been found in similar temperatures and thermal ranges as a result of ecological constraints and selective pressures such as resource allocation and predation that may have shifted their preferred temperatures  $T_{pref}$  away from their respective optimal temperatures  $T_{opt}$ . Though a lack of statistical significance resulted in analysis regarding habitat heterogeneity, more skinks were found in areas of mixed sunlight on average, and so it can be inferred that sunlight and thermal heterogeneity may still play a large role in creating suitable skink habitats.

Climate change and land use may ultimately render currently habitable skink habitats unsuitable, by altering substrate composition and reducing thermal and sunlight heterogeneity. This is reflected by the relationship between skink thermoregulatory behavior and substrate thermal properties as well as the existence of a visible trend of skinks choosing areas of mixed sunlight. Additionally, if the skinks did avoid the walkway because of its constant human presence, human land use would introduce increased human traffic in previously undisturbed habitats, driving skinks away. Further studies regarding effects of climate change and land use on habitat heterogeneity, along with investigation on how habitat heterogeneity affects *Emoia*, would help further predict skink responses to habitat modification as a result of anthropogenic

action. Studies regarding organismal behavior in urban settings would also give more insight to organismal responses to increasingly human impacted habitats. Such understanding of organismal responses to habitat change would help humans to better understand their effects on the environment and knowledgeably act to minimize the adverse effects of climate change and land use on habitats around the world and the organisms that inhabit them.

### ACKNOWLEDGMENTS

I thank everyone who came with me to the forest to ensure my safety and guard the quadrat including Chris Hernandez, Sarah Donelan, Kiranpreet Nagra, F. Dean Keck, and Tiara Drabble. More thanks go out to all of those who aided my study with their strength and agility, including those aforementioned above, Brent Humeston, Alexandra Howell, Annie Rosen, Makayla Arcara, Liz McAlpine, Charles Sawyer, Sky Poindexter, and Sachi Ihara. I want to extend appreciation to GSIs Audrey Haynes, Suzanne Kelson, and Caleb Caswell-Levy for their endless patience and guidance, no matter what time of day. I would also like to give a special thanks to Professors Vince Resh, Stephanie Carlson, Jonathon Stillman, and Brent Mishler for their knowledge, support, and constant encouragement throughout the semester. Thanks also go out to the UC Gump Station staff (Skippy, Trey, and Guinness included). Finally, thanks goes out to my family for helping make Moorea happen for me, and for their constant support despite the poor Wi-Fi.

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