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LAND-USE AND ANT BIODIVERSITY IN CALIFORNIA'S CENTRAL VALLEY

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LAND-USE AND ANT BIODIVERSITY IN CALIFORNIA'S CENTRAL VALLEY

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DEDICATION

This thesis is dedicated to my sister, Sarah Navarro. Sarah has been my biggest cheerleader and my best friend from the beginning. I hope to make you proud, sissy.

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Abstract

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The growing human population results in growing demand for land allocated to urban development and agricultural production (Godfray et al. 2010; Tilman et al. 2011; McDonnell and Hahs 2013; Alexander et al. 2015; Erlwein and Pauleit 2021). Changes to land allocation associated with agricultural and urban development will increasingly alter terrestrial ecosystems impacting biodiversity (Ricketts et al. 2001; McDonald et al. 2008). Ants are an ideal organism for monitoring changes in biodiversity related to land-use change due to their ubiquitous nature, high diversity, and their role as bioindicators. The goal of this study was to assess the diversity of the ant communities related to land-use change in the Central Valley, California addressing what factors may influence variability in the diversity of the ant communities. The results of this study showed that native taxa richness was highest in the natural sites and invasive taxa richness was highest in the urban sites. Temperature was not a major driver of changes in the diversity of the ant communities and an extended sampling period may provide more information seasonal effects on the ant communities. Sample method had the most impact on the estimated diversity metrics suggesting a multimethod approach is necessary to accurately characterize biodiversity. Pitfall trapping yielded the highest estimates of diversity due to the extended sampling period allowing for the collection of ants with different activity times. High variability among sample sites was observed in this study. Therefore, a larger sample size is recommended for future studies attempting to document the diversity of the ant communities in the Central Valley related to land-use change.

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CHAPTER 1: INTRODUCTION

The global human population is expected to continue growing and exceed 8 billion by 2030 (worldpopulationreview.com), which will drive an increase in the demand for food and housing (Godfray et al. 2010; Tilman et al. 2011; McDonnell and Hahs 2013; Erlwein and Pauleit 2021). In turn, there will be pressure on agricultural industries to increase food production, including increasing the allocation of land to agricultural production (Alexander et al. 2015). The growing agroeconomic demand for land is expected to further reduce natural habitats by 50% by the year 2050 in approximately 30% of the world's biodiversity hotspots (Habel et al. 2019). Simultaneously, demand for urban development is increasing, with as much as 80% of people in developed countries living in urban environments and the percentage of people living in urban areas is projected to continue to increase (United Nations 2018). The increase in the amount of people living in urban areas has brought on an increase in the size and number of cities globally (McDonnell and Hahs 2013). For example, in the United States from 1990 to 2000, over 1.4 million hectares of natural habitat were lost to urban development (McDonald et al. 2010). Thus, changes to land allocation associated with agricultural and urban development will increasingly alter terrestrial ecosystems.

Changes in land-use have altered global patterns of biodiversity (Ricketts et al. 2001, McDonald et al. 2008). Alterations to local biodiversity can change ecosystem services directly (e.g., by adding or removing species from the habitat) or indirectly (e.g., by modifying the behavior of the species that still inhabit the environment; Tilman et al. 2001). Ecosystem services are fundamentally important to humans, and they include decomposition, climate regulation, and air and water filtration. Yet, these services often go unacknowledged by humans (Daily 1997) even though they generate billions or trillions of dollars annually (Holzman 2012). Hymenopteran insects provide some of these services such as predation of harmful agricultural pests, crop pollination, and nutrient cycling (Kremen et al. 2002, Del Toro et al. 2012). To continue to experience the benefits of these services, we must maintain local biodiversity by better understanding animals; where they exist, what services they provide, and how susceptible they are to changes in land-use thus altering their habitat.

Ants are the most diverse and ubiquitous group of social insects, occupying and often dominating most terrestrial environments in which they preform three main functional roles (Lach et al. 2010; Del Toro et al. 2012). First, ants can regulate other animals in their communities by preying upon some groups while providing others with protection against predation (Del Toro et al. 2012). The aggression and predatory behavior of some ant species can impact the invertebrate biomass of an ecosystem, thus, ants can be used in agricultural practices for pest management (Kaspari et al. 2011; Choate and Drummond 2011). However, the mutual relationship between ants and some hemipteran insects allows for the proliferation of the hemipterans resulting in greater crop damage in an agricultural setting (Vega and Rust 2001; Wetterer et al. 2009). Second, ground nesting ants facilitate nutrient cycling, which is an important service to the overall function and health of an ecosystem (Del Toro et al. 2012). Through the formation of nests and the interactions with other soil fauna, ground dwelling ant species influence soil physical properties such as porosity and soil turnover (Briese 1982; Moutinho et al. 2003). For example, a higher rate of ant activity improved crop yield due to increased soil porosity after switching from till to no-till agricultural management (Evans et al. 2011). Further, ants can alter the decomposition rate of plant materials by preferentially selecting vegetation and altering the availability of certain environmental nutrients such as nitrogen (Wagner and Jones 2006, Ginzburg et al. 2008, Silva and Vasconcelos 2011). Third, ants promote plant proliferation as pollinators and seed dispersers (Gómez and Zamora 1992; Lengyel et al. 2010; Del Toro et al. 2012).

The ubiquity and diversity of ants makes them useful biological indicators of ecosystem functions and overall ecosystem health (Andersen and Sparling 1997; Andersen et al. 2002; Del Toro et al. 2012; Alroy 2017). Ant diversity predicts soil microbial biomass that helps plants take up nutrients thereby providing information related to plant succession (Andersen and Sparling 1997). Ant diversity mirrors the diversity of other insect groups in response to habitat disturbance, therefore, ants can be used to predict the response of other organismal groups to habitat disturbance (Alroy 2017). Ant communities can be susceptible to changes in landscape (Floren et al. 2001; Vonshak and Gordon 2015; Solar et al. 2016) and land-use changes associated with urbanization can impact ant community composition and lead to increased

invasive species distributions (Carpintero et al. 2003, Vonshak and Gordon 2015, Gippet et al. 2017). For example, the distance from buildings and impervious surfaces can be an influential anthropogenic environmental factor impacting ant distribution (Vonshak and Gordon 2015; Stahlschmidt and Johnson 2018). Additionally, land-use changes associated with agricultural land expansion alter ant communities due to reduced habitat structure, microclimatic range, and energy resources (Andersen 1995). Agricultural land-use intensification can lead to homogenization of ant communities through the loss of species that rely on resources provided by native vegetation (Ng et al. 2021). As the rate of urbanized and agricultural land expansion increases, it is essential for conservation biologists to determine the factors most influential to native and invasive ant species distributions. Therefore, ants have an increasing importance as bioindicators in the assessment of ecosystem health in the face of climate change and increasing anthropogenic disturbance to terrestrial environments (Hölldobler and Wilson 1990; King et al. 1998).

California's Central Valley is an agricultural region producing approximately one quarter of the nation's food, including nearly half of the nation's production of fruits and nuts, and eight percent of the nation's agricultural output (ca.water.usgs.gov). The Central Valley has undergone significant expansion and intensification of urbanized and agricultural land at the expense of wildlife habitat due to an increase in the human population (Matchett and Fleskes 2017). For example, in the San Joaquin County from 1992-2016, there was over 28,000 acres of natural land converted to urban and agricultural development (https://sjcog.org/). The intense changes to the terrestrial environment resulting in diminishing natural habitat in the Central Valley are cause for more conservation efforts, including monitoring biodiversity of organisms susceptible to habitat disturbance. Yet, there has not been any attempt to understand the diversity of the ant community within the Central Valley as it relates to land-use (e.g., natural, agricultural, and urban).

To better understand ant diversity in the Central Valley and how it interacts with land use, ant communities were sampled in various types of land-use and human disturbance. Based on previous findings (Vonshak and Gordon 2015), the prediction was to find a higher abundance and richness of native taxa in the natural land-use type and abundance and richness of non-native taxa to be higher in the urban and

agricultural land-use types. More generally, the prediction was to find high taxa richness of both natives and non-natives in the urban sites where non-natives are introduced, and some natives have adapted (McDonnell and Hahs 2013). Different sample methods were predicted to yield different results. Pitfall trapping was predicted to yield the highest number of taxa and highest individual abundance of those taxa collected due pitfall trapping introducing the least amount of bias with its extended sampling period. Based on previous studies, ant activity has been shown to be highest during the summer months (July through early September, Vonshak and Gordon 2015). Thus, limited variability in temperature or ant activity between the sample replicates in this study was predicted. This research will be the first to describe how diversity in the Central Valley's ground dwelling ant communities is affected by land-use change, these results will inform future decisions related to anthropogenic environmental impact.

CHAPTER 2: METHODS

Study Sites

This study repeatedly sampled 15 sites across three land-use types (natural, urban, and agricultural) within 46 square kilometers in the San Joaquin and Sacramento counties within the Central Valley of California (Fig. 1 and Table 1). The sampling took place during the ants' active season in the months of June through September (Vonshak and Gordon 2015, Johnson and Stahlschmidt 2020). Sample sites (n=5 sites per land-use type) were a minimum of 0.75 km apart (Fig. 1). At each site, five sample plots were positioned, and each sample plot was 5 m², which is an effective plot size for surveying ground-dwelling ants (Agosti et al. 2000). The five plots at each site were a minimum of 25 m apart (Laub et al. 2009). Sampling occurred between 7:00 to 13:00 PST. Each site was sampled approximately once per month from June through September 2021 for a total of four sample replicates at each site. Three different methods of sampling were used to ensure minimum sampling bias in diversity analysis (see Sampling Methods below).

Land-use types were determined by each of the site's dominant plant type. Natural sites were dominated by oak trees and native grasses, agricultural sites were predominantly composed of grape vines, and urban parks contained large fields of cultivated lawn. Oak-grass savanna sites were used to represent natural sites characterizing the least amount of anthropogenic disturbance. The natural sites were located in ecological/nature reserves that were inaccessible to the general public and a minimum of 20 m from paved roads (Fig. 1, Table 1). Mowing, irrigation, or any other land management practices did not occur in the natural sites during the entire sampling period. Public residential parks within the city of Lodi, CA were selected to represent urban sites (Fig. 1, Table 1). Plots at parks had over 50% ground cover, and were immediately adjacent to paved roads, sidewalks, and buildings. In each park, mowing occurred weekly and sprinkler irrigation occurred several times per week. Lodi Rules certified grape vineyards represented agricultural sites (Fig. 1, Table 1) and the Lodi Rules sustainable certification program promoted consistency among the agricultural sites. For example, vineyards included in this study utilized

mechanical tilling, drip irrigation, cover crops, and followed the restrictions to chemical use outlined in the certification program (lodirules.org).

Sampling Methods

To minimize sampling bias and increase sample size, three sampling methods were used to acquire information on the ground dwelling ant communities. First, pitfall traps were placed in a die formation within each plot for a total of 25 traps at each site (i.e., five traps per plot and five plots per site: Agosti et al. 2000; Banschblach et al. 2012). Plastic cups with a diameter of 40 mm and a maximum volume capacity of 120 mL were placed in the ground with the rim flush to the ground surface. Traps remained unopened for seven days prior to sampling to ensure that the disturbance from trap placement did not impact results. Then, traps were opened, and 40 mL of a 50% aqueous solution of vertebrate-safe antifreeze containing propylene glycol (Peak SIERRA and Prestone LowTox) was added to each trap as a killing agent due to its low evaporation rate. Traps remained open for a total of 7 days, after which the samples were collected, and the traps were closed until the next replicate of sampling. Once collected, the 25 plastic cups containing the yield of the pitfall traps were put into a bag together so that ten cups could be selected at random from the bag for data analysis. Ants from the ten pitfall traps were separated from the antifreeze/debris/bycatch and combined to represent one pitfall sample at the particular site for the particular sample replicate. Ants were then examined with a dissecting microscope and identified to the lowest taxonomic rank possible using available resources on morphological characteristics (Ward 2005, Fisher and Cover 2007). In some cases, identification to species was possible, however, due to taxonomic uncertainties in Formicidae and limited information on morphological characteristics between species, the majority of the taxa found were identified to genus (Ward 2005, Fisher and Cover 2007). After identification, specimens were stored in 70% ethanol.

Second, bait traps were used to sample ground dwelling ants. Bait sampling and active-search sampling (see below) occurred simultaneously during pitfall trap placement and again at collection. During bait sampling, one bait plot was positioned a minimum of 25 meters away from any pitfall plot. Within the 5-meter square plot baits were placed at each corner. Two bait types were used to account for differing

preferences in protein/carbohydrate ratios of the ant species sampled (Stahlschmidt and Johnson 2018). The baits consisted of canned shredded tuna with honey and crushed short bread cookies and were placed directly on the ground so that any ant that visited the bait would be seen and collected using an aspirator. Ants were identified in the laboratory then stored in 70% ethanol.

Third, active searching was used to ensure thorough investigation of the ground dwelling ant community. After the sampling plots were established but before pitfall traps were placed/collected, a systematic survey for ground dwelling ants within the plot was conducted for a total of 10 minutes in each plot. Ants seen during this search were collected with an aspirator and later identified then stored in 70% ethanol.

Temperature

At each site during each replicate of sampling, temperature data loggers (HOBO U23, Onset Computer Corp., Bourne, MA) were placed inside a white PVC pipe at ground level to capture soil surface temperature every hour for the duration of the pitfall trapping. The loggers were collected during the collection of the pitfall traps. Then, the hourly data was extracted and an average ground temperature for the duration of the pitfall trapping was calculated.

Diversity Indices

The following metrics were used as dependent variables to assess the variability in ant diversity. Total abundance (the number of individuals within a population) was used as an initial assessment of population size and is necessary to assess other diversity metrics such as relative abundance. However, the abundance does not provide information of the actual diversity within the community in question. In this study, total abundance was separated into native and invasive taxa abundance to provide more information on how the abundance of native and invasive taxa may be changing among the communities. This still does not provide much information about the amount of different native and invasive taxa within the communities. Richness, the number of unique taxa present in an area, is the simplest and most applied diversity metric and gives some indication of the diversity within a community but does not shed light on the proportional abundance of the specific attributes (Morris et al. 2014). In this study, total taxa richness

was separated into two categories: native and invasive taxa richness, to assess the proportion of attributes within the ant communities that are introduced or native to the area. To account for information on the proportion of each taxon within an ecosystem, Shannon diversity can be useful (Konopiński 2020) and it was used in this study. Shannon diversity attempts to compound indices considering richness and evenness by multiplying the proportion of total individuals of a species in a community by the natural logarithm of that proportion, this product is done for each species in the community, the negative sum of these multiplicates produce the Shannon diversity index of the community (Shannon and Weaver 1949, Smith and Smith 2015). The Shannon entropy provides uncertainty in the species identity of a sample rather than the number of species in the community (Jost 2006, Morris et al. 2014). Shannon diversity is sensitive to the relative weight of the attributes included (equally sensitive to rare and abundant attributes) resulting in an index of entropy rather than diversity and cannot be used to compare across probability (Jost 2006, Rajaram et al. 2017). Thus, transforming the index into true diversity (effective number of taxa) by taking the exponent of Shannon diversity (Jost 2006) allows one to capture the diversity concept more accurately as well as assess differences between communities (Jost 2006). Evenness refers to the "equiprobability" of occurrence (Rajaram et al. 2017) and represents the degree to which each attribute dominates the community. Evenness can shed light on how evenly abundant the attributes are within the community by dividing Shannon diversity by the natural log of species richness (Pielou 1966, Morris et al. 2014, Smith and Smith 2015). In this study, Shannon diversity was used to calculate taxa evenness (Smith and Smith 2015). These diversity indices will further be referred to as the dependent variables.

Statistical Analysis

Linear mixed models were used to tested for the effects of land-use type and sampling method on the variability of the dependent variables (i.e., total ant abundance, total ant taxa richness, native taxa richness, invasive taxa richness, native taxa abundance, invasive taxa abundance, Shannon diversity index (i.e., data from the sum total of ants collected by all three sampling methods: see above), effective number of taxa, and taxa evenness) while accounting for temperature and serial sampling. Specifically, sample site and replicate were included as random effects, land-use type and sampling method were included as fixed

effects, and average ground temperature was included as a covariate. Linear mixed models were used to test whether that the temperature varried significantly among sites, land-use types, or sample replicate where sample site and replicate were included as random effects while land-use type was included as a fixed effect. The function *lmer* in the package *lme4* in RStudio was used for these test (Bates et al. 2015). Then, pairwise comparisons of the linear mixed models were performed to address differences in the means of the dependent variables among the land-use types and among sample methods using the function *emmeans* in the package *emmeans* in RStudio. Percent similarity was also calculated by comparing the relative abundance of each taxon found in each of the land use types (Smith and Smith 2015).

CHAPTER 3: RESULTS

Taxa of the Ant Community

A total of 18 ground dwelling ant taxa were found in this study of which six taxa are invasive and the rest are native to North America (Table 2; Fig. 2, Ward 2005, Fisher and Cover 2007). Eight taxa were identified to species (*Linepithema humile*, *Tapinoma sessile*, *Tetramorium immigrans*, *Tetramorium simillimum, Pogonomyrmex occidentalis*, *Monomorium ergatogyna*, *Monomorium pharaonis*, and *Cardiocondyla mauritanica*) while the rest were identified to genus (Table 2) due to limited access to information on species specific morphological information such as with the genus *Myrmecosystus* (Fisher and Cover 2007) or unresolved taxonomic discrepancies as seen in the genus *Formica* (Ward 2005).

Temperature

As predicted, the variability in average ground temperature did not differ among land-use type and sample replicate ($F_{2,11.952}=3.7796$, P=0.053). Therefore, the lack of significant changes in temperature were not expected to have an impact on changes in the dependent variables tested.

Land-use Type

In contrast to my prediction, the variability in the dependent variables due to land-use type was not significant for many of the dependent variables tested (Table 3.1). The native and invasive richness were the only variables out of all the dependent variables tested in which the variability attributed to land-use type was significant (Fig. 5, Table 3.1). As predicted, the native taxa richness was highest in the natural land-use types while lowest was in the urban sites (Fig. 5, Table 3.1). Also as expected, the highest invasive taxa richness was seen in the urban sites followed by agricultural sites and the lowest was seen in the natural sites (Fig. 5, Table 3.1). The variability in all other dependent variables attributed to land-use type was not significant due to the variability between sample sites within each land-use type exceeding or nearly exceeding the variance among land-use types (see Table 3.1).

Sampling Method

The various sampling methods (i.e., pitfall trapping, active sampling, and bait sampling) did yield different results in the variability of the numerous dependent variables tested (Figs 3-5, Table 3.2). In fact, sample method was most impactful to the variability in nearly all the dependent variables tested (total taxa richness, native taxa richness, invasive taxa richness, Shannon diversity, effective number of taxa, taxa evenness, and relative abundance of the focal taxa) apart from total, native, and invasive abundance (Table 3.2). Pitfall trapping yielded the highest variability and bait sampling yielded the lowest variability for: total taxa richness (Fig. 3a, Table 3.2), Shannon diversity (Fig. 4a, Table 3), effective number of taxa (Fig 4b, Table 3.2), and taxa evenness (Fig. 4c, Table 3.2). Pitfall trapping yielded the highest variability and active sampling yielded the lowest variability for native taxa richness (Fig. 3b, Table 3.2). The average values of the diversity indices obtained by the three sample methods were significantly different except for total, native, and invasive ant abundance (Table 3.2).

CHAPTER 4: DISCUSSION

The main goal of this study was to assess the ant communities of various land-use types within the Central Valley. There were thirteen native taxa and five invasive taxa found in this study (Table 2). The richness of the ground-dwelling ant communities found in the Central Valley was similar to the richness found in other regions of Northern California (Vonshak and Gordon 2015). However, the ant communities in this study differed from other studies performed in the Central Valley (Stahlschmidt and Johnson 2018). The results of the linear mixed models showed little variability in the dependent variables among the three land-use types (Table 3.1). This result is in contrast to other findings where the level of urbanization did have a substantial impact on the ant abundance, richness, and community composition (Vonshak and Gordon 2015). The results of the linear mixed models preformed in this study showed that the variability among sample sites was greater than the variability between the land-use types for all the dependent variables accept native taxa richness and invasive taxa richness (Table 3.1). This result suggests that an increase in sample size is necessary to determine if there is a true difference in the diversity indices calculated with land-use type or that the ant communities in this region could have different patterns of diversity from those of other studies. Additionally, multiple sampling of the same sample site generally did not provide additional information regarding the ant communities (Fig. 6). The results of this study showed that temperature did not influence the changes in diversity of the ant communities and the variability among sample sites was too great to conclude any changes in patterns of diversity with land-use type. Sample method did impact the diversity estimates of the ant communities in this study.

Land-use Effects on Ant Communities

As predicted, the native taxa richness was found to be highest in the sites classified under the natural land-use type (Fig. 5). This result was expected as the natural sites contained preserved habitat with native plant species and limited anthropogenic disturbance and similar trends have been shown in other studies (Vonshak and Gordon 2015). Although the relative abundance of invasive taxa was lowest in the natural sites (Fig. 2b), all five invasive taxa were found in the natural land-use type indicating the distributions of

the invasive taxa were found to be greater than strictly urbanized environments. This suggests that all of the non-native taxa found in this study were more likely to be generalists (Fig. 2b). The presence of invasive taxa in the natural sites is of concern as it is a sign that invasive ants may be colonizing open niches as native populations decline (Diamond and Case 1986, Holway and Suarez 2006). This result contrasts with other studies where the natural sites remained free of any invasive taxa (Vonshak and Gordon 2015). However, it should be noted that direct comparisons with other studies may show contrasting results due to use of different sampling techniques (Carney et al. 2003, King and Porter 2005, Vonshak and Gordon 2015). Additionally, it is important to consider the degree of disturbance in the natural sites in this study have experienced. There is virtually no location within the Central Valley that has not received some level of anthropogenic disturbance and all natural habitats are fragmented in a matrix of urbanized and agricultural areas.

As predicted, the urban sites contained higher invasive taxa richness compared natural sites which was expected due to urbanization's association with introduction of non-natives and increased habitat favored by non-natives (McKinney 2006). Although the native taxa richness was lowest in the urban land-use types, nine native taxa were found among the urban sites suggesting that some of the native taxa are capable of adapting to urbanized environments (Table 2, Fig. 2b, these included: *Amblyopone, Tapinoma sessile, Dorymyrmex, Camponotus, Formica, Monomorium ergatogyna, Pyramica* and *Hypoponera.* These results differed from previous studies in the distribution of *M. ergatogyna* and *Formica* sp., where these two taxa were not found in urban habitat (Vonshak and Gordon 2015). However, the distribution of *Camponotus* sp. and *Tapinoma sessile* found in this study (i.e., relative abundance highest in natural sites but present in urban sites, Fig.7 and Table 2) supports the findings of previous studies that these two taxa can adapt to urban environments (Vonshak and Gordon 2015). These urban-adapting ants may benefit from the resources provided in such environments, such as nesting sites in sidewalks and buildings, water from irrigation and food from trash waste, exotic plants, and hemipteran honeydew (Tillberg et al. 2007, Vonshak and Gordon 2015). Some native species may also be capable of competing with invasives found in the urban land-use type (Andersen 1991, McKinney 2006). The abundance and richness of native taxa found

at the urban sites suggests that at least a portion of the native ant community is capable of persisting through changes in habitat allowing for biodiversity to be maintained (Table 3.1, Fig. 5b). However, the limited abundance and richness of native taxa in the urban land-use type suggest that native ants are being displaced by non-native ants as seen in other studies (Holway et al. 2002, Carpintero et al. 2003). The native taxa not found in urban sites in this study included *Liometopum, Myrmecocystus, Pogonomyrmex occidentalis, and Pheidole* (Table 2, Fig. 7)*,* these taxa can be considered "urban avoiders" possibly due to differences in resources such as loss of native plants for nesting and food as well as competition with invasive species, compared to their natural habitat (Holway and Suarez 2006, Vonshak and Gordon 2015). These results differ from other studies in the distribution of *Liometopum* which has been previously found in urban environments (Vonshak and Gordon 2015). However, the distribution of *Pheidole* sp. found in this study supports previous studies with *Pheidole* sp. excluded from urban habitat (Fig. 7, Vonshak and Gordon 2015). Again, direct comparisons with other studies should be taken cautiously as the variability in results due to differences in methods has not been specifically addressed as discussed above (Vonshak and Gordon2015).

In this study the agricultural land-use type exhibited relatively high diversity compared to the natural and urban land-use types (Fig. 2b). Agricultural sites often serve as an invasive species source through the importation of potted plants carrying introduced species (Holway et al. 2002). The long history of agricultural production may have resulted in established introduced species from imported plants while the pockets of natural habitats can be a sustained source of native species (Vonshak and Gordon 2015). This seems to be the case with a particular agricultural site used in this study, AG1, (Table 1) where there were no native taxa and three invasive taxa collected throughout the entire sampling period at this site. Total abundance was highest in the agricultural land-use type (Fig 2a, Table 3.1) possibly due to the high resource availability associated with hemipteran pests on agricultural crops (Wetterer et al. 2009). As seen in other studies, the natives of this study generally did not appear to be avoiding the agricultural sites except AG1 (Vonshak and Gordon 2015). In fact, some of the natives showed a higher relative abundance in the agricultural land-use type over the natural land-use type (Fig. 7). For example, *Myrmecocystus* is a native

genus whose presence was only detected in the agricultural land-use type in this study(Fig. 7). Whereas some natives appeared to avoid agricultural; in this study, *Tapinoma sessile* was not present in the agricultural land-use type despite showing preference for agricultural sites in other studies (Vonshak and Gordon 2015).

The direct comparisons of these results with other studies should be taken cautiously as the type of agricultural practices can vary significantly. In this study, the agricultural sample sites were all wine grape vineyards that utilized similar land management practices (e.g. crop cycle, pesticide/herbicide regulations, irrigation practices, and tilling practices) to increase consistency in the sampling design. This allowed for the assumption that variability in abiotic factors among agricultural sites would not be a driver for variability in diversity. However, grape vineyards are only a small part of the Central Valley's agricultural production (cawater.usgs.gov); the consistency limits the scope to which this study can address the various types of agricultural practices used in the Central Valley. Continued studies should consider investigation of the differences in agricultural practices to understand how the ant diversity may be impacted by the different agricultural land management techniques that comprise the Central Valley.

It is essential that diversity and conservation assessments utilize a multimethod approach to obtain accurate information on the community and ecosystem prior to implementation of management recommendations (Teasdale et al. 2013). The findings of this study are in support of other literature in that the richness was significantly different between the sampling methods used (Agosti et al. 2000). This can lead to differing outcomes of the diversity indices calculated (King and Porter 2005). Overall, pitfall trapping did yield more diversity as predicted and pitfall trapping produced more variability in diversity compared to active sampling and bait sampling (Table 3). Pitfall trapping introduces the least amount of sampling bias due to the passive method and extended sampling period (Agosti et al. 2000). Ant behavior can vary quite dramatically among the different taxa within an ant community and the yield from pitfall trapping is likely dependent on the behavior of the workers visiting the trap (Agosti et al. 2000). The richness of invasive taxa was similar with active sampling and lower than the native richness collected with pitfall trapping (Fig. 4). Based on this result, utilizing only pitfall traps would have skewed the diversity

of the ant communities towards higher abundance and richness of the native taxa and a less accurate assessment of the distribution and proportion of invasive taxa within the communities sampled.

Active sampling demonstrated that it can also offer sample bias as the consistency of the sampling effort must be maintained and the results are impacted by the activity times, foraging ranges, and nest distributions of the taxa sampled (Agosti et al. 2000). In this study, active sampling yielded low variability in ant taxa richness compared to the pitfall trapping suggesting that the active sampling method produced the more consistency in the diversity estimates (Table 3.2). However, similar invasive taxa richness was collected with active sampling and pitfall sampling (Fig. 3c, Table 3.2) showing that active sampling did contribute to the understanding of the invasive ant community.

Bait sampling introduces bias in that the different food preferences and foraging behavior of the different ant taxa can impact which ants are sampled using this method; often bias towards one or a few species dominating the bait (Agosti et al. 2000, Stahlschmidt and Johnson 2018). Previous studies have shown that some of the ants found in this study share similar protein carbohydrate ratio preferences (p:c) (Stahlschmidt and Johnson 2018), however, differences in p:c among the ant taxa were not investigated in this study. Although not specifically addressed in this study, the microclimate in which the bait is placed may also impact the abundance and richness collected with this method (Perfecto and Vandermeer 1996, Stahlschmidt and Johnson 2018). As seen in this study (Fig. 3, Table 3.2), bait sampling is often biased towards non-native ants as they are less likely to share baits with other species (Vonshak and Gordon 2015). Therefore, the use of bait sampling alone would likely skew the results to a community more dominated by invasive species than sampling with a combination of methods as seen in this study where taxa evenness obtained with bait sampling was lower than with the other two methods (Fig. 4c).

A single sampling method will not provide an accurate assessment of the richness or relative abundance of ants within an ecosystem (King and Porter 2005, Agosti et al. 2000). Rather, a combination of methods is necessary to accurately measure and compare the biodiversity among ecosystems. This study was the first to address changes in diversity of the ant communities with land-use type in the Central Valley. Therefore, to accurately assess biodiversity within ant communities, ideal sample methods are necessary.

This study utilized only a few of the numerous techniques that exist for measuring ground dwelling ants. Other techniques for sampling ground dwelling ants such as soil extractions (Agosti et al. 2000) should be considered in future studies of the ant fauna in the Central Valley to ensure accurate representation of all taxa present. Additionally, an extended sampling period is necessary to collect all taxa present in the communities (Fig. 6) thus, a larger sample size rather than multiple sample replicates is suggested for future studies. However, to observe changes in individual taxa abundance with changes in seasonality and the impact those changes have to the ant community would require sampling throughout the four seasons.

CHAPTER 5: CONCLUSION

In this study of the ant community within the Central Valley, California, type of habitat disturbance was not determined to have an impact on the diversity of the ant communities as the variability in diversity of the ant communities observed among sample sites was greater than the variability observed among land-use types (Table 3.1). Therefore, an increased sample size is suggested in order to observe the general patterns of diversity among land-use types. The dynamics of the ant communities with the different land-use types suggest that environmental alterations could result in changes to available resources within a habitat impacting competitive ability and general behavior of some ant taxa (Fig.5, Human and Gordon 1991). Natural habitat is becoming scarcer in the Central Valley with land converted to agricultural and residential use resulting in less habitat for native taxa (Matchett and Fleskes 2017). Additionally, invasive taxa are encroaching on the natural sites (Carpintero et al. 2003) which may be resulting in greater resource competition with natives ultimately impacting native taxa distribution. Some natives were found in urban habitats and the relative abundance of the most dominant native taxa did not differ between the land-use types (Table 3.1) suggesting that at least some of the native taxa are capable of adaption to more urbanized environments. Changes to the landscape are projected to continue within the Central Valley thus it is crucial to monitor the ecological community responses to these habitat changes. Continued sampling throughout all four seasons can shed light on seasonality impacts to the dynamics of an ant communities. Extended sample size will allow for further assessment of the impact different land-use classifications may have on the diversity within the ant communities. Within the agricultural land-use type specifically, additional agricultural practices should be considered in future studies to better represent the diversity of the agricultural production within the Central Valley. Additionally, other sample methods should be considered as there are numerous documented methods ideal for sampling ground-dwelling ants that were not addressed in this study such as soil extractions. Further monitoring of changes to the community in addition to assessment of changing environmental factors will provide more information on the anthropogenic impact to the wildlife community we benefit from. In this study, ant communities appear to be adapting to

environmental changes with both native and invasive taxa often found co-existing. The resiliency of the ant community sheds light on the ability of other organisms to persist through anthropogenic impacts and sustain global biodiversity in the long run.
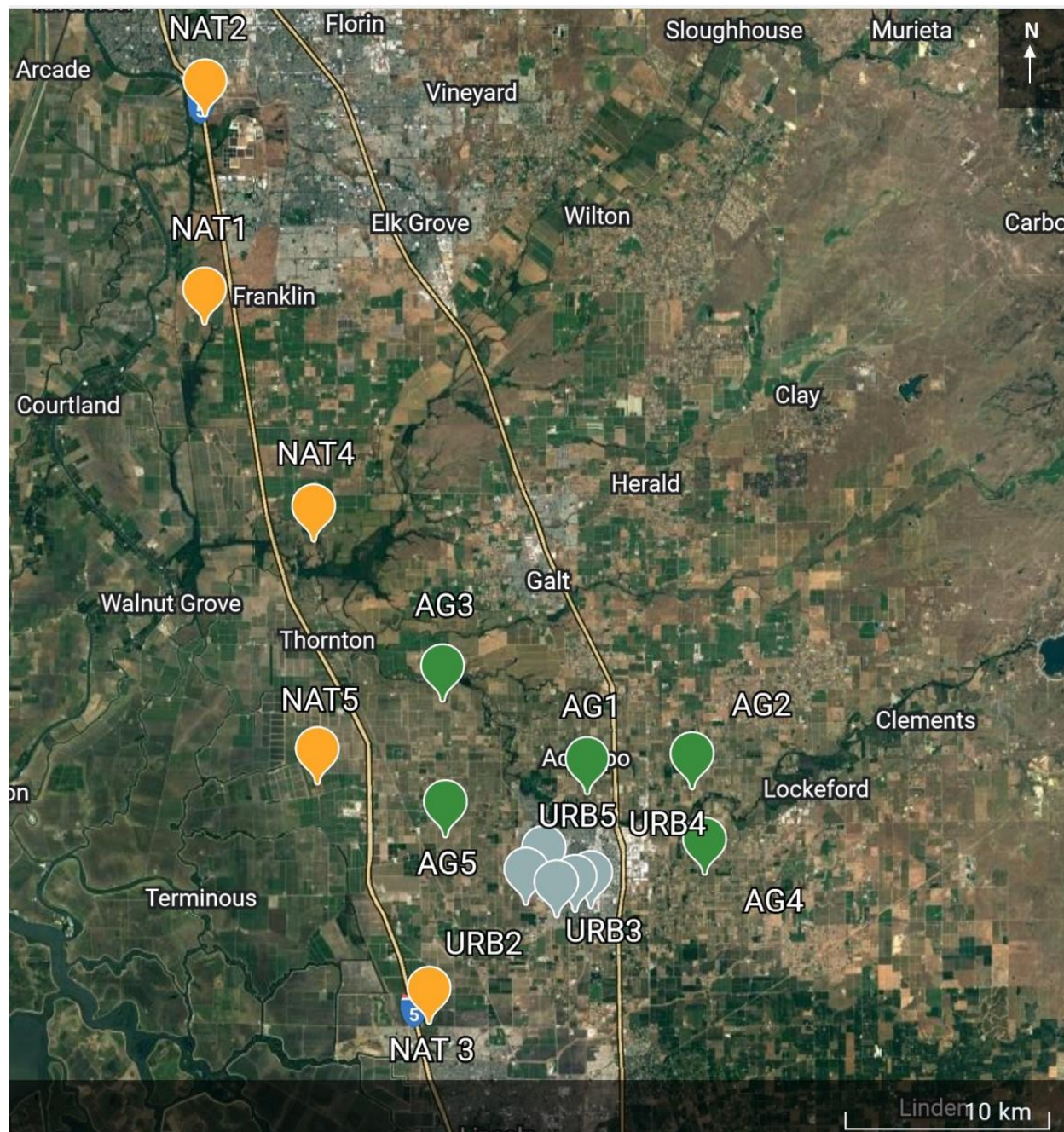
Figure 1. Map of Central Valley sample sites (Google Earth). Natural sites are golden yellow and labeled NAT1-NAT5. Urban sites are grey and labeled URB1-URB5. Agricultural sites are dark green and labeled AG1-AG5 (see Table 1).
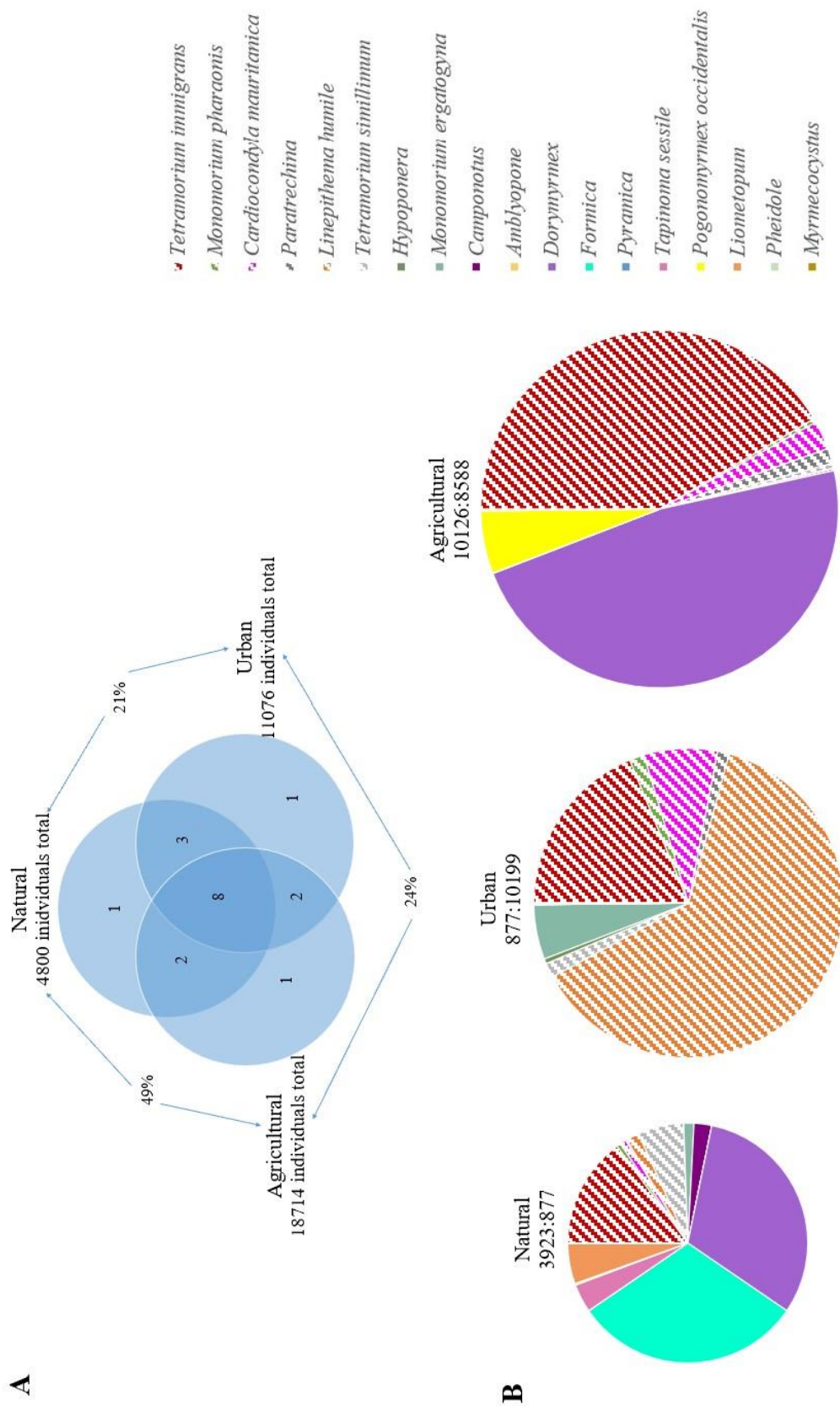
Figure 2. *A*: Venn-diagram comparing the number of taxa found at each land-use type and the percentage of taxa shared between land-use types. *B*: Pie charts of the relative taxa abundance for each land-use type, relative size of pie chart indicitive of the total number of individuals found compared to the two other land-use types. Invasive taxa indicated with line pattern. The ratios above the pie charts indicate the number of native individuals to the number of invasive individuals.
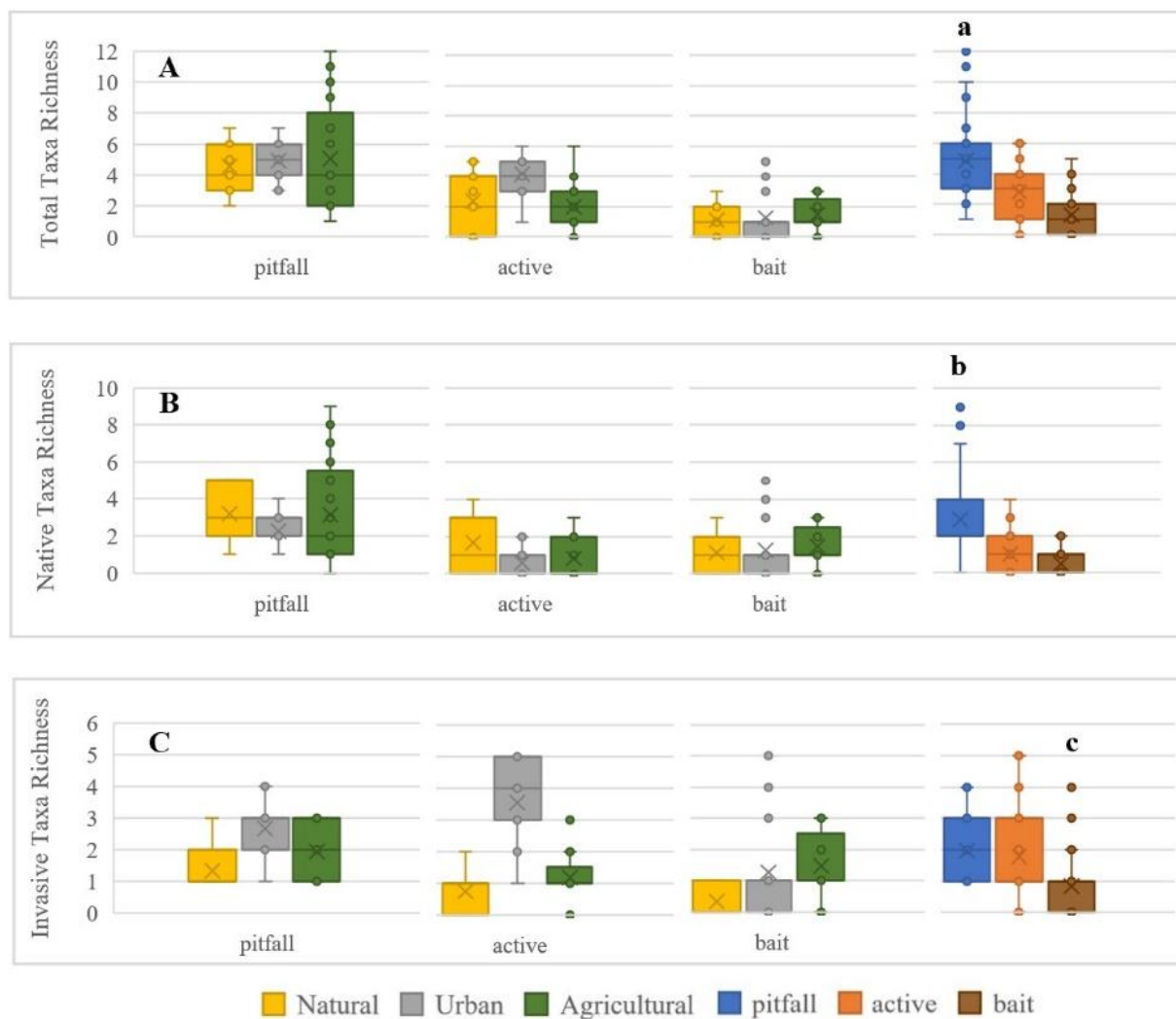
Figure 3. Boxplot of the total taxa richness, native taxa richness, and invasive taxa richness found in each land-use type with each sample method. As well as the pooled values by sample method. The X's represent the averages. Pitfall traps yielded the highest total taxa richness and native taxa richness, (*a*, *b*); active sampling and pitfall sampling yielded the higher invasive taxa richness than bait sampling (*c*).
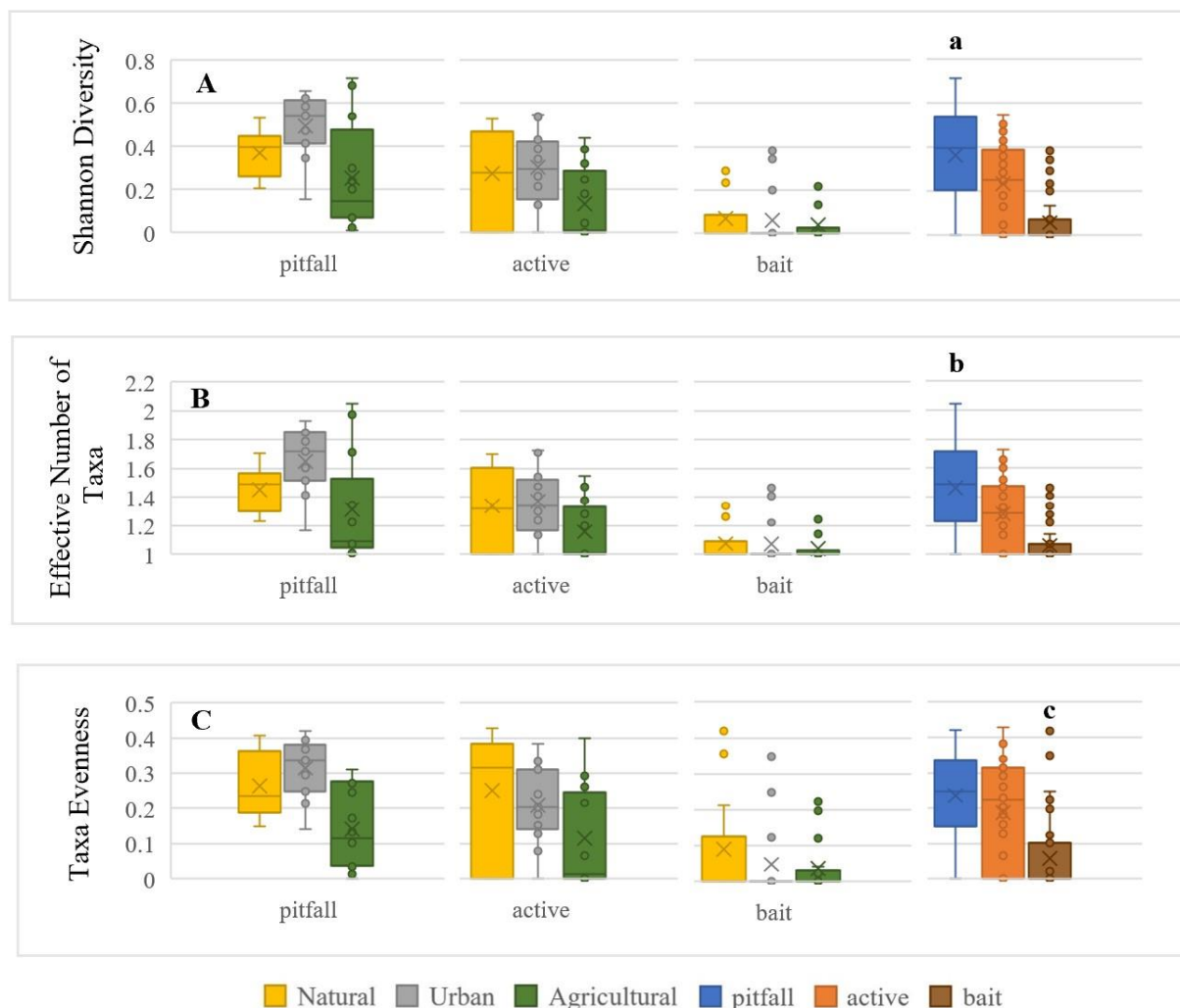
Figure 4. Shannon diversity (*A*), effective number of taxa (*B*), and taxa evenness (*C*) found in each land-use type with each sample method as well as the pooled values by sample method. The X's represent the averages. Pitfall traps yielded the highest variability of Shannon diversity, effective number of taxa, and taxa evenness compared to the other two sample methods. Pitfall traps yielded the highest average of Shannon diversity and effective number of taxa (*a* and *b*). Pitfall and active sampling yielded similar taxa evenness that were higher than bait sampling (*c*).
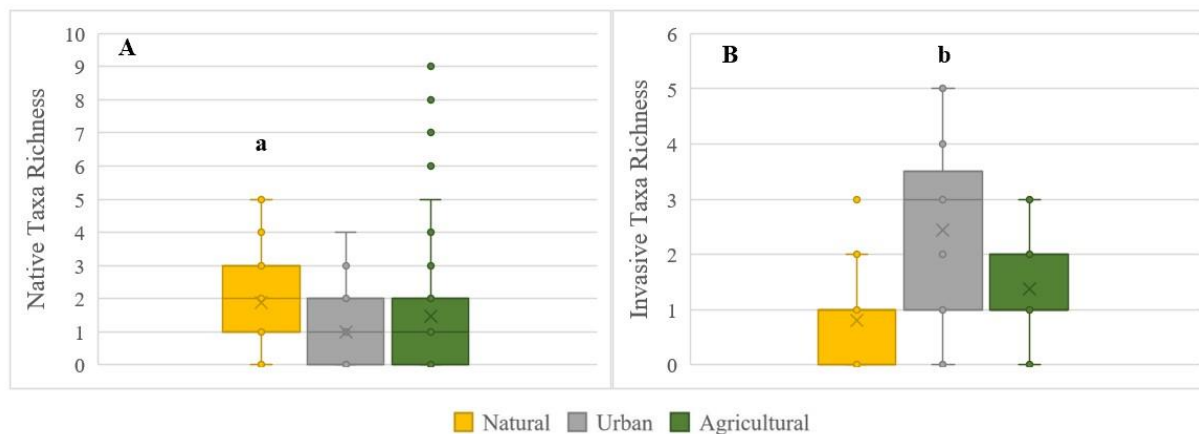
Figure 5. Average native taxa richness was highest in the natural land-use type (*a*), and average invasive taxa richness was highest in the urban land-use type (*b*).

Figure 6. Taxa accumulation curve found at the three different land-use types with increasing sample replicates, which occurred monthly through the ant's active season.

Figure 7. Relative abundance of each taxon found at each land-use type and the total abundance of each taxon in parenthesis. The proportion of individual abundances found in natural sites are shown in yellow. The proportion of individual abundances found in the urban sites are shown in grey. The proportion of individual abundances found in agricultural sites are shown in green. Invasive taxa identified by red outline.

Table 1

All Sample Sites Of the Three Land-use Types (NAT: Natural; URB: Urban; AG: Agricultural) Used During the Study Including the ID Code, Full Name Of Site, And GPS Coordinates.
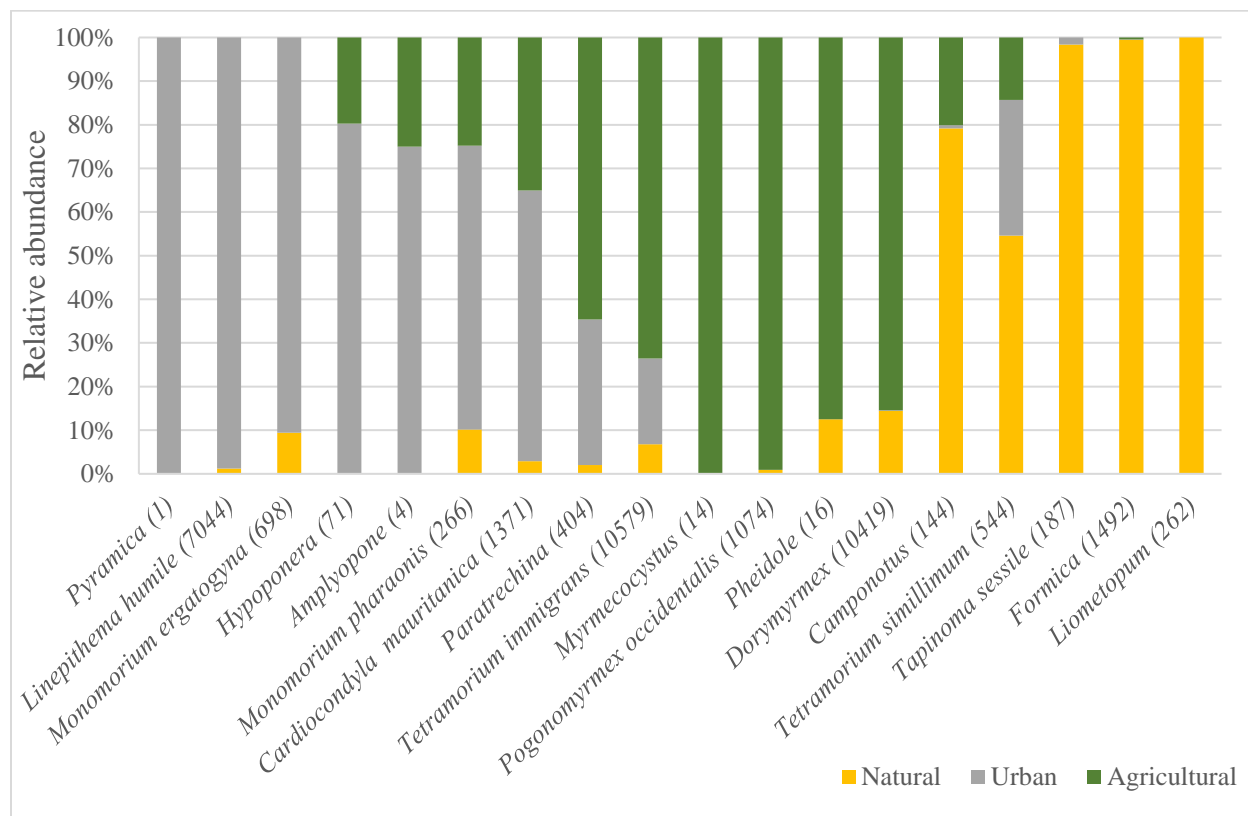
Site ID	Site name	Latitude	Longitude
NAT1	Stone Lakes National Wildlife Refuge	38.3624997	-121.4925028
NAT2	Bufferlands-Regional San	38.4533298	-121.4922003
NAT3	Oak Grove Regional Park	38.0563435	-121.365193
NAT4	Cosumnes River Preserve	38.26778	-121.4303
NAT5	Woodbridge Ecological Reserve	38.1616667	-121.4283333
URB1	Roget Park	38.1177673	-121.3015021
URB2	Century Meadows Park	38.1031673	-121.294528
URB3	Villa Fiore Park	38.1096163	-121.309887
URB4	End of Century Park	38.1075	-121.2755556
URB5	English Oaks Commons	38.1058333	-121.2836111
AG1	McKenzie Vineyard #1	38.1572222	-121.2769444
AG2	McKenzie Vineyard #2	38.1591667	-121.2183333
AG3	Oak Farm Vineyards	38.19806	-121.3586
AG4	Prie Vineyard	38.1219444	-121.2108333
AG5	Spenker Family Farm	38.1378568	-121.355652

Table 2

All Taxa Found During Sampling With the Land-use Type Each Taxon Was Found In (NAT: Natural; URB: Urban; AG: Agricultural), the Sampling Method Each Taxa Was Found With, And the Total Number Of Individuals Found Throughout the Entire Sampling Period. Taxa Names With an Asterisk (*) Indicate Invasive Species.

Taxon	land-use type	sample method	total abundance
Tetramorium immigrans*	NAT, URB, AG	all	10579
Dorymyrmex	NAT, URB, AG	all	10419
Linepithema humile*	NAT, URB	all	7044
Formica	NAT, URB, AG	all	1492
Cardiocondyla mauritanica*	NAT, URB, AG	all	1371
Pogonomyrmex occidentalis	NAT, AG	all	1074
Monomorium ergatogyna	NAT, URB	all	698
Tetramorium simillimum*	NAT, URB, AG	all	544
Paratrechina*	NAT, URB, AG	all	404
Monomorium pharaonis*	NAT, URB, AG	all	266
Liometopum	NAT	active	262
Tapinoma sessile	NAT, URB	all	187
Camponotus	NAT, URB, AG	pitfall, active	144
Hypoponera	URB, AG	pitfall, active	71
Pheidole	NAT, AG	pitfall	16
Myrmecocystus	AG	pitfall	14
Amblyopone	URB, AG	pitfall	4
Pyramica	URB	active	1

Table 3.1

Results Of the Linear Mixed Effects Model; the Variability Attributed To Land-use Type With Pairwise Comparisons Of Means. The negative coefficients Indicate a Decrease In the Variability Or Mean Whereas a Positive Coefficient Indicates an Increase in the Variability Or Mean.

Dependent Variable	site SD	land-use type variance	pairwise comparisons of mean estimates
total abundance	233.9	AG-NAT=-286.6, AG-URB=-154.4 ($F_{2,12.517}$=1.32, P=0.30)	AG-NAT=-882, P=0.25, AG-URB=425, P=0.70, NAT-URB=-457, P=0.65
native taxa abundance	146.3	AG-NAT=13.4, AG-URB=-101.1 ($F_{2,12.465}$=-0.7745, P=0.48)	AG-NAT=-48, P=0.99, AG-URB=366, P=0.48, NAT-URB=318, P=0.56
invasive taxa abundance	146.3	AG-NAT=-13.4, AG-URB=101.1 ($F_{2,12.465}$=-0.7745, P=0.48)	AG-NAT=-48, P=0.99, AG-URB=-366, P=0.48, NAT-URB=-318, P=0.56
total richness	1.38	AG-NAT=-0.4, AG-URB=0.5 ($F_{2,12.258}$=0.46, P=0.64)	AG-NAT=0.95, P=0.87, AG-URB=-0.83, P=0.90, NAT-URB=-1.78, P=0.62
native taxa richness	0.24	AG-NAT=0.5, AG-URB=-0.8 ($F_{2,12.164}$=18.73, P=0.0002)	AG-NAT=-0.64, P=0.10, AG-URB=2.14, P<0.0001, NAT-URB=2.78, P<0.0001
invasive taxa richness	0.24	AG-NAT=-0.5, AG-URB=0.8 ($F_{2,12.164}$=18.73, P=0.0002)	AG-NAT=0.64, P=0.10, AG-URB=-2.14, P<0.0001, NAT-URB=-2.78, P<0.0001
Shannon diversity	0.1	AG-NAT=0.08, AG-URB=0.13 ($F_{2,12.409}$=1.76, P=0.21)	AG-NAT=-0.16, P=0.41, AG-URB=-0.16, P=0.40, NAT-URB=-0.0018, P=1.0
effective number of taxa	0.1	AG-NAT=0.09, AG-URB=0.2 ($F_{2,12.419}$=1.62, P=0.24)	AG-NAT=-0.16, P=0.64, AG-URB=-0.18, P=0.59, NAT-URB=-0.01, P=1.0
taxa evenness	0.06	AG-NAT=0.09, AG-URB=0.08 ($F_{2,12.579}$=2.44, P=0.13)	AG-NAT=-0.15, P=0.03, AG-URB=-0.09, P=0.24, NAT-URB=0.06, P=0.43

Table 3.2

Results Of the Linear Mixed Effects Model; the Variability Attributed To Sample Method With Pairwise Comparisons Of Means. The Negative Coefficients Indicate a Decrease In the Variability or Mean Whereas a Positive Coefficient Indicates an Increase In the Variability Or Mean.

Dependent Variable	sample method variance	pairwise comparisons of mean estimates
total abundance	active-bait=79.09, active-pitfall=138 ($F_{2,120.692}$=1.53, P=0.22)	acitve-bait=-79, P=0.58, active-pitfall=-138, P=0.19, bait-pitfall=-59, P=0.74
native taxa abundance	active-bait=-17.35, active-pitfall=-58.50 ($F_{2,1119.377}$=2.31, P=0.10)	active-bait=17.3, P=0.89, active-pitfall=-58.5, P=0.26, bait-pitfall=-75.8, P=0.10
invasive taxa abundance	active-bait=-17.35, active-pitfall=-58.50 ($F_{2,1119.377}$=2.31, P=0.10)	active-bait=-17.3, P=0.89, active-pitfall=58.5, P=0.26, bait-pitfall=75.8, P=0.10
total richness	active-bait=-1.51, active-pitfall=2.04 ($F_{2,120.506}$=89.44, P<2.0×10-16)	acitve-bait=1.5, P<0.0001, active-pitfall=-2.0, P<0.0001, bait-pitfall=-3.6, P<0.0001
native taxa richness	active-bait=0.35, active-pitfall=0.63 ($F_{2,126.664}$=9.68, P<0.0002)	active-bait=-0.35, P=0.04, active-pitfall=-0.63, P=0.003, bait-pitfall=-0.27, P=0.33
invasive taxa richness	active-bait=-0.35, active-pitfall=-0.63 ($F_{2,126.664}$=-9.68, P<0.0002)	active-bait=0.35, P=0.04, active-pitfall=0.63, P=0.003, bait-pitfall=0.27, P=0.33
Shannon diversity	active-bait=-0.18, active-pitfall=0.13 ($F_{2,120.566}$=65.20, P<2.0×10-16)	active-bait=0.18, P<0.0001, active-pitfall=-0.13, P<0.0001, bait-pitfall=-0.31, P<0.0001
effective number of taxa	active-bait=-0.22, active-pitfall=0.18 ($F_{2,120.571}$=60.31, P<2.0×10-16)	active-bait=0.22, P<0.0001, active-pitfall=-0.18, P<0.0001, bait-pitfall=-0.40, P<0.0001
taxa evenness	active-bait=-0.13, active-pitfall=0.05 ($F_{2,120.654}$=36.84, P=3.25×10-13)	active-bait=0.13, P<0.0001, active-pitfall=-0.05, P=0.078, bait-pitfall=-0.18, P<0.0001

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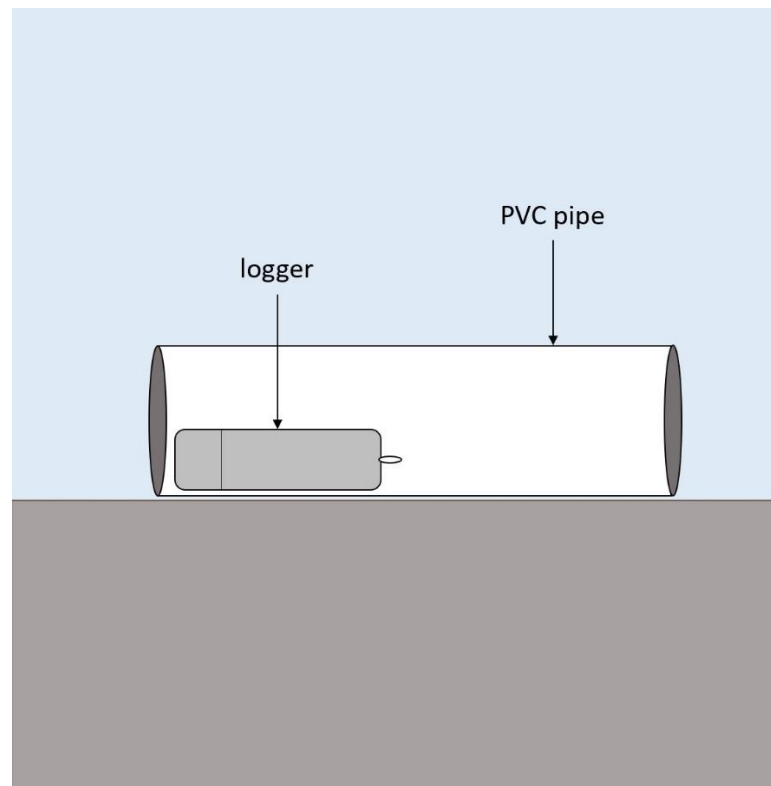
APPENDIX A: FIGURE 9

Figure 9. Cross-sectional diagram of ground temperature data logger placement at ground level inside a white PVC pipe.