Connecting People and Biodiversity

Multi-Scalar Interactions in Social-Ecological Systems

by

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ABSTRACT

Interdisciplinary research has highlighted how social-ecological dynamics drive the structure and function of the urban landscape across multiple scales. Land management decisions operate across various levels, from individuals in their backyard to local municipalities and broader political-economic forces. These decisions then scale up and down across the landscape to influence ecological functioning, such as the provisioning of biodiversity. Likewise, people are influenced by, and respond to, their environment. However, there is a lack of integrated research, especially research that considers the spatial and temporal complexities of social-ecological dynamics, to fully understand how people influence ecosystems or how the resulting landscape in turn influences human decision making, attitudes, and well-being.

My dissertation connects these interdisciplinary themes to examine three questions linked by their investigation of the interactions between people and biodiversity: (1) How do the social and spatial patterns within an arid city affect people's attitudes about their regional desert environment? (2) How are novel communities in cities assembled given the social-ecological dynamics that influence the processes that structure ecological communities? (3) How can we reposition bird species traits into a conservation framework that explains the complexity of the interactions between people and urban bird communities? I found that social-ecological dynamics between people, the environment, and biodiversity are tightly interwoven in urban ecosystems. The regional desert environment shapes people's attitudes along spatial and social configurations, which holds implications for yard management decisions. Multi-scalar management decisions then influence biodiversity throughout cities, which shifts public perceptions of urban nature. Overall, my research acts as a bridge between social and ecological sciences to theoretically and empirically integrate research focused on biodiversity conservation in complex, social-ecological systems. My goal as a scholar is to understand the balance between social and ecological implications of landscape change to support human well-being and promote biodiversity conservation.

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CHAPTER 1: INTRODUCTION

The rapid expansion of human development in the last century has intensified the need for interdisciplinary research on social-ecological dynamics. Biodiversity both shapes and is shaped by people's interactions with their environment (Head and Muir 2005). Therefore, integrated research can help develop more nuanced and effective conservation initiatives that benefit both biodiversity and human well-being (Ban et al. 2013). Drawing on the disciplines of human-environment geography and landscape ecology, the purpose of my dissertation research is to act as a bridge between the social and ecological to shift our understanding of people's relationship with nature (Turner et al. 1997). My dissertation research focuses on the hybrid spaces of residential landscapes and the "close, everyday engagements" between people and biodiversity that occur in yards and neighborhoods (Head and Muir 2006). Residential landscapes are important because they can act as a window into people's experiences and attitudes (Law 2019) and have the potential to serve as a mechanism for biodiversity conservation due to their widespread extent in developed areas (Loram et al. 2008).

The examination of multi-scalar interactions between people and biodiversity throughout the urban landscape mosaic in residential landscapes links the four chapters of my dissertation. By landscape mosaic, I mean a patch mosaic of environmentally heterogeneous conditions, from which spatial patterns emerge (Zhang et al. 2013). These chapters have three overarching research questions: (RQ1) How do social and spatial patterns within an arid city influence people's attitudes about their regional desert environment? (RQ2) How are ecological communities in cities assembled given the complex social-ecological dynamics that influence ecological community structure? (RQ3) How do bird species traits mediate the complexity of the interactions between people and urban bird communities?

My second dissertation chapter focuses on environmental attitudes, linking the attributes of residential neighborhoods and the regional landscape to people's subjective judgments about the desert. The chapter, "*Social-spatial analyses of attitudes toward the desert in a Southwestern U.S. city*" is published in the Annals of the American Association of Geographers (Andrade et al.

2019). To investigate people's attitudes toward the desert, I first developed a series of theoretical constructs that I expected would shape people's attitudes. Drawing on research done by human-environment geographers, urban ecologists, and other interdisciplinary scholars, these theories include: social legacy (Yabiku et al. 2008), social differentiation (Grove and Burch 1997), vulnerability to extreme heat (Harlan et al. 2006), and access to open space (Payne et al. 2002). This research chapter has implications for land conservation and management decisions. For example, Wheeler et al. (2020) connected people's attitudes toward the desert to yard landscaping preferences and choices in residential areas.

My third and fourth dissertation chapters address my second research question, which considers the assemblage of ecological communities in urban ecosystems. Chapter 3, "*Predicting the assembly of novel communities in urban ecosystems,*" involves the conceptual integration of multi-scalar management with community ecology theory to understand the assembly of ecological communities in urban ecosystems. I draw on metacommunity theory to consider the effects of people on biodiversity in urban ecosystems across multiple scales (modified from the model in Swan et al. 2011). Metacommunity theory combines environmental and spatial factors from local to regional scales to explain ecological community composition across the landscape (Leibold et al. 2004). I use the foundational concepts of metacommunity theory, specifically the effects of local to regional factors on biodiversity, to integrate community ecology with social-ecological models that consider the management decisions across scales (e.g., Cook et al. 2012). I empirically test the social-ecological model of novel community assembly in the fourth chapter, "*Social-ecological dynamics alter the effects of stochastic and deterministic processes in structuring urban bird communities,*" focusing on urban bird communities. Considering biodiversity in cities extends our understanding of urban ecosystems, but also existing ecological theory of community ecology and ecosystems science (Groffman et al. 2017).

My fifth chapter, "*Species traits drive people's evaluations of the urban bird community,*" also looks at urban birds in the Phoenix region. Together with the previous metacommunity chapters, I consider how people influence (Chapters 3 and 4) and are influenced by (Chapter 5) biodiversity in residential yards and neighborhoods. Specifically, my fifth dissertation chapter examines bird species traits that explain the engagements between people and wildlife in residential yards and neighborhoods (Robinson 2019). Previous research has primarily considered urban bird communities through ecological groups based on factors such as habitat guild. Although these guilds can act as a proxy for human-bird interactions or conflict, the use of ecological groups in of themselves does little to detail the ways people engage with the birds in their backyard. Instead, I suggest that conservation efforts should focus on biodiversity metrics that signal how people experience nature in cities as local stakeholders. This final chapter highlights the overall goal of my research, which is to understand how people connect with nature in cities and how these interactions, in turn, mediate human well-being and biodiversity.

CHAPTER 2: SOCIAL–SPATIAL ANALYSES OF ATTITUDES TOWARD THE DESERT IN A SOUTHWESTERN U.S. CITY

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ABSTRACT

Land change due to urbanization often results in the loss of desert ecosystems. The loss of desert land affects ecological and social processes in arid cities, such as habitat provisioning, the extent and intensity of the urban heat island, and outdoor recreation opportunities. Understanding the human–environment dynamics associated with environmental change is critical to understanding and managing the implications of urban growth. Few studies, however, have empirically examined people's attitudes about hot, arid environments such as deserts. The primary objectives of our study are to (1) identify how patterns of attitudes are spatially distributed throughout neighborhoods in metropolitan Phoenix, Arizona, and (2) determine how attitudes toward the desert are shaped by social and environmental attributes. We found that desert

attitudes are spatially clustered throughout neighborhoods. Positive views of the desert are fortified in high-income areas and those near preserved desert parks, whereas negative attitudes are clustered in areas associated with lower socioeconomic status and in neighborhoods with relatively grassy landscaping. Negative perceptions toward the desert are stronger among Latino residents and in low-income neighborhoods, where environmental hazards, especially extreme heat, and the perceived risks associated with such hazards are more prominent. Overall, we found that factors shaping attitudes in arid landscapes, including socioeconomic status and social identity, are similar to those that shape attitudes toward urban forests and greenspace in more temperate environments. Understanding attitudes toward the desert can help strengthen the connection between the regional environment and the local community, ultimately encouraging land preservation in arid cities.

1. INTRODUCTION

Urban development has led to changes in land use and land cover, often resulting in the loss of native ecosystems and increased fragmentation of habitat patches (Foley et al. 2005). This trend exists in rapidly growing cities in the southwestern United States (York et al. 2011), where development has increasingly occurred in fringe areas of a metropolitan region (Kane, Connors, and Galletti 2014). For example, in the southwestern city of Phoenix, Arizona, rural residences were built out in a "leapfrog pattern"— preserving open desert land at intermediate stages of development—followed by the infill of urban land use in desert open space over time (Keys, Wentz, and Redman 2007). This pattern of development allowed large swaths of desert land to be preserved at intermediate periods of growth. More recently, however, conversion of land to urban uses has shifted to the desert, including low-density residential development along the fringe areas of the metropolitan region, leading to high rates of land and habitat fragmentation (Shrestha et al. 2012). These shifts in land development are crucial because the associated environmental changes affect ecological and social processes and outcomes (van Vliet et al. 2016), including habitat provisioning (Seto, Guneralp, and Hutyra 2012), the extent and intensity of the urban heat island (Brazel et al. 2000; Zhang et al. 2013), and opportunities for outdoor recreation (Metzger et al. 2006). In general, understanding the human– environment dynamics associated with environmental change and land preservation in cities is critical to understanding and managing the implications of urban growth.

As a result of global climate change, a growing proportion of people in cities will be exposed to extreme heat, drought, and cascading hazards (Turner et al. 2003; McCarthy, Best, and Betts 2010), with vulnerable groups being disproportionately affected (Boone 2010; Malakar and Mishra 2017). Heat, flood, drought, and other measures of climate variability are already viewed as being among the largest risks to livelihood strategies in arid environments (Bunting et al. 2013). Socioecological shifts caused by land use and land cover conversion are significant in the context of global climate change, because they structure the impacts of extreme environmental conditions (Jenerette et al. 2011; Lindberg and Grimmond 2011; Li et al. 2017). Although land change research has shown that low-income and minority groups experience heightened exposure to environmental risks such as heat stress (Harlan et al. 2013), little is known about what people—including underrepresented groups—think about hot, arid environments such as deserts.

People might not be receptive to the creation of open space in their neighborhoods if they hold negative attitudes about the desert—despite the importance of desert lands for the overall ecosystem functioning of an arid landscape. Although deserts are often seen as harsh wastelands devoid of life (Nash 1967), these arid biomes support important ecosystem services (Kroeger and Manalo 2007). In the context of biodiversity conservation and land preservation, attitudes have been shown to act as a moderator (but not a direct driver) between experiences and environmental decisions (Barr and Gilg 2007; van Vliet et al. 2015; Soga et al. 2016). Therefore, understanding the attitudinal patterns of urban residents is a step toward providing more equitable desert open space in ways that benefit and are supported by the local community (Pincetl and Gearin 2005; Fainstein 2018). Geographers have long contributed to understanding environmental attitudes and, in particular, are uniquely poised to study such human–environment interactions due to integrated consideration of social, ecological, and spatial dynamics that affect them (Brown et al. 2004; Kates, Parris, and Leiserowitz 2005; Larson and Santelmann 2007).

Research on desert landscapes, including people's attitudes or interactions with them, is underrepresented in geography literature compared to more temperate systems (Ibes 2016). In addition, the human–environment geography literature has paid far less attention to cities in the United States compared to research in rural areas outside of North America and in the Global South (Robbins 2002; Walker 2003; Gustafson et al. 2014). Therefore, we fill this research gap by examining attitudinal patterns toward the desert, specifically by asking these questions: (1) How do spatial patterns of neighborhood characteristics affect the distribution and orientation of attitudes toward the desert throughout a metropolitan region? (2) How do social legacy, social differentiation, heat vulnerability, and access to open space shape attitudes toward the desert between individuals and across neighborhoods in a desert city?

Based on research done by human–environment geographers and transdisciplinary scholars, we hypothesized that attitudes are unevenly distributed throughout the city and variability in attitudes between neighborhoods are driven by four key theories focused on human–environment interactions, including social legacy (familiarity with a landscape; Yabiku, Casagrande, and Farley-Metzger 2008), social differentiation (social hierarchies and identity; Grove and Burch 1997), vulnerability to environmental risk (specifically extreme heat; Harlan et al. 2006), and access to open space (opportunity and proximity; Payne, Mowen, and Orsega-Smith 2002).

We tested these four theoretical constructs in the context of attitudes toward desert environments. In the following section we review the work that has been done to understand people's interactions with deserts and then explain each of the four theoretical propositions in light of the relevant literature that justifies our expectations.

Attitudes toward the Desert

Ecosystems or landscapes with mountain vistas, open water, and green vegetation are commonly seen as beautiful or desirable, whereas arid landscapes are perceived more negatively (De Lucio and Mugica 1994). Deserts have been viewed as wastelands for a variety of reasons, including aesthetic disdain and concerns about them being unsafe (Nash 1967). Time spent in the desert has also led people to a strong appreciation for its beauty (Abbey 1968). For example, painter Frederick Samuel Dellenbaugh spent a summer in southeastern Utah, after which he returned to amaze East Coast Americans with paintings of the canyon that is now Zion National Park. After spending an extended period of time in the desert working for the park service, Abbey (1968) famously penned, “There are mountain men, there are men of the sea and there are desert rats. I am a desert rat” (298–99).

Although little empirical research has focused on attitudes and experiences with desert ecosystems, a few studies from the 1980s and 1990s have informed our research. Zube, Simcox, and Law (1986) found that residents of Phoenix and Tucson appreciated the regional desert landscape in which their cities were situated. Tucson residents were also found to favor protection of desert open space, viewing its development unfavorably (Sell, Zube, and Kennedy 1988). Likewise, residents of the small town of Safford, Arizona, favored wilderness preservation of their nearby desert riparian area (Zube and Sheehan 1994). Other research, however, emphasizes more negative views of the desert. For example, Arizona residents and land managers prioritize agricultural land use over desert open space on the Upper Gila River (Zube and Simcox 1987). Another empirical study conducted in Arizona found that although 86 percent of respondents lived within 40 km of desert open space, only 11 percent included deserts when prompted to list landscapes in which they had a memorable experience (Law 1985). Beyond the few studies on land use in desert environments, more research has focused on attitudinal preferences for desert-like landscaping in private, residential parcels, specifically in metropolitan Phoenix, Arizona.

Extensive research examining preferences and practices in residential yards looks at desert-like landscaping—with gravel ground cover and plants adapted to the arid climate (commonly referred to as xeric yards; Martin, Peterson, and Stabler 2003; Larsen and Harlan 2006; Larson, Hoffman, and Ripplinger 2017). Although xeric yards mimic the native environment, desert landscaping in residential ecosystems does not replicate the desert in undeveloped areas (Stiles and Scheiner 2008). Desert enthusiasts sometimes refer to these xeric dreamscape yards as a “Disney Desert” (Larsen and Harlan 2006). This phrase reflects the prevalence of arid but nonnative plants in xeric yards compared to undeveloped Sonoran Desert. When compared to regional precipitation, these residential landscapes also typically depend on high levels of irrigation for their growth and survival. Regardless, several studies have shown substantial appreciation of these landscapes; for example, 35 percent of Phoenix residents prefer xeric landscaping to greener, mesic vegetation for front yards (Larson et al. 2009).

Although research seems to show a growing appreciation for desert-like xeric yards (Larson, Hoffman, and Ripplinger 2017), landscaping preferences at the scale of private parcels might not reflect personal attitudes toward the regional desert landscape. Thus, this critical question remains: How do residents of modern cities view undeveloped desert landscapes, and what factors explain these attitudes toward desert ecosystems? We hypothesized that legacy effects, social differentiation, heat vulnerability, and access to open space will influence attitudes toward the desert (Table 1).

Social Legacy

Interaction and familiarity with a region's unique features are often associated with positive attitudes toward that place (Wohlwill 1976; Herzog, Kaplan, and Kaplan 1982). In the Phoenix metropolitan region, Yabiku, Casagrande, and Farley-Metzger (2008) suggested that familiarity with a landscape (as measured by length of residency) can result from socialization, which is a process by which people learn to live within a particular social group or cultural context. Although socialization is a complex phenomenon, previous research indicates that the time spent in the Phoenix area affects people's views on desert landscapes. For example, residents with extended residency in Phoenix reportedly get "sick" or "tired" of desert landscaping (Martin, Peterson, and Stabler 2003; Spinti, Hilaire, and VanLeeuwen 2004; Larsen and Harlan 2006; Larson et al. 2009). Likewise, but contrary to common assumptions, newcomers to the desert metropolitan area of Phoenix prefer and have desert landscaping in their private yards more so than longer term residents, who instead tend to choose the grassy landscapes to which they have become accustomed (Larson, Hoffman, and Ripplinger 2017). The negative relationship between preferences for desert landscaping and time spent in Phoenix appears to be counterintuitive, but the distribution of biophysical properties within the city helps to explain this phenomenon.

Phoenix is located in a dry climate; however, marketing campaigns in the height of its urban development cast the city as an "oasis in the desert," offering a lush refuge from the outlying desert (Larsen and Swanbrow 2006). This historical legacy has carried through to current residential landscaping preferences and practices. In the most recent study by Larson, Hoffman, and Ripplinger (2017), ecological and social legacies of the "Phoenix Oasis" were found over time, such that residents become accustomed to the lush green landscapes that have been the historic norm in metropolitan Phoenix. Among people who have not frequently experienced the regional desert ecosystem within the city, some Phoenix residents are more familiar with, and therefore favor, more mesic landscapes (Yabiku, Casagrande, and Farley-Metzger 2008; Larson, Hoffman, and Ripplinger 2017). Similarly, studies of natural areas, preserves, and open space have shown that residents have an affinity for open spaces that match the environment to which they are accustomed (Dearden 1984).

Larson et al. (2009) outlined how the cognitive separation of the undeveloped regional landscape from human environments results in divergent attitudes toward desert-like private yards versus the undeveloped desert preserves. For example, one respondent in their qualitative study explained, "I've lived [in Phoenix] my whole life. I love the desert [but] desert landscaping is a different story from going out into the real desert" (Larson et al. 2009, 933). Conflicting priorities are one of the reasons for the dichotomy; it is the dominant desire for comfortable and leisurely landscapes that largely controls residents' yard preferences but not their attitudes toward the desert.

In short, based on previous research, we hypothesized that familiarity with the study region of Phoenix, Arizona—specifically as measured by the portion of one's life spent in the desert region—will be positively related to attitudes toward the desert. We also expected that residents with xeric, desertlike landscapes in their private yards would have more positive attitudes toward the native desert.

Access to Open Space

Accessibility and ease of use for open space and wilderness areas affects environmental attitudes. Positive attitudes toward preserved green areas increase with closeness to home for both urban parks (Dee and Liebman 1970) and natural areas (Wilhelm Stanis, Schneider, and Russell 2009). Nevertheless, perceptions of proximity are mediated by ease of access, where areas that are easier to use are perceived as being spatially closer (Ryan 2006). Kearney (2006) surveyed individuals in residential subdivisions and found that proximity to natural areas was not as important as opportunities to visit those areas. Opportunities for outdoor recreation in cities can be a function of proximity, but in sprawling cities, lack of transportation might also impede access to urban green space. Accessibility and use of urban parks can vary from neighborhood to neighborhood, and some locations might even require a private vehicle to access because of the inequities in the spatial distribution of open space (Shanahan et al. 2014; Soga and Gaston 2016).

We define access based on the distance-decay theory of spatial connectedness that is commonly used to measure and explain human–environment interactions. Distance decay is based on a core geographical concept that asserts that as the proximity between two observations decreases, the strength of their relationship also decreases (Tobler 1970); in this instance, desert access is hypothesized to decrease with proximity to the nearest desert park. Therefore, we hypothesized that individuals will hold positive attitudes toward the desert if they live closer or are able to easily commute to desert parks that are desirable for recreation.

Social Differentiation

Social differentiation is another factor in determining environmental attitudes and landscape preferences. Social differentiation is an important component of urban communities, because it incorporates the concepts of social hierarchies (e.g., wealth or socioeconomic status) and social identity (e.g., ethnicity or culture) to explain why and how societies are differentiated (Grove and Burch 1997). In Phoenix, socioeconomic status has been tied to preferences and installation of desert-like landscaping, wherein more educated and affluent neighborhoods tend to have a higher prevalence of desert landscaping, whereas middle-income residents tend to prefer grassier yards (Larsen and Harlan 2006; Larson et al. 2009). Higher socioeconomic status is also associated with an increase in park and green space visitation (Mowen et al. 2007), largely because low-income communities face more barriers to using urban green space (Wendel, Zarger, and Mihelcic 2012). Moreover, in many cities, people with lower socioeconomic status and minority groups lack access to urban greenspace because they tend to live farther away from them (Dai 2011).

Social differentiation can also be seen among racial and ethnic minorities because they are more likely to experience environmental injustices (Grusky 2010). Of particular relevance to this study, negative attitudes toward open spaces often result from the fact that minority groups can both perceive and experience natural areas as being dangerous or unsafe (Bixler et al. 1994; Wals 1994; Hong and Anderson 2006; Sharaievska et al. 2010; Finney 2014). In general, people from Latin American countries tend to view themselves as relatively interdependent with nature (Heyd 2004) and therefore more subject to associated risks such as extreme weather events. In contrast, the dominant social paradigm in white-dominated Western cultures positions humans in a place of superiority above nature (Dunlap and Liere 1984). Based on previous research that has shown the importance of social differentiation in shaping attitudes toward the environment (Schultz, Zelezny, and Dalrymple 2000), we hypothesized that people with lower income and education levels (as commonly used measures of socioeconomic status), along with those who identify as having a Mexican or Latino background, will have more negative attitudes toward the desert.

Heat Vulnerability

In Phoenix, one specific environmental risk that vulnerable people face is heat exposure. Vulnerability to risks is often defined as an individual's exposure to hazards, measured through biophysical properties (e.g., land surface temperature or time spent working outdoors) and perceptions of his or her experiences (e.g., thermal comfort relative to others), in addition to his or her ability to adapt and respond to such hazards (Turner et al. 2003). Adaptive capacity is an important component of vulnerability because it is associated with a person's ability to mitigate and cope with environmental risks such as heat stress (Harlan et al. 2006; Smit and Wandel 2006).

In Phoenix, air and surface temperatures tend to be higher in low-income communities where residents also have fewer resources to manage the effects of extreme heat (Harlan et al.

2006; Jenerette et al. 2011). Moreover, minorities and linguistically isolated residents in Phoenix make up the largest percentage of heat distress calls (Uejio et al. 2011). Individuals who work outdoors are particularly exposed to extreme temperatures, resulting in increased rates of emergency department visits for cardiac-related illnesses for outdoor workers (Culp et al. 2011). The most common way to mitigate the effects of urban heat is through centralized air conditioning (Kilbourne 2002), in either a private residence or at a public facility such as a library (Eisenman et al. 2016). The people who are the most prone to live in neighborhoods with higher temperatures, however, are also less likely to have the social and material resources, such as centralized air conditioning, to cope with the heat (Harlan 2006).

Given that certain residents are disproportionally affected by urban heat risks, and because heat exposure in desert environments can be high, we anticipate that those who are more vulnerable to heat stress will hold stronger attitudes toward the desert. Specifically, we hypothesized that vulnerability to heat—as measured by perceptions of local heat stress, exposures related to outdoor work, or a lack of air conditioning in one's home—will be associated with more negative attitudes toward the desert because people who associate the desert with extreme heat will also view it less favorably.

The preceding literature provides the theoretical foundation for the four hypotheses (legacy effects, social differentiation, heat vulnerability, and access to open space) we tested as explanations for attitudes toward the desert in the case study region of Phoenix, Arizona. In the section that follows, we lay out how data were collected and analyzed for our study.

2. METHODS

Study Area

Located in the southwestern United States and within the northern limits of the Sonoran Desert, the Phoenix metropolitan area is home to more than 4.5 million residents (Figure 1). Temperatures in the Sonoran Desert can exceed 49 °C during the summer and precipitation totals typically range between 76 and 400 mm annually (Phillips and Comus 2000). The region harbors high biological diversity; common native plants include *Parkinsonia microphylla* (foothill palo verde*), Prosopis spp.* (mesquite tree species), *Opuntia engelmannii* (prickly pear cactus), wildflowers such as *Baileya multiradiata* (desert marigold), and the iconic columnar cactus *Carnegiea gigantea* (saguaro). Perennial and ephemeral rivers provide green riparian habitats in the arid region, although most have been diverted or dammed for anthropogenic purposes.

The urban mosaic of Phoenix is defined by heterogeneous neighborhoods with distinct social and physical features. Vegetation cover and primary productivity are higher within the city than the surrounding desert, and urban plant phenology exhibits damped seasonal variation (Buyantuyev and Wu 2009). Vegetation and related land surface temperature are inequitably distributed throughout Phoenix, however (Harlan et al. 2007; Jenerette et al. 2007), creating spatial patterns of heat vulnerability (Harlan et al. 2006). Patterns of land surface temperature interact with the distribution of socioeconomic status throughout the metropolitan area, where various socioeconomic status groups can be found at the urban core and at the edge of the city limits (Chow, Chuang, and Gober 2012). In addition to the outlying desert, Phoenix has more than 16,187 ha of desert parks and preserves and more than 1,500 ponds and lakes within city boundaries, providing the potential opportunity for outdoor recreation without leaving the metropolitan area.

Sampling Design and Data Collection

We used responses from a social survey questionnaire administered by the Institute for Social Science Research at Arizona State University to determine social and spatial factors influencing attitudes toward the desert (Harlan et al. 2017). The social survey questionnaire, known as the Phoenix Area Social Survey (PASS), was established as part of the Central Arizona Phoenix Long-Term Ecological Research (CAP LTER) program’s long-term monitoring efforts. PASS was administered to forty-five neighborhoods in 2011 (Figure 1), the most recent year for which the survey is available, with the target population of the survey being the heads of all households aged eighteen or older. Surveys were given in either English or Spanish and were administered in person, online, or by telephone.

The forty-five neighborhoods, delineated by U.S. census block groups, were selected to create a balanced sample of five neighborhoods per nine groups stratified by income (low, middle, and high) and location within the urban matrix (core, suburban, or fringe). A sample goal of eighteen to twenty respondents was set for each neighborhood to achieve a target response rate of 50 percent; the final sample size was 806 respondents, giving a total average response rate of 43 percent. Response rates ranged from 23 percent to 57 percent per neighborhood. The codebook describing the full survey design and history of the PASS is available through the CAP LTER data portal (Harlan et al. 2017).

We used a total of fourteen variables for our study, including one response variable (attitudes toward the desert) and thirteen explanatory variables that were grouped by the four hypotheses (Tables 2 and 3). All fourteen variables were derived from survey questions asked in the PASS. Our study is multiscalar; variables were analyzed on individual (n = 806) and neighborhood (n = 45) scales, and both scales used the same suite of variables for analysis. Variable values at the individual scale were directly derived from the survey question responses (n = 806). Variable values at the neighborhood scale were aggregated from the individual survey responses by taking the average response value per neighborhood (Σ survey response value/total respondents in each neighborhood).

We define attitudes as evaluative judgments that hold implications for potential action about urban and environmental planning (Larson 2010). Two closed-ended survey items measured attitudes toward the desert, “the desert is an empty wasteland” and “the desert is a special place to me,” on a four-point scale ranging from 1 (strongly agree) to 4 (strongly disagree); respondents could also elect to not answer the question. The two survey questions were negatively correlated as expected (r = -0.37, p < 0.0001).

To create a composite variable, the response scale for “the desert is a special place to me” was first reversed to establish a similar directionality of positive and negative values for the two variables. The responses to the two variables were then averaged for each respondent, and the resulting response variable is referred to as attitudes toward the desert (ATD), where higher values indicate more positive attitudes (Figure 2, Table 2).

Thirteen explanatory variables were collected from the survey to test our four relevant theories (Table 3). The first theoretical perspective, relating to the social legacies of the people living in the Phoenix region (social legacy), was captured by three variables: birthplace, length of residency, and the presence of xeric yard landscaping. Consistent with the literature related to social differentiation and environmental attitudes, we selected income and educational attainment (to measure social hierarchies through socioeconomic status) and Mexican or Latino identity (as a measure of social identity) as the three variables measuring social differentiation. Heat vulnerability (including perceptions, adaptive capacity, and exposure) was assessed using the following three variables: perceptions of neighborhood heat, the use of air conditioning within a respondent's home when the weather is hot, and amount of time spent working outdoors during the summer. The ability of individuals to access desert recreational space in Phoenix was measured using three variables representing proximity (distance to closest desert park), mobility (transportation abilities), and desirability (park quality). To control for variation in respondents' broad-based environmental values, we also included the New Ecological Paradigm (NEP) scale developed by Dunlap et al. (2000). Data were tested for normality and spatial autocorrelation prior to analysis.

Statistical Analysis Question 1: Spatial Patterns of Attitudes

Our first research question asked whether attitudes toward the desert were spatially related throughout Phoenix, Arizona. We tested the distribution and orientation of attitudes based on the location of the forty-five surveyed neighborhoods. We used the neighborhood scale for spatial analysis because individual responses were not spatially explicit. We first calculated a weighted matrix defining the spatial relationship between neighbors (centroid of PASS neighborhoods) within a given threshold distance (Figure 3). We calculated the weighted neighbors list for a range of threshold distances between 5 and 25 km. The final weighted neighbors bin size was selected for the threshold distance of 17 km, so that each neighborhood had at least two neighbors and the spatial relationship between attitudes toward the desert was most significant, calculated using global Moran's I (Moran 1950).

To take the variation in the number of different neighbors per neighborhood into account, we calculated the weighted neighbors list using the row standardization scheme, where the sum of each row in the link matrix was standardized to equal one (O'Sullivan and Unwin 2014). Using the weighted neighbors list, we calculated global Moran's I, global G (Getis and Ord 2010), and

Geary's C (Geary 1954) to determine whether the response variable, attitudes toward the desert, was spatially autocorrelated (Fortin and Dale 2005).

Following the methodology of Carter et al. (2014), we calculated the Getis–Ord (local G_i^*) statistic for attitudes toward the desert in PASS neighborhoods to determine how attitudes were clustered in certain areas of the metropolitan region (Getis and Ord 2010). Significant clusters of neighborhoods with positive attitudes were those with a G_i^* > 1.96, whereas neighborhoods with significantly negative attitudes had a G_i^*< -1.96. We visualized clusters of positive and negative attitudes by mapping each neighborhood with its corresponding Getis-Ord statistic. We conducted spatial analyses using the R packages "spdep" and "rgeos" (Bivand et al. 2011; Bivand and Rundel 2013).

Statistical Analysis Question 2: Social and Environmental Models

After determining spatial patterns of attitudes toward the desert, we used linear regression models to determine how established social theories—specifically social legacies, social differentiation, heat vulnerability, and access to open space (Table 1)— shape attitudes toward the desert. For this second research question, we fit four linear models, one for each hypothesis, wherein each model was composed of a unique set of PASS variables (Table 3). The models were estimated for both individuals and neighborhoods to test for scale effects on environmental attitudes. The standardized beta coefficient (to account for different units of measurement) was calculated to determine the strength and directionality of the relationship between each of the explanatory variables and attitudes toward the desert.

Before estimating the models, we first checked for normality and homoscedasticity and then calculated a Pearson's product–moment correlation coefficient for each pair of variables to check for multicollinearity among the predictors. Because some of the covariates were correlated, we used variance inflation factor (VIF) scores to determine whether any variables needed to be dropped from a particular model. To meet statistical assumptions, per capita income (derived from the U.S. Census) was used in place of income measured via the PASS in the social differentiation model and percentage bachelor's degree was dropped from the full model at the neighborhood scale. We calculated the Moran's I statistic for the model residuals to verify that spatial relationships did not cause pseudoreplication of the samples (Hurlbert 1984); no spatial autocorrelation was present in the residuals of any model.

3. RESULTS

Phoenix residents overwhelmingly held positive attitudes toward the desert (3.22 ± 0.03). Approximately 82 percent of survey respondents disagree or strongly disagree that "the desert is an empty wasteland" and 74 percent agree or strongly agree that "the desert is a special place" (Table 2). In support of our hypothesis, attitudes toward the desert and the explanatory variables evaluated in our study were spatially structured and clustered throughout the city (Figure 2).

Question 1: Spatial Patterns of Attitudes

Global spatial statistics indicate that attitudes toward the desert exhibited positive spatial dependence throughout neighborhoods in Phoenix, Arizona ($I = 0.15$, $p < 0.003$; Table 4). Local measurements of attitudes illustrated the metro-wide spatial patterns (Figure 2). Neighborhoods with positive and negative attitudes occurred both in the central city and in fringe neighborhoods. With the exception of a few neighborhoods in the southwestern part of the study region, though, neighborhoods on the fringe of the metro region tended to hold more positive attitudes. For more central neighborhoods, positive attitudes were co-located with desert parks. The exception is the two older, mesic neighborhoods near the city core that both held strongly positive attitudes; the higher than expected positive attitudes of these neighborhoods could be attributed to social differentiation (high income and education level). Neutral attitudes were interspersed throughout Phoenix but had a higher density in the northwestern and southeastern portions of the city, neither of which offers easy access to urban desert parks or exhibits strong clustering of social variables.

The local G_i^* statistic illustrated the spatial clustering of neighborhoods by identifying two distinct hotspots of positive and negative attitudes clustering in Phoenix neighborhoods (Figure 4). Five neighborhoods in northeastern Phoenix exhibited clustering of positive attitudes. These neighborhoods were all located in a high-income area at the edge of the McDowell Preserve system, a desert park with a total area of more than 12,140 ha and more than 80 km of accessible trails. None of these neighborhoods differed significantly from one another in terms of social and physical composition, creating a fairly homogenous distribution of neighborhoods that held positive attitudes. A statistically insignificant band of urban core and suburban neighborhoods separated positive and negative attitude clusters. All of the urban core neighborhoods were in close proximity to each other but were heterogeneous in attitudinal patterns. In contrast to neighborhoods of positively clustered attitudes, negative attitudes toward the desert were aggregated within the southwestern portion of the Phoenix metropolitan area.

Question 2: Social and Environmental Models

The regression models' results varied somewhat across the individual and neighborhood scales. Aggregating variables to the neighborhood scale increased the between-sample variation because the characteristics of nearby individuals were more likely to be related (Table 3). The increase in variation at the neighborhood scale translated to models that explained more variance in attitudes toward the desert (Table 5), despite a smaller sample size (n = 45 neighborhoods compared to n = 806 individuals). All four of the models explained more variation in attitudes toward the desert at the neighborhood than the individual scale, but model and variable importance were consistent between scales. For both scales, the theoretical models that were developed from literature in non-arid systems were all significant in explaining attitudes toward the desert (Table 5).

The social differentiation model—including income, education, and Mexican or Latino identity—best explained attitudes toward the desert in Phoenix for both individuals, ($F_{(4, 651)}$ = 11.63, R^2 = 0.06, $p < 0.0001$), and neighborhoods, ($F_{(4, 40)}$ = 19.21, R^2 = 0.62, $p < 0.0001$ [Table 5]). The next most significant models were access to open space for individuals, ($F_{(4, 758)}$ = 11.27, R^2 = 0.05, $p < 0.0001$), and heat vulnerability for neighborhoods, ($F_{(4, 40)}$ = 16.08, R^2 = 0.58, $p < 0.0001$). The difference in the explained variation (R^2) between individual and neighborhood models reaffirms the spatial clustering of the social and biophysical characteristics, whereby aggregating attitudes to the neighborhood level resulted in a much stronger relationship.

Social identity measured by individuals in Phoenix who identify with being Mexican or Latino was the strongest individual factor in explaining attitudes toward the desert, wherein individuals who identified as being Mexican or Latino were more likely to hold negative judgments toward the desert. Negative attitudes toward the desert were also significantly related to variables within the heat vulnerability and access to open space hypotheses. Perceptions of living in a hotter than average neighborhood were important at both scales; exposure to heat through outdoor work was only significant at the neighborhood scale. Within the access to open space hypothesis, the lack of mobility and longer distances to desert parks were both related to more negative attitudes toward the desert.

All four models also had variables that were associated with positive attitudes toward the desert. Xeric landscaping was the only social legacy variable that was significantly related to attitudes toward the desert at both scales. As expected, residents with xeric landscaping at home viewed deserts more positively. Socioeconomic status was also related to attitudes toward the desert, where residents and neighborhoods with a higher socioeconomic status held more positive attitudes toward the desert. Unrestricted air conditioning use to mitigate high temperatures and park desirability were also related to more positive attitudes toward the desert in the less important models. As a control variable of ecological worldviews, the NEP index was strongly associated with positive attitudes toward the desert and was significant in all but one of the models.

Only two out of the thirteen variables were not significant at either scale in explaining attitudes toward the desert, which supports our approach to model specification based on our literature review. The two variables that were not significant, birthplace and amount of time residents have lived in the Phoenix metropolitan area, were both within the social legacy hypothesis and had the greatest amount of relevant literature to support their inclusion in the models, underscoring the difference between yard landscaping preferences addressed in previous studies and regional environmental attitudes addressed here.

4. DISCUSSION

Our study establishes several key insights into evaluative attitudes toward desert landscapes. First, we establish the importance of the desert to the residents of an arid city. Deserts are home to a large portion of the global population and the urban residents of the

Sonoran Desert hold strong, positive attitudes toward the desert. Contrary to historic accounts, many residents living in desert regions view these landscapes as having a special value and do not believe that they are desolate “wastelands” (Nash 1967). Instead, our study confirms the value of desert ecosystems to the residents who live in arid cities (Zube, Simcox, and Law 1986). Not all people view the desert in the same way, though, and our findings confirm the uneven social and spatial distributions of attitudes toward desert ecosystems.

Our study also confirms that the same processes shaping attitudes toward green space, parks, and wildlife in temperate climates are important in defining attitudes about more arid landscapes. Similar to the findings of Payne, Mowen, and Orsega-Smith (2002), Van den Berg and Koole (2006), and Carter et al. (2014), our study highlights how social differentiation shapes environmental attitudes. For our study, Mexican or Latino residents and socioeconomically marginalized groups in the Phoenix metropolitan area are the most likely to express negative attitudes toward the desert. The similarities between these studies, in different geographical locations with distinct attitudinal objects (i.e., deserts, nature development landscapes, and large carnivores), illustrate that environmental attitudes can share similar patterns that arise from processes of social identity and hierarchy.

Social–Spatial Patterns

Desert attitudes in Phoenix are clustered among neighborhoods in specific sections of the metropolitan region, and this clustering follows the spatial nature of the social and environmental variables we examined. Neighborhoods that hold more positive attitudes are largely located near desert parks or at the urban fringe. Owing to historical development patterns of outward sprawl, neighborhoods at the edge of the city and at the base of mountain parks—which are newer, more suburban, and wealthier—are especially positive about the local desert environment. Residents within these neighborhoods hold more positive attitudes likely due to relatively easy access to the aesthetic, leisure, and recreation opportunities of the regional desert parks and preserves.

As a result of the coupling of social and biophysical patterns in cities (Rademacher, Cadenasso, and Pickett 2018), the same neighborhoods in Phoenix that have more access to desert amenities also have higher social status and are less vulnerable to extreme heat. High-income neighborhoods closer to the desert have lower population density, leading to fewer sources of anthropogenic heat, more vegetation that provides shade, and less impervious surface (Jenerette et al. 2007), allowing nighttime temperatures to reach lower minima than in the urban core (Connors, Galletti, and Chow 2013). Jenerette et al. (2016) found that higher socioeconomic status groups are less likely to experience extreme heat conditions and are also less likely to consider heat exposure as a salient risk. Overall, advantaged groups simultaneously avoid the challenges of living in a hot, dry environment while benefiting from the aesthetic, recreational, and conservational roles of the desert (Burgess, Harrison, and Limb 1988; Byerly 1996).

In contrast, more vulnerable communities that lack the ability to consistently choose or control their environment hold more negative attitudes about the desert. Individuals in these neighborhoods are restricted in their ability to use heat mitigation strategies, such as regulating indoor temperature (Harlan et al. 2013), as evidenced by the importance of central air conditioning for predicting attitudes toward the desert. The lack of control over the environment can indeed be key in shaping attitudes and might also translate to more negative attitudes toward the desert or, as shown in other research, heightened perceptions of risks (Slovic 1987; Larson et al. 2011). Additionally, individuals who do not have the economic or social means to control their environment are often spatially located in portions of the city with higher exposure to environmental risk factors and hazards (Harlan et al. 2006; Jenerette et al. 2011), causing an interaction between social and spatial characteristics that shapes negative attitudes toward the desert.

Social Identity

Mexican or Latino identity was a strong factor in the likelihood to express negative attitudes toward the desert. Minorities often feel—and are—more vulnerable to environmental risks (Flynn, Slovic, and Mertz 1994; Parker and McDonough 1999). Another study found, for example, that only 18 percent of white respondents felt as though heat is dangerous compared to 46 percent of Latino respondents; furthermore, 65 percent of Latino respondents perceived heat exposure to be their “biggest threat” living in a desert city (Kalkstein and Sheridan 2007).

In essence, Mexican and Latino respondents might feel more vulnerable to the extreme desert conditions, thereby explaining their relatively negative attitudes toward the desert compared to others. An additional underlying explanation for this could be that people who identify as Mexican or Latino tend to see themselves as more interdependent on the natural environment, as opposed to the dominant social paradigm that positions people as superior to nature (Heyd 2004; Larson et al. 2011). Overall, the ways in which social, cultural, and economic groups interact with and perceive their environmental conditions can cause fundamental differences in attitudes.

Residential versus Regional Landscapes

Surprisingly, place of birth and tenure of residency—which have been found to be critical in explaining residential landscaping preferences in previous studies—are less important for shaping attitudes toward the desert. Social legacy, or the familiarity and experience with a landscape type (Mugica and De Lucio 1996), is a well-supported proposition that explains yard landscaping ideals (e.g., Martin, Peterson, and Stabler 2003; Larson, Hoffman, and Ripplinger 2017), but it was relatively unimportant in relation to desert attitudes. In fact, the social legacy model tested in this research explained the least amount of variation in desert attitudes for both individuals and neighborhoods.

The social legacy hypothesis has been extensively tested in relation to residential landscape typology in the U.S. Southwest. Many of the studies we cited to develop the social legacy theory (e.g., Larsen and Harlan 2006; Yabiku, Casagrande, and Farley-Metzger 2008; Larson et al. 2009) shared neighborhoods and municipalities with our own study. Therefore, we contend that the distinction we find between attitudinal factors shaping residential versus regional landscapes is not simply an artifact of different study areas or geographical regions. As residents noted in a previous study, “I love the desert, in its place,” and “The desert belongs in the desert” (Larson et al. 2009, 932–33). Together, these findings seem to suggest that interactions with landscapes in private homes versus in open space can lead to differential attitudes and drivers of them when comparing residential ecosystems to the surrounding environment.

Future Research

An interesting direction of research would be to extend the geographical scope of our study beyond a single city to include specific features of different deserts, such as biodiversity or landscape configuration, to test how different attributes of a desert affect attitudes. For example, the Sonoran Desert is the most biodiverse of the North American deserts (Phillips and Comus 2000); this could play a part in shaping attitudes about the desert because people have the potential to recognize and value ecological biodiversity (Belaire et al. 2015; Botzat, Fischer, and Kowarik 2016). The spatial extent and configuration of parks within specific desert ecosystems, as well as urban development, could also influence cross-desert attitudinal patterns.

In terms of management implications, a more in-depth, qualitative study targeting people and places that are more likely to disdain their desert environment could highlight key drivers of how and why people hold more negative views toward the desert. Overall, our study has established a baseline for understanding attitudes toward the desert that could be used in future research to evaluate the drivers of geographic and temporal shifts in attitudinal patterns. Although attitudes tend to be steadfast and resistant to change, they do change in response to specific experiences or contexts (Heberlein 2012). Thus, comparative case study research as well as longitudinal studies are worthy of pursuit to advance understanding of general human–environment attitudes and place-specific views. Going forward, the social–spatial methodology used in this article (following that of Carter et al. 2014), coupled with the theoretical propositions we derived from an in-depth review of transdisciplinary literature for the specific attitudinal object, offers an effective direction for future research on other understudied environmental attitudes.

Conclusion

Attitudes toward the desert in Phoenix are largely positive but are dependent on the social differentiation of individuals, as well as the spatial placement of neighborhoods throughout the metropolitan region. Social identity (Mexican or Latino) and social hierarchy (income and education) were the most important factors predicting attitudes toward the desert. Heat vulnerability and opportunities for recreation in the desert were also significant factors, whereas social legacy was less important than originally hypothesized.

Our study indicates that attitudes about the desert vary based on the social characteristics and geography of an individual and that different approaches to improve people's relationship with the desert are necessary for groups that are inequitably influenced by their regional environment. For example, park managers and local groups can work to create more accessible open space and experiences for disenfranchised or disadvantaged people in desert cities. Increasing the outreach about and accessibility to desert parks could increase the number of positive attitudes and reduce the environmental inequities (in terms of access and use of recreational open space) throughout a city. Overall, attitudes toward the desert are important to understand because they can help strengthen the connection between the regional environment and the local community, ultimately encouraging land preservation and sustainability efforts in arid cities (Bonaiuto et al. 2002; Brody, Highfield, and Alston 2004).

Table 1. Description of four key theories hypothesized to be important in shaping attitudes toward the desert in Phoenix, Arizona, USA. Included in the table are definitions we employed for the purposes of this study and key citations from human-environment geography and interdisciplinary literature used to formulate the hypotheses.

Theoretical Model	Hypothesis	Key Citations
Social Legacy	Familiarity of an individual with a specific landscape type and regional landscapes more broadly will result in more positive attitudes toward that landscape type (desert).	Yabiku et al. 2008, Larson et al. 2009, Larson et al. 2017
Social Differentiation	An individual's placement within social hierarchy based on socioeconomic status and that identify as a cultural or ethnic minority will affect attitudes toward the desert.	Grusky 1994, Grove & Burch 1997, Schultz et al. 2000
Heat Vulnerability	An increased potential for heat stress as measured by exposure, perceptions, and abilities to adapt to extreme heat will be associated with negative attitudes toward the desert.	Turner et al. 2003, Harlan et al. 2006, Jenerette et al. 2007
Access to Open Space	The aptitude for visiting desert parks based on proximity, transportation, and perceived quality will affect attitudes toward the desert.	Tobler 1970, Dee & Liebman 1970, Kearney et al. 2006

Table 2. Descriptive statistics of attitudes toward the desert for respondents in Phoenix, Arizona, USA (*n* = 806) measured in 45 neighborhoods as part of the Phoenix Area Social Survey. The values displayed for the question "the desert is a special place to me" are shown as the inverse scale used to create the ATD index. The two questions were averaged per respondent to create the composite ATD index, with higher values indicating more positive attitudes towards the desert.

Variable Name	Mean ± SE	Range	Strongly Agree	Agree	Disagree	Strongly disagree	Don't Know	Refuse to Answer
Attitudes toward the desert (ATD)	3.22 ± 0.03	1-4	-	-	-	-	-	-
The desert is a wasteland	3.40 ± 0.03	1-4	5.5%	8.4%	25.3%	57.6%	3.1%	0.1%
The desert is *not* a special place to me	3.10 ± 0.03	1-4	9.1%	12.4%	37.2%	37.0%	4.0%	0.3%

Table 3. Descriptive statistics and units of measurement of the thirteen explanatory variables collected for 806 Phoenix Area Social Survey (PASS) respondents across 45 neighborhoods during 2011 in Phoenix, Arizona, USA. Variables are grouped by theoretical model (Table 1). Variables were measured at the individual scale and aggregated to the neighborhood by averaging the total value by the number of respondents per neighborhood.

Model / Variable	Description	Individual Mean ± SE	Neighborhood Mean ± SE
Social Legacy			
Birthplace	Respondent born in Arizona (residency) – binomial yes or no	0.20 ± 0.01	0.20 ± 0.02
Length of Residency	Percentage of life spent living in Phoenix, Arizona (residency) – percent out of 100	0.47 ± 0.01	0.47 ± 0.02
Xeric Yards	Percentage of yards in neighborhood with desert-like, xeric landscaping (landscape familiarity) – percent out of 100	0.30 ± 0.02	0.30 ± 0.04
Social Differentiation			
Income	Income (social hierarchy) – ordinal ranged 1-11	3.97 ± 0.10	3.19 ± 0.32
Education	Highest level of education obtained (social hierarchy) – ordinal ranged 1-7	4.78 ± 0.06	4.74 ± 0.16
Mexican/Latino Identity	Identifies as Mexican or Latino (social identity) – binomial yes or no	0.21 ± 0.01	0.22 ± 0.04
Heat Vulnerability			
Heat Perceptions	Perception of temperatures in neighborhood relative to other areas (heat risks) – binomial hotter or cooler neighborhood	0.83 ± 0.01	0.83 ± 0.02
Outdoor Work	Amount of time spent working outdoors in the summer (exposure) – ordinal ranged 14	1.48 ± 0.03	1.49 ± 0.04
AC Use	No restrictions in using central air conditioning during the summer (adaptive capacity) – binomial yes or no	0.55 ± 0.02	0.54 ± 0.03

Table 3. Continued…

Model / Variable	Description	Individual Mean ± SE	Neighborhood Mean ± SE
Access to Open Space			
Desert Park Proximity	Distance from neighborhood centroid to the edge closest desert park (proximity) – distance in km	8.41 ± 0.18	8.44 ± 0.77
Mobility	Infrequent access to a private form of transportation (lack of mobility) – binomial yes or no	0.10 ± 0.16	0.10 ± 0.02
Park Desirability	Perception of the quality of parks and open spaces (desirability) – ordinal ranged 1-4	3.10 ± 0.03	3.09 ± 0.06
NEP Index (New Ecological Paradigm)	"Pro-ecological" or biocentric worldviews constitute broad-based beliefs about people's relationship with nature – ordinal ranged 1-4	2.88 ± 0.02	2.88 ± 0.02

Table 4. Global statistics used to determine if attitudes toward the desert were spatially associated in Phoenix, Arizona, USA, across (n = 45) neighborhoods.

Test	Test Statistic	Expectation	Variance	*p*-value
Moran's *I*	0.151	-0.023	0.004	0.003
Geary's *C*	0.836	1.000	0.004	0.006
Global *G*	0.263	0.271	0.000	0.015

Table 5. Linear regression results from the four hypothesized models testing for the effects of social and environmental characteristics on attitudes towards the desert for 806 individuals in 45 neighborhoods located across Phoenix, Arizona. Table gives values for standardized beta coefficients for the variables included in the model, the adjusted R^2, and overall significance of each model for both individual and neighborhood scales. Significance is denoted by * for P-values <0.1, ** for P-values <0.001, and *** for P-values <0.0001.

Variable	Model 1	Model 2	Model 3	Model 4
Individual Scale	*Social Legacy*	*Social Differentiation*	*Heat Vulnerability*	*Access to Open Space*
Intercept	2.75	2.64	2.64	2.38
Birthplace	-0.02			
Length of Residency	0.05			
Xeric Yards	0.1**			
Income		0.03		
Education		0.12**		
Mexican/Latino		-0.15***		
Heat Perceptions			-0.08*	
Outdoor Work			0.02	
AC Use			0.11**	
Desert Park Proximity				-0.11**
Mobility				-0.07*
Park Desirability				0.17***
NEP Index	0.08*	0.08*	0.14***	0.12***
R^2	0.01	0.06	0.03	0.05
$F_{(df)}$	$3.49_{(4, 751)}$	$11.63_{(4, 651)}$	$6.32_{(4, 689)}$	$11.27_{(4, 758)}$

Table 5. *Continued…*

Variable	Model 1	Model 2	Model 3	Model 4
Neighborhood Scale	*Social Legacy*	*Social Differentiation*	*Heat Vulnerability*	*Access to Open Space*
Intercept	1.98	2.96	2.05	1.20
Birthplace	-0.30			
Length of Residency	0.01			
Xeric Yards	0.31*			
Income		0.43**		
Education		-0.12		
Mexican/Latino		-0.58***		
Heat Perceptions			-0.19*	
Outdoor Work			-0.27*	
AC Use			0.50***	
Desert Park Proximity				-0.32*
Mobility				-0.30*
Park Desirability				0.40**
NEP	0.24*	0.07	0.27*	0.26*
R^2	0.25	0.62	0.58	0.37
$F_{(df)}$	$4.63_{(4, 40)}$	$19.21_{(4, 40)}$	$16.08_{(4, 40)}$	$7.58_{(4, 40)}$

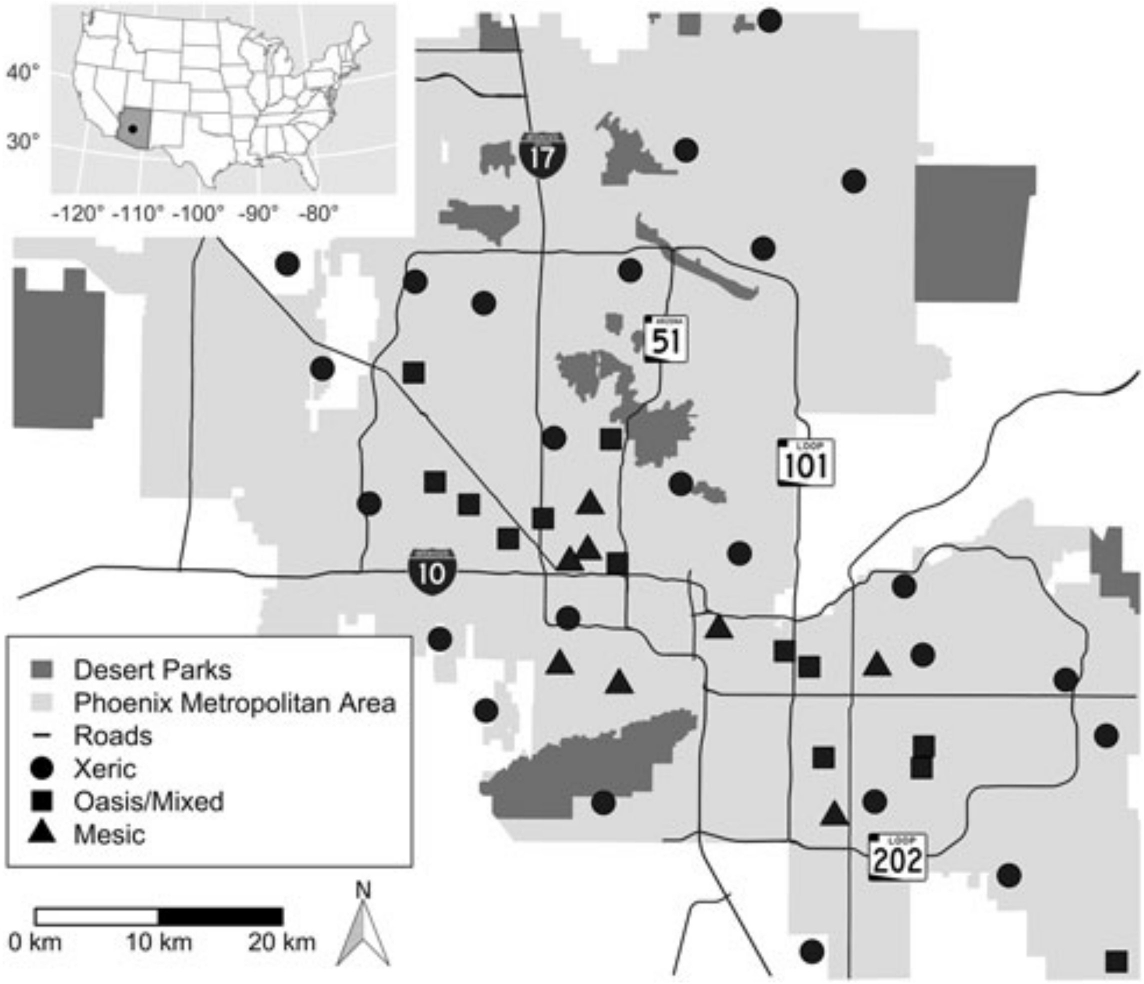

Figure 1. Study area map of the Phoenix metropolitan region, located in the southwestern United States, with the spatial distribution of the forty-five Phoenix Area Social Survey neighborhoods in 2011. Phoenix Area Social Survey neighborhoods are indicated by their centroid. Circles represent neighborhoods with predominately xeric landscaping, triangles represent mesic landscaping, and squares represent mixed xeric/mesic or oasis yard landscaping.

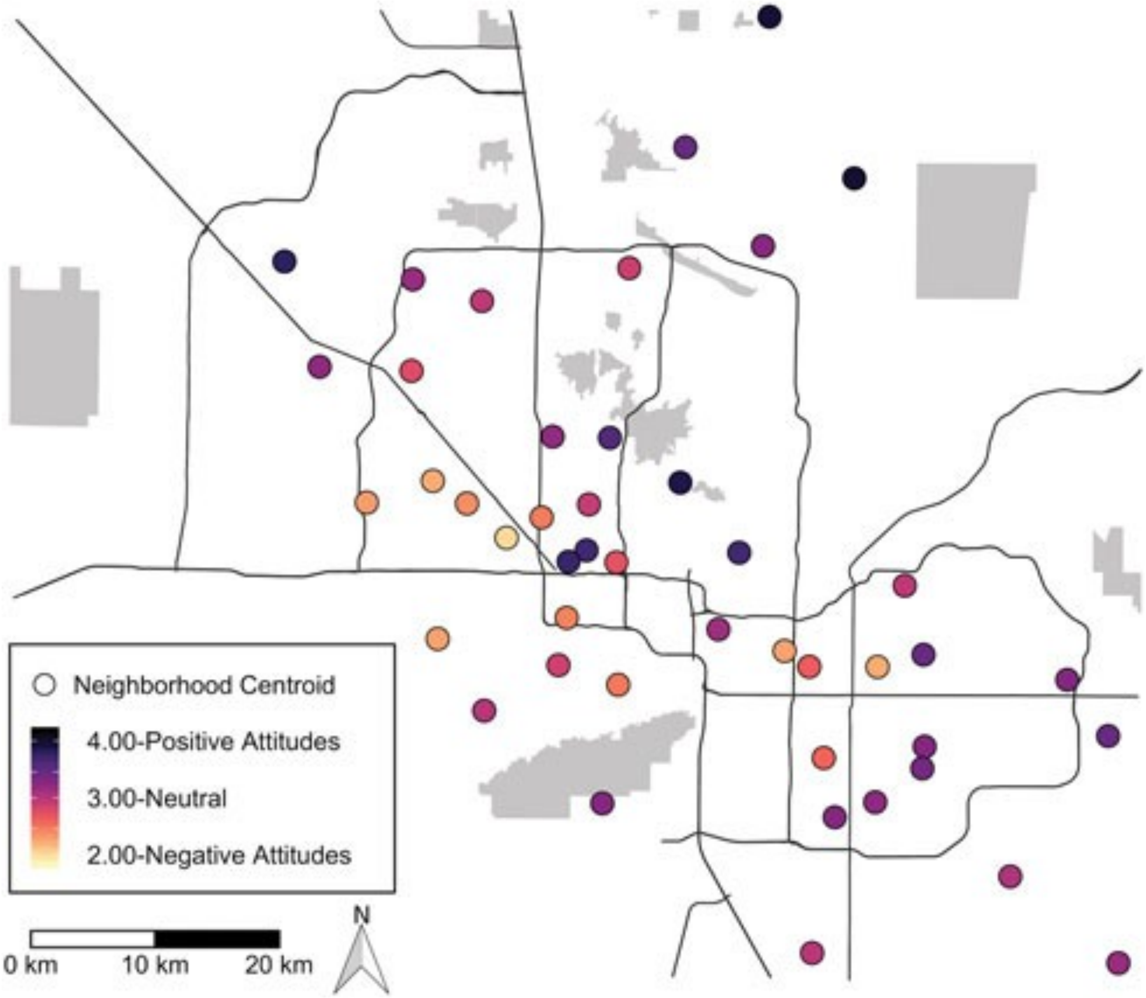

Figure 2. Average value and spatial distribution of attitudes toward the desert in forty-five neighborhoods located in Phoenix, Arizona. Color indicates attitudinal scale measuring attitudes toward the desert, where dark purple indicates positive attitudes toward the desert, pink represents neutral attitudes, and yellow-orange indicates negative attitudes toward the desert.

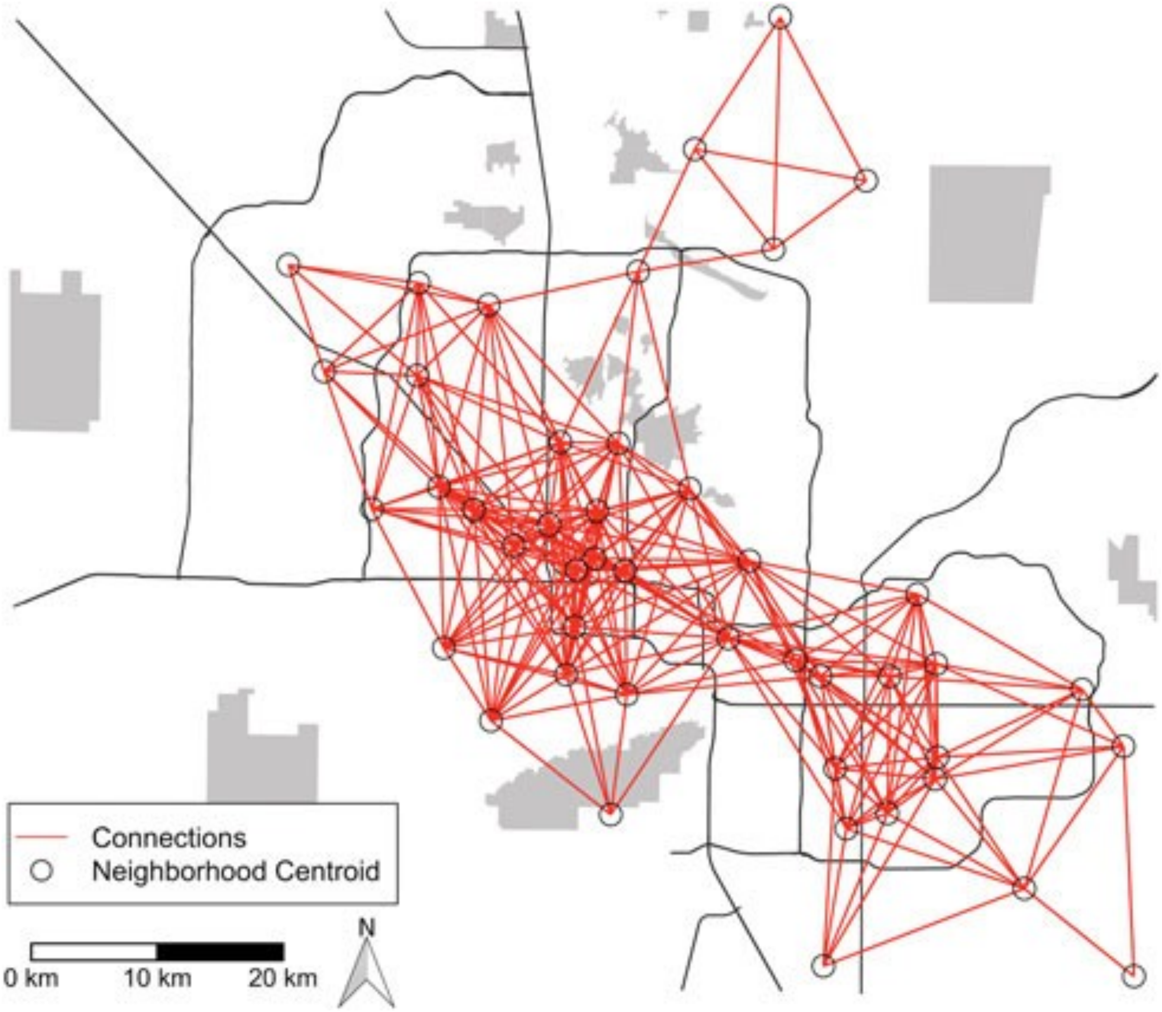

Figure 3. Neighborhood linkages (connections) for final bin size of 17 km, selected to maximize spatial relationship (Moran's I) of attitudes toward the desert where every neighborhood has at least two connections.

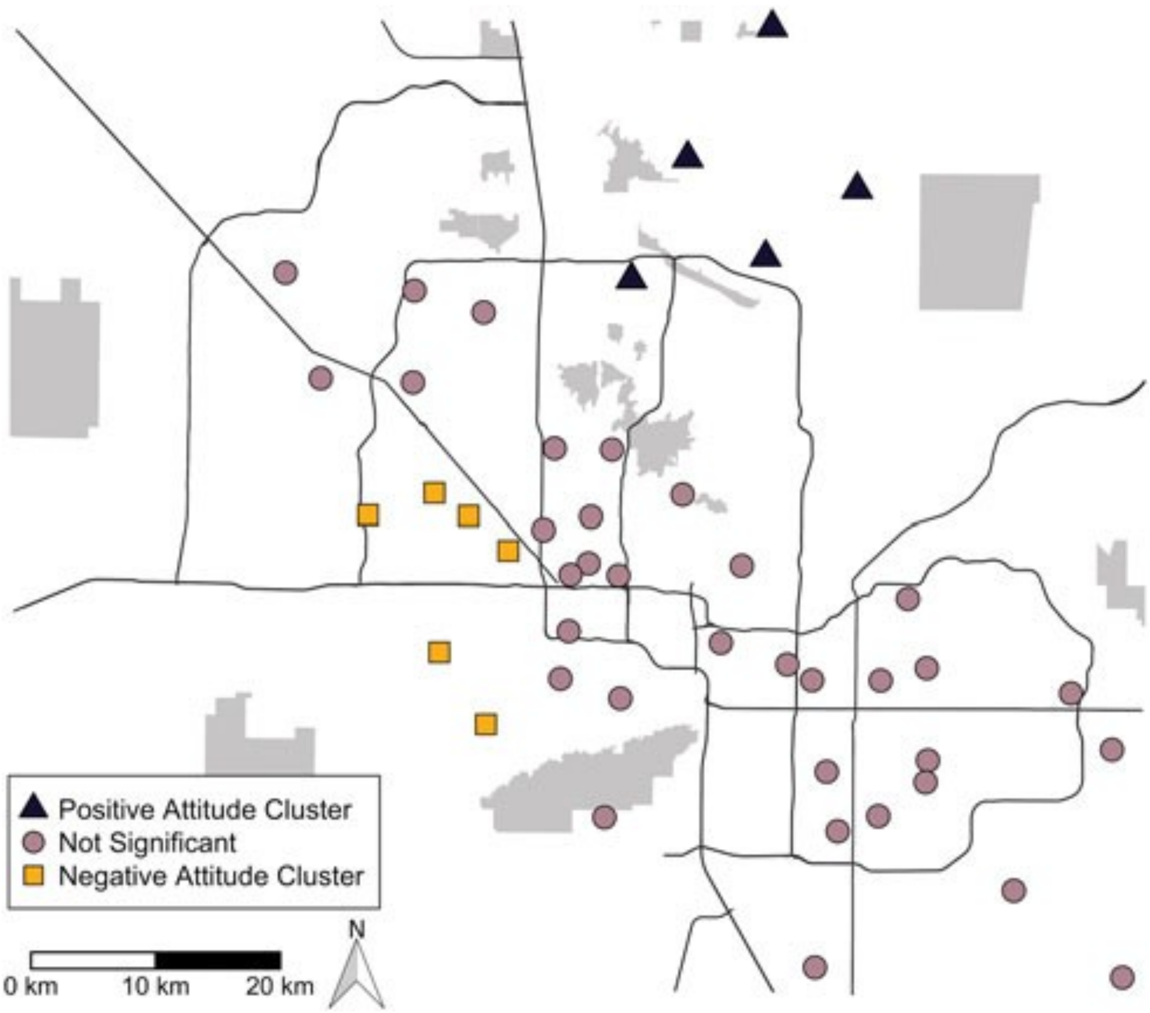

Figure 4. Spatial clusters of attitudes toward the desert measured across forty-five neighborhoods in Phoenix, Arizona, using the Getis–Ord local statistic. Color and shape indicate the significance of the clustering statistic within each neighborhood. Dark purple triangles indicate a hotspot, or clustering of more positive attitudes toward the desert ($p < 0.05$), and orange squares indicate spatial clustering of negative attitudes toward the desert ($p < 0.05$); the mauve-colored circles represent neighborhoods with no significant clustering of attitudes.

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CHAPTER 3: PREDICTING THE ASSEMBLY OF NOVEL COMMUNITIES IN URBAN ECOSYSTEMS

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ABSTRACT

Ecological communities in urban ecosystems are assembled through ecological processes such as species interactions, dispersal, and environmental filtering, but also through human factors that create and modify the landscape across multiple scales. The complex interactions among people, vegetation, and wildlife communities make it difficult to untangle the relationships between social-ecological dynamics and urban biodiversity. As a result, there has been a call for research to address how human activities influence the processes by which ecological communities are structured in urban ecosystems. Here, we address this research challenge using core concepts from landscape ecology to develop a framework that links social-ecological processes to ecological communities using metacommunity theory. Metacommunity theory distinguishes between the effects of local environmental heterogeneity and regional spatial processes in structuring ecological communities. Both of which are shaped by social-ecological dynamics in cities. Metacommunity theory is a useful framework to explore the assembly of novel communities because it considers the explicit roles of space and scale relative to local interactions, environmental heterogeneity, and the spatial configuration of patches throughout the urban landscape. In this paper, we theoretically define the social, environmental, and spatial processes that structure metacommunities, and ultimately biodiversity, in cities. We then address how our framework may be useful in empirical studies to understand multi-scalar patterns in urban ecosystems using established methodology. Overall, our framework provides a theoretical and empirical foundation for transdisciplinary research to examine how social-ecological dynamics mediate the assembly of novel communities in urban ecosystems.

1. INTRODUCTION

Urbanization is increasing globally, both in terms of human population and land use, including the rapid expansion of urban land use in global biodiversity hotspots (Seto et al. 2012). Since the majority of the global population lives in urban areas, cities are a nexus for human-environment interactions, which can ultimately influence global biodiversity (Grimm et al. 2008). However, the ecological effects of human activity are highly variable across geographic scales, as well as across taxonomic and functional groups (Chase et al. 2019).

Social-ecological interactions add a level of complexity to ecological patterns and processes in urban ecosystems (Swan et al. 2011). People influence the composition and configuration of habitat patches across temporal and spatial scales, which in turn structure biodiversity (Aronson et al. 2016). Management decisions at scales ranging from individuals and households to developers and government entities shape and reshape the landscape mosaic. In turn, the urban landscape provides ecosystem services and constrains management decisions (Pickett and Cadenasso 2008). As a result, human-environment interactions drive the landscape through iterative feedbacks, which ultimately influence regional patterns of biodiversity and human well-being (Wu 2008).

Beginning in the 1990's, there has been an emergence of interdisciplinary research to understand social-ecological dynamics in urban ecosystems (Machlis et al. 1997; Alberti et al. 2003; Childers et al. 2014; Pickett et al. 2017). These efforts have paved the way for an urban ecosystem science that considers people and social institutions as interacting components of ecosystems (Pickett and Grove 2009; Warren et al. 2010). However, the literature lacks a theoretical framework to address interactions between social dynamics and ecological processes that specifically shape ecological communities and associated biodiversity, especially one that considers social-ecological dynamics across spatial and temporal scales. Here, we use a multi-scalar approach to address current research challenges in urban ecosystem science presented by Groffman et al. (2017), which are: (1) predicting the assembly of novel ecological communities under altered environmental conditions, and (2) integrating humans as components of ecosystems, rather than separate entities or outside forces. Drawing from interdisciplinary literature (Goddard et al. 2010; Swan et al. 2011; Cook et al. 2012; Aronson et al. 2016), our theoretical framework links environmental, social, and spatial dynamics that drive community composition, and therefore biodiversity, to address these research priorities for urban ecosystems (Figure 1).

2. Metacommunity theory applied to urban biodiversity

Urban ecosystems are environmentally heterogeneous, spatially structured landscapes, making the concept of metacommunities a useful tool to understand the processes shaping biodiversity patterns. Metacommunity theory places community ecology within a spatial context by taking local groups of interacting species and placing them on the landscape (Leibold et al. 2004). Four models are used in metacommunity theory to distinguish the relative effects of spatial and environmental drivers from local to regional scales on metacommunity dynamics and biodiversity patterns: patch dynamics, species sorting, mass effects, and the neutral model (Holyoak et al. 2005; Table 1). These models are not mutually exclusive but have different assumptions about the importance of local and regional scale processes that structure community composition, as well as the resulting metacommunity structure (Leibold and Chase 2017a).

The patch dynamics model assumes a homogenous environment and limited dispersal of species, whereby tradeoffs in colonization and competition shape community composition (Slatkin 1974). In contrast, species sorting assumes environmental heterogeneity is a key driver of biodiversity patterns through niche partitioning and resource gradients (Whittaker 1962; Aronson et al. 2016). Similar to species sorting, the mass effects model assumes that species are associated more strongly with some habitats over others (Shmida & Wilson 1985); however, under mass effects, dispersal between patches structures the ecological community, creating source-sink dynamics (Pulliam 1988). Under source-sink dynamics a population can persist in less favorable environmental conditions as species disperse from suitable habitat elsewhere on the landscape (Holt 1985). Neutral theory assumes species are functionally equivalent, thereby emphasizing random demographic effects and dispersal limitation over environmental heterogeneity (Hubbell 2001). However, these models, as well as most empirical studies applying metacommunity theory, do not explicitly consider the effects of human activity (McGill et al. 2015).

We base our framework on concepts from landscape and urban ecology (Pickett and Cadenasso 2017), such as the use of heterogeneous patches spatially distributed throughout the landscape mosaic, to predict the assemblage of novel ecological communities in urban ecosystems through metacommunity theory (Teixeira and Fernandes 2020). *Environmental factors* are determined by patch composition, or the biophysical characteristics of a patch. *Spatial factors* are characterized by the distribution of patches throughout a landscape (patch configuration), which are connected by dispersal. We also add the concept of *social factors,* defined as the land management decisions made by individual people and organizations that influence patch composition and spatial configuration. Local and regional scale processes structure metacommunity dynamics, and ultimately biodiversity, through these environmental, spatial, and social factors.

3. Processes driving metacommunity dynamics

Local environmental processes: patch composition and heterogeneity

Deterministic processes structure ecological communities through environmental heterogeneity and resource utilization. In particular, models such as species sorting recognize the importance of local effects driven by environmental heterogeneity (Chase and Leibold 2003). However, the ecological niche, formed by the combination of species interactions and the local environment (Leibold 1995), is influenced by human activities in urban ecosystems. Anthropologists have used the term “niche construction” to describe the capacity of people to construct, modify, and select components of their environment to influence global biodiversity (Boivin et al. 2016). Developers, homeowners, commercial property owners, and other urban land managers often remove and replace biophysical features of the landscape during development (Pincetl 2012). Local management decisions then further shape the biophysical characteristics and resource availability of habitat patches.

Over time, management of land parcels creates environmentally heterogeneous habitat patches throughout the urban mosaic (Cook et al. 2012). Local environmental heterogeneity drives metacommunity dynamics through processes such as environmental filtering and interspecific interactions, connecting management decisions to biodiversity patterns (Nielsen et al. 2014). The relationship between social factors and local environmental heterogeneity through management decisions can be specified as a human-mediated process in urban ecosystems. For example, differences in management regimes in green spaces (e.g., parks, cemeteries, and golf courses), lead to variation in local patch composition, thereby affecting colonization, persistence, and metacommunity structure (Gallo et al. 2017).

Although deterministic processes actively link management decisions to metacommunity dynamics, niche-based environmental effects can also structure ecological communities in less actively managed land, such as preserved open space, grassland, or vacant lots (Swan et al. 2011; Kattwinkel et al. 2011). For example, Johnson et al. (2018) found that previous land-use decisions influencing local environmental heterogeneity in Baltimore, Maryland carried forward over 20 years to affect current ecological community composition in vacant lots. Ripplinger et al. (2016) found that plant communities became "weedier", with more spontaneous annual vegetation during the Great Recession as a result of people's homes being foreclosed upon. The importance of local environmental factors become more pronounced in unmanaged land parcels, such as open space or vacant lots, where limiting resources without anthropogenic inputs impose strong environmental filters (Calfapietra et al. 2015; Swan et al. 2017).

Local environmental effects: the ecological niche

Management decisions influence local interspecific interactions by shifting biophysical constraints imposed by limiting resources in cities. Urban ecosystems often provide greater availability of resources, such as water and nutrients, from human activities (Faeth et al. 2005). As a result, synanthropic—or human-associated—species gain advantage in urban ecosystems, whereas others suffer due to increased competition and risk exposure (Bradley and Altizer 2007; Shochat et al. 2010a), resulting in shifts in species dominance.

Organisms that succeed in cities by taking advantage of the balance between stress and resource availability have been hypothesized to be "living on credit" (Shochat 2004). As a tradeoff, these individuals may have lower fitness than their non-urban counterparts (Shochat et al. 2010b). Urban bird species frequently have higher survival rates (Evans et al. 2015), but smaller clutch sizes compared to rural birds, likely due to the balance of resources and risk in cities (Sepp et al. 2018). Along with differences in reproductive strategies (Ryder et al. 2010), a set of studies found that common urban species are also efficient foragers and may even change foraging behavior depending on habitat type (Shochat et al. 2004; Lerman et al. 2012a). Together, interspecific interactions and environmental heterogeneity represent deterministic mechanisms that structure metacommunities, where niche-related dynamics and environmental conditions of the system over time and space predict community assembly. Both species sorting and mass effects rely heavily on deterministic processes to predict metacommunity dynamics, which further links these models to social factors through human-mediated resource subsidies.

Environmental and spatial effects: disturbance

Spatial factors, such as dispersal limitations and spatially structured stochastic events (e.g., disturbance), can counteract deterministic mechanisms, such as competition, in structuring metacommunities (Chesson 1985). Stochastic events causing an externally imposed mortality factor, partially explain the high degree of temporal and spatial turnover in cities (Allen et al. 2019), which are more prone to these stochastic disturbances (Sattler et al. 2010). There is support for both the intermediate disturbance and ecosystem stress hypotheses in urban ecosystems (Lepczyk et al. 2008), which emphasize the effects of disturbance on biodiversity (Connell 1978; Rapport et al. 1985; Menge & Sutherland 1987). The intermediate disturbance hypothesis explains the hump-shaped relationship between human-induced disturbance and diversity, whereby areas of intermediate urban land use support the highest levels of diversity (McDonnell and Picket 1990; Lepczyk et al. 2008; Andrade et al. 2017). In contrast, the ecosystem stress hypothesis suggests a negative relationship between urban development and diversity (Faeth et al. 2011).

Disturbance also influences competition and colonization tradeoffs (Leibold and Chase 2017b). For example, under the ecosystem stress hypothesis, community assemblages will converge around species with high population growth rates that disperse well, but are weaker local competitors, thus competition versus colonization. Frequent disturbance prevents persistence of superior competitors and instead favors better disperses that can occupy the patch post-disturbance (Schwartz et al. 2006), which aligns with the colonization-competition tradeoffs in the patch dynamics model. In particular, patch dynamics considers how disturbances allow for species to coexist because both superior competitors and colonizers are prevented from excluding one another (Leibold and Chase 2017a).

Spatial effects: active and human-mediated dispersal

The spatial configuration of the landscape mosaic, availability of suitable habitat patches to colonize, and functional traits of an organism can all affect dispersal (Starrfelt and Kokko 2012). In turn, dispersal ability mediates the role of environmental and spatial heterogeneity on metacommunity structure (Padial et al. 2014; Jacobson and Peres-Neto 2010). For example, mass effects predicts scenarios in which inferior competitors persist throughout the landscape as a result of dispersal. When dispersal is an important factor driving metacommunity dynamics, competition becomes less critical as inferior competitors with high dispersal rates swamp out locally superior competitors (Leibold and Chase 2017a). Although dispersal is unimpeded for some urban adapted species by human-based barriers such as roads (Fey et al. 2015), habitat fragmentation due to roads and fences can also severely limit dispersal (Shepard et al. 2008).

Urbanization limits dispersal for certain organisms, but human activity can also generate unlimited dispersal as people distribute species throughout the landscape (La Sorte et al. 2007). Although human-mediated dispersal can occur across many taxa, it is most applicable to vegetation. Human-mediated dispersal can be considered a social-spatial process, where people introduce an organism to a local habitat patch from another source habitat. The importance of dispersal, as in mass effects, can be particularly relevant in urban ecosystems, where people act as a dispersal agent, moving species throughout the landscape, and changing local environmental conditions that support specific organisms (Swan et al. 2011). However, once a species is introduced into the local species pool, organisms are still subject to deterministic and stochastic processes (Cubino et al. 2019), such as speciation/extinction or limitations in dispersal to other patches.

The functional traits related to natural dispersal (such as wing length; Piano et al. 2017), are not necessarily the same species traits that support human-mediated dispersal (Mack and Lonsdale 2001). Instead, human-mediated dispersal is largely driven by traits desirable to people, such as being relatively low maintenance or aesthetically pleasing (Cubino et al. 2019). However, other human-mediated dispersal may be unintentional, such as the movement of insects in untreated firewood (Jacobi et al. 2011). Species traits can also influence resource dynamics when people make management decisions to support specific taxa in local habitat patches, such as putting out food for hummingbirds. As a result, a common and widespread species may have been purposefully attracted and curated as a reflection of its popularity rather than its ability to disperse or compete (Avolio et al. 2015). Thus, human-mediated dispersal directly connects social and spatial factors with biodiversity in urban ecosystems.

Summarizing spatial and environmental effects

The spatial configuration of patches within the urban landscape mosaic, as well as environmental heterogeneity, are influenced by the interplay of social and environmental factors that influence and constrain one another (Pickett and Cadenasso 2008). Under models that emphasize the importance of local deterministic processes, such as species sorting (Figure 2a) and mass effects (Figure 2b), we would expect local environmental characteristics of human-constructed niches to structure ecological communities (e.g., Sattler et al. 2010). However, mass effects assumes the importance of spatially structured environmental heterogeneity, which drives source-sink dynamics and explains why species can be present in otherwise poor-quality habitats (Figure 2b). Stochastic events, such as disturbance, link to patch dynamics and coexistence under competition (Figure 2c; Leibold and Chase 2017a). Finally, neutral theory acts as the null model and instead explains random processes not attributed to traits or environmental conditions drive patterns of community composition, however random processes may still be spatially structured throughout the landscape (Figure 2d).

4. Integrating social factors into metacommunity dynamics

Understanding social dynamics and land management across scales

Habitat patches are typically managed along human-constructed boundaries in cities (e.g., parcels owned by private or public entities). However, the scales at which species and ecological communities respond often transcend social-political boundaries (Cumming et al. 2006). Therefore, management decisions on individual parcels scale up or down to create habitat patches (Goddard et al. 2010). To address these cross-scalar implications, we consider metacommunity theory in the light of management decisions, as well as the broader scale forces at neighborhood, municipal, and regional levels. Local land management that influences environmental heterogeneity links social factors to deterministic models of species sorting and mass effects. Conversely, the patch dynamics and neutral theory models, which emphasize the importance of spatial and stochastic processes, are linked to social factors through management decisions that affect the configuration of the urban landscape.

Different disciplines and research traditions hold varying assumptions on the freedom of choice that goes into land management decisions. The decisions people make based on preferences, priorities, and desires is a common, 'agency-based' approach to understanding how management decisions affect ecological outcomes (e.g., Yabiku et al. 2008; Larson et al. 2010; Harris et al. 2013). However, other arguments posit that external factors, as opposed to preferences and desires, control or constrain decision-making (Robbins and Sharp 2003a). The biophysical and social factors that restrict agency in decision-making are commonly known as structural constraints (Larson et al. 2010; Chowdhury et al. 2011). Management decisions are constrained by factors that are reinforced through time, such as financial resources, social and neighborhood norms, current environmental conditions, and local or broader scale policies (Cook et al. 2012). As a result, homeowners, developers, governments, and market forces all exert control over one another to influence land-management decisions (Robbins et al. 2001), which then structure metacommunity dynamics (Swan et al. 2011).

Deterministic models vary under the influence of agency versus structure

The social science concepts of agency and structure in land management decisions connect to metacommunity models that assume the influence of deterministic, or environmental, processes. For example, species sorting assumes that local environmental conditions, and not geographic space, structure metacommunity dynamics (Leibold and Chase 2017c). Species sorting could apply to conditions where individual agency—based on people's preferences, desires, and motivations—was the dominant driver of management decisions (e.g., Cubino et al. 2020). Here, an individual would make decisions based on their attitudes, beliefs, or emotions

(Harris et al. 2013) and individual experiences of the landscape would influence people's roles in tending to their local environmental, such as planting wildlife friendly gardens (Musacchio 2013). This is decoupled from spatial processes of social norms across multiple scales, e.g., from individually held beliefs to widespread customs, or neighborhood-level effects such as development patterns and mimicry that control landscaping choices (Minor et al. 2016). As a result, local decisions and environmental heterogeneity would structure metacommunities without spatial factors (Figure 2a).

Despite the relative importance of preferences and motivations on landscaping choices, social and environmental factors across multiple spatial scales constrain people from doing what they want (Larson et al. 2010). Developers often plan and install the landscapes surrounding homes, which are often homogenous (Pincetl 2012). These original landscaping decisions often dictate subsequent management decisions, and thereby influence local ecological communities (Larson et al. 2017). For example, if a developer installs a xeric yard, then the next land manager may be inclined to keep the landscape in place, rather than replace it (Wheeler et al. 2020).

In addition to development patterns constraining management decisions, factors such as social norms and codified rules from Homeowner's Associates or municipal ordinances also exert control over local decisions (Chowdhury et al. 2011; Cook et al. 2012). For example, the maintenance of grassy lawns and palm trees in historic preservation districts in Phoenix, AZ are reinforced through time by the expectations of neighbors and through codified rules regulating the preservation of mesic landscaping (Larson and Brumand 2014). As rules are enforced through sanctions, social norms further hold up formalized constraints through expectations of social obligations and the conceptualization of land management as a civic responsibility (Robbins 2007). As a result, formal institutions, such as municipal ordinances, are both produced and reinforced through social norms to constrain local land management decisions (Nassauer et al. 2009), such as neighbors enforcing weed height restrictions (Sisser et al. 2016).

The mass effects model can be used to explain the influence of structural constraints, which are often spatially clustered, on metacommunity dynamics (Figure 2b). Although the mass effects model emphasizes the importance of local environmental factors (or deterministic processes) in explaining metacommunity dynamics, mass effects differs from species sorting in that community composition also depends on spatial structure (Leibold and Chase 2017a). Social norms and mimicry, as well as clustered social factors (York et al. 2011), can result in environmental homogeneity at local scales within a neighborhood, with increased heterogeneity at larger scales between neighborhoods. As a result of external pressures such as social norms, houses closer together have similar community assemblages due to uniform management decisions, creating socially driven spatial structure to local environmental factors (Locke et al. 2018). In metacommunities where structural constraints such as regulations or widespread norms prevail, we can expect spatial structure to influence community composition along with environmental factors, at least within socially constructed boundaries that restrict decisions (Hunter and Brown 2012)

Social dynamics influence environmental and spatial factors

The same spatial and environmental factors that are important determinants of metacommunity dynamics, such as landscape structure and dispersal, are also influenced by human activity and management decisions in urban ecosystems (Leibold and Chase 2017d). People influence the structural composition of a landscape, such as tree canopy in residential yards increasing connectivity in fragmented urban mosaic (Ossola et al. 2019). Additionally, market and economic pressures dictate the inventory available at nurseries and other commercial stores, influencing the region species pool (Aronson et al. 2016), which people disperse from nurseries and other nearby sources into local habitat patches (Avolio et al. 2018). The variety and functional traits of plant species offered at nurseries and selected by individuals change over time, which creates temporal turnover in novel ecological communities (Pincetl et al. 2013).

The marketing of the industrial lawn throughout the United States is another social factor that homogenizes community composition through the enforcement of mesic landscapes in public and private greenspace (Robbins and Sharp 2003a; Robbins and Sharp 2003b). However, even in heavily managed landscapes such as manicured lawns, the occurrence of spontaneous vegetation is widespread (Wheeler et al. 2017; Lerman et al. 2018). These spontaneous plant communities colonize actively managed patches from other habitat patches throughout the urban landscape mosaic, rupturing human control over the ecological processes and disrupting people's expectations and selection for a neat and kempt aesthetic (Head and Muir 2006).

Multi-level shifts in authority—which determines how control over the land is exercised and to what extent individuals can determine their local environment—results in a dynamic locus of control that influences spatial and environmental heterogeneity (Grove et al. 2005). Top-down effects, such as early land-use institutions (e.g., zoning), shape development patterns, and the spatial configuration of the urban landscape mosaic (York et al. 2014). However, bottom-up effects from individual homeowners can also influence social-ecological dynamics. For example, support for impact fees in higher-income neighborhoods controls development at the urban fringe, resulting in more preserved open space (York et al. 2017). In terms of source-sink dynamics under mass effects, dispersal to and from source habitat of nearby open space could influence local community composition in these neighborhoods. Therefore, we may see biodiversity positively associated with high-income neighborhoods, where native and specialist species can occupy a patch despite its local environmental conditions (such as homogenous lawn cover) due to proximity to open space (Davis et al. 2012).

5. Applying the Framework

The expected importance of social, environmental, and spatial factors in our conceptual model can be tested with a methodology put forward by Chase et al. (2005) using regression techniques (Swan et al. 2011). Using this methodology, community similarity (e.g., beta-diversity) is used as the dependent variable to compare how species composition changes with environmental and spatial distance (e.g., heterogeneity or dissimilarity) between patches. These techniques are also commonly paired with variation partitioning on a community matrix (a table of species occurrence or abundance across sites) to abstract the spatial and environmental effects on biodiversity (Borcard et al. 1992; Legendre 2008) and distinguish between deterministic versus stochastic processes (Smith and Lundholm 2010).

When local, deterministic processes, or environmental heterogeneity, structure communities, we can expect a positive relationship between beta-diversity and environmental heterogeneity between patches, irrespective of spatial distance (Figure 2a, Figure 2b). If spatial effects are important due to stochastic processes or dispersal limitation, then spatial distance between patches will likely have a strong, negative relationship with community similarity (Figure 2b-d). Our proposed model also encompasses human dimensions of urban ecosystems by integrating the concept of 'social factors' (Figure 2).

To empirically test social factors within a metacommunity framework, social distances can be calculated as the magnitude of differences between multiple social variables in the same way we evaluate environmental or spatial distance. For example, a low-income neighborhood would be socioeconomically distinct from a high-income neighborhood, so we would expect to see a difference in ecological community composition between these neighborhoods (Grove et al. 2006; Leong et al. 2018). Overall, our framework, which includes social factors, better encompasses the dynamics of urban ecosystems and can be applied to better predict ecological communities because it considers people as an active component of the ecosystem.

Summarizing social, environmental, and spatial factors in urban metacommunity theory

Based on the extant social-ecological literature and metacommunity theory, we predict that all four metacommunity models have utility in urban ecosystems (Figure 2). Under the species sorting model, we expect local social and environmental factors, decoupled from spatial processes, to influence metacommunity structure (Figure 2a). In patches with a large degree of human investment and decision making based on preferences, we expect that social factors will be the most strongly related to beta-diversity under species sorting. However, in unmanaged patches (such as preserved open space or vacant lots), local environmental factors driving deterministic processes may be more important to community assembly than social factors. In contrast to the deterministic model of species sorting, patch dynamics assumes the importance of spatial configuration. Here, social factors become important and would share a degree of variation with spatial factors because urban landscapes are often structured along social boundaries such as neighborhoods and municipalities (Figure 2c). The patch dynamics model also uniquely explains the high spatial and temporal turnover in cities through processes such as ecological disturbance (Lepczyk et al. 2008; Ripplinger et al. 2016; Grimm et al. 2017). Neutral theory (Figure 2d) captures the stochasticity characterizing novel communities in urban landscapes (Sattler et al. 2010), which highlights the key roles of dispersal limitation and evolution on metacommunity structure (Rosindell et al. 2011).

In addition to species sorting, patch dynamics, and neutral theory, we posit that mass effects best explains metacommunity patterns in urban ecosystems through social-ecological dynamics (Figure 2b). We base this on the prevalence of studies that suggest that urban assemblages are primarily driven by social and environmental controls (Lerman and Warren 2011; Lerman et al. 2012b, Cook et al. 2012; Belaire et al. 2014; Lerman et al. 2018; Warren et al. 2019). Studies also demonstrate the importance of neighborhood-level social norms or regulations (Nassauer et al. 2009; Minor et al. 2016; Sisser et al. 2016; Locke et al. 2018), management decisions across the landscape, and spatial factors in influencing biodiversity (e.g., Avolio et al. 2018; Goddard et al. 2017; Gallo et al. 2017)

6. Conclusion

Land use and land management decisions influence the assembly of ecological communities and the resulting biodiversity in cities. However, there is a lack of consensus on which models best predict the assembly of novel ecological communities, or how to incorporate human dimensions into ecological community theory to support predictions. The field of Landscape Ecology is well positioned to connect social-ecological dynamics in cities by linking multi-scalar concepts, such as metacommunity theory and the social processes at various levels that structure land management decisions (Wu and Hobbs 2007). Here we link the concepts of spatial and environmental heterogeneity to social dynamics to explain the processes by which novel ecological communities assemble in urban ecosystems. Overall, our conceptual model contributes to the current understanding of urban ecology and more specifically, how human-environment interactions mediate metacommunity structure, and thus biodiversity in cities. We suggest future research directions test our multi-scalar model with data, including metacommunities from different taxonomic and functional groups across diverse metropolitan areas. Continued work to increase the interdisciplinary understanding of complex interactions between people and biodiversity in cities can further improve efforts to better predict and manage urban and other ecosystems driven by social-ecological dynamics.

Table 1. Glossary of key concepts

1. Metacommunity Theory	
Metacommunity	Ecological communities (plants and/or animals) linked by habitat patches throughout a landscape. Metacommunity theory is based on deterministic and stochastic processes from local to regional scales.
Species Sorting	Metacommunity dynamics driven by local environmental heterogeneity and resource utilization.
Mass Effects	Metacommunity dynamics driven by spatial and environmental factors. Source-sink dynamics where species disperse to local patches.
Patch Dynamics	Metacommunity dynamics driven by spatial effects of dispersal and colonization-competition tradeoffs. Assumes no spatially fixed environmental heterogeneity.
Neutral Theory	Metacommunity dynamics randomly determined by processes such as speciation and extinction.
2. Factors Structuring Metacommunity Dynamics in Urban Ecosystems	
Environmental	Biophysical characteristics and heterogeneity of parcels that scale up or down to create habitat patches. Environmental factors include environmental filtering and resource dynamics that influence species interactions.
Spatial	The structure or configuration of habitat patches throughout the landscape. Spatial factors include dispersal, source-sink dynamics, and colonization. In urban ecosystems, people can also override spatial structure by facilitating dispersal.
Social	Individual people and organizations that interact with local ecological communities and who make decisions that impact environmental and spatial factors.
3. Social and Ecological Processes	
Deterministic	Niche-related processes related to environmental heterogeneity (Mass effects and Species Sorting).
Stochastic	Unpredictability, random and/or neutral processes, typically related to spatial structure (Patch Dynamics and Neutral Theory).
Structural Constraints	External factors (e.g., social norms, development history, land use, climate), which constrain management decisions and the regional species pool.

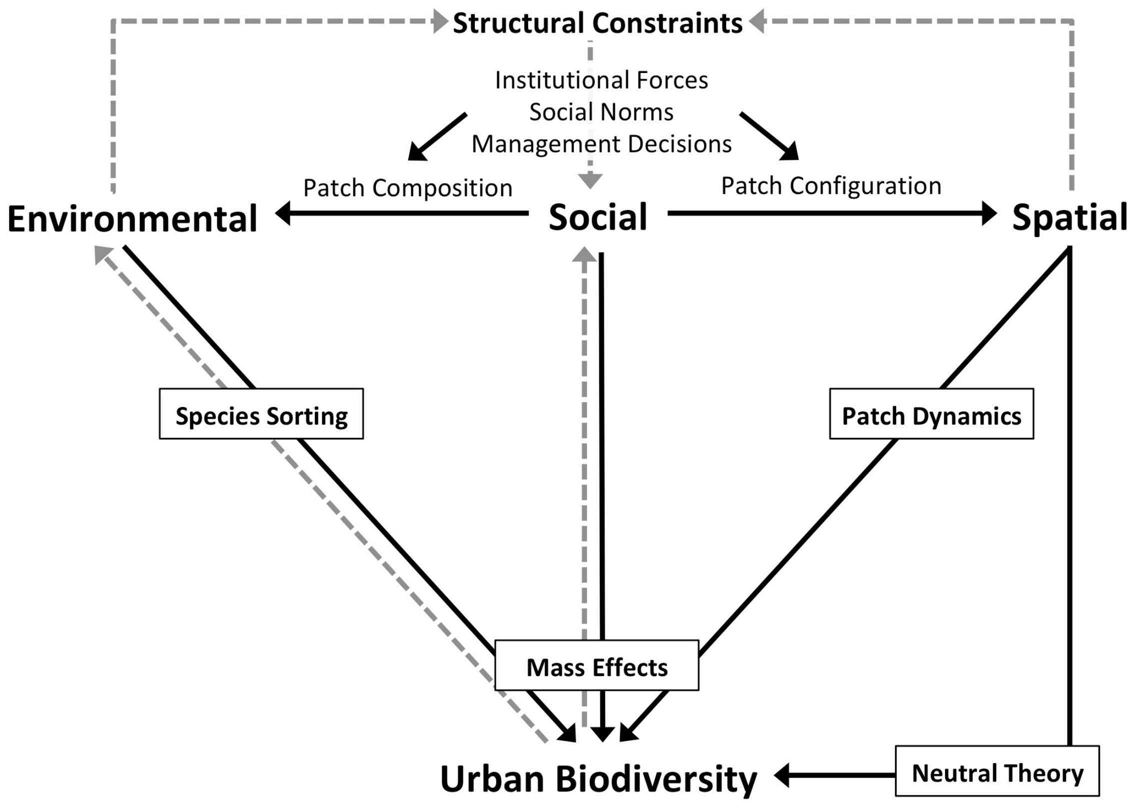

Figure 1. Local to regional scale processes categorized into environmental, social, and spatial factors, which structure metacommunity dynamics (Species Sorting, Patch Dynamics, Mass Effects, and Neutral Theory) and therefore, biodiversity in urban ecosystems. People (social factors) influence biodiversity by dispersing species and through management decisions, which shape habitat patch composition (environmental factors) and configuration (spatial factors) across the landscape. Structural constraints, including the environmental heterogeneity and spatial configuration of the urban landscape constrain management decisions across multiple scales. Grey-dotted arrows indicate feedbacks reproduced in the system, which further influence environmental and social factors over time.

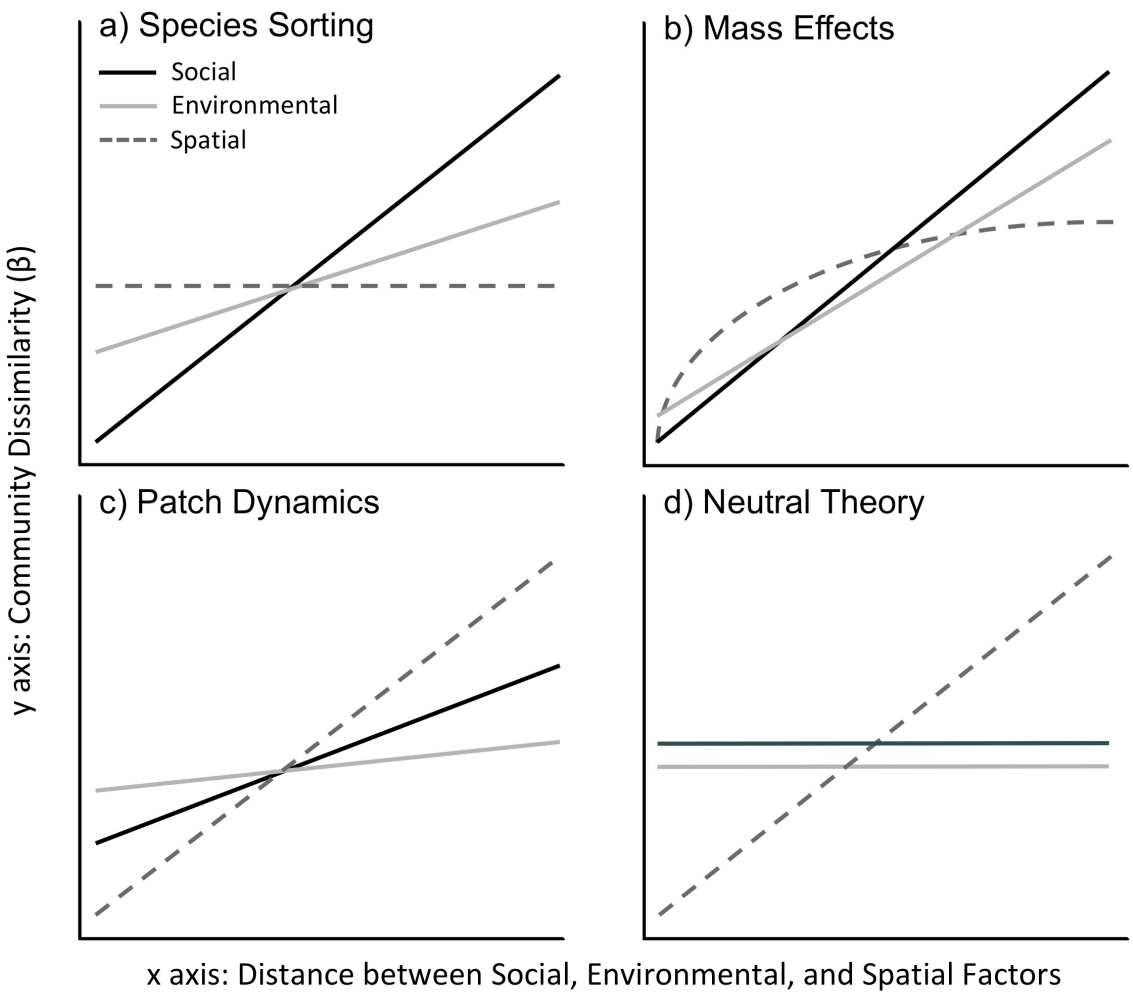

Figure 2. Predictions of how urban biodiversity will vary between sites that differ in social, environmental, and spatial factors under: a) Species Sorting, b) Mass Effects, c) Patch Dynamics, and d) Neutral Theory metacommunity models. We include predictions based on social factors from our conceptual framework. The x-axis represents the variation (or pairwise distance) between social, spatial, and environmental factors between patches. The y-axis represents the dissimilarity in the species composition between patches (β-diversity). Modified from Leibold and Chase (2017) and Chase (2005).

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CHAPTER 4: SOCIAL-ECOLOGICAL DYNAMICS ALTER THE EFFECTS OF STOCHASTIC AND DETERMINISTIC PROCESSES IN STRUCTURING URBAN BIRD COMMUNITIES

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ABSTRACT

Ecological communities are assembled through multi-scalar processes, such as environmental filtering and dispersal. However, it remains unclear how human activities mediate processes by which ecological communities are assembled in urban ecosystems. We used metacommunity theory, which spatially places ecological communities onto the landscape, to determine how environmental, social, and spatial factors influence bird communities in 36 residential neighborhoods throughout Phoenix, Arizona, USA. Deterministic processes related to environmental heterogeneity had the most substantial influence on bird communities, which had a relatively weak relationship with neighborhood spatial structure. Social factors were important but were associated with environmental heterogeneity, likely due to the relationship between management decisions and sociodemographics. Bird communities at the urban-open had high levels of turnover and a richer species pool (α-diversity). Conversely, bird communities in the intra-city had lower α-diversity and were stochastic, likely due to spatial processes linked to ecological disturbance. Our analysis suggests strong environmental filtering imposed on urban bird communities and that human activity creates variability in the processes that structure ecological communities.

1. INTRODUCTION

Urbanization is a global driver of biogeographical change through shifts in local and regional processes that influence community composition and, ultimately, biodiversity (Piano et al. 2019). The growth of urban land area into the 21st-century places emphasis on understanding biodiversity in urban ecosystems (Seto et al. 2012). Although urbanization can be viewed as an endpoint of ecological disturbance, research indicates that cities are dynamic, complex ecosystems (Grimm et al. 2017). Environmental and spatial factors, in addition to human activities, all influence the organization of ecological communities in cities (Alberti et al. 2003). As a result, urban ecological communities are assembled through processes such as intraspecific interactions, dispersal, and resource dynamics, but also through interactions with people (Aronson et al. 2016). The effects of human activities shifting—and sometimes bypassing—expected ecological patterns provides an opportunity for urban ecological research to inform existing ecological theory, as well as develop new theory that explains the complexity of social-ecological dynamics in community ecology (Groffman et al. 2017).

Metacommunity theory offers an ideal framework to study the effects of human activity on biodiversity because it considers the spatial, heterogeneous nature of landscapes (Leibold et al. 2004). Human activities like management decisions are spatially explicit, shaping the landscape along socially constructed boundaries, such as yards and parks (Cumming et al. 2006), which follows the conceptual underpinnings of metacommunity theory (Swan et al. 2011; Faeth et al. 2012). Deterministic processes structure metacommunities through environmental heterogeneity (Leibold and Chase 2017a), which is influenced by the management decisions made by individuals and organizations in cities (Nilon 2011). Conversely, stochasticity captures the unpredictability in community assemblages (Vellend 2010). External factors, such as disturbance, can shift the relative importance of deterministic and stochastic processes within the same regional species pool (Chase and Myers 2011). The concept of press-pulse dynamics to explain the influence of human activity as an ecological disturbance (Collins et al. 2011) may then have utility to explain the assembly of novel ecological communities within the urban landscape (Grimm et al. 2017). Ecological disturbances such as the urban heat island (press disturbances) or human development (pulse disturbances) result in temporal and spatial turnover of ecological communities (Allen et al. 2019) and differentiate the relative influence of deterministic versus stochastic processes in non-urban systems (e.g., Chase 2007).

Empirical studies suggest that ecological communities in cities can be stochastic, but are largely structured by factors such as environmental heterogeneity over multiple scales (Sattler et al. 2010; Aronson et al. 2016) as compared to non-urban ecosystems (Cottenie 2005). The strong influence of environmental factors follows the species-sorting paradigm, which predicts that metacommunities are largely aspatial and instead structured by environmental differences between habitat patches (Leibold et al. 2004). The influence of environmental versus spatial factors in urban ecosystems may be attributed to the fact that individual yard management decisions decouple spatial auto-correlations (Faeth et al. 2005). A single wildlife-friendly yard may be surrounded by homogenous lawn-dominated yards, based on landscaping choices by individual householders (Harris et al. 2012). However, still other studies have found that social dynamics, such as mimicry and development patterns within neighborhoods, can create spatially structured patterns in the environment (Locke et al. 2018). The complex relationship between people, biodiversity, and the resultant habitat patches leaves open the question of how social, environmental, and spatial processes structuring community composition vary throughout a city due to human activity.

We focus on urban bird communities in residential neighborhoods, where we can test the effects of human activity as individual householders managing local yards, which scale up to create local habitat patches throughout the city (Goddard et al. 2010). Residential yards area ubiquitous, but relatively understudied, component of biodiversity because of their large spatial extent and potential to provide connected green space in otherwise developed landscaped (Lorman et al. 2007). Management decisions made by householders, such as resource provisioning and landscaping choices, are heavily restricted by structural constraints, including income, social norms, and local ordinances (Lerman et al. 2012a; Goddard et al. 2013; Sisser et al. 2016). As a result, shifts in bird community composition from one residential neighborhood to another (β-diversity) are related to environmental heterogeneity, such as the provisioning of local resources (Lerman and Warren 2011). Still, they are also linked to social factors such as income, life stage, and attitudinal patterns (Belaire et al., 2016).

By considering shifts in species composition from one residential neighborhood to another (β-diversity), we can untangle the mechanisms resulting in the high degree of intra-urban variability that occurs in urban ecosystems (Beninde et al. 2015). Surprisingly, very few studies have considered the social-ecological connections of bird biodiversity across multiple scales (Goddard et al. 2017). Here, our research focuses on key environmental and spatial factors that shape intra-urban variability in community composition (β-diversity), and how people (social factors) may shift ecological patterns and processes in cities (Swan et al. 2011). We integrated social and ecological data collected as part of the Central Arizona-Phoenix Long-term Ecological Research project in neighborhoods throughout Metropolitan Phoenix, AZ, USA to answer the following research questions: (1) How do bird community metrics vary between residential neighborhoods with varying disturbance patterns? 2) How are environmental, social, and spatial factors related to bird community composition? And, 3) Do differences among neighborhoods influence the effects of social, environmental, and spatial factors on bird community composition?

2. METHODS

Study Area and Experimental Design

Social-ecological data were collected in residential neighborhoods across the Phoenix metropolitan area (Figure 1). The Phoenix metropolitan area is an arid city located in the Sonoran Desert of the Southwest United States (33.427, -111.933). Home to 4.5 million residents (U.S. Census 2017), the urban morphology is sprawling and largely residential, with the majority of new growth occurring at the edges of the city and then backfilling (Keys et al. 2007). As a result, newer neighborhoods tend to be located closer to desert open space (wildlands) at the fringe of the city. The preservation of open space within the urban perimeter and increase in vegetation are associated with lower land surface temperature and higher NDVI values than urban core neighborhoods (Jenerette et al. 2011). Phoenix, AZ (the core municipality of the metropolitan area) has a large Hispanic/Latinx population, which composes 31.3% of the population. The median household income between 2014 and 2018 is $61,606, and 32.0% of the population has a Bachelor’s degree or higher (U.S. Census Bureau, 2019).

Our research design integrates long-term data collected in neighborhoods as part of the Central Arizona-Phoenix Long-term Ecological Research project (CAP LTER). Launched in 1997, the CAP LTER site covers 6400 km^2 of the urban landscape to monitor social and ecological change in the urban ecosystem. These data are available through the LTER data repository

(Bateman et al. 2016; Larson et al. 2019). The neighborhoods were selected based several factors, including proximity to open space, income, ethnicity, and development regimes (Larson et al. 2019). We used these social-ecological stratifications to categorize neighborhoods into *intra-city* and *urban-open* groups in our research design and analysis (Figure 1). Based on the press-pulse dynamic concept (Collins et al. 2011), we predicted that these two neighborhood groups would vary in press-pulse dynamics, including temperature and NDVI (Jenerette et al. 2016), structural constraints such as local ordinances influencing environmental change (Larson and Brumand 2014), and management decisions based on social patterns (Wheeler et al. 2020).

Bird surveys

We used bird community data collected by the CAP LTER between 2017 and 2018 at 36 independent point-counts, hereafter referred to as bird-points. The 36 bird points were randomly placed at least 200 m apart in the Phoenix Area Social Survey (PASS) neighborhoods, for a total of three points per neighborhood (Bateman et al. 2016). Bird surveys were conducted in the winter and spring seasons (December-February, March-May), with three visits per season, for a total of six surveys per year per site. Trained observers recorded all birds seen or heard for 15-minute intervals within a 40 m radius of the point (Ralph et al. 1995). We calculated the maximum number of each species recorded per site over the survey visits to consider seasonal variation between winter and spring migration. Species observed at <10% of the sites were omitted from further analysis focused on community composition because rare species can have a disproportionate influence on β-diversity calculations (McGarigal et al. 2013). Bird species were classified into desert specialist, generalist, and urban guilds following a classification scheme modified from Lerman and Warren (2011).

Social Factors

We used long-term social survey data, collected by CAP LTER, co-located with the 36 bird-points to measure sociodemographics of individual households using the PASS conducted in the summer of 2017 (Larson et al. 2019). Originally established in 2001, the survey is part of the CAP LTER project and measures values, attitudes, and behaviors about a variety of social-ecological topics longitudinally. The 2017 PASS was administered to 1,400 households using a mail-only survey design in neighborhoods delineated by Census Block Group boundaries. A total of 39.4 % of householders responded for a final sample of 496 households. Survey responses were paired with the 36 bird-points using the spatial distance from the parcel associated with the response to the closest bird-point in the residential neighborhood. Additional details of survey data sampling design are available online (Larson et al. 2019).

We used survey responses to measure social factors hypothesized to structure bird community composition, including income, ethnicity, and householder age by aggregating households within the PASS neighborhoods to their closet bird-point (Supplementary Table S2). We asked respondents to select which income category best represented the total combined income for their household before taxes. Responses were coded by $20,000 increments on an 11-point scale: from (1) $20,000 and under to (11) More than $200,000. We then calculated the mean household income for each bird-point from the associated respondents. Hispanic/Latinx identity was coded using the following question: Do you consider yourself to be Mexican, Mexican-American, Chicano, Hispanic, Latino, or of Spanish background? Respondents who selected “Yes” were coded as 1 to calculate the percent of respondents who identified as Hispanic or Latinx. Lastly, we calculated householder age as the average age of respondents.

Environmental Factors

Environmental factors were used to determine the effect of deterministic processes on community composition. Following Warren et al. (2019), we also used responses from the PASS to determine yard-landscaping typologies surrounding the bird-points (Supplementary Table S2). Warren et al. (2019) found that respondents’ yard classifications were comparable to ecological measurements of groundcover for xeric and mesic landscaping and were significantly related to bird community composition. Yard type was recorded by asking respondents which of the following typologies best resembled their front and back yard. Mesic yards were coded as responses that selected “A yard with grass, some shrubs and leafy trees,” and xeric yards were coded as: “A yard with crushed stone and native desert plants and trees.” We then calculated the percent of mesic and xeric yards per bird-point. We also calculated the average lot-size of residential yards per bird-point using land parcel data provided by the Maricopa County Assessor's Office (Parcel Secured Master 2017).

We used satellite imagery and Census data to measure regional-scale environmental filters in urban ecosystems, including Land Surface Temperature (LST), Normalized Vegetation Index (NDVI), proximity to desert open space, and human-population size. LST was calculated using the online global Land Surface Temperature Estimation tool (Parastatidis et al. 2017) by taking the median LST within a 100 m radius of each bird-point for 2017. We used a raster of the NDVI, computed using the near-infrared (NIR) and red (RED) bands: NDVI=(NIR-RED)/(NIR+RED) with National Agriculture Imagery Program (NAIP) imagery (Stuhlmacher 2019), to calculate the median NDVI within the same 100 m radius of each bird-point in 2017. We calculated proximity to desert open space as the distance in meters from the bird-point to the closest edge of desert land use cover, which was generated from a Land-use Land-cover (LULC) classification of 30-m resolution Landsat TM5 (Li 2015). To ensure the variable was expressed as a measure of proximity, we inverted the distance, so that larger values represent closer proximity to desert open space. We collected human-population data from the 2010 Census (U.S. Census Bureau 2010), which calculates population as the number of people per land area in the Census Block Group that the bird-point occurred in (U.S. CBG have a target size of 1,500 people).

Spatial Factors

We used Moran's eigenvector maps (MEMs) to calculate spatial variables explaining the spatial structure of the 36 bird-points (Dray et al. 2006). MEMs use connectivity matrices to calculate orthogonal eigenvectors representing the spatial configuration of patches throughout the landscape. Similar to principal components, these orthogonal eigenvectors can be used as continuous explanatory variables to explain the effects of spatial structure on ecological communities (Dray et al. 2006). We used Delaunay triangulation from package "spdep" (Bivand et al. 2015) to define spatial neighbors around the bird-points (see Supplementary Material for neighbors map) and then calculated the weighted neighbors list using row-standardization so that the row sums are equal (O'Sullivan and Unwin 2014). We retained the first eleven eigenvectors significant at $P<0.05$ as explanatory variables measuring spatial factors related to bird community composition. We calculated spatial MEM eigenvector variables using the ‘adespatial’ package (Dray et al. 2019) in program R (R Core Team 2018).

Analysis

Our first research question (RQ1) asked how diversity metrics of the bird community vary between intra-city and urban-open neighborhoods. We first tested the differences in social and environmental factors between the intra-city and urban-open neighborhoods using a Student’s t-test (Supplementary Table S2). We then calculated β-diversity, turnover, and nestedness using the ‘betapart’ package (Baselga et al. 2018). We determined whether local species richness (α-diversity) and abundance differed using a Student’s t-test. We then tested for differences in β-diversity, including turnover and nestedness, using the multivariate homogeneity of group dispersions procedure from the ‘betadisper’ function in the ‘Vegan’ package (Oksanen et al. 2018). We used the modified Raup-Crick metric (Raup and Crick 1979) to test whether communities in intra-city and urban-open neighborhoods were stochastically or deterministically assembled (Chase and Myers 2011). The modified Raup-Crick metric, determines if pairwise communities are more or less dissimilar than expected by chance. The metric ranges from -1 to 1. Values close to 0 represent no difference in observed dissimilarity from the null expectation, indicating stochastic assemblages. Values closer to -1 or 1 represent less or more dissimilarity than expected, respectively, indicating deterministic processes are structuring the community. We used the ‘raupcrick’ function in Vegan using half tied simulation values (average raupcrick results with chase=TRUE and chase=FALSE) and then standardized the metric to range from -1 to 1 (Chase et al. 2011). We used the R2 null model (Wright et al. 1998) to account for widespread species in the bird metacommunity (Supplementary Table S1). We then tested if the mean value of the metric statistically varied from 0 or if the metric differed between intra-urban and urban-open neighborhoods using one- and two-sided Student’s t-tests.

We used multivariate ordination techniques to address our second research question (RQ2), which asked how bird community composition in residential neighborhoods was related to environmental, social, and spatial factors. To do so, we examined the bird community in multivariate space using non-metric multidimensional scaling (NMDS) with Bray-Curtis distance using a square root transformation on the bird community matrix (Clarke 1993) using the Vegan package in R (Oksanen et al. 2018). We visualized the predicted separation of intra-city versus urban-open neighborhoods in species space using dispersion ellipses and tested the differences between the groups using an Analysis of Similarities (ANOSIM). We then fitted social, environmental, and spatial (MEMs) variables to the ordination plot using the 'envfit' function to determine the relationship between the environmental, social, and spatial variables and the bird community in multivariate space. Several of the spatial variables were insignificant in describing differences in community composition, which we dropped from subsequent analysis.

Our third research question asked if the effects of environmental, social, and spatial factors on bird community composition differ within and between intra-city and urban-open neighborhoods (RQ3). Following the methodology proposed by Chase et al. (2005), we used the Bray-Curtis distance matrix to test the social, environmental, and spatial factors related to pairwise differences between all bird-points, between intra-city neighborhoods, between urban-open neighborhoods, and the community similarly between intra-city and urban-open neighborhoods. To do so, we first computed the dissimilarity of social, environmental, and spatial variables between sites using Gower's distance (Gower 1971), which detects underlying ecological gradients and has the flexibility to calculate distances across variables with varying distributions (Faith et al. 1987). We then used a Mantel test based on Pearson correlation with the 'mantel' function in package Vegan to determine the relationship between the community dissimilarity (e.g., β-diversity) and social, environmental, and spatial dissimilarity. The Mantel test is a correlation between two dissimilarity matrices using permutations of the rows and columns of the matrix (Bocard and Legendre 2012). We ran all analyses in program R version 3.5.1 with the 'tidyverse' (Wickham 2017) and 'psych' (Revelle 2018) packages for data cleaning and descriptive statistics (R Core Team 2018).

3. RESULTS

Characterizing residential neighborhoods (RQ1)

There were a total of 60 bird species and 2,128 individuals recorded in residential neighborhoods between 2017 and 2018, with a regional species pool (γ-diversity) of 60 species.

After excluding rare species, which made up less than 3% of the total individuals, we observed 2,072 individuals and 33 unique bird species. Supporting our original expectation of trends in press-pulse dynamics, urban-open neighborhoods were closer to desert open space and were less dense with larger lot sizes then intra-city neighborhoods (Supplementary Table S2). NDVI was higher and LST was lower in urban-open neighborhoods than intra-city neighborhoods. Urban-open neighborhoods had older, higher-income householders, with fewer householders who identified as Hispanic or Latinx than those in the intra-city. MEM1, MEM2, and MEM4 (Supplementary Figure S1) differentiated the two neighborhood groups spatially.

Local bird communities varied between intra-city and urban-open neighborhoods (Table 1). Overall bird abundance was not significantly different (Table 1). However, intra-city neighborhoods had a lower abundance of desert specialist species (t=-5.73, P<0.0001) and lower species richness (t=-9.40, P<0.0001) than urban-open neighborhoods (Table 1). Likewise, urban-open neighborhoods had a higher richness of desert specialist species (t=-6.95, P<0.0001). β-diversity varied between intra-urban and urban-open neighborhoods (F=8.48, P <0.006), due to differences in turnover, which indicates the uniqueness of the species assemblage in a given community (F=7.49, P<0.009). Nestedness did not vary between neighborhoods.

We also tested if communities were stochastically or deterministically assembled using the Raup-Crick metric (Table 1). We found that the urban metacommunity as a whole was deterministically assembled (β_{RC}= 0.29; T-test: mean is not equal to 0, t= 14.7, P<0.0001). However, intra-city neighborhoods did not statistically differ from 0, indicating they were stochastically assembled (β_{RC}=-0.07; T-test: mean is not equal to 0, t=-2.3, P=0.09), whereas urban-open neighborhoods were deterministically assembled (β_{RC}=0.55; T-test: mean is not equal to 0, t= 26.1, P<0.0001). Positive β_{RC} values indicate a "checkerboard" pattern of dissimilar local bird assemblages throughout the urban landscape. The β_{RC} metric was significantly different between bird communities in intra-city and urban-open neighborhoods (t=16.6, P<0.0001).

Bird Community Composition in Residential Neighborhoods (RQ2)

We used an NMDS with a two-axis solution (NMDS stress=0.16, R^2=0.97) to visualize bird community composition (Figure 2). The NMDS1 axis separated urban-open and intra-city neighborhoods (ANOSIM statistic *R*=0.44, P<0.001). NMDS1 represented an urban gradient along the intra-city to urban-open sites, separating urban and desert bird species. MEM1 and MEM2 spatially connect bird-points in neighborhoods at the desert fringe, whereas MEM5 and MEM7 spatially connect intra-city sites along the NMDS 1 axis. NMDS2 represented a spatially structured environmental gradient, where increasing y-values along the axis were mesic yards spatially intermixed throughout the urban matrix (MEM4 and MEM6).

Desert specialist species were associated with urban-open neighborhoods in closer to desert open-space (R^2=0.58, P<0.001), with higher income (R^2=0.77, P<0.001), older householder age (R^2=0.28, P<0.008), higher NDVI (R^2=0.19, P<0.037), and larger lot size (R^2=0.42, P<0.001). The differences between bird-points intra-city and urban-open neighborhoods were largely represented along NMDS1 (Figure 2). Urban and generalist bird species were positively associated with Latinx householders (R^2=0.39, P<0.001), denser human-population (R^2=0.28, P<0.005), and hotter temperatures (R^2=0.59, P<0.001) in intra-city neighborhoods along NMDS1; as well as mesic yards to a lesser extent (R^2=0.16, P<0.05) along NMDS2. Bird community composition was also associated with two of the eleven spatial eigenvector variables. Desert specialist species were positively associated with MEM1 (R^2=0.25, P<0.0009). MEM2, MEM4, MEM5, and MEM7 were not significant at P<0.05. MEM6 (R^2=0.24, P<0.008) followed a similar association as mesic yards with bird communities composed of urban and generalist species (Figure 2).

The influence of environmental, social, and spatial factors (RQ3)

β-diversity (bird community dissimilarity) increased with social, environmental, and spatial distances between neighborhoods (Figure 3). However, the influence of these factors shifted between intra-city and urban-open neighborhoods (Figure 4). For the urban metacommunity as a whole, dissimilarity in social factors was related to both environmental (mantel test *r*=0.49*, P*<0.0001) and spatial dissimilarity (mantel test *r*=0.15*, P*<0.001; Phoenix Metro Box, Figure 4). Environmental and spatial dissimilarity were not significantly related. As social and environmental factors became more dissimilar between a pair of bird-points, so did bird community composition (environmental mantel test *r*=0.58*, P*<0.001; social mantel test *r*=0.48*, P*<0.0001). Spatial factors also influenced community structure but to a lesser extent (mantel test *r*=0.16*, P*<0.0001).

Bird communities in intra-urban neighborhoods were more unpredictable in terms of environmental and social factors (Figure 3). Social and environmental dissimilarity were related (mantel test *r*=0.30*, P*<0.02), but not with dissimilarity in spatial factors (Figure 4). Only spatial dissimilarity was related to community dissimilarity in intra-urban neighborhoods (mantel test *r*=0.18*, P*<0.04). Social dissimilarity in urban-open neighborhoods was related to the dissimilarity of environmental (mantel test *r*=0.26*, P*<0.005), and spatial factors (mantel test *r*=0.20*, P*<0.007). Dissimilarity in bird communities increased with environmental and social factors for urban-open neighborhoods (environmental mantel test *r*=0.59*, P*<0.0001; social mantel test *r*=0.24*, P*<0.01), but spatial dissimilarity was not significant (Figure 4).

4. DISCUSSION

Our study reveals how ecological processes that structure bird communities can vary within urban ecosystems, resulting in novel community assemblages (Figure 4). Specifically, the influence of deterministic versus stochastic processes in structuring urban bird communities differed amongst residential neighborhoods in the urban landscape (Figure 4). Our results align with the Chase and Myers (2011) framework, which posits that external factors can shift the relative influence of deterministic processes on community structure within the same regional species pool (Stegen et al. 2013). Additionally, our study highlights that purely spatial processes for structuring metacommunities are less important than in non-urban landscapes (Cottenie 2005). However, other studies have found that spatial factors such as isolation and habitat connectivity do impact urban metacommunities (e.g., Parris et al. 2006; Braaker et al. 2014). Although spatial factors had a minimal influence overall for our urban bird metacommunity, they became more important in our study for local bird communities in intra-urban neighborhoods that are further away (and potentially more isolated) from desert open space. The bird community in intra-city neighborhoods was more stochastic, as evidenced by the Raup-Crick metric (Table 1), as well as the relative importance of spatial factors in association with bird community dissimilarity (Figure 4). Conversely, deterministic processes were more important for structuring bird communities in urban-open neighborhoods (Figure 4).

We found that urban-open neighborhoods structured by deterministic processes had a higher degree of predictability than their low-income intra-city counterparts (Figure 4). We related the differentiation in community structure to the pulse-press dynamics in intra-city versus urban-open neighborhoods. In non-urban systems, deterministic processes are more influential in more stable environments (Daniel et al. 2019). In our study, stability may be related to urban-open neighborhoods with higher SES. For example, these neighborhoods are buffered against press events, such as increases in temperature due to the urban heat island (Jenerette et al. 2007). Standardizing pressures such as HOAs or social norms governing yard-care decisions could further create stability in these heavily managed neighborhoods (Larson et al. 2010, Lerman et al. 2012a, Larson and Brumand 2014). York et al. (2017) give a relevant example of higher-income neighborhoods at the urban-open being buffered from the effects of environmental change. Specifically, they found that householder support for impact fees in high-income neighborhoods controls residential development at the urban fringe, resulting in the preservation of open space (York et al. 2017). Although turnover in plant species composition is high in urban ecosystems (Avolio et al. 2019), the ability of people to control their environment may then act as a stabilizing force in residential neighborhoods in terms of resources provisioning, such as stability in vegetation structure (Templeton et al. 2019). As a result, deterministic processes related to environmental factors may become more prominent in structuring metacommunities in neighborhoods whose residents have more ability to control their environment.

Environmental filters on the urban bird community

Deterministic processes related to environmental and social factors structured bird community composition within urban-open neighborhoods (Figure 4). As such, our study supports the growing body of evidence that urban ecosystems weaken the effects of spatial factors related to community composition compared to environmental factors (Angold et al. 2006; Sattler et al. 2010; Baldissera et al. 2012; Chang and Lee 2016; Tsang and Bonebrake 2017). The active management of small, individual parcels (e.g., yards) decouples the spatial autocorrelations in the environment that would normally be expected in non-urban systems (Faeth et al. 2005). For example, lush mesic lawns in our study system can be located directly next to xeriscaping with crushed gravel and desert vegetation. These patterns in residential landscaping would reflect a checkerboard pattern, where dissimilar environments can be located next to one another due to management decisions (Picket et al. 2017). Species can then move a very short distance in geographical space, but be in a distinct habitat in environmental space. Our findings of locally heterogeneous bird communities reflect patterns in residential landscaping choices. Specifically, we found that urban bird communities that were more dissimilar than expected by chance in urban-open neighborhoods (Raup-Crick metric, Table 1), which indicates that environmental filters create local communities that are very dissimilar from one another (Diamond 1975, Chase et al. 2011). Bird turnover in the urban-open neighborhoods was also high, further indicating unique community assemblages (Table 1).

The importance of environmental factors in urban-open neighborhoods relates to the metacommunity theory of species sorting (Swan et al. 2011). Species sorting assumes that local differences in environmental factors structure ecological communities, and in cities we can see that environmental heterogeneity is also related to the social template because the environment in residential neighborhoods is mediated by people's yard management decisions (Figure 4). Following predictions of species sorting metacommunity structure (Leibold et al. 2004), we found that the unique suite of species at any given neighborhood was due to environmental factors. In particular, we found that specialist birds in Phoenix are associated with desert landscaping found in residential yards that mirror the natural environment (also see, Lerman and Warren 2011; Warren et al. 2019). Native landscaping in cities provides local habitat where native specialist species can outcompete urban-dwellers (Goddard et al. 2017). On the other hand, urban species often switch between food sources and consume more types of resources than desert specialist species, allowing them to capitalize on patches with lower habitat quality and persist in a larger variety of yard landscaping designs, but do worse in xeric neighborhoods that desert specialist species are adapted to (Lerman et al. 2012b). As a result, urban species may be excluded from neighborhoods with desert environments, but have a broader distribution with other habitat types throughout the city.

The role of stochasticity

Overall, bird community assembly in intra-city neighborhoods exhibited a higher level of stochasticity. One explanation is that biodiversity lower-income neighborhoods are more influenced by Press-Pulse Dynamics (e.g., drought). Following the metacommunity theory of patch dynamics, if community structure is influenced by spatially structured disturbance causing mortality events, we would expect to see relatively stochastic communities that are related to the spatial configuration of the landscape (Leibold and Chase 2017b). We observed these patterns in our intra-city neighborhoods (Figure 4). The ecosystem stress hypothesis can be used to help explain the relationship between urban development and biodiversity due to disturbance. For example, Lepczyk et al. (2008) found that 40% of bird species in the Midwestern US were negatively associated with increasing human influence (measured by anthropogenic land cover and housing units). The effects of human development on local bird diversity increase over time (Pidgeon et al. 2013). Similarly, our intra-city neighborhoods were older, which could also have amplified the differences between neighborhood types in terms of species richness and diversity (Table 1). We might also expect varying levels of disturbance within a city based on social-ecological factors (Grimm et al. 2017) and that shifts in ecological disturbance would be reflected in the processes which structure communities.

Local resource inputs such as irrigation or the selection of drought-tolerant plants to adapt to climate change (Fan et al. 2017) may further exacerbate differences in press-pulse dynamics within a city. Additionally, pulse events, such as householder turnover (which occurs more in lower-income neighborhoods) can potentially disrupt the existing environmental conditions to influence biodiversity (Ossola et al. 2018). In general, disturbance events favor good dispersers and generalist species that can successfully occupy a patch post-disturbance, which describes the functional traits of many urban bird species (Schwartz et al. 2006). Additionally, urban bird species often have broad diets and the ability to resource switch, and as a result, are able to persist in a variety of habitat types, making their occurrence in any given habitat type less predictable based on social or environmental factors (Shochat et al. 2010).

The lack of significance in describing differences between bird diversity in intra-urban neighborhoods may be due to variable selection. However, the variables we used to describe environmental, social, and spatial factors explained a large degree of variation for β-diversity for the bird metacommunity as a whole (Figure 4). Therefore, a completely different suite of variables either drives variation in bird diversity for the intra-urban neighborhoods or bird community composition is more random in these neighborhoods compared to high-income fringe neighborhoods. Additionally, the Raup-Crick metric not statistically deviating from 0 further confirms the role of stochasticity in these neighborhoods (Table 1). Overall, our findings in intra-city neighborhoods further support that press-pulse dynamics can influence the processes by which ecological communities are structured.

5. CONCLUSION

Our results emphasize the importance of environmental heterogeneity—influenced by individual people and organizations—in filtering bird community composition in residential neighborhoods (Aronson et al. 2016). Likewise, we found that purely spatial processes were less important for structuring local bird communities than social or environmental factors. The interrelationship between social-ecological dynamics across scales is unsurprising considering local to regional landscaping decisions that control environmental conditions. Future work further unpacking the multi-scalar effects of people (e.g., Cook et al. 2012), such as the effects of local resource provisioning buffering regional-scale environmental conditions such as drought, would further reveal how novel ecological communities are structured over space and time in urban ecosystems. The findings from our study have utility in understanding novel community assemblages in urban ecosystems, but can also be used to inform community ecology broadly. Specifically, shifts in the influence of deterministic versus stochastic processes can be expected in areas that humans interact with the environment. However, people bypassing expected ecological processes in ununiformed patterns across the landscape. As a result, the effects of environmental and spatial drivers of community composition may be better understood through the consideration of more complex social factors, such as management decisions (and the factors that control these decisions) that are made throughout a landscape.

Table 1. Descriptive statistics for biodiversity metrics used in our analysis to determine bird metacommunity structure in the Phoenix metropolitan region. We calculated diversity metrics for the urban landscape as a whole (Phoenix Metro, n=36 bird points), as well as for intra-city (n=15) and urban-open neighborhoods (n=21). We report mean values and standard deviation for the metrics, with the exception of the three Beta-diversity metrics.

Diversity Metric	Phoenix Metro	Intra-City	Uban-Open
Abundance	59.11 ± 18.54	59.53 ± 23.99	58.81 ± 14.08
Desert Abundance	11.03 ± 9.35	4.00 ± 2.20	16.05 ± 9.27
Urban Abundance	25.58 ± 19.57	38.67 ± 22.24	16.24 ± 10.18
Generalist Abundance	22.50 ± 10.12	16.87 ± 7.47	26.52 ± 9.96
Species Richness (α)	18.67 ± 4.89	13.93 ± 1.94	22.05 ± 3.22
Desert Richness (α)	6.11 ± 3.69	3.00 ± 1.13	8.33 ± 3.25
Urban Richness (α)	3.94 ± 1.22	4.40 ± 0.74	3.62 ± 1.40
Generalist Richness (α)	8.61 ± 2.48	6.53 ± 1.25	10.10 ± 2.02
Beta-Diversity (β)	0.86	0.67	0.78
Turnover	0.78	0.58	0.73
Nestedness	0.08	0.09	0.05
Raup-Crick (β_{RC})	0.29 ± 0.71	-0.07 ± 0.71	0.55 ± 0.58

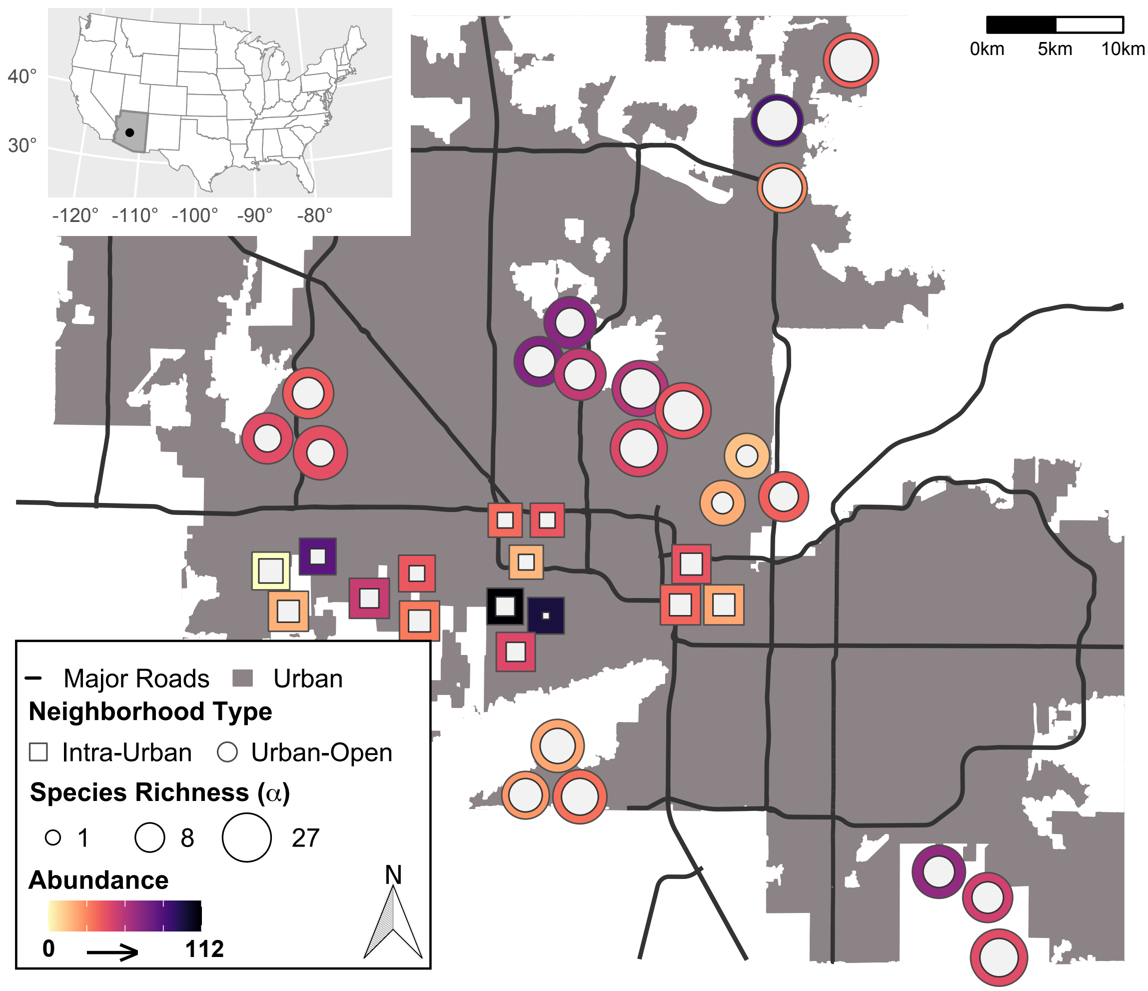

Figure 1. Aerial view of the Phoenix metropolitan area showing the extent of the study area, including urban land use in grey, and location of 36 bird-points. Bird-points were classified by their residential neighborhood type: intra-urban represented by squares (bird-points located within urban core and suburban neighborhoods, n=15) and urban-open (bird-points located at the interface of the city and desert open-space, n=21). We visualized local alpha-diversity at the bird-points by shape size, where the outer shape size represents total species richness and the inner shape size represents desert-specialist richness.

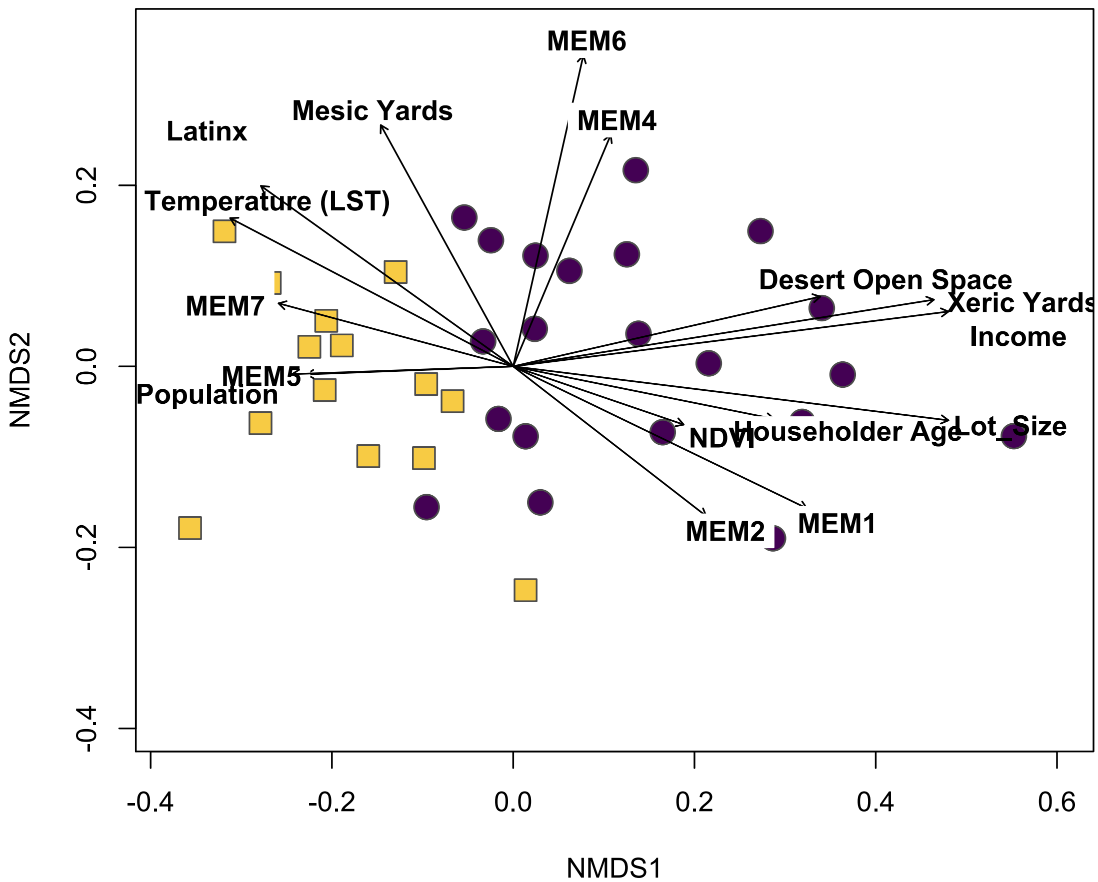

Figure 2. We visualized bird-points located in intra-city and urban-open neighborhoods throughout the Phoenix metropolitan area in bird species space using Non-metric multidimensional scaling (NMDS). Bird-points in intra-city neighborhoods are represented as squares and in urban-open neighborhoods as circles. Sites closer together are more similar in terms of bird species composition. The relationship between species composition and environmental, social, and spatial variables are displayed as vectors, the length of vector represents relative significance with the ordination axes.

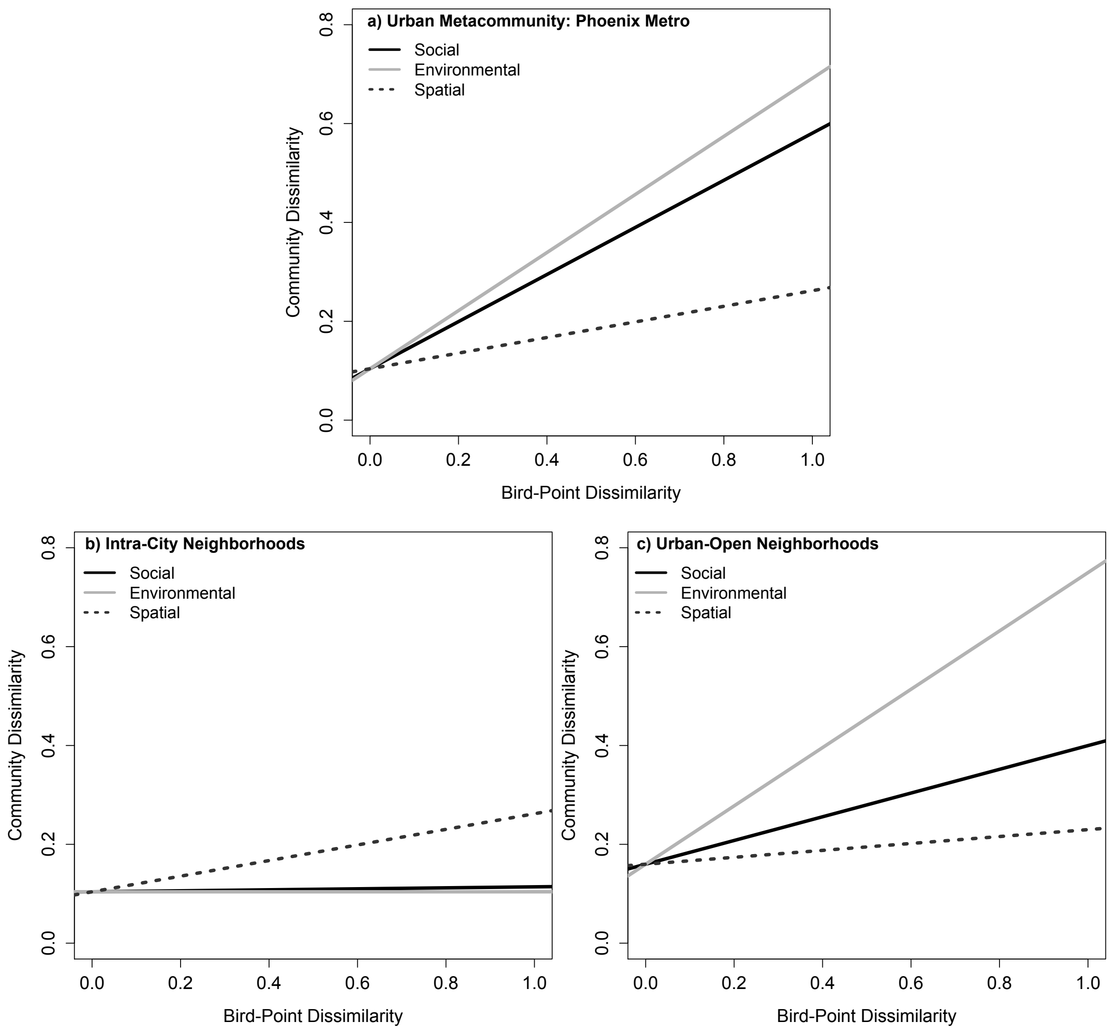

Figure 3. We tested the pairwise relationship (Pearson correlation) between dissimilarity in environmental, social, and spatial factors for bird-points in intra-city and urban-open neighborhoods (x-axis) with the dissimilarity of the bird community (y-axis) using a mantel test. As y-values increase, the bird community is more dissimilar and as x-values increase, environmental, social, or spatial factors of bird-points are more dissimilar.

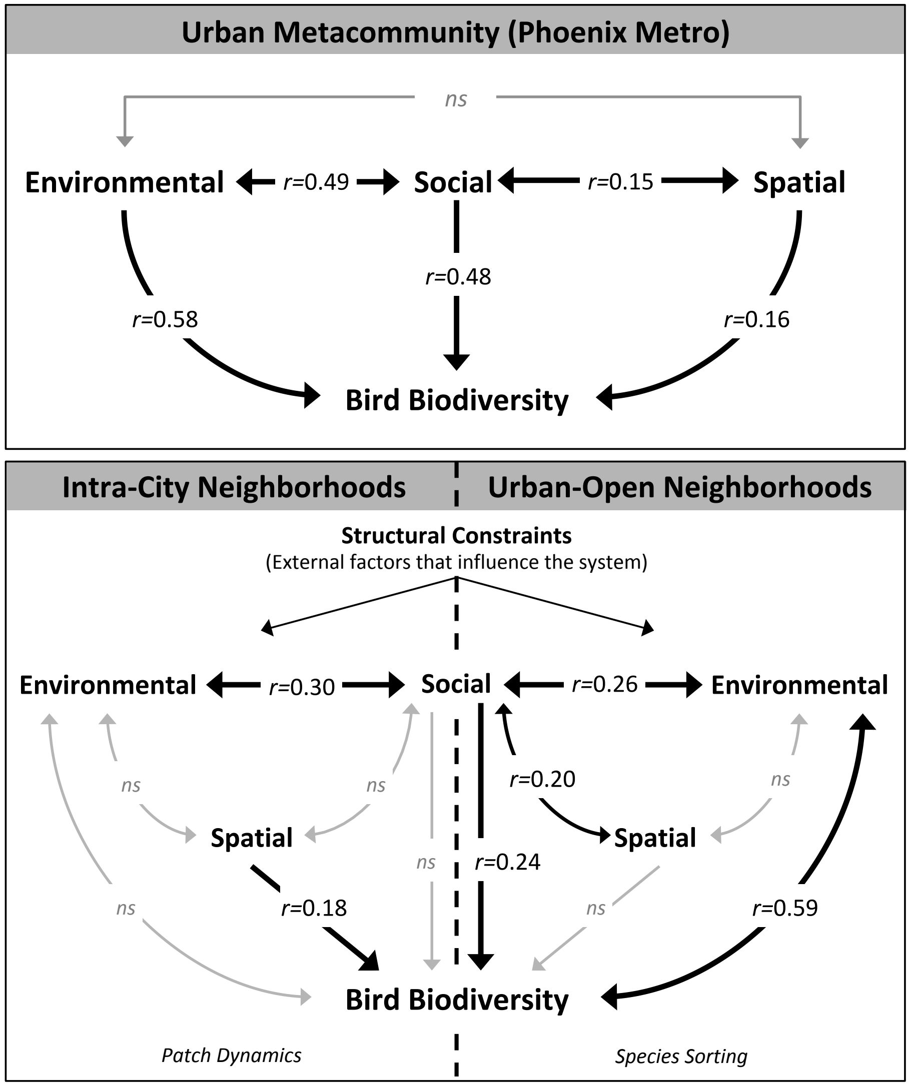

Figure 4. Summary of the relationship between environmental, social, and spatial dissimilarity with bird metacommunity structure in the Phoenix metropolitan area. We classified bird-points based on their location within intra-city or urban-open neighborhoods to test if structural constraints related to press-pulse dynamics shift the effects of deterministic versus stochastic processes on community structure. We assumed that intra-city neighborhoods further from desert open space would experience more press disturbances and more pulse disturbances based on social factors, which impede the capacity of people to control their environment. Likewise, we assumed urban-open neighborhoods closer to desert-open space would not be as impacted by ecological disturbance. We could expect that stochastic processes would be more important for bird communities in neighborhoods with higher levels of disturbance, which was supported.

Supplementary Materials

Table S1. Bird species observed in residential neighborhoods (n=36 bird-points) throughout the Phoenix Metropolitan area. We report abundance (the maximum abundance for a given species during any one of the six sampling counts) and the percent of sites (n=36 bird-points) that each bird species was observed.

Species Code	Common Name	Guild	Percent Sites	Abundance	Intra-City	Urban-Open
ABTO	Abert's Towhee	desert	52.78	34	3	31
AMKE	American Kestrel	generalist	8.33	3	0	3
AMRO	American Robin	generalist	5.56	2	0	2
ANHU	Anna's Hummingbird	generalist	91.67	49	17	32
ATFL	Ash-throated Flycatcher	desert	13.89	6	0	6
BCHU	Black-chinned Hummingbird	desert	11.11	4	1	3
BHCO	Brown-headed Cowbird	generalist	36.11	19	1	18
BHGR	Black-headed Grosbeak	generalist	2.78	1	0	1
BLPH	Black Phoebe	generalist	2.78	1	1	0
BROC	Bronzed Cowbird	generalist	5.56	4	2	2
BRSP	Brewer's Sparrow	generalist	5.56	4	0	4
BTGN	Black-tailed Gnatcatcher	desert	13.89	6	0	6
BTSP	Black-throated Sparrow	desert	2.78	1	0	1
CACW	Cactus Wren	desert	16.67	11	0	11
CBTH	Curve-billed Thrasher	desert	69.44	39	6	33
COHA	Cooper's Hawk	generalist	2.78	1	0	1
COHU	Costa's Hummingbird	desert	38.89	18	1	17
DEJU	Dark-eyed Junco	generalist	2.78	1	0	1
EUCD	Eurasian Collared-Dove	urban	83.33	178	139	39
EUST	European Starling	urban	80.56	153	56	97
GAQU	Gambel's Quail	desert	27.78	63	0	63
GIFL	Gilded Flicker	desert	11.11	6	0	6
GIWO	Gila Woodpecker	desert	69.44	45	7	38
GTGR	Great-tailed Grackle	generalist	88.89	133	61	72
GTTO	Green-tailed Towhee	generalist	5.56	2	2	0
HOFI	House Finch	generalist	100.00	137	50	87

Table S1. Continued…

Species Code	Common Name	Guild	Percent Sites	Abundance	Intra-City	Urban-Open
HOOR	Hooded Oriole	generalist	8.33	5	0	5
HOSP	House Sparrow	urban	100.00	337	215	122
HOWR	House Wren	generalist	2.78	1	0	1
INDO	Inca Dove	urban	50.00	43	23	20
LAZB	Lazuli Bunting	generalist	2.78	2	0	2
LBWO	Ladder-backed Woodpecker	desert	8.33	3	0	3
LEGO	Lesser Goldfinch	desert	50.00	32	6	26
LUWA	Lucy's Warbler	desert	2.78	1	0	1
MODO	Mourning Dove	generalist	94.44	214	66	148
NOCA	Northern Cardinal	generalist	11.11	5	0	5
NOFL	Northern Flicker	generalist	16.67	8	0	8
NOMO	Northern Mockingbird	generalist	80.56	48	16	32
NRWS	Northern Rough-winged Swallow	generalist	30.56	14	2	12
OCWA	Orange-crowned Warbler	generalist	47.22	19	5	14
PHAI	Phainopepla	desert	8.33	6	0	6
PSFL	Pacific-slope Flycatcher	desert	2.78	1	0	1
RCKI	Ruby-crowned Kinglet	generalist	38.89	15	3	12
RFLO	Rosy-faced Lovebird	urban	8.33	6	2	4
ROPI	Rock Pigeon	urban	72.22	204	145	59
ROWR	Rock Wren	desert	5.56	2	0	2
RTHA	Red-tailed Hawk	generalist	2.78	1	0	1
RWBL	Red-winged Blackbird	generalist	5.56	2	0	2
SAPH	Say's Phoebe	desert	44.44	17	6	11
SOSP	Song Sparrow	generalist	2.78	1	0	1
SSHA	Sharp-shinned Hawk	generalist	2.78	1	0	1
VERD	Verdin	desert	97.22	63	22	41
WAVI	Warbling Vireo	generalist	2.78	1	0	1
WCSP	White-crowned Sparrow	generalist	41.67	53	3	50
WEKI	Western Kingbird	generalist	11.11	6	0	6
WETA	Western Tanager	desert	2.78	1	0	1
WWDO	White-winged Dove	desert	61.11	38	8	30
YEWA	Yellow Warbler	generalist	2.78	2	0	2
YRWA	Yellow-rumped Warbler	generalist	97.22	55	24	31

Table S2. Mean and standard deviations of environmental, social, and spatial factors used in our analysis. We report values for the Phoenix metropolitan area, as well as the mean values for the 36 bird-points located in either intra-city or open-space neighborhoods.

Variable	**Type**	**Phoenix Metro**	**Intra-City**	**Urban-Open**
Desert proximity (km)	Environmental	5.33 ± 2.45	3.03 ± 1.85	6.98 ± 1.15
LST (^{o}C)	Environmental	42.02 ± 1.69	43.16 ± 1.41	41.21 ± 1.38
Population	Environmental	2948.53 ± 1965.27	3821.61 ± 2210.30	2324.90 ± 1535.95
Lot Size (sq. ft.)	Environmental	9718.58 ± 5529.27	7412.82 ± 3561.31	11365.56 ± 6147.26
NDVI	Environmental	0.18 ± 0.04	0.16 ± 0.03	0.19 ± 0.04
Mesic Yards (%)	Environmental	0.05 ± 0.07	0.06 ± 0.07	0.05 ± 0.07
Xeric Yards (%)	Environmental	0.29 ± 0.26	0.20 ± 0.23	0.36 ± 0.27
Income (1=<20,000 to 11=>200,000)	Social	4.89 ± 2.19	3.12 ± 0.96	6.16 ± 1.92
Householder Age (years)	Social	49.22 ± 11.12	40.80 ± 7.65	55.24 ± 9.16
Latinx (%)	Social	0.29 ± 0.31	0.72 ± 0.20	0.23 ± 0.25
MEM1	Spatial	0.00 ± 1.01	-0.65 ± 0.99	0.47 ± 0.75
MEM2	Spatial	0.00 ± 1.01	-0.46 ± 0.72	0.33 ± 1.08
MEM4	Spatial	0.00 ± 1.01	-0.39 ± 0.87	0.28 ± 1.04
MEM5	Spatial	0.00 ± 1.01	0.12 ± 1.04	-0.08 ± 1.01
MEM6	Spatial	0.00 ± 1.01	-0.22 ± 0.83	0.16 ± 1.12
MEM7	Spatial	0.00 ± 1.01	0.18 ± 1.10	-0.13 ± 0.95

Table S3. Results from Principal Component Analysis (PCA) for environmental factors. Loadings for components with eigenvalues <1 are displayed. The first two components were retained for dissimilarity analysis.

Environmental Variable	**PCA 1**	**PCA 2**
Desert proximity (km)	-0.43	-0.16
LST (^oC)	0.41	0.28
Population	0.37	-0.33
Lot Size (sq. ft.)	-0.44	-0.03
NDVI	-0.31	-0.51
Mesic Yards (%)	0.16	-0.66
Xeric Yards (%)	-0.45	0.29
Proportion of Variance	**0.46**	**0.22**
Eigenvalue	**3.24**	**1.56**

Table S4. Results from Principal Component Analysis (PCA) for social factors. Loadings for components with eigenvalues <1 are displayed. The first two components were retained for dissimilarity analysis.

Environmental Variable	**PCA 1**
Income (range 1-11)	0.58
Householder Age (years)	-0.61
Latinx (%)	0.55
Proportion of Variance	**0.71**
Eigenvalue	**2.12**

Table S5. Results from Non-metric multidimensional scaling (NMDS), used to visualize bird-points in species space. We fit social, environmental, and spatial variables onto the multivariate ordination to determine their relationship with bird species composition in residential neighborhoods.

Variable	**NMDS1**	**NMDS2**	R^2	***P-value***
Environmental Factors				
Desert proximity (km)	0.98	0.22	0.58	0.001
LST (^{o}C)	-0.89	0.46	0.59	0.001
Population Density	-1.00	-0.04	0.28	0.006
Lot Size (sq. ft.)	0.99	-0.12	0.42	0.001
NDVI	0.95	-0.32	0.19	0.037
Mesic Yards (%)	-0.48	0.88	0.16	0.057
Xeric Yards (%)	0.99	0.16	0.39	0.001
Social Factors				
Income (range 1-11)	0.99	0.13	0.77	0.001
Householder Age (years)	0.98	-0.20	0.28	0.008
Latinx (%)	-0.81	0.58	0.39	0.001
Spatial Factors				
MEM1	0.90	-0.44	0.25	0.009
MEM2	0.79	-0.61	0.14	0.097
MEM4	0.39	0.92	0.15	0.071
MEM5	-1.00	-0.04	0.10	0.181
MEM6	0.22	0.98	0.24	0.008
MEM7	-0.97	0.26	0.14	0.079

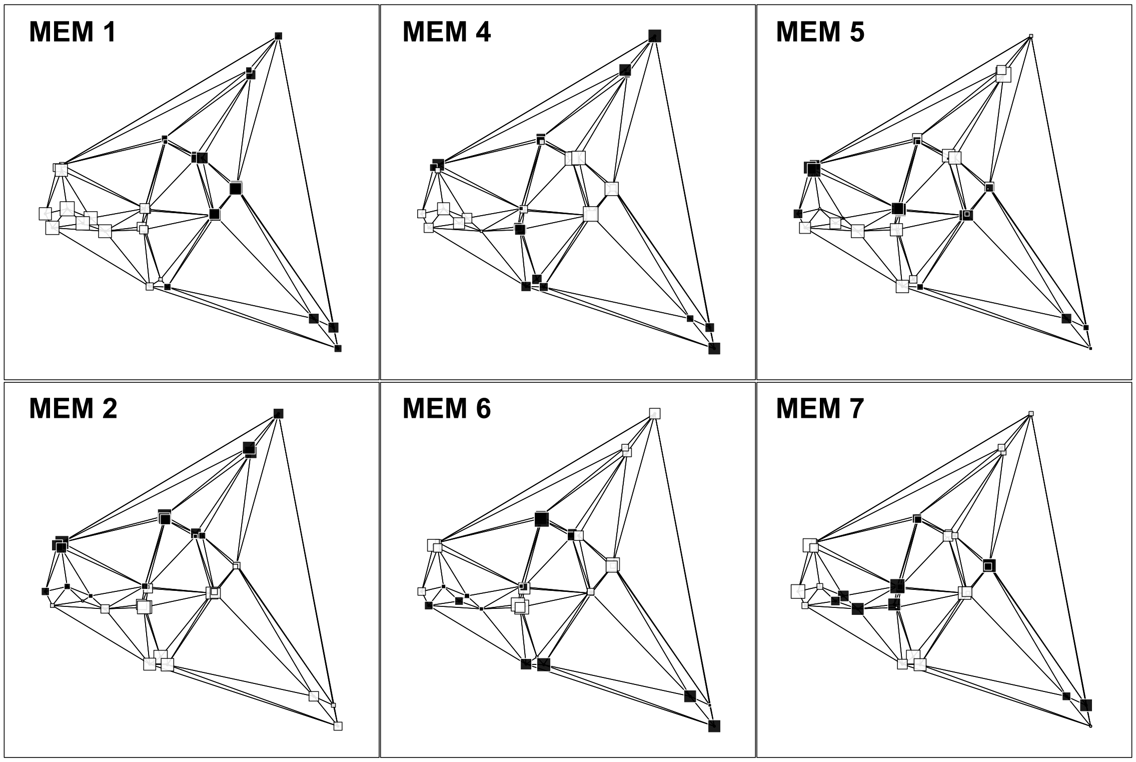

Figure S1. Moran's eigenvector maps (MEM), based on the geographic locations of the 36 bird-points selected for analysis as a measure of urban spatial structure. Squares represent the n=36 bird-points. If spatial structure for the variable significantly influences the community, than squares with similar size and color would also be more similar in terms of beta-diversity. Twelve MEM maps were originally selected based significant autocorrelation (Moran's I, $P<0.05$), and were then further reduced to MEM1, MEM2, MEM4, MEM6, MEM5, and MEM7 because they were the significant spatial variables in the NMDS explaining community composition.

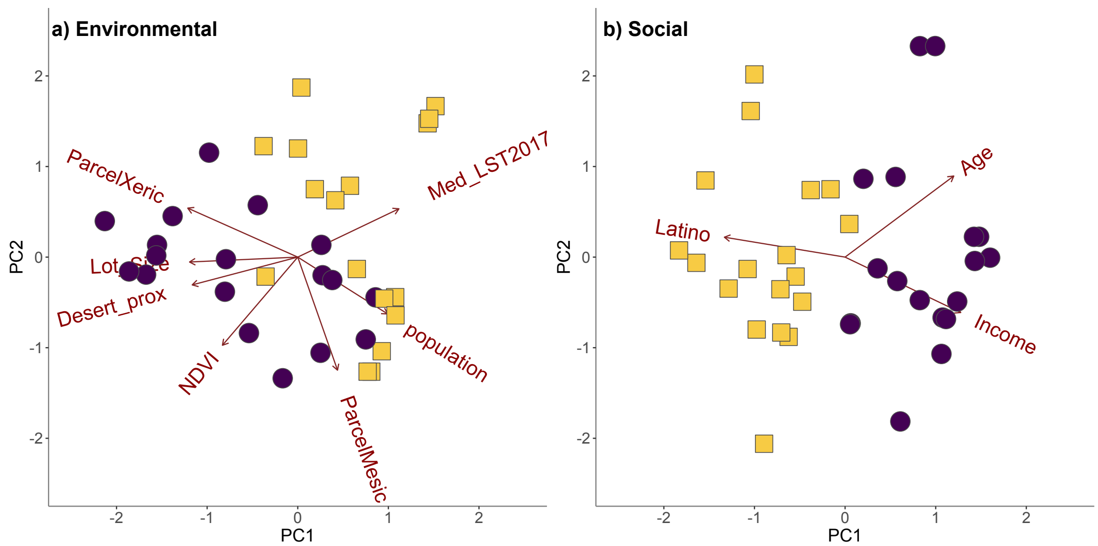

Figure S2. Distance between bird points (n=36) for intra-city, represented by squares, and urban-open, represented by circles for (a) environmental, and (b) social variables. We retained components with eigenvalues<1 to calculate dissimilarity between bird-points.

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CHAPTER 5: SPECIES TRAITS DRIVE PEOPLE'S EVALUATIONS OF THE URBAN BIRD COMMUNITY

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ABSTRACT

The impacts of urbanization on bird biodiversity depend on human-environment interactions that drive local management decisions. Commonly used ecological measurements from the literature, such as habitat guild, do not capture the complexity of interactions between people and birds in cities. People's attitudes—that is, their perceptions and evaluations—are also key components to understand human-wildlife interactions. However, comparatively less research has considered how the public evaluates bird communities. Here, we used social survey and ecological data collected in the metropolitan region of Phoenix, Arizona, USA, to determine how bird assemblages influence attitudes, defined as subjective evaluations. We used a trait-based approach to classify birds by attributes such as physical features, diet, and song, as well as their cultural niche space based on popularity and geographic specificity. Our classification scheme identified four bird groups: Metropolitan, Drab Generalist, Distinctive, and Hummingbird species. Strongly held evaluations were more consistent across the suite of attributes than neutral attitudes, which were more malleable to change based on specific experiences. The belief that birds in a neighborhood were colorful and unique to the desert fortified attitudinal consistency and positive evaluations. Birds belonging to the Distinctive and Hummingbird species clusters, as well as affluent neighborhoods close to natural preserves were related to positive attitudes. Likewise, people evaluated Metropolitan species in city core neighborhoods negatively, based on traits such as foraging strategies that increase human-wildlife conflict. Our results highlight that aesthetics, especially color and song, as well as foraging behavior and position in cultural niche space are the primary drivers of people's evaluations of birds. Increasing interactions with iconic

species with distinctive physical attributes could therefore improve people's attitudes and potentially their support for future conservation initiatives.

1. INTRODUCTION

Urbanization impacts global biodiversity; however, the effects are not homogenous across taxa, study systems, or spatial extents (McKinney 2008). Urban areas can lead to losses in habitat, connectivity, and native species, but can also subsidize biodiversity depending on local environmental conditions (McDonald et al., 2013). Residential yards are of particular conservation value in cities, partly due to their dominance as an urban land use (DeStefano et al. 2005). Residential yards in the United Kingdom are estimated to cover twice as much total area as nature reserves (Chamberlain et al., 2004) and equate to 35-47% of all urban green space (Loram et al. 2007). Thus, residential areas have a significant capacity to harbor biodiversity in cities (Tratalos et al. 2007). For example, suburban land use is often associated with peaks in bird richness and abundance (Blair and Johnson 2008). Residential landscapes also offer nearby opportunities for urban residents to experience nature in cities (DeStefano and DeGraaf 2003).

Research on birds in residential landscapes has largely focused on how social and ecological factors influence community composition and biodiversity (Warren et al. 2010). For example, bird diversity has been shown to align with socioeconomic gradients, where species richness is frequently higher in affluent neighborhoods, due in part to relatively abundant native vegetation (Lerman and Warren 2011, Kuras et al., in press). People's experiences with birds also influence public perceptions in ways that signal the potential for participation in conservation through habitat stewardship (Manfredo 2008). As a result, bird conservation in residential landscapes depends on individual homeowners as stakeholders (Goddard et al. 2017). However, relatively little research has examined the factors that influence people's evaluations about the urban bird community people readily encounter or how the traits influence public perceptions.

Social-ecological drivers of subjective evaluations

Schuetz and Johnston (2018) describe people's experiences with birds as "cultural niches", measured by Google search interest, to differentiate from the typical ecological measurements such as habitat guild. To extend the concept of cultural niches, Robinson (2019) calls for the need to explicitly consider people's different responses to birds. Environmental attitudes are a useful construct that can be used to measure the responses of people to wildlife (Heberlein 2012). As a component of environmental attitudes, subjective evaluations are a person's positive or negative judgments about some object or phenomenon (Thurston 1928; Stern 2000). Subjective evaluations encompass perceptions, or in other words beliefs, about the birds found in people's yards and neighborhoods. Subjective evaluations can be separated to measure potentially positive and negative components of the environment (e.g., Belaire et al. 2015; Larson et al. 2019). It is also useful to consider how evaluations vary in their consistency (Manfredo 2008). Strongly held beliefs tend to be more resistant to change and are more likely to influence behavior (Howe and Krosnick 2017). Therefore, we focus both on the direction and strength of subjective evaluations, and how they are influenced by people's experiences with the local bird community.

Ecological factors such as bird species diversity, species composition, and functional traits have been shown to influence people's experiences and evaluations (e.g., Clergeau et al. 2001; Clucas et al. 2011; Ainsworth et al. 2018). Native species (Dayer et al. 2016), as well as specialist species and higher levels of biodiversity, tend to be positively associated with perceptions of birds (Lerman and Warren 2011, Warren et al. 2019). The likeability of native, specialist species can also influence perceptions toward urban dwelling and invasive species. Larson et al. (2016) found that citizen scientists who engaged in monitoring projects negatively responded to invasive House Sparrows (*Passer domesticus)* because they outcompeted native songbirds for nesting sites. People are often more interested in species that they encounter more readily. For example, Schuetz and Johnston (2018) found a strong, positive relationship between the encounter rate and the popularity of bird species, which they used to characterize cultural niches. However, Schuetz and Johnston's paper used Google searches to assess people's experiences, which has limitations in measuring responses to birds (Robinson 2019). People can typically only identify a few bird species and not always by name (Cox and Gaston, 2015), which might influence their use of an online search about the birds they are encountering in their yards and neighborhoods. In general, the public does not assess biodiversity along the same metrics as ecologists, creating a mismatch between cultural and ecological assessments of constructs such as biodiversity (Dallimer et al., 2012). It is likely that judgments are, in part, driven by people's observations of species traits, which are more varied in biodiverse communities (Petchey and Gaston 2002).

The traits of bird species, such as diet or physical appearance, have been linked to cultural ecosystem services (Echeverri et al. 2019), conflict (Charles and Linklater 2013), and popularity (Schuetz and Johnston 2018). Bird species that feed on the ground or understory may cause conflict by influencing perceptions that the birds are destroying the householder's planted vegetation (Belaire et al. 2016). Additionally, urban dwelling species with broad diets can reach large abundances in local habitat patches, which are then likely to create negative interactions (Charles and Linklater 2013). People prefer small, colorful birds with melodic calls (Garnett et al. 2018), with particular emphasis given to colorful species (Lišková et al. 2015; Schuetz and Johnston 2018). People are more likely to state they enjoy watching or are excited to find a particular bird species if that species has colorful plumage (Echeverri et al. 2019). In addition to aesthetics, bird song is also an important trait (Belaire et al. 2016). Bird song can create an emotional response in people (Hedblom et al. 2017). For instance, bird songs remembered from childhood positively influence human well-being and have a restorative effect (Ratcliffe et al., 2006). However, harsh or loud calls, with greater fundamental frequency of the harmonic spectrum, are considered annoying and less preferred (Björk 1986; Clucas et al., 2011).

Although people's evaluations of ecological traits are directly influenced by the characteristics of the observed object, the characteristics of the person observing the object are also important (Tribot et al. 2018). For example, people's views of wildlife vary with their income, gender, age, level of education, and cultural identity (Heberlein 2012). In general, older and wealthier individuals tend to hold more positive attitudes about local bird communities (Belaire et al. 2015; Cox and Gaston 2015), as do individuals with higher levels of education (Bjerke and Østdahl 2004). Pro-ecological worldviews are also associated with conservation attitudes (Manfredo et al. 2008). People who identify as Hispanic and Latinx tend to view themselves as interdependent with nature (Heyd 2005) and (Chase 2016). Similarly, women may be more likely to view certain taxa as dangerous due to perceptions regarding disease (Hanisch-Kirkbride et al. 2013). Overall, these differences associated with sociodemographics can influence perceptions of birds or other wildlife.

Based on interdisciplinary literature (e.g., Belaire et al. 2015; Cox and Gaston 2015; Echeverri et al. 2019), we expect that attributes of bird species, especially those related to diet and aesthetics, will influence people's attitudes. However, attitudes will also be based on the individual characteristics of the person, such as socioeconomic status. Here, we used the theoretical construct of attitudes, based on people's subjective evaluations of birds they encounter in their residential yards and neighborhoods to ask: 1) How do patterns of bird community composition link to the actual species traits present? 2) How do people subjectively evaluate various traits of the birds found in their yards and neighborhoods? And 3) How are people's subjective evaluations influenced by their sociodemographic attributes, bird traits and cultural niche, and ecological community diversity?

2. METHODS

Study Area

Our study takes place in the Central Arizona-Phoenix Long-term Ecological Research (CAP LTER) site, located in Phoenix, Arizona, U.S.A (Figure 1). Metropolitan Phoenix is situated in the Sonoran Desert of the American Southwest (33.427, -111.933) and is characterized by a hot, dry climate. Summer temperatures can reach 49 degrees Celsius; biannual Monsoon and winter rainy seasons bring 76-400 mm of precipitation a year (Phillips and Comus 2000). Although Phoenix is located in an arid environment, cultural legacies from the city's early stages of development have shaped the ideal of Phoenix as a "desert oasis" (Larson et al. 2017). As a result, the city has a high prevalence of mesic landscaping, with about 50% of yards having some grass, which contrasts with xeric yards landscaped to reflect the native desert environment (Wheeler et al. 2020).

Data Collection: Bird Diversity and Interaction Traits

We placed three independent point counts spaced at least 200 m apart in 12 neighborhoods where social survey data were also collected for a total of 36 sites (see below for neighborhood selection and description). Bird surveys were conducted in the winter (December-February) and spring (March-May) of 2017 and 2018. Trained observers recorded all birds seen or heard within a 40 m radius for 15 minutes three times per season for a total of six visits per site per year. We excluded species recorded in less than one site from our analysis because rare species have a disproportionate influence on biodiversity metrics and are unlikely to reflect everyday engagements between people and birds (Fuller et al. 2013).

We used bird community data to derive a number of biodiversity metrics including: abundance, species richness, Shannon Diversity Index (H), and evenness (Table in supplementary materials). We defined abundance as the maximum number of individuals recorded for each species throughout the six visits. Species richness was calculated as the number of unique species found per site. We also calculated Shannon diversity and community evenness using the Vegan package in R (Oksanen et al. 2018).

We curated data about traits related to body size, foraging strategy, diet, song, plumage color, and cultural niches for the bird species observed during our study (Table in supplementary materials). We derived bird size and foraging traits from the EltonTraits database (Wilman et al. 2014). Bird size was the average mass of each species in grams. Foraging strategy was determined as percent of time each species spends foraging in a strata type: ground, understory, mid to high, canopy, and aerial. Feeding guilds for each species was based on their diet percentages: plants, seeds, invertebrate (insects), fruit, and nectar (Wilman et al. 2014). We described the cultural niche of bird species as “Celebrity”, “Friend”, “Neighbor”, and “Stranger” using bird species popularity and geographic congruence as described by Schuetz and Johnston (2018; Figure 3). Using Google search interest, popularity was defined as the relative interest in a species, controlling for encounter rates. Congruence was the slope of the line describing the alignment between interest and species distribution. Celebrity species had above average Google search popularity for the United States, even outside their geographic distribution. Conversely, Friend species had above average Google search popularity for the United States, but searches were primarily from people living within the species range. Neighborhood species had below average Google search popularity on a national scale, but the search activity that did occur was aligned with the species distribution. Stranger species had both below average popularity that was not associated with their distribution.

Using song descriptions from the Birds of North America (BNA) database (Rodewald, 2015), we qualitatively classified bird song along three axes. These song classifications were not mutually exclusive. We coded the first variable for songs or calls that were described as being "familiar", the second variable for song or calls were "loud" or "harsh", and the third variable for songs that were described as "musical". For example, Cactus Wrens (*Campylorhynchus brunneicapillus*) were described as having a "quintessential sound of the desert" and also a "loud series of harsh 'char' notes" and, thus, we categorized it as both familiar and loud/harsh song.

Finally, we used the colordistance package (Weller 2019) to determine differences in feather color. We used representative photographs of breeding males obtained from the Birds of North America database (Rodewald, 2015). We first removed all of the background colors, then randomly sampled 10,000 pixels to determine the similarity between red, green, and blue color composition of each bird species. Following methodology by Weller (2019), we used the histogram method to classify the pixels into 8 color bins. Using Ward's D clustering, bird species were then grouped into three clusters: "grey", "brown" (e.g. muted browns and yellows), and "colorful" (e.g. bright orange, red, green).

Phoenix Area Social Survey

We collected data on residents' subjective evaluations of birds, along with demographic characteristics, through the 2017 Phoenix Area Social Survey (PASS) (Larson et al. 2019). The survey targeted the twelve neighborhoods described above where we placed our point count surveys —delineated by Census Block Group boundaries, selected to cover urban, suburban, and exurban areas of the metropolitan regions while also representing low-to-high income areas. The University of Wisconsin Survey Center administered the survey from May-September of 2017. The survey was mailed to 1,400 addresses in the targeted neighborhoods from the U.S.

Postal Service's Delivery Sequence Files. The first mailing included the full survey, as well as a postage-paid card requesting a Spanish version. The second mailing included a reminder postcard, and the final two waves included the full survey packet. All participants received a pre-incentive of $5 included in the first packet. Participants were also assigned to post-incentive groups, which included rewards to either the participant or a charity. The final response rate was 39.4% (n=496).

Subjective Evaluations

We used ten questions to measure subjective evaluations of birds; the first 8-items were adapted from Belaire et al. (2015). Using a similar approach, our questions captured beliefs about specific attributes of the bird community to determine how people observe the birds in their neighborhoods (Table 1). Measured on a 5-point scale with (1) not at all, (2) a little, (3) somewhat, (4) very, and (5) extremely, the verbatim questions were: (1) "How unique to the desert are the birds in your neighborhood" (2) "How easy to see and watch are the birds in your neighborhood", (3) "How colorful are the birds in your neighborhood", (4) "How pleasant are the noises the birds in your neighborhood make", (5) "How likely is it that the birds in your neighborhood cause messes", (6) "How likely is it that the birds in your neighborhood eat your plants and trees", (7) "How likely is it that the birds in your neighborhood carry diseases", (8) "How unpleasant are the noises the birds in your neighborhood make".

We asked two additional questions about satisfaction with local birds and perceptions of risks posed by birds (Table 1). Specifically, respondents were asked: "To what extent are [birds] a problem for you at your current neighborhood", with a response scale of (1) not at all a problem, (2) a small problem, (3) a moderate problem, (4) a big problem, and (5) a very big problem. Participants were also asked "How dissatisfied or satisfied are you with [the variety of birds] in and around your neighborhood," also on a 5-point scale: (1) strongly dissatisfied, (2) somewhat dissatisfied, (3) neither dissatisfied nor satisfied, (4) somewhat satisfied, and (5) strongly satisfied (5). We tested the validity of the evaluative scale that we developed for our study using Cronbach's alpha. Cronbach's alpha is a measure of reliability for groups of social survey questions measuring a single construct, with alpha values above 0.7 reliable (Santos 1999).

Social Factors

Respondents self-reported a number of sociodemographic variables in the survey: income, education, age, gender, Hispanic/Latinx identity, and ecological worldviews. We coded household income on an 11-point scale starting at (1) $20,000 and increasing in $20,000 increments to (11) more than $200,000. We coded education on a binary scale (0,1) to represent respondents that had a Bachelor's degree or higher (1). Each respondent was asked to provide their date of birth, which we used to calculate their age. Gender was coded as a male (0) and female (1). Hispanic and/or Latinx identity was also coded as a binary variable by asking the respondent whether they identified as Hispanic or Latinx (including Mexican, Mexican-American, Chicano, Hispanic, or Latinx). Finally, we measured ecological worldviews, or value orientations, using the 15 questions from the New Ecological Paradigm (NEP) scale (Dunlap et al. 2000). Orientations related to human-centered views were reverse coded (Supplementary Table B), and then responses to 15 statements were averaged to create a single variable ranging from 1-5, where higher values reflect biocentric (ecological) worldviews and lower values reflect human-centered orientations.

Statistical Analysis

We used bird community data to address our first question focused on quantifying the traits of birds found in residential yards and neighborhoods that mediate interactions with householders. We first decomposed trait data into orthogonal eigenvectors using Principal Component Analysis (PCA) to standardize the scales and reduce redundancy amongst related traits, which stabilizes clustering results (Husson et al. 2010). We applied Hierarchical agglomerative clustering to the unrotated principal components using Euclidean distance and Ward's linkage to cluster bird species into representative trait groups. We selected the final clusters to maximize inertia gain and capture meaningful components of bird community traits. We used the V test (Husson et al. 2010) to calculate the cluster description by the variables. We preformed our cluster analysis using the 'FactoMineR' package in R (Le et al. 2008). We then used the Pearson's correlation coefficient to determine the relationship between bird trait groups identified from our cluster analysis and the cultural niche groups (Celebrity, Friend, Neighbor, Stranger) defined in Schuetz and Johnston (2018).

Our second question considered perceptions of the bird community, focusing on attitudinal patterns and consistency. We predicted a quadratic relationship between attitudinal direction and strength because we expected positive and negative attitudes to be relatively fortified and unlikely to change (e.g. consistent) across question responses evaluating local birds (Howe and Krosnick 2017). We used logistic regression, which included a squared term to determine if a significant quadratic curve fit the data, with a binomial distribution to explore the relationship between attitudes and consistency. To measure consistency in attitudes about birds, we specified the number of times a person responded the same way across each of the ten subjective evaluation questions ("successes"). Inconsistencies ("failures") were classified as the number of times the person selected a different response. We inverted evaluations of negative traits (problematic, disease, mess, eats plants, noisy) prior to counting successes and failures so all ten-question scales had the same directionality. We also calculated an overall model by regressing total successes and failures for each respondent by their median response value for the ten evaluative questions. We then calculated the turning point (TP; $-b/2a$) for each regression model to quantitatively interpret the shape of the relationship. We used turning points (TP) to quantitatively interpret the shape of the quadratic relationship (Table 3). Higher TP values (>3) indicate that negative evaluations were more consistent than positive evaluations. Conversely, lower values (<3) indicate that positive evaluations were more consistent than negative evaluations.

To answer our third question, we used a multivariate analysis to measure the association between people's perceptions to the bird community with the actual bird species present in the respondent's yard and neighborhood. We first visualized attitudes with respect to traits, diversity metrics, and social factors using non-metric multidimensional scaling (NMDS) based on Gower's distance (Oksanen et al. 2018). NMDS is a multivariate technique that maximizes the rank correlation between distance measures. In this instance, NMDS was used to visualize sites in attitudinal space, where sites closer on the ordination represented relatively similar attitudes. We fitted ecological (diversity metrics), social (worldviews and sociodemographic), and human-bird interaction (trait clusters and cultural niche) variables to the ordination plot to visualize the correlation of these factors with attitudinal patterns regarding birds. Lastly, we tested the overall and shared effects of ecological factors, social factors, and human-bird interactions on subjective evaluations by partitioning the variance between these factors on the averaged scale that captures overall perceptions of local birds. All statistical analyses were performed in R version 3.5.1 (R Core Team 2018).

3. RESULTS

Identifying bird trait clusters

We identified four distinct trait groups of species using hierarchical cluster analysis (Figure 2). We defined cluster 1 as "Metropolitan" based on urban-dwelling species within the group, such as Rock Pigeons (*Columba livia*) (Figure 2). Species in this group were described as having a loud song, grey coloring, and were large granivores foraging low to the ground (Table 2). Species classified into the Metropolitan group were positively related to the Celebrity cultural niche group ($r= 0.74$, $P<0.0001$), but was negatively related to the Friend ($r=- 0.45$, $P<0.0005$), Neighbor ($r= -0.52$, $P<0.001$), and Stranger groups ($r=- 0.49$, $P<0.002$).

Cluster 2, "Drab Generalists", included many generalist species, such as Great-tailed Grackles (*Quiscalus mexicanus*), as well desert species present within urban or suburban areas (Lerman and Warren 2011), including Verdins (*Auriparus flaviceps*), Curve-billed Thrashers (*Toxostoma curvirostre*), and Cactus Wrens (*Campylorhynchus brunneicapillus*). Species in this group were shades of brown and their song is described as being 'familiar' (Table 2). The occurrence of species in the Drab Generalists group was positively related to the Friend cultural niche group ($r= 0.52$, $P<0.001$), but negatively related to the occurrence of Celebrity species ($r=- 0.44$, $P<0.007$).

Cluster 3, "Distinctive Species", consisted of bird species with distinctive aesthetic traits that people likely notice, such as colorful birds described as having a musical song (Table 2), e.g., Northern Cardinals (*Cardinalis cardinalis*). The diets of bird species within this group were varied, but species tended to be smaller (Table 2). Many species foraged in the higher vegetation strata (Table 2), such as Phainopepla (*Phainopepla nitens*) and Western Kingbirds (*Tyrannus verticalis*). The occurrence of species that had distinctive aesthetic traits was positively related to both the Neighbor (r= 0.56, P<0.0003) and Stranger cultural niche groups (r= 0.48, P<0.003), but negatively related to the occurrence of Celebrity species (r=- 0.58, P<0.0001).

All hummingbird species, including Anna's (*Calypte anna*), Costa's (*Calypte costae*), and Black-chinned (*Archilochus alexandri*), were clustered into their own group (Cluster 4), aptly named "Hummingbirds" (Figure 2). Species in this group shared traits related to a nectar diet, color, foraging height, and a small body size (Table 2). Overall, both the Distinctive Species and Hummingbirds were composed of colorful birds that foraged in vegetation higher from the ground than species in the Metropolitan and Drab Generalist clusters. The birds classified into the Hummingbird group were positively related to classification into the Neighbor cultural niche (r= 0.66, P<0.0001), but negatively related to Celebrity species (r=- 0.56, P<0.0003).

Public perceptions of bird community attributes

On average, people held positive attitudes towards the birds in their neighborhoods (3.4 ± 0.4; Table 1), however response distributions varied depending on specific characteristics evaluated. Survey respondents were more likely to disagree with the statement that birds in their neighborhoods exhibited negative characteristics, such as making a mess, than agree with the statement that birds exhibited positive characteristics such as being colorful (Table 1). In particular, people disagreed that birds in their neighborhood were problematic (1.5 ± 1.1) or made unpleasant noises (1.6 ± 1.1). The majority of respondents also disagreed that birds in their neighborhood were colorful (2.6 ± 1.1) or unique to the desert (2.9 ± 1.2), but this did not lead to dissatisfaction with the overall variety of birds (3.6 ± 0.9).

Our prediction that extremely negative and positive attitudes would be more strongly held than neutral attitudes was supported using logistic regression (Figure 3). Of the ten evaluative variables, nine exhibited a significant quadratic relationship with attitudinal consistency (Table 3), with the exception of perceptions that birds had a pleasant song. The belief that birds were problematic and noisy exhibited the highest consistencies for negative attitudinal values, whereas consistency for birds being colorful or unique to the desert was the highest for positive attitudes (Table 3).

Perceptions that birds were noisy (TP= 4.04) or problematic (TP= 3.98) fortified negative evaluations (Table 3). Conversely, if a person believed that birds in their neighborhood were unique to the desert (TP= 2.02), colorful (TP= 1.95), or that they were not messy (TP= 1.62), then that respondent was more likely to consistently evaluate bird attributes positively. The logistic regressions using the overall attitudinal scale (TP= 2.88) and satisfaction with the variety of birds (TP= 2.98) exhibited the highest centrality, meaning that both strongly positive and negative attitudes were comparable in determining consistency.

Social-ecological drivers of bird perceptions

Subject evaluations were related to social factors, bird species traits, and diversity metrics, as shown in the NMDS and subsequent variance partitioning (Figure 4). A two-axis solution was reached to ordinate sites in attitudinal space (NMDS stress=0.11; *non-metric fit* R^2= 0.97*; linear fit* R^2= 0.93). Subjective evaluations became more positive along the NMDS1 axis, as did desert specialist species observed within the neighborhoods (Figure 4). A mixture of social factors, bird traits and cultural niche groups, and diversity metrics explained people's evaluations about birds (Table 4). Significant social factors driving positive evaluations included income (R^2=0.49, P<0.001), education (R^2=0.53, P<0.001), and age (R^2=0.43, P<0.001), whereas people identifying as Hispanic or Latinx held less positive attitudes (R^2=0.52, P<0.001). Gender and ecological orientations were not significantly associated with attitudinal patterns.

Birds within Metropolitan traits, including being loud or foraging on seeds close to the ground, were related to negative evaluations (R^2=0.22, P=0.021). Conversely, Distinctive species with traits such as a musical song and colorful plumage (R^2=0.26, P=0.008), as well as Hummingbirds (R^2=0.41, P<0.001) positively influenced evaluations (Figure 4). Species in the Celebrity cultural niche were related to negative attitudes (R^2=0.47, P<0.001), likely due to the prevalence of urban-dwelling species within the group. The Friend (R^2=0.30, P<0.002) and Neighbor cultural niche groups (R^2=0.38, P<0.001) were positively related to attitudes (Table 4). People also held more positive attitudes in neighborhoods with higher bird diversity, measured by species richness (R^2=0.45, P<0.001), Shannon diversity (R^2=0.41, P<0.001), and evenness (R^2=0.18, P=0.024), but there was no association with higher bird abundance (R^2=0.06, P=0.381).

Our variation partitioning determined the effects of social factors, bird species traits, and diversity metrics, which explained 78.8% of the variation of people's perceptions living around the 36 bird-point counts. Variables that described the interactions between people and birds explained the most amount of variance in perceptions (about 19.6%), followed by social factors (5.8%; Table 4). Diversity metrics only exclusively explained 1.9% of the total variance (Table 4). The effects of bird community diversity were shared with sociodemographics of people living in the neighborhoods, which together explained 4.5% of the variance. Likewise, variables measuring people's interactions with birds, along with social factors also shared 13.2% of the total explained variance. The shared combination of bird traits and cultural niche, social factors, and community diversity was also important for subjective evaluations, explaining 33.1% of variance.

4. DISCUSSION

Our research addresses how social-ecological interactions influence subjective evaluations of the birds they encounter in their neighborhoods. We found that bird traits and cultural niche were better predictors of subjective evaluations than common biodiversity metrics such as abundance and richness. We also found that subjective evaluations varied depending of the specific attribute of the bird community being evaluated. As a result, certain attributes such as people's belief that birds in their neighborhood are unique to the desert were reliable indicators of attitudinal consistency. One of the primary contributions of our research is clarifying the pathway between ecological metrics, such as biodiversity, to public perception and potential conservation signals (Dallimer et al., 2012).

The traits related to subjective evaluations in our study were not clearly delineated along common ecological metrics of bird conservation, such as non-native, generalist, and specialist species (e.g. Lerman and Warren 2011, Warren et al. 2019). Under our classification scheme, some non-native species such as Rosy Faced Lovebirds (*Agapornis roseicollis*) were clustered into the Distinctive Species group, which was related to positive evaluations. Traits associated with diet and foraging patterns, as well as aesthetic traits linked to physical distinctiveness differentiated positive and negative attitudes. These findings (Figure 4) align with other studies that emphasize the importance of distinguishing characteristics, such as colorful feather patterns (Echeverri et al. 2019). However, our study also places these findings in the context of everyday nature experiences between people and birds in residential yards. These findings further suggest that conservation efforts could benefit from advocating for species that have socially, as well as ecologically, meaningful characteristics (Garnett et al. 2018). For example, the relationship between traits such as diet and foraging strategy are likely mediated by the interactions they create (Charles and Linklater 2013). Diet for granivores foraging low to the ground is socially meaningful because these bird species may be perceived negatively for "messing up" landscaping such as newly sowed grass.

In terms of socially meaningful characteristics, our research expands on the idea of cultural niches to that birds with specific traits fill (Schuetz and Johnston 2018) by measuring subjective evaluations within neighborhoods (Robinson 2019). Interestingly, Metropolitan species from our trait classification were also commonly assigned by Schuetz and Johnston as celebrity species based on their popularity and congruence (Table 2). Birds that represented both groups included Eurasian Collared-Doves (*Streptopelia decaocto*), European Starling (*Sturnus vulgaris)*, Mourning Dove (*Zenaida macroura*), Northern Mockingbirds (*Mimus polyglottos*), and Rock Pigeons (*Columba livia*). It is unsurprising that common urban species are well known to people across the United States, and many of these species also occur globally. However, this attention is not always necessarily good, as we found these species in Phoenix to be associated with negative evaluations (Figure 4). Our analysis also highlights how some people's experiences with birds may not be accurately captured by their ability to identify and then search for the species online. Specifically, distinctive species were positively related to Schuetz and Johnston's (2018) stranger and neighbor cultural niche groups (Table 2). Both of these cultural niche groups indicate unpopularity in regards to national-level interest. The mismatch between search interest and positive evaluations for distinctive bird species may be because these species were also more unique to a specific region. For example, Phainopepla (*Phainopepla nitens*) are silky black birds with a prominent crest. However, these species only occur in parts of the Southwestern United States. Phainopepla were classified to be Neighbor species, which means they garner local attention but less national interest based on their encounter rates. Therefore, using birds such as Phainopepla as a flagship conservation species may be fairly meaningless for the entirety of the United States, but could hold local significance for states such as Arizona, California, and New Mexico. Many experiences are place-specific, and as a result we need more refined measures to determine what bird species may hold local importance for conservation initiatives.

Our study demonstrates the complexity of attitudes, which complicates the conservation applications of social-ecological research related to people’s values, beliefs, and behaviors. Although attitudes are insightful, they are often only peripherally related to management decisions (Heberlein, 2012). This is because measured attitudes need to conceptually match behaviors in terms of specificity (general attitudes due not influence specific behavior) and consistency (inconsistent attitudes are less likely to influence behavior). Likewise, we found that relatively neutral or mild attitudes tend to be inconsistent across the evaluation of traits and therefore are malleable when defining experiences came into play (Manfredo 2008). The strength and consistency of attitudes can, in part, pinpoint where attitudes are most likely to influence behavior (Heberlein 2012). For example, people who have positive, but weakly held attitudes are unlikely to act based on their attitude. Rather, they act according to more pertinent controls, such as norms dictating engagement in habitat stewardship (Goddard et al. 2013) or landscaping choices that emphasize aesthetics and low maintenance priorities (Larson et al. 2009, 2016). In this instance, educating people about the conservation outcomes of their decisions is unlikely to shift behavior (Heberlein, 2012). Instead, efforts could be made to create more specific and stronger attitudes about urban birds, which is more likely to influence conservation decisions (Manfredo 2008).

Aesthetic traits and regional links best serve as conservation indicators

People with strongly held beliefs are often more resistant to change, whereas inconsistent attitudes are a less reliable metric for conservation potential (Manfredo 2008).

Therefore, considering what factors increase attitudinal consistency about positive or negative evaluations would also increase our ability to use attitudes as a conservation indicator. We identified a sub-group of attributes that could be used as signals of broader attitudinal patterns and conservation support. The belief that birds were colorful and were unique to the desert fortified positive evaluations (Figure 3). This finding also reflects patterns in the actual bird community, where birds belonging to the Distinctive Species and Hummingbird groups were associated with positive attitudes (Figure 4).

People's evaluations of specific traits, especially those related to distinguishing physical characteristics such as color, may hold more explanatory power than others. In our study, respondents evaluated birds in their neighborhood as colorful or unique to the desert less frequently (Table 1), but those who did also had the most consistently positive attitudes (Figure 3). Public perceptions tend to be positive towards charismatic bird species with conspicuous and colorful attributes, such as hummingbirds, which creates positive interactions between people and birds (Hedblom et al., 2017). Additionally, the particular importance of desert species in the Southwestern United States fills the Neighborhood cultural niche and links to sense of place. Native and endemic wildlife that are tied to a specific region can elicit societal interest for conservation initiatives (Dayer et al., 2016). This suggests that conservation efforts could benefit from a focus on flagship species with regional relevance, focusing on species with distinguishing physical traits (Ainsworth et al., 2018). Distinguishing physical traits may also make a species easier to identify, thereby increasing its national and local popularity in cultural niche space (Schuetz and Johnston 2018).

The belief that birds were problematic was also a good predictor of attitudinal consistency and was associated with traits related to urban dwelling bird species. Specifically, traits associated with Metropolitan birds such as Rock Pigeons, elicited negative responses from householders in our survey. One respondent even used the margins of the survey to elaborate on their dislike of pigeons: "there should be a law that you can trap or kill pigeons—they cause physical damage to your home and surrounding areas". In general, this sentiment is widely shared across multiple species, where birds that occur in large numbers are often perceived as “pests” (Belaire et al., 2015; Clergeau et al. 2001) or “nuisances” (Cox et al., 2015). People’s tolerance for urban birds, and wildlife in general, can be easily overstepped when human property is damaged (Clergeau et al. 2001; Clucas et al. 2011). However, people living in cities most frequently interact with urban-dwelling wildlife, suggesting there might be untapped potential for these species to act as urban ambassadors and foster positive attitudes toward typically disliked species (Dunn et al, 2006).

Attitudinal implications of intra-urban variation in bird biodiversity

Other studies have differentiated by nature “quality”, (e.g. bird biodiversity), versus nature “quantity” (e.g. bird abundance) in defining attitudinal patterns (Cox et al. 2015). Our study supports the Cox et al. (2015) assertion that nature quality, or biodiversity, is positively related to people’s attitudes about birds. However, we also found that the effects of biodiversity (such as species richness and abundance) were filtered by the sociodemographics of people and the characteristics of the bird species present in neighborhoods (Figure 1). For example, Latinx respondents had less positive attitudes about bird species present in their yards and were more likely to consider birds a problem or carry disease. In general, people who identify as Latinx felt more subject to the risks that wildlife species pose (Chase et al. 2016). However, the bird community in Latinx neighborhoods throughout Phoenix also had higher abundances of Metropolitan species(e.g., House Sparrows and European Starlings) with lower native biodiversity. Thus, negative perceptions are likely due to an interaction between personal characteristics and the bird species present. However, some social factors, such as broad-based value orientations (e.g., pro-ecological world-views) were insignificant and instead trumped by the traits of the bird species present.

The relationship between biodiversity and sociodemographics in cities is complex (Warren et al. 2010; Leong et al. 2018). Low-income and Hispanic/Latinx populations are less likely to live in proximity to natural areas and have less vegetation in Phoenix neighborhoods (Jeanerette et al. 2011). People with lower incomes in the Phoenix metropolitan area also experience less biodiverse bird communities (Kinzig et al. 2005, Lerman and Warren 2011), which influences the ecosystem services derived from the bird community (Cox et al. 2017). The unequal distribution of urban ecological infrastructure and therefore potential of positive nature experiences, skews perceptions along socioeconomic divides. For example, Larson et al. 2019 found that people's perceptions of ecosystem services provided by their neighborhood environment were socially stratified in the Phoenix metropolitan area. Specifically, people's subjective evaluations in predominately low income and Hispanic/Latinx neighborhoods were significantly lower than those in high income areas at the desert fringe.

Our study further confirms that these differences in the urban environment are reflected in people's different experiences, and therefore evaluations of urban birds. Neighborhood socioeconomic status can influence the actual bird community present, including the prevalence of bird species with traits our study identified as important for people's perceived experiences, such as Hummingbirds (Hedblom et al. 2017). As a result, bird community traits, diversity and social factors were tightly coupled in their influence in people's subjective evaluations. This holds conservation implications across a range of ecological dimensions. If people hold negative environmental attitudes then they are less likely to make management decisions based on their desire to attract or protect wildlife (Soga and Gaston 2020). Therefore, engagement with stakeholders across residential landscapes in a variety of socioeconomic stratifications will be imperative to create connected wildlife habitat in cities (Goddard et al. 2017).

5. CONCLUSION

Overall, our study identifies the importance of species traits in defining human-bird engagements in residential yards and neighborhoods. Previous research has largely characterized urban wildlife by predetermined categories based on ecological factors such as species distribution or by habitat breadth. For example, a common technique in urban ecology is to group species as urban, generalist, and specialist bird species (e.g., Blair 1996, Lerman and Warren 2011). Although we found that people's perceptions that birds in their neighborhood were desert species strengthened positive attitudes, the actual presence of desert species alone did not equate to positive evaluations. We attribute this to the fact that people are unlikely to link many endemic or desert species, such as Verdin, to the regional desert environment. Instead, people are reacting to distinguishing traits such as physical appearance and foraging habits.

Urban wildlife such as birds can elicit both positive engagements, such as opportunities to experience nature in cities, as well as negative encounters, yielding human-wildlife conflict, for people living in cities. Understanding how people view these interactions is important because positive perceptions can drive habitat stewardship and resource provisioning in residential yards, which supports biodiversity within the city and at broader scales (Belaire et al. 2016). Therefore, focusing on biodiversity metrics that signal how people experience nature in cities can help reposition conservation efforts to engage urbanites as local stakeholders in urban biodiversity conservation.

Table 1. Dependent Variable: Survey scale measuring subjective evaluations.

Variables	Evaluative Construct	Mean ± SD	Frequency of Responses				
			1	**2**	**3**	**4**	**5**
Attitudes Scale		3.4 ± 0.4					
To what extent are [birds] a problem for you at your current home?	Risk Perceptions[a]	1.5 ± 1.1	355	82	31	14	12
How dissatisfied or satisfied are you with [the variety of birds in and around your neighborhood?	Satisfaction[b]	3.6 ± 0.9	18	55	146	138	138
How colorful are the birds in your neighborhood?	Beliefs[c]	2.6 ± 1.1	84	127	145	70	21
How easy is it to see and watch the birds in your neighborhood?	Beliefs	3.4 ± 1.2	37	79	114	145	95
How unique to the desert are the birds in your neighborhood?	Beliefs	2.9 ± 1.2	69	79	134	81	42
How pleasant are the noises the birds in your neighborhood make?	Beliefs	3.4 ± 1.2	45	61	119	145	100
How likely is it that the birds in your neighborhood carry diseases?	Beliefs	2.5 ± 1.2	71	84	76	24	24
How likely is it that the birds in your neighborhood cause messes?	Beliefs	3.0 ± 1.3	58	123	104	93	81
How likely is it that the birds in your neighborhood eat your plants and trees?	Beliefs	2.5 ± 1.2	99	128	106	47	31
How unpleasant are the noises the birds in your neighborhood make?	Beliefs	1.6 ± 1.1	308	75	52	18	16

[a] 1= Strongly Dissatisfied, 2=Somewhat Dissatisfied, 3=Neither dissatisfied nor satisfied, 4=Somewhat Satisfied, 5=Strongly Satisfied
[b] 1= Not a problem, 2=A small problem, 3=A moderate problem, 4=A big problem, 5=A very big problem
[c] 1= Not at all, A little, Somewhat, Very, Extremely

Table 2. V-tests of traits used to classify bird species into clusters. Positive v-values indicate that the value for a trait was greater within a cluster and negative values indicate the trait was less. Bolded values indicate P<0.05. Cultural niche indicates a positive, significant relationship (P<0.05) between bird interaction trait and cultural niche groups in Schuetz and Johnston (2018).

Traits	**Metro-politan**	**Drab**	**Distinctive**	**Hummingbird**
Cultural Niche	**Celebrity** (*r*= 0.74)	**Friend** (*r*= 0.52)	**Neighbor** (*r*= 0.56) **Stranger** (*r*= 0.48)	**Neighbor** (*r*= 0.66)
Song: Musical	**-2.32**	-1.47	**4.13**	-1.23
Song: Familiar	-1.47	**2.02**	-0.38	-0.78
Song: Loud	**2.21**	0.02	-1.46	-0.85
Aesthetic: Body Mass	**3.25**	1.11	**-2.06**	**-3.45**
Aesthetic: Brown	**-2.83**	**5.88**	**-2.74**	-1.51
Aesthetic: Grey	**4.80**	**-3.47**	0.08	-1.23
Aesthetic: Colorful	-1.95	**-2.92**	**3.02**	**3.03**
Diet: Insect	**-2.18**	1.56	1.33	-1.97
Diet: Fruit	1.01	-1.76	1.71	-1.48
Diet: Nectar	-1.02	-1.49	-0.99	**6.30**
Diet: Seed	**2.44**	0.97	**-2.23**	-1.55
Diet: Plants	0.02	-0.66	1.13	-0.89
Foraging Strata	**-2.41**	**-3.08**	**3.87**	**2.46**

Table 3. Logistic regression results on binomial distribution.

Subjective Evaluation	**Turning Point ($-\beta x/2*\beta x^2$)**	**β-estimate x, x^2**	**z-value x, x^2**	**Significance x, x^2**
Attitudinal Scale	2.88	-2.14, 0.37	-25.74, 28.41	P<0.0001, P<0.0001
Problematic	3.98	-0.61, 0.08	-2.83, 2.49	P<0.005, P<0.01
Variety of birds	2.89	-1.03, 0.18	-6.01, 7.22	P<0.0001, P<0.0001
Colorful	1.95	-0.82, 0.21	-5.44, 7.99	P<0.0001, P<0.0001
Easy to observe	2.49	-0.72, 0.15	-4.87, 6.40	P<0.0001, P<0.0001
Unique to the desert	2.02	-0.68, 0.17	-4.69, 7.02	P<0.0001, P<0.0001
Pleasant noises (song)	2.56	-0.78, 0.1	-5.65, 7.13	P<0.0001, P<0.0001
Carry disease	2.54	-0.67, 0.13	-3.74, 4.82	P<0.0002, P<0.0001
Messy	1.69	-0.37, 0.11	-2.62, 4.76	P<0.009, P<0.0001
Eat plants and trees[a]	0.99	-0.08, 0.04	-0.51, 1.72	P<0.61, P<0.09
Noisy	4.04	-0.77, 0.09	-4.08, 3.52	P<0.0001, P<0.0005

[a]Linear model without quadratic term significant (β=0.19, z=6.05, P<0.0001)

Table 4. Non-metric multidimensional scaling (NMDS) of people's subjective evaluations about their local bird community, correlated with social factors, bird traits and cultural niche groups, and biodiversity metrics. NMDS1 and NMDS2 are the relative positive of the explanatory factors driving people's subjective evaluations in multivariate space. We partitioned the variance independently explained by the social factors, bird interaction factors, and diversity metrics.

Variable	**NMDS (1, 2)**	R^2	***P-value***
Social Factors *(5.8% of variance)*			
Income	(0.93, 0.36)	0.49	0.001
Gender (Women)	(-0.31, 0.94)	0.16	0.069
Education	(0.99, 0.14)	0.53	0.001
Age	(0.84, 0.53)	0.43	0.001
Pro-ecological Orientation	(0.71, 0.71)	0.10	0.192
Latinx Identity	(-0.95, -0.31)	0.52	0.001
Bird Interaction Factors *(19.6% of variance)*			
Metropolitan (Trait Cluster)	(-0.97, 0.22)	0.22	0.021
Drab (Trait Cluster)	(0.65, 0.75)	0.02	0.691
Distinctive (Trait Cluster)	(0.85, -0.52)	0.26	0.008
Hummingbird (Trait Cluster)	(0.99, -0.13)	0.41	0.001
Celebrity (Cultural Niche)	(-0.99, -0.09)	0.47	0.001
Friend (Cultural Niche)	(0.99, -0.01)	0.30	0.002
Neighbor (Cultural Niche)	(0.98, 0.16)	0.38	0.001
Stranger (Cultural Niche)	(0.99, -0.13)	0.00	0.941
Diversity Metrics *(1.9% of variance)*			
Abundance	(-0.78, 0.62)	0.06	0.384
Richness	(0.97, 0.23)	0.45	0.001
Shannon Diversity	(-1.00, 0.00)	0.41	0.001
Evenness	(0.91, -0.39)	0.19	0.038

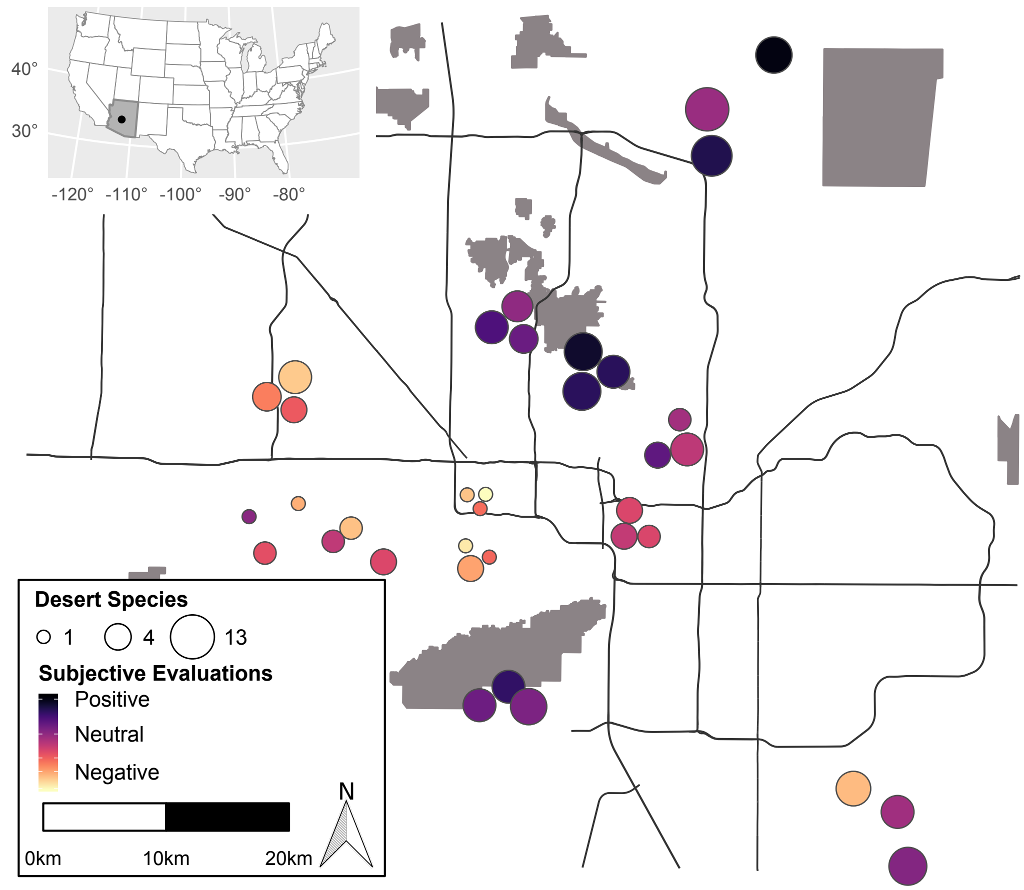


Figure 1. Study area map of 36 bird-point counts co-located with neighborhoods from the Phoenix Area Social Survey showing people's subjective evaluations of their local bird community. Larger circles indicate greater desert species richness measured during bird surveys and darker colored circles are more positive attitudes of people living around the site based on survey responses.

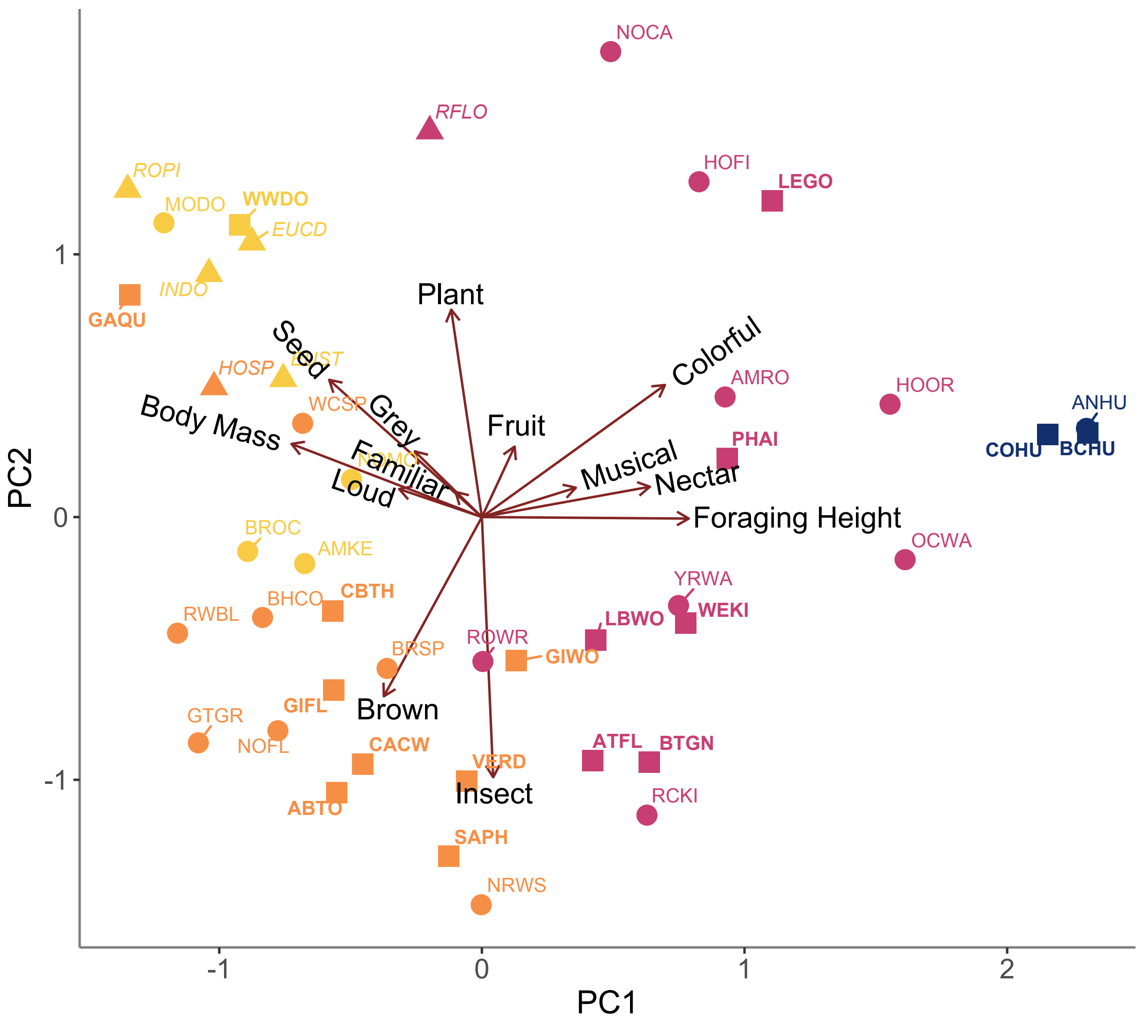


Figure 2. Bird species visualized in orthogonal trait space used to describe the interactions between people and birds. PC1 and PC2 explained 39.9% of the total variance. Six total components were retained based on their eigenvalue and used in the cluster analysis. The principal components were used to cluster bird species into four groups: Metropolitan, Drab Generalist, Distinctive, and Hummingbird species. A list of bird species codes and trait interaction clusters can be found in the supplementary materials.

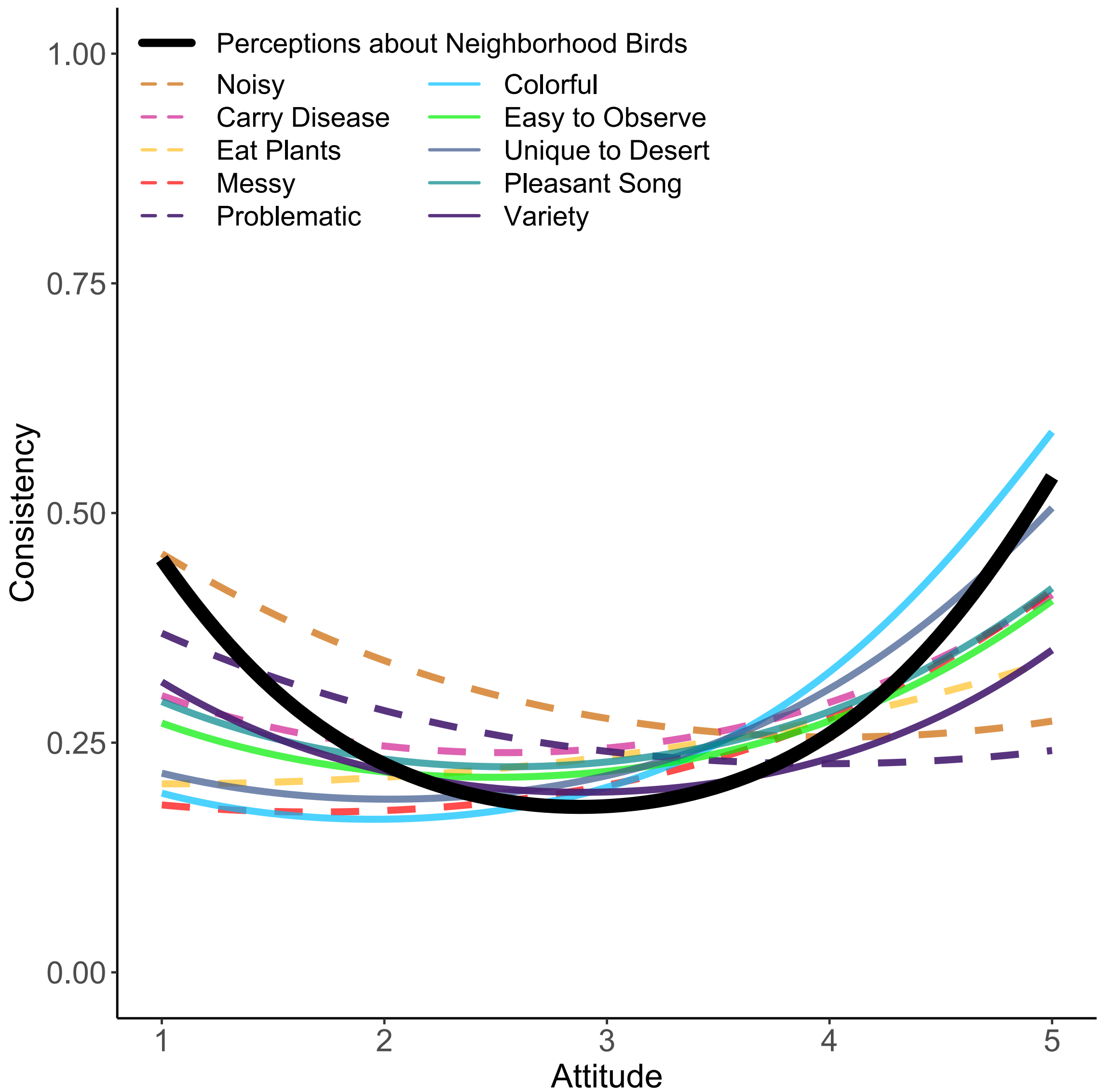


Figure 3. Logistic regression curves for the 10 survey questions measuring subjective evaluations. Attitudes are displayed on the x-axis and the y-axis represents the consistency of responses. Smaller x-axis values indicate negative attitudes and positive values indicate positive attitudes. The y-axis represents the probability that the respondent selects the same response for all of the survey questions based on their response to each particular question. The thick black line shows respondents' average overall attitude about the birds in their neighborhood.

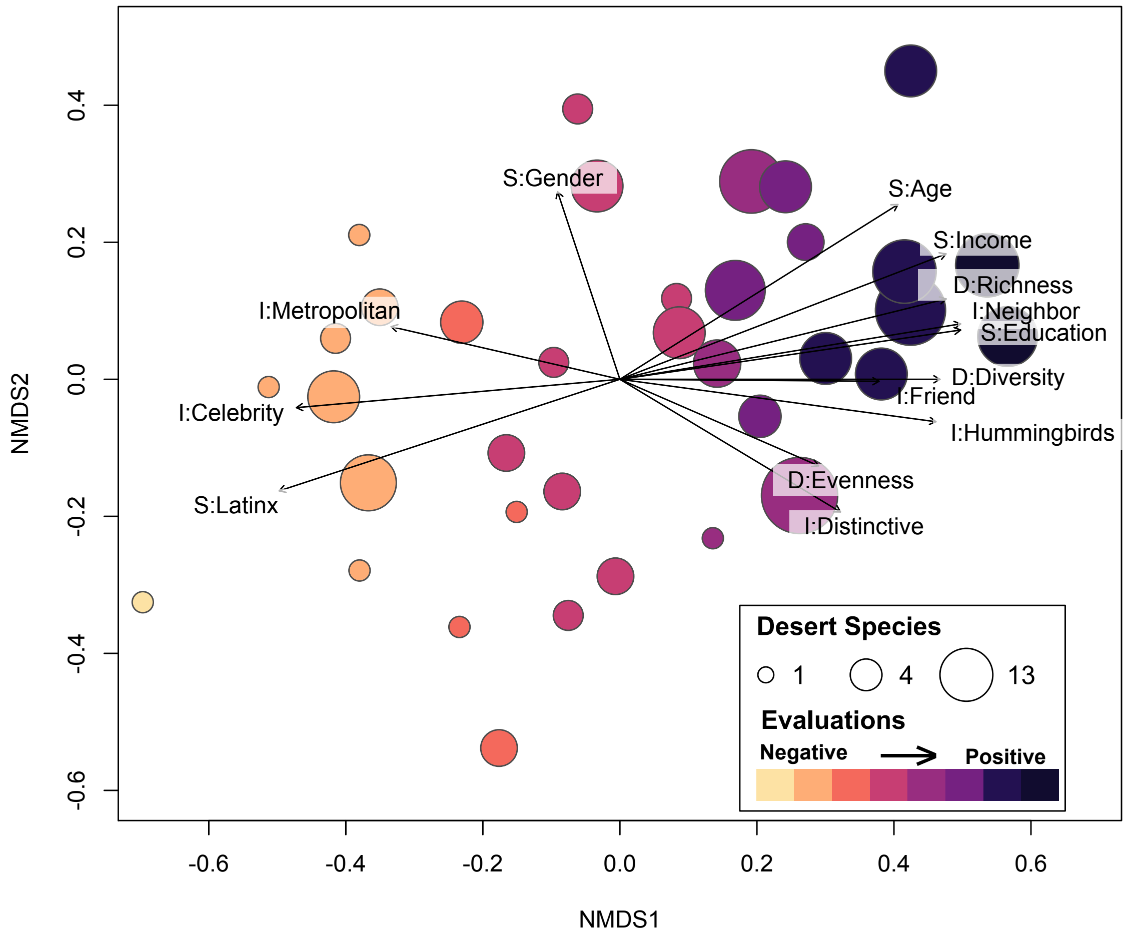


Figure 4. Sites arrayed in two dimensional space based on non-metric multidimensional scaling applied to a Gower distance matrix on people's subjective evaluations of the bird community in their neighborhood. Sites (circles) are plotted in attitudinal space based on the 10-question evaluative scale (Table 1). Circles represent residential neighborhoods where bird point-counts and social survey data were co-located. Larger circles indicate greater desert species richness and darker colored circles are more positive attitudes of people living around the site. Significant explanatory variables are displayed in the text boxes, and categorized into social factors (S:Income, S:Education, S:Age, and S:Latinx), bird interaction factors including bird trait clusters (I: Metropolitan, I:Distinctive, and I:Hummingbird) and cultural niche (I:Celebrity, I:Friend, I:Neighbor), and diversity metrics (D:Richness, and D:ShannonDiversity, D:Evenness). Vector length indicates degree of correlation between explanatory variables and ordination axes (NMDS1 and NMDS2)

SUPPLEMENTARY MATERIALS

Supplementary Table S1. Descriptive statistics of explanatory variables, categorized into social factors, traits, and diversity metrics, used to explain subjective evaluations about the birds present in their yards and neighborhoods.

Variable	Mean	SD	Median	Range
Social Factors: Individual PASS Respondents (n=496)				
Income (5=$80,000-100,000)	5.3	3.2	4	1-11
Gender (1=female)	0.4	0.49	0	0-1
Education (1=Bachelor's degree or higher)	0.57	0.5	1	0-1
Age	51.37	17.9	51	18-96
Pro-ecological Orientation (5=pro-ecological)	3.7	0.7	3.71	1.5-5.0
Latinx Identity (1=Latinx/ Hispanic)	0.22	0.41	0	0-1
Bird Interaction Traits: Bird-point Counts (n=36)				
Song: Musical	0.19	0.1	0.17	0.04-0.41
Song: Familiar	0.11	0.1	0.07	0.01-0.41
Song: Loud	0.32	0.11	0.3	0.08-0.59
Body Mass	1.72	0.13	1.71	1.46-1.96
Brown	0.41	0.1	0.42	0.26-0.63
Grey	0.44	0.12	0.47	0.16-0.67
Colorful	0.14	0.06	0.15	0.03-0.27
Diet: Insect	0.26	0.06	0.25	0.15-0.39
Diet: Fruit	0.12	0.03	0.12	0.04-0.18
Diet: Nectar	0.05	0.03	0.05	0.01-0.13
Diet: Seed	0.41	0.07	0.4	0.26-0.59
Diet: Plants	0.15	0.04	0.15	0.06-0.22
Foraging Strata	1.53	0.1	1.52	1.34-1.83
Diversity Metrics: Bird-point Counts (n=36)				
Abundance	59.11	18.54	56.5	25-112
Richness	18.67	4.89	19	11-27
Shannon Diversity	2.49	0.38	2.54	1.58-3.09
Evenness	0.86	0.08	0.88	0.62-0.95

Supplementary Table S2. Birds observed in the in Phoenix metropolitan neighborhoods. Three categorization schemes are given, including habitat use (ecological), interaction trait cluster (social), and cultural niche (social).

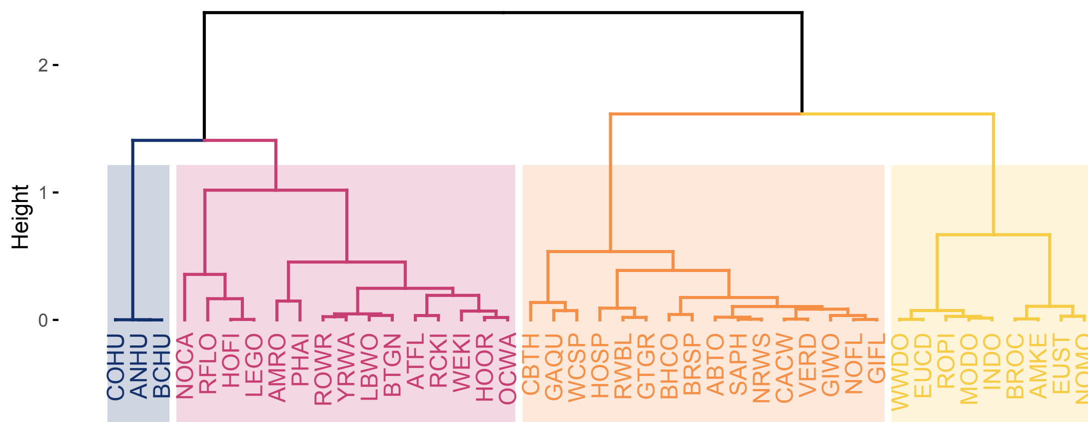
Species	**Name**	**Habitat Guild**	**Trait Cluster**	**Cultural Niche**
ABTO	Abert's Towhee	Desert	Drab generalist	Neighbor
AMKE	American Kestrel	Generalist	Metropolitan	Celebrity
AMRO	American Robin	Generalist	Distinctive	Friend
ANHU	Anna's Hummingbird	Generalist	Hummingbird	Neighbor
ATFL	Ash-throated Flycatcher	Desert	Distinctive	Neighbor
BCHU	Black-chinned Hummingbird	Desert	Hummingbird	Friend
BHCO	Brown-headed Cowbird	Generalist	Drab generalist	Neighbor
BROC	Bronzed Cowbird	Generalist	Metropolitan	Neighbor
BRSP	Brewer's Sparrow	Generalist	Drab generalist	Stranger
BTGN	Black-tailed Gnatcatcher	Desert	Distinctive	NA
CACW	Cactus Wren	Desert	Drab generalist	Friend
CBTH	Curve-billed Thrasher	Desert	Drab generalist	Neighbor
COHU	Costa's Hummingbird	Desert	Hummingbird	Neighbor
EUCD	Eurasian Collared-Dove	Urban	Metropolitan	Celebrity
EUST	European Starling	Urban	Metropolitan	Celebrity
GAQU	Gambel's Quail	Desert	Drab generalist	Friend
GIFL	Gilded Flicker	Desert	Drab generalist	Neighbor
GIWO	Gila Woodpecker	Desert	Drab generalist	Neighbor
GTGR	Great-tailed Grackle	Generalist	Drab generalist	Neighbor
HOFI	House Finch	Generalist	Distinctive	Celebrity
HOOR	Hooded Oriole	Generalist	Distinctive	Friend
HOSP	House Sparrow	Urban	Drab generalist	Celebrity
INDO	Inca Dove	Urban	Metropolitan	Neighbor
LBWO	Ladder-backed Woodpecker	Desert	Distinctive	Neighbor
LEGO	Lesser Goldfinch	Desert	Distinctive	Neighbor
MODO	Mourning Dove	Generalist	Metropolitan	Celebrity
NOCA	Northern Cardinal	Generalist	Distinctive	Celebrity
NOFL	Northern Flicker	Generalist	Drab generalist	Friend
NOMO	Northern Mockingbird	Generalist	Metropolitan	Celebrity
NRWS	Northern Rough-winged Swallow	Generalist	Drab generalist	Stranger
OCWA	Orange-crowned Warbler	Generalist	Distinctive	Stranger
PHAI	Phainopepla	Desert	Distinctive	Neighbor
RCKI	Ruby-crowned Kinglet	Generalist	Distinctive	Stranger
RFLO	Rosy-faced Lovebird	Urban	Distinctive	NA
ROPI	Rock Pigeon	Urban	Metropolitan	Celebrity
ROWR	Rock Wren	Generalist	Distinctive	Stranger
RWBL	Red-winged Blackbird	Generalist	Drab generalist	Celebrity
SAPH	Say's Phoebe	Desert	Drab generalist	Neighbor
VERD	Verdin	Desert	Drab generalist	Neighbor
WCSP	White-crowned Sparrow	Generalist	Drab generalist	Stranger
WEKI	Western Kingbird	Desert	Distinctive	Stranger
WWDO	White-winged Dove	Desert	Metropolitan	Neighbor
YRWA	Yellow-rumped Warbler	Generalist	Distinctive	Stranger

Supplementary Table S3. Results from Principal Component Analysis (PCA) of species traits. Loadings (correlation coefficient) are displayed for components explaining at least 5% of the total variance, for a cumulative 83% of the variation from the trait data. The orthogonal principal components were used to cluster bird species into "trait groups" using hierarchical cluster analysis.

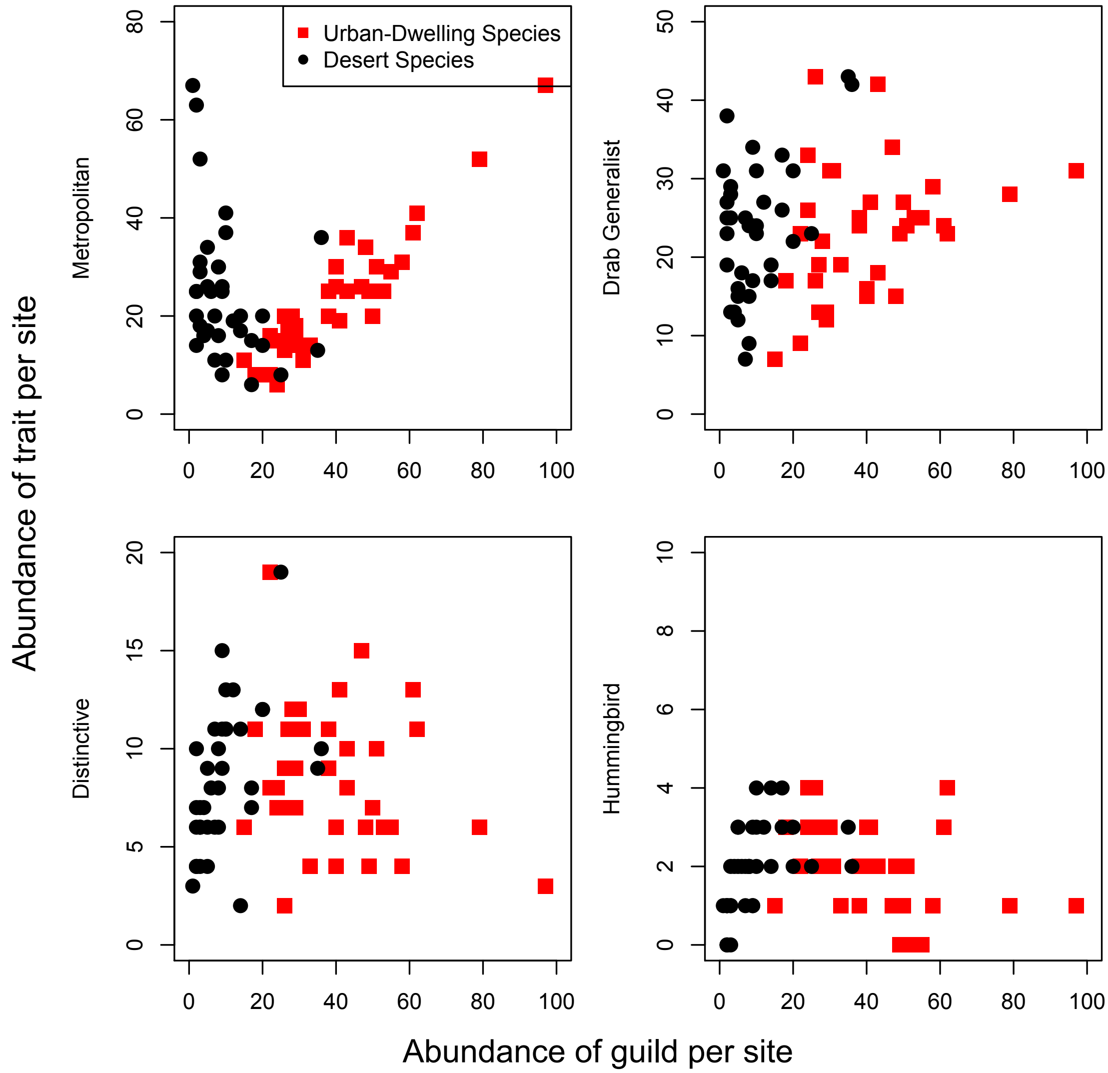
Trait Variable	**PCA 1**	**PCA 2**	**PCA 3**	**PCA 4**	**PCA 5**	**PCA 6**
Song: Musical	0.38	0.10	0.25	0.66	-0.17	-0.39
Song: Familiar	-0.11	0.08	0.65	0.38	0.16	0.33
Song: Loud	-0.33	0.09	-0.20	-0.06	0.81	-0.10
Body Mass	-0.77	0.25	-0.09	0.20	0.11	0.24
Brown[1]	-0.40	-0.61	0.60	-0.05	-0.07	0.07
Grey	-0.27	0.22	-0.84	0.11	-0.08	-0.07
Color	0.74	0.45	0.22	-0.06	0.17	0.00
Diet: Insect	0.05	-0.88	-0.13	0.24	0.19	-0.17
Diet: Fruit	0.13	0.24	-0.28	0.73	-0.11	0.41
Diet: Nectar	0.68	0.10	0.00	-0.57	0.03	0.32
Diet: Seed	-0.62	0.46	0.15	-0.28	-0.43	-0.17
Diet: Plants	-0.12	0.70	0.42	0.08	0.27	-0.27
Foraging Strata	0.83	-0.01	-0.17	0.12	0.01	-0.07
Variation (%)	**24.64**	**17.29**	**15.16**	**12.81**	**8.28**	**5.78**
Eigenvalue	**3.20**	**2.25**	**1.97**	**1.66**	**1.07**	**0.75**

Supplementary Table S4. Correlation table to compare cultural niche and trait space, used to define the interactions between people and birds in Phoenix, Arizona. We adjusted the confidence level to 0.997 to account for the 4x4 way correlation matrix.

Cultural Niche	**Interaction Trait Cluster Relationship**			
	Metropolitan	**Drab**	**Distinctive**	**Hummingbird**
Celebrity	*r*= 0.74, *P*< 0.0001	*r*= -0.44, *P*< 0.007	*r*= -0.58 *P*< 0.0001	*r*= -0.56 *P*< 0.0003
Friend	*r*= -0.45, *P*< 0.005	*r*= 0.52 *P*< 0.001	*r*= 0.08 *P*=0.64	*r*= 0.11 *P*=0.53
Neighbor	*r*= -0.52 *P*< 0.001	*r*= 0.15 *P*= 0.37	*r*= 0.56 *P*< 0.0003	*r*= 0.66 *P*< 0.0001
Stranger	*r*= -0.49 *P*< 0.002	*r*= 0.26 *P*= 0.12	*r*= 0.48 *P*< 0.003	*r*= 0.23 *P*=0.17



Supplementary Figure S1. Birds were clustered into trait groups using hierarchical clustering (Euclidean distance and Ward's linkage) on principal components. Four clusters were selected to maximize inertia gain and explain unique groupings of traits.



Supplementary Figure S2. Correlation plots between species composition and trait cluster abundance at the 36 bird point-counts. Urban-dweller species were positively related to Metropolitan traits (rho=0.88, P<0.0001) and Drab Generalist (rho=0.3, P<0.016) traits, but negatively related to Hummingbirds (rho=-0.43, P<0.008). Desert specialist species exhibited traits associated with mainly Distinctive (rho=0.62, P<0.0001) and Hummingbird species (rho=0.46, P<0.004), but negatively related to Metropolitan species (rho=-0.38, P<0.02).

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CHAPTER 6: CONCLUSION

My dissertation research is linked by three interconnected research questions focused on the everyday interactions between people and biodiversity in residential landscapes. These research questions are: (1) How do the social and spatial patterns within an arid city affect people's attitudes about their regional desert environment? (2) How are ecological communities in cities assembled given the complex social-ecological dynamics that influence ecological community structure? (3) How can we reposition bird species traits into a conservation framework that explains the complexity of the interactions between people and urban bird communities? In the following section I discuss the interconnections between the major findings from my dissertation, then review the major limitations and delimitations of my work within the broader context of the challenges that have emerged in social-ecological research.

The regional desert landscape in the Phoenix metropolitan area acts as a strong structural control, influencing people's attitudes (Andrade et al. 2019) and yard management decisions (Yabiku et al. 2008, Wheeler et al. 2020). In turn, people's attitudes act as a signal for the support of conservation initiatives, such as engaging in habitat stewardship through yard management decisions (Goddard et al. 2013, Belaire et al. 2016). My study on attitudes toward the desert emphasizes the importance of the social and spatial configuration of the urban landscape in influencing environmental attitudes (Andrade et al. 2019). Vulnerable populations in the Phoenix metropolitan area view the desert negatively, largely due to the lack of adaptive capacity to mitigate the risk that comes with a desert environment (Chapter 2, Table 1.5). Conversely, positive attitudes are fortified in affluent areas close to desert parks, where people access natural amenities while maintaining control of their environment (Chapter 2, Figure 1.4).

The effects of people's attitudes about the desert landscape and the desire for environmental control during the early development of Phoenix as a city in the 1900s has led to the ideal of Phoenix as a 'desert oasis' (Larsen and Swanbrow 2006), which can be used to explain spatial-temporal patterns of water-intensive lawns throughout the city (Larson et al. 2017). Scaled up, lawns and other ornamental vegetation are drivers of habitat patch quality and the ecological homogenization of urban ecosystems (Goddard et al. 2010). My dissertation research on metacommunity theory examines multi-scalar management decisions (Cook et al. 2012), and how people may influence ecological processes which structure biodiversity in urban ecosystems (Swan et al. 2011) to address the influence of people on novel ecological community assemblages (Groffman et al. 2017). I developed a conceptual framework linking structural constraints and management decisions across scales (e.g., formal institutions and social norms) to spatial, social, and environmental heterogeneity in the city (Chapter 3, Figure 2.1). The heterogeneity of these components, in turn, influences the biodiversity of local ecological communities.

In Chapter 4 I empirically tested my conceptual framework from Chapter 3 using the urban bird metacommunity in residential neighborhoods throughout the Phoenix metropolitan region (Figure 3.1). I used local environmental variables such as yard landscaping and land surface temperature (LST), social variables such as income and householder age, and spatial variables derived from Moran's Eigenvector Maps (MEMs) to test how local ecological communities differed amongst residential neighborhoods. I found that ecological disturbance, measured by neighborhood typologies, influenced the processes by which ecological communities are structured in urban ecosystems (Figure 3.4). Similar to other urban studies (Angold et al. 2006; Sattler et al. 2010; Chang and Lee 2015; Tsang and Bonebrake 2017), environmental heterogeneity was particularity dominant force for determining local bird communities in Phoenix (Figure 3.3). These findings further link to the connections between people and biodiversity because yard management decisions directly influence the local environment of residential yards and neighborhoods (Pincetl 2012). As a result, drivers of ecological communities are both environmentally and socially configured in spatially distinct patterns (Pickett et al. 2017).

Urban biodiversity further connects social-ecological dynamics by eliciting both positive engagements such as opportunities to experience nature in cities and negative experiences such as human-wildlife conflict (e.g., Belaire et al. 2015). My final chapter uses an integrative approach to consider people's subjective evaluations about the birds they encounter in their residential yards and neighborhoods. I addressed this topic by considering which bird traits hold cultural or social importance through people's interactions and experiences (Robinson 2019). I found that traits linked to distinct physical appearance were the strongest drivers of subjective evaluations about birds whereas foraging traits associated with urban-dwelling bird species eliciting views of human-wildlife conflict (Chapter 5, Figure 4.4). The implications of this chapter suggest that conservation efforts should focus on biodiversity metrics that signal how people experience nature in cities as local stakeholders.

Limitations and Delimitations

My dissertation work is based in the Central Arizona-Phoenix Long-term Ecological Research project, located in Phoenix, Arizona as a study area. I used multivariate analysis to link social data with ecological community data. Specifically, I integrated data from the 2011 and 2017 Phoenix Area Social Surveys, known as PASS (Larson et al. 2019), with bird community data collected in the PASS neighborhoods between 2016 and 2019 (Bateman et al. 2017). The integration of both social and ecological data allowed me to investigate interdisciplinary issues that define urban ecosystems, such as human-wildlife interactions. My dissertation projects all share an interdisciplinary approach to social-ecological research and are similarly limited in several key areas. Some of the limitations to my research are based on my use of data from a single study system over a relatively short period of time. However, other research barriers that I encountered during this work reflect broad challenges to the field of urban ecology and social-ecological research broadly.

One main limitation specific to my research is that I am using data from a single metropolitan area (Phoenix) for a relatively short period of time (2011-2017). However, the use of a single study system is common artifact of both urban ecology and non-urban ecological studies. Although using Phoenix as my study system impedes my ability to generalize my results to urban ecosystems broadly, it also allowed me to develop a deep theoretical and empirical understanding of the current and historical processes driving social-ecological dynamics in a desert city of the U.S. I also engaged in several projects where Phoenix was one of several urban systems considered, which allows for cross regional comparisons driven by local experts knowledgeable in their particular study system. Additionally, my study does not have a temporal component associated with my questions. However, I plan to pursue research on the stability in both attitudes and biodiversity components in relationship to landscape change over time and across geographical places, which would enhance the associations and predictive capacity.

Working on interdisciplinary research questions has highlighted several common challenges that occur when linking social-ecological dynamics. One of the key challenges I faced was integrating data collected from disparate disciplinary approaches. Both social and ecological sciences have rigorous methodology in research design and analysis. However, ecological data often do not temporally, spatially, or methodologically align with social data collection, or vice versa. One of the key challenges in social-ecological research is integrating people as components of ecosystems, rather than separate entities or outside forces (Groffman et al. 2017). To overcome this barrier inhibiting interdisciplinary research, scientists with theoretical understanding of the disciplinary perspectives can co-design research initiatives that capture both the social and the ecological patterns and processes of dynamic systems. To do so we need to theoretically align the spatial mismatches between the boundaries at which social dynamics, such as decision-making and land management, play out versus the ecological patterns and processes occurring. Overall, my goal as a scholar is to address these pressing research topics focused on balancing biodiversity and human well-being by studying human-environment interactions.

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APPENDIX I

APPROVAL OF CO-AUTHORS

Co-authors have given their permission for the following published work to be included as a dissertation chapter for Riley Andrade. This is a published manuscript of an article published by Taylor & Francis Group *in Annals of the American Association of Geographers* on 09/05/2019. Available online: https://www.tandfonline.com/doi/abs/10.1080/24694452.2019.1580498

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Co-authors have given their permission for works that have not yet been accepted for publication in a peer-reviewed journal to be listed as dissertation chapters.