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Urban Biodiversity Experience and Exposure: Intervention and Inequality at the Local and Global Scale

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Urban Biodiversity Experience and Exposure:
Intervention and Inequality at the Local and Global Scale

A Thesis Presented

by

EVAN R. KURAS

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University of Massachusetts Amherst in partial fulfillment
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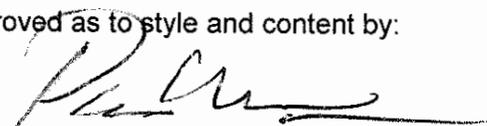
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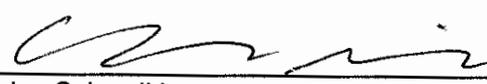
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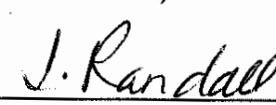
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ABSTRACT

URBAN BIODIVERSITY EXPERIENCE AND EXPOSURE: INTERVENTION AND INEQUALITY AT THE LOCAL AND GLOBAL SCALE

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As cities expand globally, researchers must clarify how human activities and institutions shape biodiversity and conversely, how ecological processes shape human outcomes. Two features of contemporary cities motivate this thesis. First, urban residents, and especially children, are spending less time in nature and consequently, miss out on healthy and formative experiences with biodiversity. Second, residents with the least access to biodiversity tend to be those with the lowest socioeconomic status (SES). Together, these patterns convey a multi-layered environmental injustice: not only might urbanites become increasingly estranged from biodiversity, disinterested from its conservation, and disconnected from its benefits, but these outcomes may be most acute in communities already suffering from inequality in terms of exposure to hazards or limited economic opportunity. The first chapter explores how children's behaviors and interests change after learning about animal habitats first-hand in an environmental education program. I conducted an evaluation of the ECOS program in Springfield, Massachusetts, in which I surveyed elementary school students about their memories of ECOS and their related environmental behaviors. Students with parents or peers that had participated in ECOS were more likely to repeat or discuss program activities after the program's end. Findings will aid educators in Springfield and beyond in improving program impacts and sustainability. The second chapter explains under what conditions socioeconomic inequality becomes linked with biodiversity. I conducted a meta-analysis of published research that assessed SES-biodiversity relationships in 34 cities using fuzzy-set Qualitative Comparative Analysis. I evaluated the contributions of study design and city-level conditions in shaping SES-biodiversity relationships for various taxonomic groups. The meta-analysis highlighted the contributions of residential and municipal decisions in differentially promoting biodiversity along socioeconomic lines. Further, we identified circumstances in which inequality in biodiversity was ameliorated or negated by urban form, social policy, or collective human preference. Findings will aid researchers and managers in understanding human drivers of biodiversity in their cities and how access to biodiversity may be unequally distributed. In sum, this thesis advances our knowledge about how biodiversity is structured in cities, who gets to experience it, and how such experiences influence our behaviors and interests.

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CHAPTER I
EXPERIENCING NATURE IN AND OUT OF SCHOOL:
A REPORT FOR ECOS AND THE SPRINGFIELD PUBLIC SCHOOLS

A. Introduction

1. Springfield and the ECOS Program

Springfield, Massachusetts is a city of approximately 154,000 residents, located in Western Massachusetts along the Connecticut River. The city was founded in the 1600s and bloomed during the 19th and 20th century as an industrial, commercial, and financial center. During the mid-late 1900s, manufacturing shifted elsewhere and the city lost many of its higher paying jobs. As residents started leaving the city, abundant housing attracted migrants from southern states and other countries (Foster et al. 2006). During the 1960s, Springfield engaged in a process of Urban Renewal, removing, closing, and relocating houses and businesses to make way for interstate highways and other developments. Today, the city is primarily residential and retains a large amount of industrial jobs and land.

Springfield is also home to numerous greenspaces in the form of conservation land, cemeteries, and public parks. The largest park in Springfield, Forest Park, was donated to the city in 1884 and has served as a resource for biodiversity, recreation, and social gatherings ever since (Bischoff 1994). In the 1970s, Forest Park embraced a more formal connection with environmental education in the form of a Zoo and the ECOS (Environmental Center for Our Schools) program. ECOS began in 1970 through a collaboration between the Springfield Park Department and the Springfield Public Schools (SPS), originally as part of the Elementary and Secondary Education Act's Title

III program. The ESEA had the broad goal of combatting poverty through improved access to quality education for all students.

Today, ECOS is a curriculum-based environmental science education program within SPS¹ with the following Mission Statement.

“ECOS provides outdoor environmental education for the Springfield Public Schools using Forest Park as an outdoor classroom. At ECOS, students engage in scientific inquiry through the use of science and engineering practices to develop an attitude of respect and stewardship for the natural world.”

To achieve its mission, ECOS brings SPS students from Grade 4 through Grade 7 to Forest Park for two consecutive days (one day in Grade 7) throughout the school year to learn about nature and environmental science. In Grades 4 and 5, students explore biodiverse habitats, do ecological science experiments, and learn about history of Forest Park. In Grades 6 and 7, students apply lessons from thermal physics and geography to outdoor activities such as fire-making, shelter-building, and orienteering.² Activities are led by dedicated ECOS teachers with backgrounds in environmental and science education. Classroom teachers accompany their students to ECOS but do not deliver content during the program.

2. The Program Evaluation

This study was initiated in 2015 by Evan Kuras, a Master’s of Science student at the University of Massachusetts Amherst. Mr. Kuras was interested in young people’s experiences with biodiversity in cities, in both formal and day-to-day settings. ECOS teachers and staff wanted to learn how their program influenced environmental attitudes and behaviors. Mr. Kuras and the ECOS teachers identified research questions Mr.

¹ <http://www.springfieldpublicschools.com/schools/ecos>

² This paragraph describes the ECOS program as of the 2016-2017 academic year.

Kuras could investigate as part of his Master's research and in doing so, provide insights that are difficult to obtain through traditional testing or other means.

ECOS teachers and staff worked with Mr. Kuras to articulate the *purpose* of the program evaluation: **to understand how ECOS influences students' environmental attitudes and behaviors**. Teachers were also interested in understanding how their students experience nature outside of school and the social and environmental context in which those experiences occur.

The Grade 4 program was selected for investigation for numerous reasons. First, students in Grade 4 learn about animal habitats and life cycles. This highly tactile, small-scale, and biodiversity-rich curriculum is not only developmentally appropriate for students in middle childhood, but more psychologically meaningful than learning about or interacting with larger elements of nature such as forests or watersheds (Chawla 2007). Second, as it is the first year of the ECOS program we can ensure that all participants are experiencing the program for the first time.³ Third, the Grade 4 program is considered to be quite memorable. Indeed, ECOS teachers report that the two most common memories adults share about ECOS are making fires for Winter Survival (Grade 6) and catching frogs in the pond (Grade 4) (personal communication).

The results obtained from this study will be used for program improvement within SPS and beyond. Stakeholders include ECOS teachers and staff, the SPS Science Director and Senior Leadership, and elementary school teachers and administrators in SPS.

³ In Spring 2017, ECOS initiated a Grade 3 program. However, Grade 4 was the first year of ECOS for the current study participants.

3. Theory of Change

The program evaluation was motivated by a “theory of change” that explains how resources and motivations (“inputs”) within the school district deliver services to participants (“outputs”). Students demonstrate outcomes after receiving these services, as shaped by their own social and environmental contexts. Figure 1.1 and the text that follows illustrate the flow of inputs, outputs, contexts, and outcomes, specific to the ECOS program.

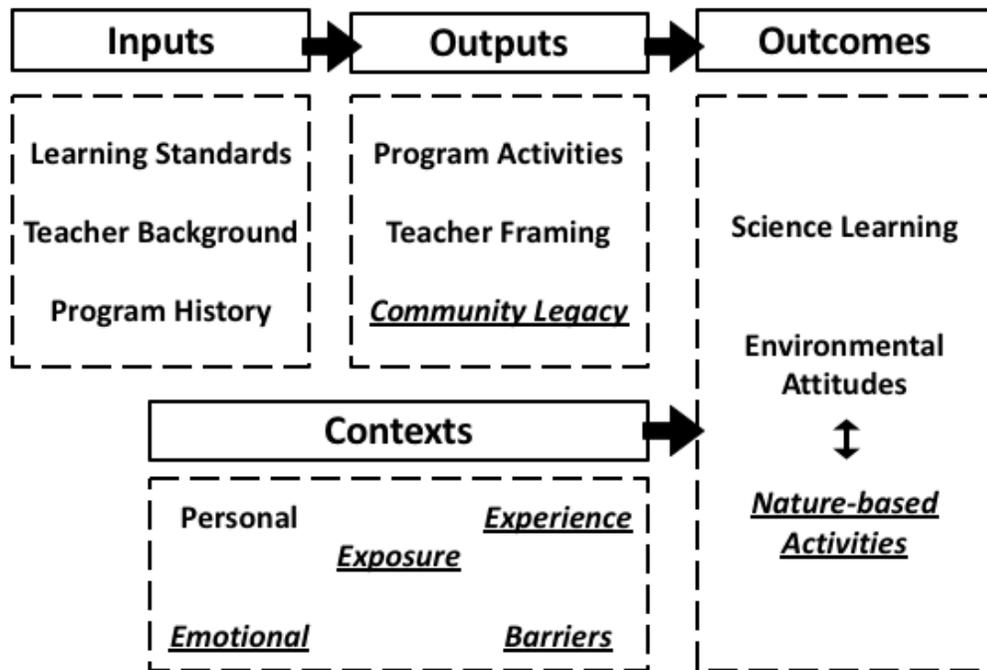


Figure 1.1. The logic and theory motivating the program evaluation. Inputs from SPS and the ECOS teachers lead to the Outputs of the program. Participating students demonstrate program Outcomes, shaped by specific social and environmental contexts that affects how children make meaning of environmental experiences in and out of school. The research survey conducted by Mr. Kuras primarily measures Outcomes and Contexts in order to understand exactly how and why students’ interests in the environment change after participating in ECOS. Items directly measured in the survey are emotional and barriers.

Inputs: As an academic program,⁴ ECOS aims to impart knowledge around four important Learning Standards from the 2006 Massachusetts Science and Technology/Engineering Curriculum Framework. Specifically, students learn about plant biology,⁵ life cycles (especially those of the frog and butterfly),⁶ and photosynthesis and the food chain.⁷ Lessons and activities are led by dedicated ECOS teachers with backgrounds in environmental and science education. ECOS teachers self-identify as “outdoors people” and participate in environmental activities and nature appreciation beyond the program (personal communication). The long history of ECOS shapes many of the activities that teachers lead each session. Catching frogs in the pond and tasting the bubblegum tree, for example, are traditions that many students expect to partake in, having heard about these activities from siblings, parents, and even grandparents that went through the program. Indeed, ECOS is a rare environmental education program in that it is multi-year and district-wide, ensuring that the majority of Springfield residents have a connection to the program. As such, ECOS staff have honed a curriculum that improves test scores, exposes children to the nature of Forest Park, and harnesses a community bank of memory and expectations.

Outputs: During the Grade 4 ECOS program, students learn about animal habitats and life cycles by doing activities in pond, field, and forest habitats. In each location, students catch small animals (bugs, frogs, tadpoles) in order to understand the diversity of

⁴ <http://www.emfoley.com/ecos/archives/4thgrade-curriculum-standards/>

⁵ Learning Standard #2: Identify the structures in plants that are responsible for food production, support, water transport, reproduction, growth, and protection.

⁶ Learning Standard #3: Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death.

Learning Standard #4: Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis.

⁷ Learning Standard #11: Describe how energy derived from the sun is used by plants to produce sugars (photosynthesis) and is transferred within a food chain from producers (plants) to consumers to decomposers.

organisms that exist in different places and why. Grade 4 students also explore the nature of Forest Park through a “discovery hike” in which ECOS teachers guide students through various habitats, discussing and answering questions about plants and animals encountered along the way. Many classes also do a “silent sit” where students find a quiet place to sit, listen to natural sounds, and reflect. Other classes do scavenger hunts for different natural elements and/or do leaf rubbings. At the end of the program, students usually visit the “bubblegum tree” (*Betula lenta*) and taste the minty stems. Throughout all these activities, teachers strive to impart a love of and care for nature while also framing activities in terms of scientific inquiry, skill-development, and/or confidence-building. Often, teachers will highlight feelings of appreciation and relaxation that can come from being in nature (personal observations).

Beyond the two days that SPS students attend ECOS, they are surrounded by a community legacy comprised of both formal and informal chatter about the program. To start, ECOS teachers visit each school to conduct an orientation before that school comes to Forest Park. During the orientation, ECOS teachers explain what students should expect to do and learn. Students then bring home Registration and Permission Packets for parents or guardians to sign. Between the orientations and forms, students have many informal opportunities to hear about ECOS. In the school setting, many classroom teachers discuss ECOS activities as a way to reinforce science concepts throughout the year. Older students may also talk about the program as younger students prepare to depart. Outside of school, many students hear about the ECOS from parents, older siblings, and friends, especially when they bring home the Registration and Permission Packet. Further, students may hear about ECOS when they visit Forest Park for other reasons and see the building where ECOS takes place.

Contexts: A number of contextual factors influence the extent to which program inputs produce desired outcomes, especially regarding environmental attitudes and behaviors. Past studies have found that children's emotions about nature can greatly influence their interest in participating in nature-based activities (Cheng and Monroe 2012). For example, children who express disgust toward certain activities are particularly keen to avoid those activities and associated places (Bixler and Floyd 1997, 1999). While this may be true for some ECOS students, for others a disgusting activity or one that feels challenging may enhance their interest or confidence in doing that activity or talking about it with others. In a grander sense, children that didn't enjoy their time at ECOS overall may not be interested in repeating those activities again. Further, aspects of students' personal contexts may alter their experiences with ECOS. Perceptions about what is appropriate for students of different gender, racial, ethnic identities may influence how interested students are in repeating activities, for example (Kellert et al. 2017; Zelezny et al. 2000).

A child's general exposure to nature and previous experiences doing activities in nature may also influence the extent to which ECOS fosters environmental attitudes and behaviors. Increasing urbanization has placed the majority of city residents in nature-poor settings (Turner et al. 2004) such that not all young people have access to wetland habitats for catching tadpoles, for example. Indeed, numerous studies of both children and adults in cities show generally positive relationships between greenness where individuals live, be it formal parks or grassy backyards, and how often residents visit green areas and engage in physical activity there (Almanza et al. 2012; Lin et al. 2014). Mere exposure can also increase familiarity with nature, such that nature experiences are more likely to be meaningful if and when they occur (Clayton et al. 2016). Yet, although many cities have a surprising amount of natural areas and biodiversity, urban

populations tend to spend very little of their time *intentionally* with nature (Cox et al. 2017).

Louv (2005) discusses a number of barriers that prevent children from spending time in nature, including difficulty of access, safety concerns, incompatible schedules, and discomfort outdoors. Indeed, barriers real or perceived are commonly included in assessments of children's engagement in outdoor or nature activities. In their study of attitudes toward outdoor play, Beyer et al. (2015) included barriers such as fears or dislikes of getting lost, strangers, wild animals, getting hurt, and people doing drugs.

Outcomes: The mission of ECOS is for students to engage in scientific inquiry "to develop an attitude of respect and stewardship for the natural world." Certainly, SPS students show an improved understanding of environmental science concepts, especially the learning standards previously discussed (personal communication). Science learning outcomes are already directly measured by ECOS teachers using a pre-post quiz as well as indirectly measured through Grade 5 MCAS testing. Yet increasing knowledge alone is insufficient to produce attitudes of respect and stewardship, the ultimate goal (Cheng and Monroe 2012). Attitudes are created slowly and don't become salient until young adulthood. During middle childhood, engagement in both nature exploration and formal activities like ECOS, especially with peers and family, is critical for young people to eventually develop environmental attitudes over time (James et al. 2010; Wells and Lekies 2006).

ECOS achieves its mission if, after participating in the program, students are more interested in nature-based activities, such as those they learned at ECOS. Students may also draw value from the program by using ECOS activities either as a source of

discussion or shared memory, or as a source of confidence and pride (Liddicoat and Krasny 2014). These outcomes are linked and potentially reinforcing. For example, a young person talking about a prior success catching frogs may strengthen their sense of confidence. Similarly, if a child participates in a behavior frequently, they are more likely to talk about it with others (Pillemer 2009). These outcomes are likely strengthened year-to-year as students continue participating in ECOS and engaging in nature-based activities, conversations, or reflections. For the remainder of the report, “Activity Outcomes” will refer to activity repetition, activity discussion, and activity confidence, as discussed above.

4. Research Objectives

a. Objective 1: Describe the Environmental and Social Contexts of ECOS students.

- What natural environments are students exposed to at home? What animals do students see where they live? Do students live close to parks and other open spaces? How green are their neighborhoods overall?
- How do students experience nature outside of school? What activities do students do in nature? How are different types of activities related to each other?
- What barriers prevent students from participating in nature-based activities?
- How do students feel about doing activities in nature (i.e., emotions)? How did they like ECOS?
- To what extent are students surrounded by an ECOS community legacy?⁸ How often do classroom teachers talk about ECOS? Who do students repeat ECOS activities with and who do students know that have done ECOS before? What do people say about ECOS activities?

⁸ In the introduction, I describe “community legacy” as an output rather than a context. However, the legacy of the ECOS program effectively becomes a type of “social context” that surrounds students in the form of conversation and shared memory.

b. Objective 2: Understand what students do after they finish ECOS and why.

- What activities do students remember doing at ECOS?
- To what degree have students repeated, discussed, and felt confident about those activities? How are activity outcomes related to each other?
- How do students' social and environmental contexts (described in Objective 1) relate to their reported activity outcomes?

B. Methods

Mr. Kuras developed multiple drafts of the research survey, receiving teacher feedback throughout. This process allowed ECOS teachers and staff and Mr. Kuras to hone their specific research questions and goals. In June 2016, Mr. Kuras pre-tested survey questions with small focus groups of Grade 4 students to better understand how they interpreted the questions. The survey was then pilot tested in small “chunks” with Grade 4 students in June 2016 and with Grade 5 students in Fall 2016. The final version of the survey was approved by SPS, the Institutional Review Board at the University of Massachusetts Amherst (Protocol 2016-3043), ECOS teachers and staff and survey researchers at UMass.

1. Sample

The survey was designed for ~600 Grade 5 students within SPS (there are ~2,000 students in the grade) about their memories of the Grade 4 program. The majority of the sample lived in Springfield, MA, and was between the ages of 9 and 11. Gender and ethnic background (“personal context”) was mixed although such information was not collected.

Surveys took place in spring 2017 and therefore asked participants about their memories of ECOS from the 2015-2016 academic year. During fall 2015, the ECOS building was under construction. As such, some Grade 5 students in the research sample attended ECOS at an alternate location while they were in Grade 4 (Camp Wilder). Eighteen elementary schools participated in ECOS in spring 2017 and schools that went to Camp Wilder were not included in this study (Table 1.1).

Schools that attended the:	
Grade 4 ECOS program in Forest Park, spring 2016	Homer Street School, Daniel B. Brunton School, White Street School, Hiram L. Dorman School, Warner School, Indian Orchard Elementary, Springfield Public Day Elementary School, Mary O. Pottenger School, German Gerena Community School, Frederick Harris School, Milton Bradley School
Grade 4 ECOS program at Camp Wilder, fall 2015	Washington School, Edward P. Boland School, Rebecca Johnson School, Thomas M. Balliet School, Lincoln Elementary School, Arthur T. Talmadge School, Brightwood Elementary School

Table 1.1. Grade 5 schools participating in ECOS in spring 2017 and the location where those schools participated in ECOS during grade 5 (2015-2016 academic year).

Principals of eligible schools were informed about the study and asked if their schools wanted to participate. All schools agreed to participate in the study with the exception of Springfield Public Day. All Grade 5 students in participating schools had the opportunity to partake in the study if parental consent and minor assent were obtained (see A2: Ethical Considerations, pg. 107).

2. Survey Instrument

The survey consisted of two double-sided pages. Questions in the first half of the survey (first double-sided page) collected information about biodiversity close to home (exposure), past participation in various nature activities (experience), barriers to participating in nature activities, and if the student participated in ECOS the previous year. Students that answered “yes” to the final question continued on to the second half of the survey (second double-sided page), which asked each student to recall a single

specific activity they did during ECOS (hereafter their “chosen activity”) and to answer a series of questions aimed at revealing to what extent the student repeated, discussed, and felt confident about doing that activity. Each chosen activity was sorted into a domain by activity and habitat type, specifically 1) small animal activities in the pond, 2) small animal activities in the field or forest, and 3) other activities in the forest such as hiking, exploring, and silent sit (see Appendix A: Survey Processing and Validity, pg. 109, for more information about sorting). Students were also asked how they liked ECOS and how they felt doing their chosen activity (emotions). Students that did not attend ECOS were given a separate double-sided page (the “no ECOS” page) which asks students to recall *any* environmental activity they have participated in and to answer questions that were essentially identical to those who did ECOS the year before. All students were also asked questions about the community legacy around their chosen activities, including how often classroom teachers talk about the activity, who they do their chosen activity with, who they know that has done that activity at ECOS, and what people say about the activity.

During the consent process, parents and guardians were asked for permission to use address information in a “Neighborhood Habitat Analysis” (see Appendix A: Ethical Considerations, pg. 107). If consent was obtained, addresses were geocoded⁹ using Texas A&M University GeoServices¹⁰ and further processed in ArcMap10 to obtain two additional exposure variables. “Nearby Open Space” describes the availability of parks, conservation areas, cemeteries, and other protected greenspaces that students have access to within 500-meters of the home address. “Surrounding Greenness” describes

⁹ When only streets were given as addresses, the midpoint address was selected (GER-M-10 and GER-C-09)

¹⁰ <https://geoservices.tamu.edu/>

the general amount of grass, trees, and vegetation within 500-meters of the home address, regardless of whether those features are public or private. Figure 1.2 shows overall open space and greenness in Springfield, MA, in order to illustrate potential exposure to nature for students participating in the study. See A2: Neighborhood Habitat Analysis for more information about spatial data processing.

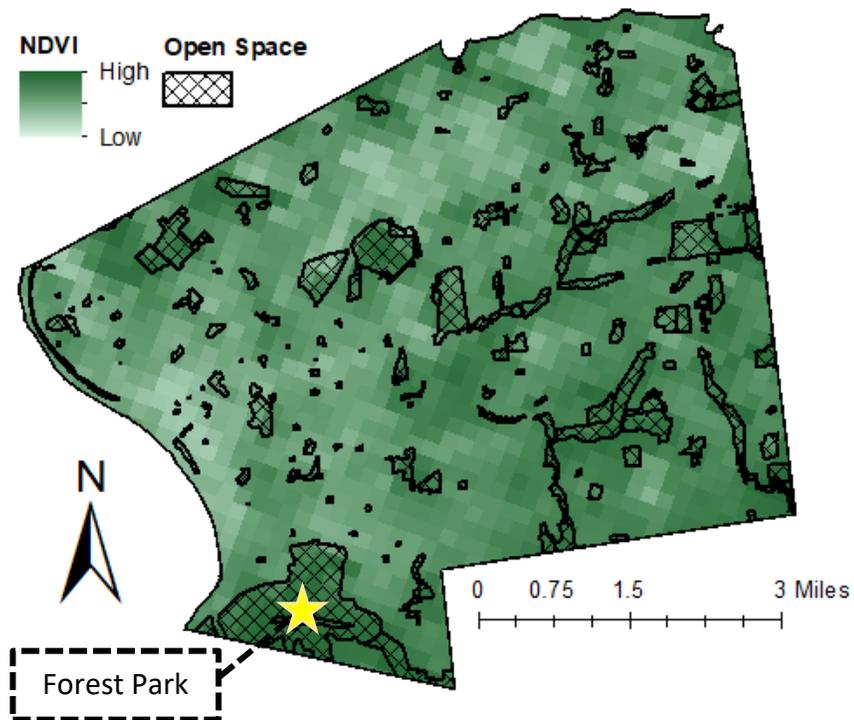


Figure 1.2. Open space and greenness in Springfield, MA.

Surveys were conducted March 21 - May 4, 2017 (see Appendix A: Implementation, pg. 108), processed using Qualtrics, and checked for input accuracy. Four logic checks were employed to assess internal validity (see Appendix A: Survey Processing and Validity, pg. 109). Text responses were coded in excel and converted into categorical responses. The dataset was exported to R for further analysis (version 3.2.4).

3. Analysis

a. Objective 1: Describe the environmental and social contexts of ECOS students.

Individual survey questions concerning exposure, experience, barriers, emotions, and legacy were examined and reported independently using descriptive statistics (Objectives 1A-1E). Nearby Open Space and Surrounding Greenness were also summarized descriptively and visually (1A). Chi-Square and Kruskal-Wallis tests were employed to investigate internal relationships between types of nature experiences (1B) and types of barriers (1C).

These two tests were also used to look for relationship between chosen activities and both emotions (1D) and teacher talk (1E). Association tests were used to examine relationships between chosen activities, who students do chosen activities with, and who students know that have done that activity at ECOS, as well as between chosen activities and what people say about those activities (1E). For both the questions about who students do chosen activities with and who students know that have done that activity at ECOS (Questions 16 and 17), a subset of responses was examined with only students that repeated ECOS activities in the past year. Chi Square tests were employed to assess relationships between the individuals that students knew had done ECOS and the individuals that students repeat ECOS activities with.

b. Objective 2: Understand what students do after they finish ECOS and why.

For Objective 2A, chosen activities are reported descriptively. For Objective 2B, activity outcomes¹¹ are reported in their original 5-point form and differences in outcomes based

¹¹ Activity outcomes were originally collected on a 5-point ordinal scale but for some analyses, outcomes were converted into binary responses (see Appendix A: Survey Processing and Validity, pg. 36).

on chosen activities were assessed using Kruskal-Wallis tests. Figure 1.11 visually represents differences between outcomes by chosen activity based on the binary form of the outcome. To understand how activity outcomes were related to each other, pairwise comparisons of outcomes were conducted using Chi Square tests for the binary form and Spearman-Rank correlations for 5-point form.

Two analyses were employed for Objective 2C, both of which sought to explain why students reported different activity outcomes. Survey questions about environmental and social contexts were used as variables to explain these differences (Table 1.2). First, two groups of students were compared: those that demonstrated all three activity outcomes and those that demonstrated none of the three outcomes. One-way ordinal permutation tests, Chi Square tests, and t-tests were used to examine differences between the two groups in terms of all the variables listed in Table 1.2.

Variable	Explanation	Type	Survey Question
Wild Habitat	perceived diversity of forest and pond animals close to home	Exposure	1
City Habitat	perceived diversity of field and urban animals close to home	Exposure	1
Nearby Open Space	parks, conservation areas, cemeteries, and other protected greenspaces within 500-m of residence	Exposure	(address information)
Surrounding Greenness	general amount of grass, trees, and vegetation within 500-m of residence	Exposure	(address information)
Recreational Experience	hiking, camping, fishing, biking in the woods, and swimming in a natural place	Experience	2
Domestic Experience	going to a park, zoo, or aquarium, taking care of plants, and picking or planting vegetables, flowers, or trees.	Experience	2
Immersive Experience	catching small animals, collecting things from nature, exploring in nature	Experience	3
Disinterest	whether or not student said they like to do outdoor activities	Barrier	4
Place Barriers	access, friendliness, safety, and pests associated with natural places	Barrier	4

General Barriers	too busy, no nature companions, don't know where to do activities	Barrier	4
Liked ECOS	rating of how much student liked ECOS	Emotions	6
Teacher Talk	how often classroom teacher talked about ECOS	Legacy	14
Did Parents	if parents or grandparents did the chosen activity at ECOS	Legacy	17
Did Peers	if friends or siblings did the chosen activity at ECOS	Legacy	17

Table 1.2. Variables generated from survey questions and address information, including a brief explanation, type of variable, and source.

Second, the three outcomes for the small animal activities at the pond (SAP) activity were modeled using binomial logistic regression and an information theoretic approach. Four hypotheses were tested to explain each activity outcome: exposure to nature, nature experiences, emotional context, and community legacy (Table 1.3). Place-based barriers were combined with the exposure hypothesis with the reasoning that even if students live in green areas, perceptions of unfriendliness or lack of safety may deter students from using those spaces. General barriers were combined with the emotional context hypothesis because even if students liked ECOS, disinterest or busy-ness may deter students from engaging in outdoor activities directly or through conversation. For the exposure hypothesis, two sources of information were considered: survey questions about perceived habitat close to home and spatially-derived information about open space and greenness. Model selection was used to compare the efficacy of both survey questions and spatial information in explaining activity outcomes (see Appendix B: Neighborhood Habitat Analysis, pg. 111). Given the weaker explanatory power of the spatial variables and lower associated sample size, the two survey variables (Wild Habitat, City Habitat) were selected for modeling purposes. After model assumptions were evaluated, a candidate model list was generated that included each hypothesis independently, the six pair-wise combinations of hypotheses, a null model, and a global model (Table 1.3). All models were multi-level, with responses grouped by school

Accountability and Assistance Level (see Appendix A: Accountability and Assistance Level, pg. 112). Models were ranked and selected based on weights of the Akaike's Information Criterion (AIC) corrected for small sample sizes (AICc). Model averaging with shrinkage estimates was used to obtain odds ratios, confidence intervals, and variable importance for all predictor variables.

Model	Formula
Null (none of the hypotheses included)	outcome ~ (1 AAL)
Exposure	outcome ~ hab_wild + hab_city + bar_pla (1 AAL)
Experience	outcome ~ exp_rec + exp_dom + exp_imm* + (1 AAL)
Emotions	outcome ~ lik_ECOS + bar_gen2 + bar_a + (1 AAL)
Legacy	outcome ~ teacher +did_parent +did_peer + (1 AAL)
Exposure + Experience	outcome ~ hab_city + hab_wild + bar_pla + exp_rec + exp_dom + exp_imm* + (1 AAL)
Exposure + Legacy	outcome ~ hab_city + hab_wild + bar_pla + teacher + did_parent + did_peer + (1 AAL)
Experience + Emotions	outcome ~ exp_rec + exp_dom + exp_imm* + lik_ECOS + bar_gen2 + bar_a + (1 AAL)
Emotion + Legacy	outcome ~ teacher +did_parent +did_peer + lik_ECOS + bar_gen2 + bar_a + (1 AAL)
Exposure + Emotion	outcome ~ hab_city + hab_wild + bar_pla + lik_ECOS + bar_gen2 + bar_a + (1 AAL)
Experience + Legacy	outcome ~ exp_rec + exp_dom + exp_imm* + teacher + did_parent + did_peer + (1 AAL)
Global (Exposure + Legacy + Experience + Emotions)	outcome ~ hab_city + hab_wild + bar_pla + exp_rec + exp_dom + exp_imm* + teacher +did_parent +did_peer + lik_ECOS + bar_gen2 + bar_a + (1 AAL)

Table 1.3. Candidate model list and associated formulas. AAL = Accountability and Assistance Level. *Immersive experience (exp_imm) was not included when modeling Activity Repetition because the survey questions used to derive Immersive experience were too similar in content to the SAP chosen activity.

C. Results

In total, 562 students completed the survey among 27 classes from 10 schools. Surveys took ~17 minutes on average to complete. 87.5% of students gave assent and 72.8% of parents gave consent for survey responses to be used for research purposes, resulting in a sample of 364 surveys (64.8%) in which both consent and assent were obtained. Parents provided address information for 214 of these surveys (58.8%). Four surveys were excluded from analysis based on results from the logic check (see Appendix A: Survey Processing and Validity, pg. 109), including two with associated addresses. Further, 37 students did not previously participate in ECOS (see Appendix B: Who did ECOS?, pg. 113) and 73 surveys were either incomplete or the chosen activity was incompatible with the analysis. As a result, 360 surveys were variably available for question-by-question analysis and 250 surveys were available for modeling (Objective 2C, pg. 9). For analyses involving addresses, 212 were available for question-by-question analysis and 157 surveys were available for modeling. For each survey question described in the following results, the number of responses used for analysis is reported.

1. Objective 1: Describe the environmental and social contexts of ECOS students

a. Exposure to Nature

What animal species do students see close to home (n = 349)?¹² Students most commonly report seeing urban animals (pigeon and squirrel) close to home, followed by field animals (dragonfly and grasshopper). Forest animals (deer and snake) and pond animals (frog and turtle) were less frequently reported (Figure 1.3).

¹² Survey Question 1 (Appendix C).

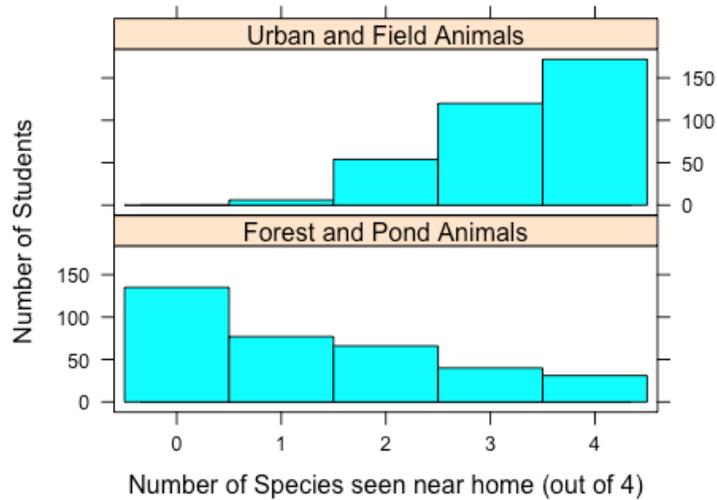


Figure 1.3. Number of students who report seeing different animal species outside where they live. Urban and field animals include pigeons, squirrels, dragonflies and grasshoppers. Forest and pond animals include deer, snakes, frogs, and turtles.

Do students live close to parks and other open spaces (n = 222)?¹³ The majority of students (75.7%) live in areas with very little green open space (less than 10% of area within 500-meter radius of home is considered open space). Only 4.5% of students live with 20% or more of their home area occupied by green open space (Figure 1.4).

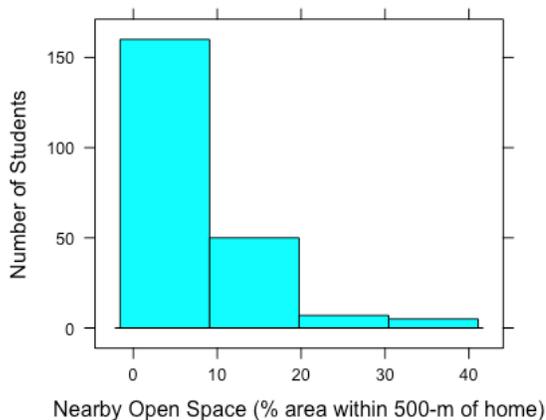


Figure 1.4. Number of students who live within walking distance (500-meters) of different amounts of Open Space (% area).

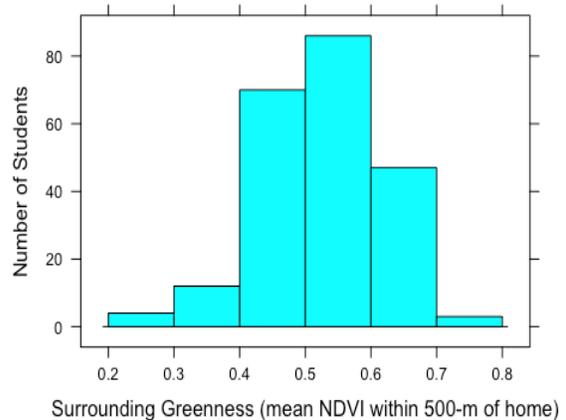


Figure 1.5. Surrounding Greenness (mean NDVI) within walking distance (500-meters) of student addresses. NDVI values closer to 1 indicate a higher density and health of vegetation.

¹³ Variables derived from address information.

How green are students' neighborhoods overall (n = 222)?¹⁴ In contrast to the findings for open space, very few students (7.2%) live in areas with low Surrounding Greenness (or Normalized Difference Vegetation Index (NDVI) values less than 0.4, which would indicate sparse or unhealthy vegetation). Indeed, 22.5% of students live in areas with NDVI values over 0.6 while the majority of students (70.3%) live in areas with moderate NDVI values between 0.4 and 0.6 (Figure 1.5).

b. Experiences in Nature

What types of activities do students do in nature (n = 358)?¹⁵ One dominant hypothesis in environmental education suggests that repeated immersive experiences with wild nature (e.g., catching bugs in the forest) are most effective at forming pro-environmental attitudes, behaviors, and interests among children (Kellert 2002). Contact with nature that is more recreational or domestic in character can also be influential, but to a lesser degree. The typical (median) student reported doing all three immersive nature activities (catching small animals, collecting things from nature, and playing or exploring in nature). These activities are often considered the epitome of developmentally appropriate activities for a 10-year-old child (e.g., Louv 2005). Conversely, the typical student did two recreational and two domestic nature activities (Figure 1.6).

“Recreational” activities included hiking, camping, fishing, biking in the woods, and swimming in a natural place. “Domestic” activities included going to a park, zoo, or aquarium, taking care of indoor or outdoor plants, and picking or planting fruits, vegetables, flowers, seeds, or trees.

¹⁴ Variables derived from address information.

¹⁵ Survey Questions 2 and 3 (Appendix C).

Types of Nature-based Activities

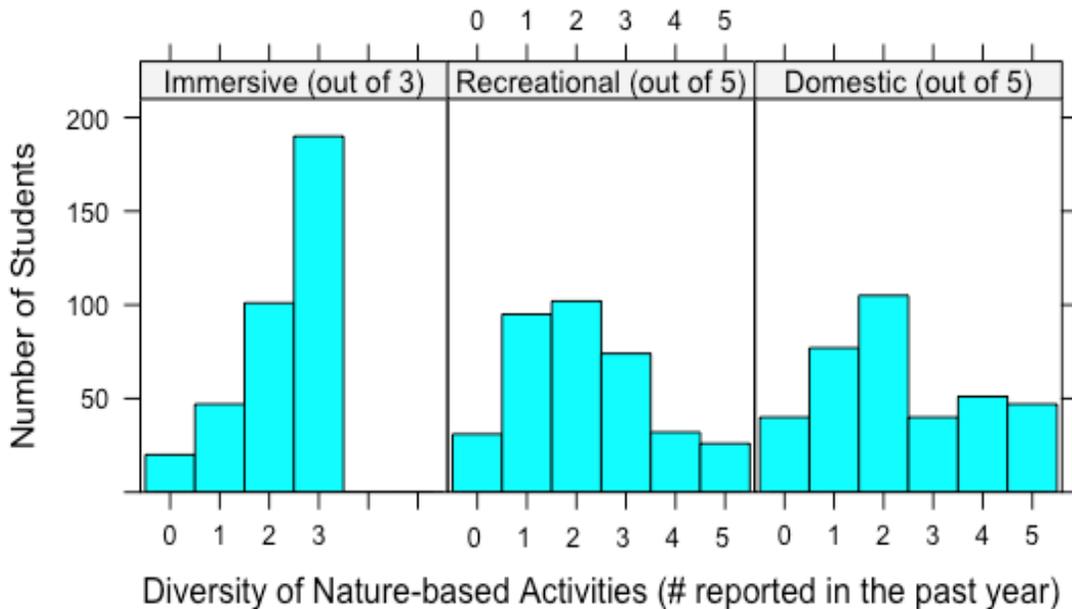


Figure 1.6. Number of students who participate in three types of nature activities as well as the diversity of activities within each type. Students were asked how many immersive, recreational, and domestic activities they have done in the past year and were given 3, 5, and 5 options for each, respectively.

How are different types of activities related to each other?¹⁶ All three types of nature activities were highly related to each other (recreational-domestic $X^2 = 108.62$, $df = 25$, $p < 0.001$; recreational-immersive $X^2 = 54.61$, $df = 15$, $p < 0.001$; domestic-immersive $X^2 = 56.102$, $df = 15$, $p < 0.001$).

c. Barriers

What barriers prevent students from participating in nature-based activities ($n = 352$)?¹⁷

Overwhelmingly, students reported that there were very few barriers preventing them from participating in nature-based activities. The most common barrier was pests such

¹⁶ Survey Questions 2 and 3 (Appendix C).

¹⁷ Survey Question 4 (Appendix C).

as mosquitos (47.9% reporting) followed by difficulties getting to the places students want to do activities (31.1%).

The least common barrier was places being unfriendly (12.9%) followed by lack of interest in doing activities (14.5%). General barriers, such as (time, companions, and knowledge) were significantly associated with place-based barriers (access, friendliness, safety, pests) ($X^2 = 44.889$, $df = 12$, $p < 0.001$) but the “lack of interest” barrier was independent of the remaining seven ($X^2 = 10.451$, $df = 7$, $p = 0.1644$).

d. Emotions

How did students like ECOS (n = 318)?¹⁸ The vast majority of students that participated in ECOS enjoyed the program (89.6%), selecting between the two positive emoji’s (Figure 1.7). Only 33 students out of 318 selected a neutral or negative emoji.

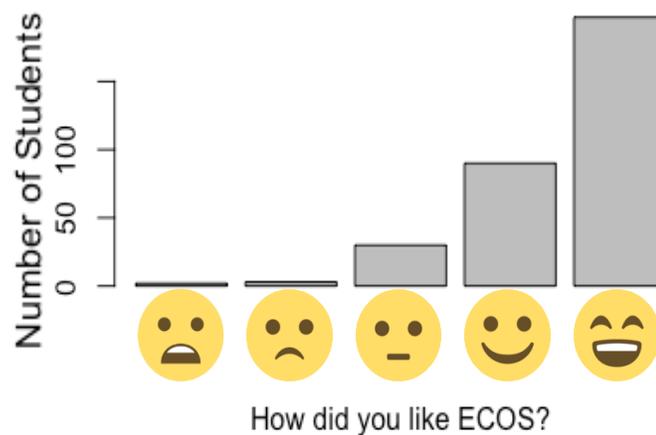


Figure 1.7. Students’ feelings towards the ECOS program.

¹⁸ Survey Question 6 (Appendix C).

How do students feel about doing activities in nature (n = 300)?¹⁹ Students overwhelmingly remembered positive feelings (happy or silly) when doing their chosen activity in nature (Figure 1.8). No more than 30 students selected any one of the five non-positive faces (surprised, neutral, bored, angry, disgusted). When divided by activity, emotions were associated with activities to a significant degree ($X^2 = 10.396$, $df = 4$, $p = 0.03426$). Fewer students than expected by chance felt negatively about doing small activities in the forest and field and more students than expected by chance felt a mix of positive and non-positive emotions. For small animal activities at the pond, fewer students than expected by chance felt a mix of emotions.

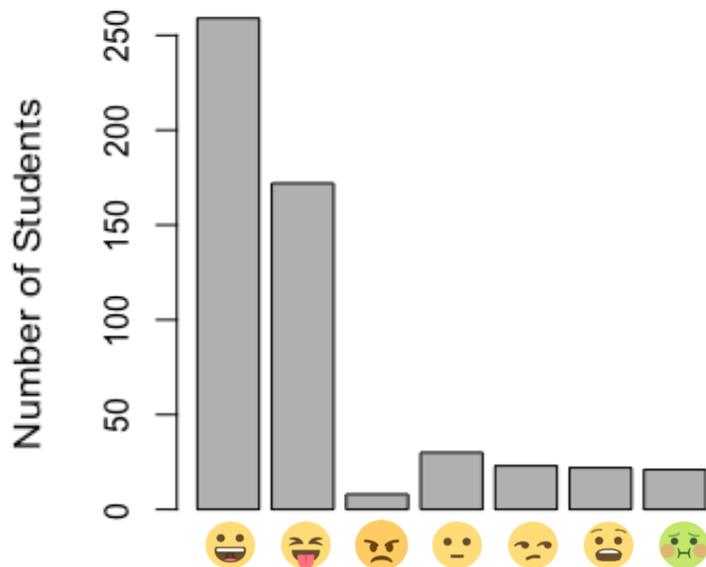


Figure 1.8. Emotions surrounding chosen activities.

e. Legacy

How often do classroom teachers talk about ECOS activities (n = 299)?²⁰ Most students (58.9%) reported that their teachers “never” or “almost never” talk about their chosen

¹⁹ Survey Question 9 (Appendix C). From left to right, emoji faces indicate the following: happy, silly, surprised, neutral, bored, angry, and disgusted.

²⁰ Survey Question 14 (Appendix C).

activity. Responses did not differ significantly between activities (Kruskal-Wallis $X^2 = 2.9139$, $df = 2$, $p = 0.2329$)

Who do students repeat ECOS activities with and who do students know that have done ECOS before (n = 303 for both)?²¹ Students reported doing their chosen activity primarily with friends, followed by siblings and cousins or relatives. Similarly, students primarily reported that friends, siblings, cousins and relatives had done their chosen activity at ECOS before.²² There were no significant associations between either chosen activities and who students do activities with or chosen activities and who students know that have done those activities at ECOS. However, of the students that did repeat ECOS activities (n = 134), 40.9% reported doing those activities with parents or grandparents while 80% reported doing them with friends and siblings. However, students were significantly more likely to repeat ECOS activities *with parents* if those parents had done the activity at ECOS before ($X^2 = 14.509$, $df = 1$, $p < 0.001$).

What do people say about ECOS activities (n = 360)?²³ Students shared a wide range of responses. Prominent themes included emotional characterizations, activity outcomes, learning outcomes, or simply details about what the activity was like (Table 1.4; Figure 1.9).

Theme	Included...	Freq.	Examples
Emotion: fun	The word "fun" or similar ideas	29.9%	"It is fun for them to catch the toads in the forest"
Emotion: great	great, good, love, like, happy	16.8%	"It was my favorite part when we went to the lake"
Emotion: wow!	cool, awesome, wow, exciting	12.9%	"Yay we're catching bugs"

²¹ Survey Questions 16 and 17 (Appendix C).

²² Specifically, 65.9% of students say their friend or sibling did their chosen activity. 16% of students say their parent or grandparent did their chosen activity at ECOS.

²³ Survey Question 18 (Appendix C).

2. Objective 2: Understand what students do after they finish ECOS and why

a. The Chosen Activity

What activities do students remember doing at ECOS (n = 303)?²⁴ Students were asked to answer survey questions about a “Chosen Activity” that they remembered from the Grade 4 program. Responses were sorted by domain by activity and habitat type, specifically: 1) small animal activities in the pond [hereafter “SAP”], 2) small animal activities in the field or forest [“SAF”], and 3) other activities in the forest [“OAF”] such as hiking, exploring, and silent sit (for information about chosen activity responses, see Appendix B: Chosen Activity on page 113). SAP was by far the most popular chosen activity. OAF followed in second as only slightly more commonly chosen than SAF (Figure 1.10).

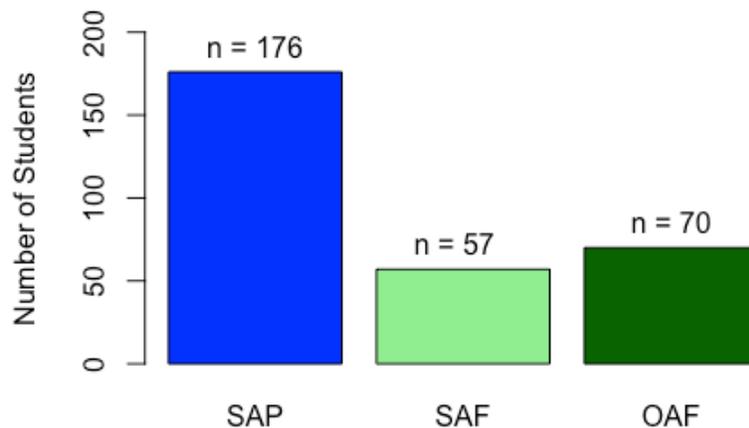


Figure 1.10. Chosen Activity selections.

b. Activity Outcomes

To what degree have students **repeated** their chosen activity (n = 297)?²⁵ When students were asked how often they have done their chosen activity in the past year, the

²⁴ Survey Questions 7, 8, and 11 (Appendix C).

²⁵ Survey Question 15 (Appendix C).

most common response was “never” (39.9%). Even so, 46.7% of students said they “sometimes,” “often,” or “very often” repeat their Chosen Activity. Responses differed significantly between chosen activities, however (Kruskal-Wallis $X^2 = 27.062$; $df = 2$; $p < 0.001$). Students who chose SAP reported doing the activity again with significantly less frequency than students who chose SAF or OAF (Dunn post-hoc test with a Benjamini-Hochberg p -value adjustment). Interestingly, between the activities involving small animals, only two respondents (out of 226) said that they have “often” done the activity again. In contrast, 11 out of 67 students said they have “often” done OAF again.

To what degree have students **discussed** their chosen activity ($n = 300$)?²⁶ Most students indicated that they only “sometimes” talk about their chosen activity with friends or family (41.0% across all three activities) and 32.5% of students “often” or “very often” talk about it. Student’s responses were not significantly different between activity domains (Kruskal-Wallis $X^2 = 0.45326$; $df = 2$; $p = 0.7972$) (for differences between discussions with friends versus family, see Appendix B: Discussion with Friends versus Family on page 114).

To what degree do students **feel confident** about doing their chosen activity ($n = 300$)?²⁷ Students overwhelmingly felt pretty sure or certain that they could do their chosen activity on their own (71.3% across all three activities). Compared to the other two activity outcomes, confidence had the highest number of positive responses (Figure 1.11) and student’s responses were not significantly different between activities (Kruskal-Wallis $X^2 = 1.4222$; $df = 2$; $p = 0.4911$).

²⁶ Survey Questions 12 and 13 (Appendix C).

²⁷ Survey Question 10 (Appendix C).

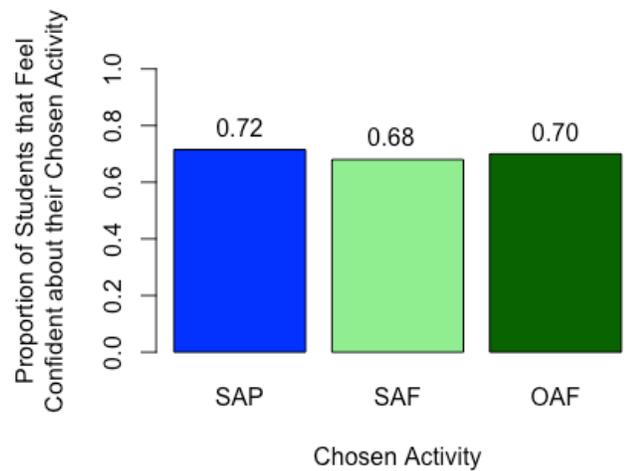
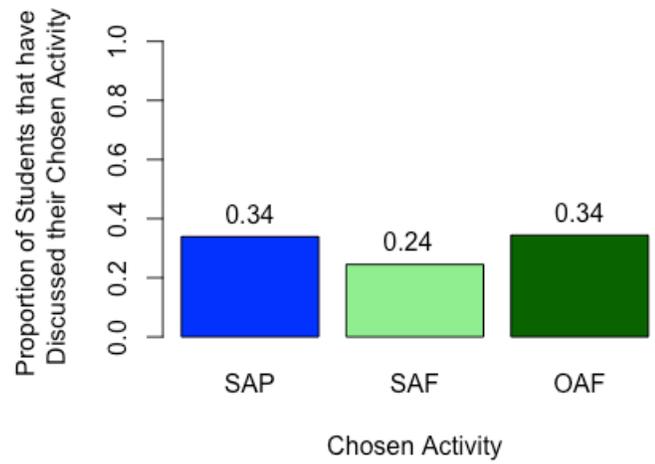
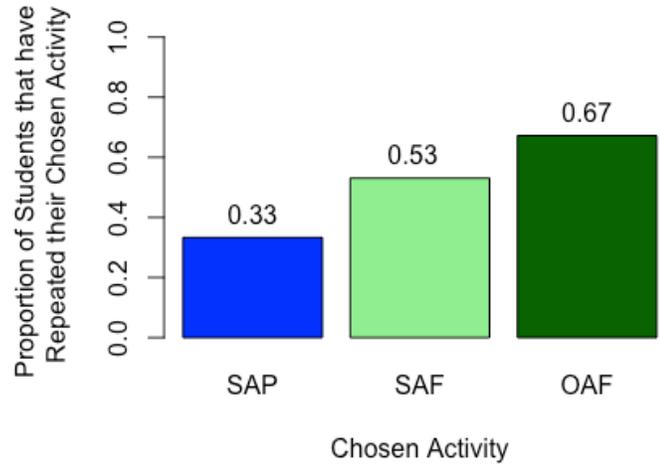


Figure 1.11. Proportion of students that reported repeating (top left), discussing (top right), and feeling confident (bottom left) about their chosen activity.

SAP: small animal activities in the pond
 SAF: small animal activities in the field or forest
 OAF: other activities in the forest

How are Activity Outcomes related to each other (n = 297)? Students that repeated their chosen activity were more likely to discuss the activity and feel confident about it (Table 1.5), suggesting that students tend to benefit from ECOS in multiple ways. This pattern also tells us that there is a cluster of students not repeating, discussing, or feeling confident about the activity.

Activity Outcome Comparison	X ² statistic (binary)	Significance (binary)	Spearman-Rank Correlation (5-point outcome)
Repetition and Discussion	X ² = 15.065	p < 0.001	R ² = 0.23
Repetition and Confidence	X ² = 13.005	p < 0.001	R ² = 0.22
Confidence and Discussion	X ² = 8.235	p < 0.01	R ² = 0.17

Table 1.5. Pairwise comparisons between the three activity outcomes using a Chi Square test for the binary form (yes/no) and a Spearman-Rank correlation for the original 5-point form. These comparisons show that regardless of how outcomes are analyzed, each one is related to the other two. For example, a student that discusses their chosen activity is more likely to repeat the activity and feel confident about it.

c. Explaining Patterns in Activity Outcomes

How do students who demonstrate all three activity outcomes differ from students who demonstrate none of the outcomes (n = 87)? Students that repeated, discussed, **and** felt confident about their chosen activity (the “yes” group; n = 39) reported doing a significantly greater diversity of recreational, domestic, and immersive nature activities (specifically 1 additional activity each) compared with students that demonstrated none of the three activity outcomes (the “no” group; n = 48). In addition, “yes” group students reported significantly fewer general barriers (1 less barrier) and liked ECOS significantly more than the “no” group. For all other variables examined, the two groups were not statistically different (Table 1.6).

Variable	“No” Group Responses	“Yes” Group Responses	Significance
<i>ordinal</i>	<i>median values reported</i>		<i>permutation test</i>
Wild Habitat	1 of 4 forest or pond animals seen near home	1 of 4 forest or pond animals seen near home	0
City Habitat	3 of 4 urban or field animals seen near home	4 of 4 urban or field animals seen near home	0
Recreational Experience	2 of 5 activities selected	3 of 5 activities selected	**
Domestic Experience	2 of 5 activities selected	3 of 5 activities selected	**
Immersive Experience	2 of 3 activities selected	3 of 3 activities selected	***
General Barriers	1 of 3 general barriers selected	0 of 3 general barriers selected	*
Place Barriers	1 of 4 place-based barriers selected	1 of 4 place-based barriers selected	0
Liked ECOS			**
Teacher Talk	“almost never”	“sometimes”	0
<i>binary</i>	<i>group proportions reported</i>		<i>chi square test</i>
Disinterest	27.1% said they don’t want to do outside activities	10.2% said they don’t want to do outside activities	0
Did Parents	10.4% said their parents did their chosen activity at ECOS	25.6% said their parents did their chosen activity at ECOS	0
Did Peers	68.8% said their peers did their chosen activity at ECOS	66.7% said their peers did their chosen activity at ECOS	0
<i>continuous</i>	<i>mean values reported</i>		<i>t-test</i>
Nearby Open Space	7.3% (n = 21)	10.7% (n = 25)	0
Surrounding Greenness	0.520 (n = 21)	0.532 (n = 25)	0

Table 1.6. Differences in responses between two groups of students. The “yes” group demonstrated all three activity outcomes (repeated, discussed, and felt confident about their chosen activity) and the “no” group demonstrated none of the outcomes (did not repeat, discuss, or feel confident). For each variable, the typical student response depends on the way the variable was measured. Medians are reported for ordinal variables, proportions are reported for binary variables, and means are reported for continuous variables (Nearby Open Space and Surrounding Greenness). Permutations tests were used to compare group differences for ordinal variables, Chi Square tests were used for binary variables, and t-tests were used for continuous variables. For group comparisons with Nearby Open Space and Surrounding Greenness, the sample only included students with associated address information (n = 46).

⁰ $p > 0.05$; * $p < 0.05$; ** $p < 0.01$.

How do students' social and environmental contexts relate to their SAP activity outcomes (n = 250)? Students were more likely to repeat SAP if they had previous experiences doing outdoor activities and if they felt positively about ECOS (Table 1.7). For example, a student that reported doing 4 recreational activities would be 1.6 times more likely to repeat SAP compared with a student only doing 3 recreational activities ("Odds Ratio" of 1.6). Students that liked ECOS the most were 9.5 times more likely to repeat SAP compared to students that felt neutral about the program (Table 1.8).

Students were more likely to discuss SAP if they had previous experiences doing outdoor activities and if they were surrounded by an ECOS community legacy (Table 1.7). For example, a student that reported doing 3 different immersive activities would be 2.1 times more likely to talk about SAP with their friends or family compared with a student only doing 2 activities. Students whose parents did SAP at ECOS were 3.2 times more likely to talk about their chosen activity compared to students whose parents did not. Similarly, students whose classroom teacher "often" talks about the ECOS activity were 1.5 times more likely to talk about it on their own compared with a student whose teacher only talks about the activity "sometimes" (Table 1.8).

The two best models to explain why some students reported confidence surrounding their chosen activity were the null model and the model including emotion-related variables (Table 1.7). However, none of variables from the survey were significantly linked to the outcome (Table 1.8). In sum, variables derived from survey questions did not help explain the different degrees of confidence students felt doing SAP.

Activity Outcome	Top Model		Model 2		
	Hypothesis	Weight	Hypothesis	$\Delta AICc$	Weight
Repetition	Experience + Emotions	0.94			
Discussion	Experience + Legacy	0.85			
Confidence	Null	0.41	Emotions	0.74	0.28

Table 1.7. Top models selected using $AICc < 2$. See Table 1.3 for model formulas.

Variable	Repetition		Discussion		Confidence	
	OR (CI)	Imp.	OR (CI)	Imp.	OR (CI)	Imp.
Wild Habitat	1.00 (0.92, 1.77)	0.02	0.99 (0.57, 1.17)	0.05	1.01 (0.77, 1.4)	0.19
City Habitat	1.00 (0.71, 2.21)	0.02	1.00 (0.58, 1.74)	0.05	0.98 (0.55, 1.44)	0.19
Place Barriers	1.00 (0.7, 1.52)	0.02	1.01 (0.78, 1.8)	0.05	0.95 (0.53, 1.07)	0.19
Recreational Experience	<u>1.61 (1.16, 2.23)</u>	1	1.22 (0.9, 1.7)	0.93	1.00 (0.7, 1.3)	0.07
Domestic Experience	1.28 (0.97, 1.7)	1	0.93 (0.71, 1.22)	0.93	1.00 (0.77, 1.32)	0.07
Immersive Experience	<i>not included in this model</i>		<u>2.06 (1.25, 3.73)</u>	0.93	1.02 (0.83, 1.97)	0.07
Disinterest	1.57 (0.43, 5.96)	0.96	1.05 (0.38, 6.47)	0.11	0.75 (0.15, 1.29)	0.35
General Barriers	1.09 (0.72, 1.67)	0.96	0.97 (0.45, 1.17)	0.11	0.94 (0.56, 1.23)	0.35
Liked ECOS	<u>3.08 (1.59, 6.6)</u>	0.96	1.07 (0.93, 3.66)	0.11	1.08 (0.74, 2.07)	0.35
Teacher Talk	1.00 (0.84, 1.64)	0.01	<u>1.45 (1.09, 2.02)</u>	0.94	0.99 (0.63, 1.13)	0.07
Did Parents	1.00 (0.42, 3.02)	0.01	<u>3.14 (1.3, 8.68)</u>	0.94	1.00 (0.41, 2.64)	0.07
Did Peers	1.00 (0.31, 1.87)	0.01	0.8 (0.35, 1.81)	0.94	0.98 (0.37, 1.78)	0.07

Table 1.8. Odds ratios (OR) for all predictor variables for each activity outcome, obtained through model averaging with shrinkage estimates. Each OR is accompanied by a confidence interval (CI), which encompasses OR estimates for 95% of the modeled population. In theory, 2.5% of the population would fall below the lower number and 2.5% would fall above the higher number. Variable importance (Imp.) is also represented for each predictor variable, also obtained through model averaging. Variables included in the top models for each activity outcome (with $\Delta AICc < 2$; Table 1.7) are represented by shaded cells. Underlined OR's are statistically significant at the $p < 0.05$ level.

D. Discussion

1. Summary and Interpretation

The underlying logic of this program evaluation is that inputs from SPS and the ECOS teachers motivate or produce program outputs. Students may demonstrate program outcomes after experiencing these outputs, shaped by their specific social and environmental contexts (Figure 1.1 on page 4). In the summary to follow, three hypothetical students and their stories are displayed to illustrate how outputs and contexts influence outcomes (Figures 1.12 - 1.14).

a. Objective 1: Describe the environmental and social contexts of ECOS students.

Exposure: Most students in Springfield live in a typical urban setting with the bulk of available nature consisting of lawns and grassy fields. Although students may be surrounded by greenness, they have limited access to formal open space, forests, or wetland areas close to home (Figure 1.12).

Experience: Generally, students were most likely to experience nature through immersive activities. However, students that did more immersive activities also did more domestic and recreational activities, suggesting that if students are doing outside activities at all, they are engaging in a wide range of activities. Meanwhile, it was common for students to report only doing two or fewer recreational or domestic nature activities, suggesting that many students do a limited range of activities in nature (Figure 1.12).

Natalia lives in an apartment complex, far from any natural areas. When she has the chance, Natalia loves exploring in nature, catching tadpoles and collecting rocks. She also goes hiking and fishing with her cousins and helps take care of plants at home. Natalia often begs her parents to go to her favorite park or the zoo.

Nigel lives in the same complex as Natalia. He sometimes will ride his bike in the woods and go to the park, but not too frequently.

Roman lives in a greener part of the city with a forest patch behind his home. He loves collecting from nature and swimming in the river when his family goes camping.

Figure 1.12. Student stories, Part 1.

Barriers and Emotions: The majority of students do not see barriers preventing them from participating in immersive nature activities. But 1 out of 3 students feel that there are multiple things holding them back, especially pests and challenges getting to prime locations for outdoor activities. For a minority of students, disinterest is the only barrier in their way, reinforcing the finding that the vast majority of students enjoyed the ECOS program, especially the activities involving small animals (Figure 1.13).

Legacy: Students most commonly repeat ECOS activities with their friends, siblings, and cousins and hear about ECOS from this same group. Conversely, students reported that parents were less likely to do their chosen activities with them and said that teachers rarely discuss ECOS activities in class. Regardless, the most common thing people say about the program is that it is fun (Figure 1.13)! This finding agrees with the overwhelmingly positive perception of ECOS among Springfield residents (personal observations).

If you ask them, Roman and Nigel would agree that there is not much holding them back from doing outdoor activities except maybe there are too many mosquitoes. That, and Nigel isn't the biggest fan of doing things outside.

Roman does outdoor activities with his parents and younger brother. His mother likes to tell the story about how she had fun catching frogs at ECOS. Roman's classroom teacher sometimes references ECOS when talking about animal lifecycles.

Natalia does outdoor activities with her cousins and her siblings but says she is sometimes too busy and it is hard to get to good places to do activities.

Did they like ECOS? Of course!

Figure 1.13. Student stories, Part 2.

b. Objective 2: Understand what students do after ECOS and why.

Activity Outcomes: Overall, ECOS is most consistent at boosting student confidence across all major activities that occur during the Grade 4 program. Most students say they “sometimes” talk about the activities they did at ECOS and the average student “sometimes” repeats SAF and OAF and “never” repeats SAP, likely due to fewer opportunities (and resources like nets). Activity outcomes were related to each other such that students tended to either demonstrate all three or none at all (Figure 1.14).

Patterns in Activity Outcomes: Students that demonstrated all three outcomes of repetition, discussion, and confidence had more experience doing activities in nature, fewer barriers, and warmer feelings towards ECOS compared with students who demonstrated none of the outcomes. Participating in a range of activities also explained why some students were more likely to repeat SAP and discuss the activity with friends and family. In addition, students surrounded by an ECOS community legacy were more likely to discuss SAP. None of the survey variables helped explain patterns in reported levels of confidence. Interestingly, differences in availability of and access to natural areas did not explain why students responded to ECOS in different ways (Figure 1.14).

Natalia's chosen activity was SAF. She sometimes talks about this activity with her older brother that did ECOS and repeats it when she has the chance.

Nigel chose SAP and sometimes talks about it with friends or family but he doesn't go out of his way to catch slimy frogs. His friends did ECOS but his younger sister did not, nor did his parents.

Roman also chose SAP. He likes to do this activity and to talk about it with his mother because she did ECOS when she was his age.

All three students would say they feel confident about doing their chosen activity.

Figure 1.14. Student stories, Part 3.

Immersive nature experiences like catching small animals and collecting things from nature are often considered the epitome of developmentally appropriate environmental activities for a 10-year-old child (e.g., Louv 2005). Past studies have found that, while catching small animals may be a meaningful activity (Chipeniuk 1995), it is uncommon among children, especially when those animals include amphibians, reptiles, fish, worms, and snails (Lekies and Beery 2013). This could in part be that children in cities have limited access to good places to engage in those activities, or even if those places exist, students are disinterested (Simmons 1994). Indeed, a minority of ECOS students reported seeing pond and forest animals outside where they live. Sousa et al. (2016) found that high school students' attitudes towards ponds as habitats and amphibians improved after spending a year learning about ponds and participating in hands-on pond activities. This and the present findings suggest that interacting with small animals and wetland habitats may be especially salient and memorable in programmatic settings like ECOS, even if students do not repeat those activities frequently. Without exposure in school, the students may grow up without engaging in these specific activities or developing conservation-oriented attitudes. ECOS successfully provides these opportunities and meanwhile instills a sense of happiness and confidence surrounding nature-based activities.

Retrospective studies with adults have demonstrated that time spent in nature during childhood helps explain adult environmental attitudes and behaviors, like valuing natural areas and participating in stewardship activities (Tanner 1980; Wells and Lekies 2006). However, it is still possible for children to develop environmental attitudes without spending such time in natural areas. In fact, some researchers have suggested that children may receive social cues from family members to appreciate wild areas even if they have little direct experience (Bixler et al. 2002). More broadly, children develop behaviors, expectations, and values by watching, learning, and interacting with key members of their social lives (Chawla 2009). Survey findings, as illustrated by the stories of Natalia, Nigel, and Roman, highlight that the key socializers for ECOS students tend to be peers rather than parents or teachers. This suggests an untapped opportunity for adult role models to engage with students around activities in nature, as demonstrated by Roman's story. Indeed, two of the variables that best explained why students discussed their chosen activity after ECOS were 1) if parents had done the chosen activity at ECOS, and 2) how often classroom teachers talk about the chosen activity.

For many SPS students, ECOS is their only experience with environmental education and associated activities like catching frogs and tadpoles in the pond (Janes 2016). Conversations that occur as a result of ECOS may therefore play a valuable role in stimulating children's care for the environment and confidence around and interest in environmental activities and behaviors (Kellert 2002; Soga et al. 2016).

2. Program Recommendations

The survey results, as illustrated by Natalia, Nigel, and Roman, point to a mild polarization in SPS students' experiences with nature. Natalia and Roman do a wide range of outdoor activities while Nigel does few. Roman and Nigel don't feel like they

have many barriers in their way, unlike Natalia. Natalia and Roman benefit from ECOS by repeating, discussing, and feeling confident about outdoor activities, while Nigel only feels confident.

As part of ESEA's Title III program, ECOS was originally designed as an innovative way to combat poverty and inequality by bringing all SPS students into a common environment where they could learn about nature. While poverty remains in Springfield,²⁸ ECOS continues to serve an important function in bringing every student to Forest Park and including them in a community conversation and legacy around ECOS activities. Further, ECOS provides a safe and supportive environment for students to develop skills and confidence around activities like finding and handling small animals and navigating difficult trails and natural spaces.

Most importantly, ECOS provides a multi-year experience for students to continuously experience nature. The following program recommendations are informed by survey results and aimed at 1) addressing ECOS' mission of helping students "develop an attitude of respect and stewardship for the natural world," 2) creating lifelong learners and responsible citizens that are curious, competent, and caring, and 3) effectively delivering and reinforcing environmental science curriculum as students move through SPS. In essence, these recommendations recognize that repetition and discussion of ECOS activities work toward that goal and that there are opportunities to amplify these outcomes through the district, parents, and other environmental organizations.

²⁸ The median household income in Springfield was estimated to be \$34,728 in 2015. For children under 18 years, 43.8% live in households below the poverty level and 64.4% live in households that are eligible for public assistance (US Census Bureau).

District: *Improve continuity and reach of ECOS beyond Forest Park.*

The 1971 ECOS Curriculum Guide relayed the following note to classroom teachers:

“Some follow-up activities will be suggested by the staff. If you would like help in carrying out these activities, Mrs. Ide or Miss Donelan will be able to assist you. The staff is hopeful that you will think of other ways to use this experience in your classroom in many subject areas, and that you will share these ideas with them at a future date.”

In the present survey, the majority of students reported that classroom teachers “never” or “almost never” talk about their chosen activity. Instead, classroom teachers could leverage the community legacy of ECOS to promote conversation and motivate repetition while at the same time reinforcing environmental science concepts. A number of classroom teachers already reference ECOS and the activities students do there as creative writing prompts or refreshers about science topics (personal communication). Further, some upper-level schools, like Duggan Academy, the Renaissance School, and Putnam Vocational-Technical Academy, include environmental science education in the form of visits to natural areas, stewardship, or horticulture. Making explicit references to ECOS during these experiences could amplify the legacy of the program and demonstrate to students the many ways one can learn about and experience nature.

ECOS teachers can also widen the framing they use during activities such as “This is something you can do again!” (repetition), “Ask your parents about when they did ECOS” (discussion), or “You succeeded at this activity - be proud of yourself” (confidence).

The long-term continuity of ECOS is also important given its almost 50-year history in Springfield and place in the city’s public memory. Indeed, part of the success of ECOS is that so many siblings, cousins, teachers, and parents have experienced the program first-hand and can talk about it with current students. Circumstances that prevent full

student participation in ECOS will weaken program outcomes for the students that *do* participate by weakening the community legacy.

Parents: Ask about ECOS and repeat the activities again with your children

Of the students that repeat ECOS activities, 40.9% do those activities with parents and 80% do them with peers. This finding echoes national survey results that students primarily do outdoor activities with friends, siblings, and parents (Kellert et al. 2017).

While some parents may actively discourage their children from getting dirty or touching animals (personal communication; also Louv 2005), it is remarkable that almost half of students that repeat ECOS activities do so with parents! Further, parents that did ECOS themselves were significantly more likely to do nature-based activities with their children.

Past research has highlighted the important role parents play in linking children with opportunities in nature and modeling appropriate behavior outdoors (Bixler et al. 2002; Chawla 2007). ECOS should leverage pre-existing parent interest and memories of the program to encourage parents to do follow-up activities in nature with their children. One potential intervention could be a “take-home resource”²⁹ for parents about how and where to do nature-based activities with their children, specifically those most similar to the ECOS programming (see Appendix D: Take-Home Resource, pg. 39). In fact, ECOS students report doing immersive nature-based activities more frequently than surveys with similar populations would suggest (Ernst and Theimer 2011), though often these activities occur beyond the borders of Springfield (personal communication). Regardless,

²⁹ ECOS already uses a newsletter and a Facebook page (<https://www.facebook.com/springfieldforestpark/>) to share information and photos about the program with parents and community members. The “take-home resource” serves as a complementary source of information tailored for parents immediately after their child has participated in ECOS. See Appendix D: Take-Home Resource

a take-home resource could facilitate conversation between parents and children about what they learned at ECOS and provide ideas for how to follow-up in the most ECOS-relevant fashion.

Finally, parents may need more opportunities to witness ECOS first-hand, as volunteers or chaperones. For parents that have done ECOS, experiencing the program again with their children could provide rich opportunities for reminiscing, intergenerational conversation, and relationship-building. For parents that have not done ECOS, experiencing the program might inspire them to repeat those activities with their children.

Other environmental organizations: *Remind participants about ECOS*

Throughout the greater Springfield area, there are a number of organizations that seek to connect students with nature. In September 2015, the Springfield Urban Wildlife Refuge Partnership³⁰ was established to bring together federal agencies, universities, community groups and schools to expand environmental restoration and education in Springfield. ReGreen Springfield³¹ works with community groups and businesses to plant trees. Gardening the Community³² engages youth in urban farming efforts and Springfield Museums³³ provides science field trips to local schools about reptiles and animal adaptations. Boy Scouts and Girl Scouts³⁴ troops include environmental themes and nature-based activities as do numerous summer camps, such as Camp Massasoit, On the Wilder Side, and Zoo Camp.³⁵

³⁰ <https://www.fws.gov/urban/partnerships.php>

³¹ <http://regreenspringfield.com/>

³² <http://www.gardeningthecommunity.org/>

³³ <https://springfieldmuseums.org/groups/school/field-trips/science/>

³⁴ <https://www.wmascouting.org/general-knox> and <http://www.gscwm.org/>

³⁵ <https://springfield.edu/east-campus/camp-massasoit>, <http://www.nextleveladventures.net/summer-camps>, and <https://www.forestparkzoo.org/programs/zoo-camp>

For most SPS students, ECOS is their first (and only) experience with environmental education. The organizations previously discussed should remind their participants about ECOS as a means of both boosting the ECOS community legacy and increasing buy-in and engagement in their own programmatic activities.

3. Limitations and Future Directions

There are a number of features of the entailed research that limit its interpretation and application.

- *Nonresponse Bias*: Not all survey responses were analyzed in the research due to missing assent or consent. It is possible that students missing consent and/or assent were different from students for whom assent and consent were obtained, especially if the former group of students and their parents held negative feelings towards ECOS or the environment.
- *Recall and Comprehension*: Students completed the survey in the spring, at least a full year from when they participated in the Grade 4 ECOS program. While the majority of questions on the survey focused on student's general contexts and what they have done *since* the program, it is possible that memories and interpretations of the program have shifted over time. Similarly, some of the questions asked about the frequency to which students engaged in different activities in the past year. Students tended to answer this question easily, but we cannot say for certain that they were evaluating their entire past year, including the summer. Some of the survey questions, like how frequently teachers talk about chosen activities or who students do chosen activities with received some may have been difficult to comprehend, despite early positive outcomes during pre-testing. These two questions were

flagged by ECOS teachers and logic checks, respectively, as potential sources of inconsistency. Regardless, all questions were framed to be as concrete as possible and require minimal reflection.

- *Testing environment:* Students completed the survey in the ECOS building, directed by ECOS teachers. It is therefore possible that students felt pressure or were primed to report more positively about ECOS than they authentically felt. Further, although students were instructed to complete their surveys independently, some students may have looked to their neighbors or teachers for help interpreting questions and selecting responses.
- *Causality:* Given that the survey only took place *after* ECOS and there was no comparison to a “control” group that did not participate in ECOS, it is impossible to assume that participating in ECOS necessarily was the cause of any outcomes reported.
- *Demographics:* The survey did not collect information about students’ ethnicity, race, or gender. Yet, past studies have emphasized the importance of these attributes in explaining differences in attitudes towards the environment and experiences during environmental education (Zelezny et al. 2000). Similarly, students of different ethnic origins may talk about past experiences with friends or family in culturally specific ways or to different extents, which could affect the “activity discussion” outcome (Pillemer 2009).

While the present study documented the success of ECOS in promoting confidence and opportunities for students to further discuss and repeat nature-based activities, there is much still to learn about the long-term benefits of the program. Surveys or interviews with high school or college-aged students could link program participation with interest in

environmental science as an academic major. Retrospective interviews with ECOS alumni that are environmental professionals, hobbyists, or conservations would help the program understand its influence in directing longer term career decisions.

ECOS teachers could also benefit from understanding how classroom teachers throughout ECOS make use of the program as a reference point when teaching environmental science. Resulting collaboration or coordination around curriculum would increase the relevance of ECOS activities to every-day learning.

Finally, ECOS is a unique urban environmental education program because it is multi-year, district-wide, and close to 50 years in age. As such, future research with ECOS that more deeply investigates its community legacy could help other environmental programs build similar esteem or help educators better understand how social and conversational environments influence program outcomes.

CHAPTER II

WHEN THE STARLINGS ALIGN: HOW SOCIOECONOMIC INEQUALITY SHAPES BIODIVERSITY, FROM BUJUMBURA TO BEIJING

A. Introduction

Take a walk across any city in the world and you will notice that the biological community changes as you go. Indeed, cities are spatially heterogeneous entities given a diversity of intersecting human and biophysical drivers operating at different scales (Cadenasso et al. 2007). A given species such as the Hooded Oriole (*Icterus cucullatus*), a bird native to the American Southwest, must “pass” through a series of filters based on its life history and functional traits in order to contribute to local community assembly (Aronson et al. 2016). Climatic and biogeographical factors, introductions and extirpations, urban form and development history, socioeconomic and cultural factors, and species interactions all determine the whether the Hooded Oriole shows up in a given backyard or city park (Aronson et al. 2016). Just as cities are heterogeneous, so too is biodiversity within the city, as species pass through filters with variable success.

Many drivers of biodiversity in the city are anthropogenic, from building density and surface imperviousness (Chace and Walsh 2006; La Sorte et al. 2018; Luck et al. 2013) to park and green space siting, size, connectivity, and management (Beninde et al. 2015; Do et al. 2014; Nielsen et al. 2014). At the household scale, human preferences and needs vary across the city; residents may favor certain cultivated plant species over others or eliminate native weeds and animal pests, further driving biodiversity (e.g., Baker and Harris 2007, Wang et al. 2017). Cumulatively, these anthropogenic factors can alter the relative importance of ecological processes, such as resource availability,

competition, and predation, acting on local biological communities (Chace and Walsh 2006; Faeth et al. 2005).

Some of the anthropogenic drivers shaping biodiversity in the city are socioeconomic, from the expensive food resources that attract Hooded Orioles to differences in public tree plantings within economically segregated cities. In general, social theory and field studies suggest that human wealth elevates environmental quality (Logan and Molotch 1987; Pickett and Pearl 2001) though the exact mechanisms through which this process unfolds remain debated. Hope et al. (2003) applied the term, “luxury effect,” to describe how economic wherewithal (e.g., income, education, access to resources) allows individuals to live in landscapes with higher biodiversity, due to either greater opportunities in choosing where to live or active modification of private gardens. Concentrated socioeconomic power and political capital may also allow residents to better attract municipal investments in greening efforts such as tree plantings (Grove et al. 2006). Kinzig et al. (2005) classified socioeconomic or cultural factors shaping biodiversity into two categories: bottom-up (the integrated outcomes of small-scale actions or decisions by individuals or households) and top-down (neighborhood or city-level strategies, decisions, or policies). These factors can work to improve environmental quality and promote biodiversity, degrade quality and diversity, or induce counteracting effects. Some factors, such as the provision of expensive bird food, may be fundamentally linked to socioeconomic difference (Lepczyk and Warren 2012), while other factors, such as an urban foresters’ use of certain street tree species, may be linked indirectly or not at all (Pickett et al. 2017). Yet again, other factors that shape biodiversity within a city, such as soil quality or traffic noise, may be beyond reach of immediate bottom-up or top-down decisions nor clearly linked with socioeconomic or cultural difference (Aronson et al. 2016).

Cities are sites of stark socioeconomic inequality, often manifesting in adverse social and material outcomes for the poor, such as increased exposure to hazards or diminished access to economic opportunity (Massey 1996; Strife and Downey 2009). As such, the alignment of socioeconomic inequality with differences in urban biodiversity may be problematic for two reasons. First, if residents with lower socioeconomic status live amid lower biodiversity (or “biological poverty”) then they are disproportionately disenfranchised from associated ecosystem services, such as improved ecological function, health and well-being assets, and meaningful nature experiences (Fuller et al. 2007; Hanski et al. 2012; Luck et al. 2011; Rook 2013; Turner et al. 2004, 2012). Second, alignment between socioeconomic inequality and biodiversity may be problematic for the persistence of certain species or the ecological functioning of the city as low socioeconomic conditions create pockets of unsuitable habitat (Bonnington et al. 2015; Lepczyk et al. 2017). Taken together, these two problems do not bode well for the future of nature conservation either within the city or beyond (Dunn et al. 2006; Louv 2005; Miller 2005; Pyle 1993; Soga and Gaston 2016). **The important questions we must answer are, how widespread and salient are such alignments between socioeconomics and biodiversity throughout the world’s cities, how and why such patterns differ city to city, and what, if any, unifying mechanisms may explain the patterns we see.**

While Hope et al. (2003) was the first to coin the “luxury effect” term, dozens of researchers before and after have explored relationships between socioeconomic status (hereafter “SES”) and urban biodiversity. In their review of the “luxury effect,” Leong et al. (2018) note that positive SES-biodiversity relationships in cities are commonly observed by researchers, though null results may be underreported. Indeed, even

researchers investigating such relationships at the regional or multi-city scale tend to find similar patterns as those within individual cities (see Appendix E, also Kuruneri-Chitepo and Shackleton, 2011; MacGregor-Fors and Schondube, 2011; Smallbone, Luck and Wassens, 2011; Luck, Smallbone and Sheffield, 2013; Junker et al. 2015; Hand et al. 2016; Mills, Cunningham and Donovan, 2016). Interestingly, biodiversity is not the only feature that sometimes aligns with SES in cities. In a global meta-analysis, Gerrish and Watkins, (2018) found a heterogeneous but consistent and meaningful positive relationship between income and forest cover. In a parallel analysis, the same authors found a significant relationship between race and urban forest cover (where minority populations are associated with less forest cover) but suggest that income appears to mediate the relationship between race and urban forest cover (Watkins and Gerrish 2018).

This paper examines what we know and don't know about SES-biodiversity relationships in cities throughout the world via meta-analysis. In doing so, we tested whether cases in which researchers have found or not found associations between SES and biodiversity shared similar characteristics, such as the taxonomic group in question, study design, or city-level features. In the following section, we articulated the influence we hypothesized these characteristics to have. Because multiple factors likely combine to shape SES-biodiversity relationships and their detectability, we employed fuzzy-set Qualitative Comparative Analysis ("fsQCA"), a method that allows us to identify "recipes" of conditions associated with SES-biodiversity relationships. We then interpreted shared mechanisms among fsQCA recipes and synthesized unifying patterns to suggest future directions for research and practice.

1. Hypotheses

a. Taxonomic Group

We assessed two aspects of the taxonomic group in question: the taxonomic group itself and the native status of the species considered. We expected taxa with different life histories and functional traits to respond differently to factors associated with SES, depending on the spatial and temporal scale in which such responses are considered. Spatially, higher mobility taxa with larger home ranges (birds, bats, insect pollinators, *etc.*) may be more sensitive to neighborhood-scale differences in SES while lower-mobility taxa with smaller home ranges (small mammals, lizards, *etc.*) or stationary taxa (plants) may be more sensitive to household-scale differences. Temporally, taxa such as trees, birds, and larger mammals take longer to grow and react to anthropogenic influences related to SES compared with taxa such as herbaceous plants or aquatic insects. We therefore expected the plant template to be most closely linked to SES, while taxa dependent on plants would respond in a weaker fashion, indirectly due to plant availability or community composition (Daniels and Kirkpatrick 2006; Faeth et al. 2011).

Within each taxonomic group, we expected different responses of native versus non-native species diversity to SES. For native plant taxa, we expected higher diversity in areas with remnant patches of vegetation, which may be more common in lower SES residential areas via spontaneous or weedy plants. For non-native plants, we expected higher diversity in areas with more intentional cultivation of ornamental plantings, which may be more common in higher SES residential areas (*e.g.*, Lowenstein and Minor 2016). For non-native plants considered invasive species, several socio-ecological factors may influence their distribution, such as plant life histories, urban development

patterns, and maintenance regimes (e.g., Staudhammer et al. 2015). In general, however, we expected invasive species diversity to be higher in lower SES areas where active maintenance may be less common. Compared with non-native animal diversity, native animal diversity may be higher in areas with more native vegetation and lower disturbance, which may be associated with higher SES areas. It is also possible that some non-native animals are ubiquitous enough throughout the city so as to demonstrate no significant association with SES (McKinney 2002).

Complicating these SES-biodiversity predictions are inter-species interactions. Resource inputs may flow upward from plants to insects to birds, with potential unintended consequences (Faeth et al. 2005). For example, lawn fertilization that increases flowering plant diversity may adversely affect pond invertebrate biodiversity (e.g., Gledhill and James 2012). In some cases, very specific plant or prey species may be necessary for other species or species groups to flourish. Competition and predation may also be influenced by human actions (Shochat et al. 2010). Wildlife resources in yards that promote mammal diversity may diminish bird diversity through depredation, for example, or high quality nesting habitat for an agonistic bird species may diminish local bird diversity despite other positive habitat features (e.g., Belaire et al. 2014, Zivanovic and Luck 2016).

b. Study Design

The degree to which researchers consider bottom-up and top-down factors in their study designs likely affects their abilities to detect the presence or strength of SES-biodiversity relationships. Much of these considerations rely on the spatial scales researchers use to collect and relate SES and biodiversity information. We assessed three aspects of study

design: land uses considered, measurement scales for both SES and biodiversity, and sampling stratification scheme.

In general, we expected measurements at the household scale and on residential land to better capture bottom-up decisions related to parcel-scale land management (e.g., bird feeding, fertilizer application, and plant species selection) (Goddard et al. 2013; Harris et al. 2012; Jenerette et al. 2011; Kendal et al. 2012a; Marco et al. 2010). By contrast, we expected measurements at the neighborhood scale and that include non-residential land to better capture top-down effects related to site quality or site management (Walker et al. 2009).

Land use: Residents make bottom-up decisions on residential land within constraints posed by their SES and top-down limitations. Institutions such as municipalities, industries, and schools, make top-down decisions on non-residential land in line with their institutional objectives, which may or may not take surrounding residential SES into account (Kinzig et al. 2005). Non-residential land may also consist of community gardens or agricultural plots; spaces residents can actively modify aside from where they live (Clarke and Jenerette 2015). As such, we expected to see a different character of SES-biodiversity relationship depending on which land uses researchers considered.

Biodiversity sampling unit: Studies vary in the spatial grain of sampling, from fine grained sampling at the parcel level, such as individual yards, to coarser grained studies that sample at multi-parcel levels, such as transects along residential streets. When researchers measure biodiversity within single parcels, they are better able to capture the array of decisions made by individual households. We therefore expected greater detectability of fine grained SES-biodiversity relationships in settings where bottom-up

drivers are dominant and aligned with SES. When researchers measure biodiversity across parcels, they capture the cumulative effect of decisions made by multiple residents and institutions. We therefore expected greater detectability of coarse-grained SES-biodiversity relationships in settings where top-down drivers are dominant and aligned with SES. When researchers measure biodiversity at a different scale than that at which the underlying drivers are operating, we expected researchers not to detect directional SES-biodiversity relationships.

SES measurement scale: When researchers measure SES at the level of household, they are better able to capture the diversity of options and limitations that households have regarding biodiversity on their properties. When researchers measure SES at the level of neighborhood, they capture a sense of neighborhood opportunities, expectations, and limitations related to social dynamics and physical space (Beninde et al. 2015; Grove et al. 2006). Broad SES measurements can also better account for the effects of zoning and segregation on residential gardens. As with biodiversity sampling considerations, we expected neighborhood scale SES units to better detect top-down drivers, household scale SES units to better detect bottom-up drivers, and mismatches between scale and drivers to reduce the likelihood of detection.

Sampling stratification by SES: In general, we expected stratification to aid in the detection of SES-biodiversity relationships. When researchers stratify their sampling by SES, they capture a cleaner and more even gradient with which to observe variation in biodiversity across a city. Under study designs with low-replication, researchers can compare neighborhoods individually and explain differences based on unique histories. Under study designs with high-replication, researchers can point to systematic differences between SES groups across the city.

c. City Conditions

We assessed six city-level features that we expected to shape SES-biodiversity relationships or their detectability: aridity, tropicality, density, age, economic inequality, and national development.

Aridity: Climatic conditions dictate both the amount of resources (time, labor, materials) needed to change local environments as well as the extent to which resource inputs cascade to affect the wider biological community. In arid climates, characterized by a lack of life-promoting moisture, human actors need more material resources to overcome limitations posed by water scarcity (e.g., Avolio et al. 2015). The provisioning of these resources, be it through tree planting or bird feeding, may overpower background biotic processes and influence animal diversity more substantially compared to cities in higher-resource mesic regions (Faeth et al. 2005). We therefore expected both plant and animal diversity to align with SES in arid cities.

Tropicality: Socioeconomic factors may influence biodiversity differently in tropical versus temperate regions (or in different biogeographic realms) either due to the size of the species pool or its character. For example, a native species pool with a high degree of endemism, specialization, or sensitivity to human impacts may respond more acutely to differential human resource inputs on the landscape while a large species pool may be more robust to human influences (Seto et al. 2012). Relatedly, the non-native species pool may operate independently of latitude or biogeography. Given that the majority of studies about urban biodiversity have occurred in temperate regions, there remains uncertainty about how SES-related mechanisms may differ throughout the world

(Aronson et al. 2016). As such, we did not form a directional hypothesis regarding tropicality.

Population Density: We expected that conditions of high human population density would diminish both the manifestation and detectability of relationships between SES and biodiversity. Regarding manifestation, population density can signal various features of urban form and geography. With higher human population density comes a greater alteration of the previous landscape, while lower population densities can allow for greater amounts of public green space, remnant native vegetation, and residential yards. Regarding detectability, high population density may obscure potential SES-biodiversity relationships if decisions made at the household level are less salient in affecting biodiversity since there is less (or no) private space to manipulate. Researchers may only detect those changes in low density settings where residents have private lots and spaces that may be used for gardens, bird feeders, and the like.

City Age: Histories of investment and disinvestment shape biological communities over time through mechanisms related to urban form, development history, and time lags. First, older, pre-industrial cities tend to be built around an urban core with mixed land uses while younger, post-industrial and post-WWII cities may be characterized by polycentricity, lower densities, and segregated land uses (Warren et al. 2010). Second, through ecological succession, age should increase the diversity of plants (especially native remnant vegetation; Aronson et al. 2016) and birds (especially predatory species; Chace and Walsh, 2006), but may decrease the diversity of species that depend on early successional habitat (such as butterflies; Ockinger et al. 2009). Different urban drivers potentially related to SES may also shape biodiversity in old versus new cities via disturbance and fragmentation, respectively (Ramalho and Hobbs 2012). Third, time

lags may dampen detectability of SES effects on biodiversity. Indeed, landscapes can reflect decades of management decisions, previous land use legacies, and past economic activity (Essl et al. 2011; Roman et al. 2018). We therefore expected SES-biodiversity relationships to be more detectable in newer cities where historical legacies, such as colonialism or past discrimination, have had less time to manifest themselves in vegetation patterns (e.g. Grove et al. 2006). In older cities with low residential turnover, we also expected higher detectability, as management decisions reflecting the residents' economic character accumulate over time (Cilliers et al. 2013).

Economic Inequality: It is likely that a relatively high degree of social stratification must be present in a city in order for SES-biodiversity relationships to become manifest or detectable. Under the same logic, SES-biodiversity relationships are less likely to arise in cities that with lower economic inequality, or those relationships are harder to detect given the shallower gradient of socioeconomic difference and a potentially greater focus on the equitable distribution of city resources (Leong et al. 2018). High levels of economic inequality may also fundamentally influence the nature of a city and has been associated with greater landscape fragmentation, for example (Dobbs et al. 2017). We therefore expected that in cities where there are higher levels of economic inequality, SES may have a stronger influence on biodiversity.

National Development: The ways in which cities develop and the mechanisms shaping patterns of biodiversity may differ between developing and developed countries. First, governance structures and development patterns may shape green areas differently. Cities in developing countries are often structured by a more heterogeneous set of actors and feature a more blurred distinction between private/public and formal/informal spaces, due to the influence of Non-Governmental Organizations, private restricted

access communities, and residents themselves via “informal settlements” (Seto et al. 2010; Sletto and Palmer 2017). Rapid urbanization and fast population growth also create an urban form in cities in developing countries that are characterized by compactness in the urban core, a high degree of fragmentation, and potentially greater remnant vegetation and biodiversity in the edges of the city (Dobbs et al. 2014). Second, resource availability and public service provision may be lower in developing countries, leading to different preferences surrounding public green space and ecosystem services (Botzat et al. 2016; Chamberlain et al. 2017; Shackleton and Blair 2013). Similarly, utilitarian plant species, as opposed to ornamental species, appear to be more common in the cities of developing countries, perhaps to provide food security or a source of income (Kendal et al. 2012b). We expected national development to shape SES-biodiversity relationships, but with a directionality dependent on the other conditions present.

Combinatorial effects: While we have presented most of these hypotheses for city conditions in isolation, it is more likely that combinations of conditions will give rise to SES-biodiversity relationships. For example, we may expect young cities with high inequality to demonstrate stronger links between SES and biodiversity while we may see that native plant diversity decouples from SES in older cities. Further, legacies of colonialism differ throughout the world and may be captured by combinations of city age, tropicality, and national development. Similarly, denser cities in developing countries may show different patterns compared with less dense cities, if for example, informal settlements are characterized by either dense housing agglomerations or enough green space for gardens where diverse plants are cultivated as economic supplements. In the analysis that follows, we identify some of these key combinations of conditions that give rise to different SES-biodiversity relationships.

B. Methods

We conducted a meta-analysis using peer-reviewed academic publications in which researchers had assessed relationships between SES and the diversity of a specific taxonomic group in a particular city. Three limitations of the available case studies informed our analytical approach. First, cases were limited in taxonomic and geographic diversity and primarily considered birds and plants in temperate cities. Second, usable cases were diverse in terms of study design. And third, we suspected that outcomes were combinatorial. In other words, an observed positive relationship between SES and species diversity may be explained by a combination of the characteristics of the city under investigation, the taxonomic group in question, and study design choices.

We therefore used fuzzy-set Qualitative Comparative Analysis (“fsQCA”) to understand how combinations of conditions related to taxonomic group, study design, and city features, account for observed differences in relationships between SES and urban biodiversity (Ragin 2014). Importantly, fsQCA utilizes principles of “set membership” rather than continuous variation. While a quantitative meta-analysis may require the exact population density of Chicago, fsQCA is primarily concerned with whether Chicago is a member of the set of dense cities or not and secondarily concerned with its degree of membership. If we suppose that “dense” cities are those that exceed 4,000 persons/km², we can then compare cases across our set of dense cities which may range from 5,000 to 10,000 persons/km². fsQCA pools similar cases together into a logical “truth table” where conditions, such as density, are met or not to various degrees. The production of this truth table is iterative and requires discipline-specific theory to ensure that conditions are causally relevant and useful in the formulation of a general explanation (Ragin 2014). Boolean algebra is then used to produce minimized “recipes”

in which the included conditions combine meaningfully to explain the outcome. Unlike traditional quantitative meta-analysis, therefore, fsQCA does not emphasize each variable's net contribution to a given outcome, but rather treats cases as whole configurations of conditions (*i.e.*, instead of generating an "effect size" for density, we will better understand how density combines with taxonomic group, study design choices, or other city characteristics, to produce the outcome).

fsQCA addresses the three limitations of the available cases previously discussed. First, because it pools similar cases together, fsQCA does not "wash out" cases different from the norm. Second, the use of set membership allows for comparison of cases that differ in the details of their study design or city characteristics because we can apply external criteria to group similar cases together. The use of fuzzy-set membership also allows analysts to build in uncertainty and error into their groups. For example, a case may be coded as simply "more in than out" of the target set (see Coding Case Conditions section below). Third, the use of boolean algebra allows fsQCA to consider all possible combinations of conditions more deftly than a traditional regression analysis can handle the same number of interactions between variables (Ragin 2008).

fsQCA combines the benefits of the rich qualitative case study focusing on local phenomena and systematic meta-analysis that compares cases at a global scale. Rudel (2008) argues that fsQCA is an ideal method for investigating environmental change at regional and global scales due to its ability to create groupings of cases with shared conditions, such as climate or population density. Such groups allow the analyst to more precisely draw conclusions about subsets of cases (*e.g.*, bird diversity in dense cities or tree diversity in arid cities). Indeed, fsQCA is an increasingly popular method for studying environmental change (*e.g.* Rudel and Roper 1996, Qin and Liao 2016).

We followed recommendations for coding cases, implementing the fsQCA, and interpreting the output from Rudel (2008), Ragin (2008), Schneider and Wagemann (2010), and Legewie (2013)

1. Case Selection

To perform fsQCA, one needs empirical evidence about an outcome of interest and sufficient background information about environmental and social conditions (Qin and Liao 2016). To that end we developed a database of peer-reviewed academic publications, each of which related SES with some measure of urban biodiversity. Since some assessments of SES-biodiversity relationships may not be highlighted in the title, keywords, or abstract of a given publication, we used a combination of approaches to ensure the database was as comprehensive as possible. First, we conducted a database search using key terms. Second, we searched for articles citing four of the commonly referenced papers that investigate SES-biodiversity relationships in cities (*i.e.*, Hope et al. 2003b, Kinzig et al. 2005, Loss et al. 2009, Lubbe et al. 2010). Third, we read through papers selected from the first two steps and sought citations for other studies about SES-biodiversity relationships in cities that we had not yet encountered. In the end, we identified 49 publications for inclusion in the analysis. For more detailed information, see Appendix F.

We defined a “case” as single relationship between SES and biodiversity within a single city. Each case specified a single taxonomic group and set of study design decisions. As such, some publications included multiple cases.

We extracted 84 cases from our 49 publications and named each case with the publication number (sorted alphabetically by first author) and the letters A, B, or C for plant cases and X, Y, or Z for animal cases. For example, 49A represents a case in Sydney by Zivanovic and Luck (2016) concerning mixed plants while 01X represents a case in Phoenix by Ackley et al. (2015) concerning lizards (Table 2.3). Two mixed plants cases from Maastricht and Phoenix came from the same publication (Beumer and Martens 2016) and were named 05Am and 05Ap, respectively.

This project is part of a larger effort within the Urban Biodiversity Research Network (“UrBioNet”),³⁶ a global network for urban biodiversity research and practice. Within UrBioNet, the Socio-ecological Linkages Working Group seeks to identify underlying causes and patterns that relate SES with biodiversity in cities throughout the world (Aronson et al. 2016).

2. Coding Case Conditions

fsQCA operationalizes cases as combinations of conditions each calibrated between 0 and 1. A degree of membership > 0.5 indicates the case is “more in than out” of the target set while membership < 0.5 indicates the case is “more out than in.” At 0.5, a case would be considered maximally ambiguous. As such, the 0.5 value serves as a “crossover point” that distinguishes between members and non-members.

Conventionally, QCA sets are named for the condition of membership and written in caps and italics while non-membership is identified by lower case and italics (e.g., *DENSE* vs. *dense*). In slight deviation from convention, we refer to non-members with a name that characterizes non-membership (e.g., *DENSE* vs. *sparse*).

³⁶ <http://urbionet.weebly.com/>

We calibrated taxonomic group and study design conditions using a four-value fuzzy set (Table 2.1). Through this “indirect method” (Ragin 2008), we sorted cases into different levels of membership, then assigned interval scale scores. Full members in a target set were assigned a value of 1 while full non-members were assigned a value of 0. If a case was “more in than out” we assigned the value 0.67 while cases “more out than in” were assigned the value 0.33. Not all conditions included these intermediate fuzzy values.

Condition (<i>MEMBERSHIP</i> and <i>non-membership</i>)	Full Membership	More in than out	More out than in	Full Non-membership
Taxonomic Group: Plants (<i>WOODY</i> or <i>mixed</i>)	Trees, shrubs, or woody plants only	NA	Mix of woody plants and non-woody plants or not specified	Herbaceous plants only
Taxonomic Group: Animals (<i>MOBILE</i> or <i>low mobility</i>)	Animals with broad ranges (birds, bats, meso-predators, pollinators)	NA	NA	Animals with small ranges (aquatic invertebrates, herpetofauna, small mammals, indoor arthropods)
Native Status (<i>NATIVE</i> or <i>exotic</i>)	Native species only	All species: sample includes more native than non-native species, or not specified	All species: sample includes more non-native than native species	Non-native species only
Land Uses considered (<i>CITY</i> or <i>residential</i>)	Non-residential land uses only	Mix of non-residential and residential land uses	NA	Residential land uses only
Biodiversity sampling unit (<i>BROAD BD</i> or <i>fine bd</i>)	Multiple parcels included in measurement	NA	NA	A single parcel included in measurement
Scale of SES measurement (<i>BROAD SES</i> or <i>fine ses</i>)	Neighborhood scale measurement	NA	NA	Household scale measurement
Sampling stratified scheme (<i>STRATIFIED</i> or <i>not strat</i>)	Sampling stratified by SES	NA	NA	Sampling not stratified by SES

Table 2.1. Coding and calibration scheme for taxonomic and study design conditions. For more information, see Appendix G.

We calibrated city conditions using both the indirect method and the direct method (Table 2.2). The “direct method” utilizes three qualitative anchors to calibrate cases: full membership, full non-membership, and the crossover point. We collected external information about each case city from a variety of sources such as the United Nations, national census bureaus, and wikipedia. Information obtained for each city was applied to all cases occurring in that city with one exception. Population density was obtained to match the spatial extent of each case rather than each city since some cases occurred exclusively within the dense city limits while other cases considered the broader, sparser, metropolitan region. In Beijing and Chicago, cases occurred in both high- and low-density settings; for clarity we use the convention “City” and “Metro” to distinguish between cases occurring in the high and low density settings, respectively. After obtaining city-level information we applied our own theoretically substantial criteria to choose anchors that were relevant to the cases. Log odds of membership were calculated then exponentiated into simple odds ranging from 0-1 (Ragin 2008). For example, we chose 35° as the crossover point between tropical and not tropical (temperate) cases based on the definition of “subtropics” from the American Meteorological Association (American Meteorological Society 2012). A case in Raleigh, North Carolina, with a latitude of 35.78°N, is more in the set of “not tropical” cases than it is in the set of tropical cases, but barely. As such, we may determine that the degree of the Raleigh case’s membership in the set of tropical cases is 0.481. In contrast, a case in Kigali, Rwanda, is closer to being a full member in the set of tropical cases (latitude = 1.97°S, membership = 0.999) while a case in Stockholm, Sweden, is closer to being a full non-member (latitude = 59.33°N, membership = 0.101). We used the direct method for tropicality, aridity, density, and city age. We used the indirect method of sorting and assigning interval scale values for economic inequality and national development.

3. Coding Outcome Membership

We conceptualized three types of relationships between SES and biodiversity: positive, negative, and no relationship/neutral. Within positive and negative relationships, we identified three degrees of membership based on the strength and certainty reported by researchers: strong, intermediate, and weak. We then considered two versions of the outcome, the Positive Set and the Negative Set. For the Positive Set, strong relationships were coded at 1.0, intermediate cases at 0.85, and weak cases at 0.7. Non-member cases included those with no relationship and negative cases. Strong negative cases were coded at 0.0, intermediate cases at 0.15, and weak cases at 0.3. Cases with no relationship were coded at 0.45, just below the maximally ambiguous crossover point of 0.5 to indicate that these cases do not belong in the set of Cases with a Positive Relationship but are far from full non-members either. For the Negative Set, we used inverse coding, except for cases with no relationship, which were again coded at 0.45. Two members of the research team coded each case and in situations where there was disagreement, the entire research team convened to make a coding determination. For more information, see Appendix G.

4. Analysis

We conducted four analyses using the fsQCA software (version 3.0, Ragin and Davey 2016). First, we divided cases taxonomically into Plant and Animal groups with the reasoning that people do not directly modify animal communities to the same degree that they modify plant communities (Leong et al. 2018). Because different mechanisms occur between the two groups, separate analyses should provide greater clarity in identifying relevant mechanisms. Within each taxonomic group, we ran an analysis using outcome scores from the Positive Set and from the Negative Set.

For both plant and animal analyses, we ran our initial fsQCA with all conditions of interest. We later dropped conditions that we deemed did not add value to the interpretation, either because they were redundant with other conditions or because membership differences within a condition only accounted for three or fewer cases. For plants, *BROAD BD* was redundant with both *BROAD SES* and *CITY*. Namely, all *fine bd* cases were also *residential* cases and all *BROAD BD* cases were *BROAD SES* cases. We therefore dropped *BROAD BD* from the analysis. For animals, all cases but one occurred in cities that are in *DEVELOPED* countries. We therefore dropped *DEVELOPED* for the animal analyses. In addition, only three animal cases were *fine bd* or *fine ses*. We dropped those two conditions as well.

fsQCA software constructed a truth table in which each row represented a unique combination of conditions. Boolean minimization was used to assign cases to the rows in which they were members with corresponding consistency values indicating how well cases agree in demonstrating the outcome. For example, if three cases share membership in a set (*i.e.*, are on the same row of the truth table), but only two of those cases show the same outcome, then the set will have a low consistency value. For the plant analyses, cases in rows with consistency values above 0.8 almost exclusively included cases in which the outcome value was above 0.5. We therefore used 0.8 as our consistency cut-off, coding rows with consistency above 0.8 as demonstrating the outcome. The same considerations were used for the animal analyses, in which we used a higher consistency cut-off value of 0.9. We utilized output recipes in the “complex” solution, in which fsQCA does not consider simplifying assumptions to reduce recipes.

Within the plant and animal analyses, we combined output recipes from both the Positive Set and Negative Set analyses. We then iteratively grouped sets of recipes together based on shared conditions that aligned with common mechanisms posed by case authors. This process yielded discrete sets of recipes with common characteristics as well as subsets within those sets that provided further nuance. As such, each set and subset yielded a “solution formula” of conditions common to all recipes and “necessary” for the outcome to occur. Other conditions differed between recipes in a set but in combination with other conditions are “sufficient” for the outcome to occur. In reporting results, we refer to “included” recipes as those generated by fsQCA. We also identified “omitted” recipes; namely, those with shared conditions of a set or subset but with consistency values below our cut-off. Omitted recipes occurred either because case researchers found no relationship between SES and biodiversity or because cases in the recipe presented contradictory outcomes. Cases in omitted outputs were examined to either limit the applicability of shared mechanisms among the set or to illustrate how unique features of a case may remove it from the set despite the apparently shared conditions. To facilitate interpretation, we assigned numbers to included recipes (*e.g.*, Recipe 1, Recipe 2) and letters to omitted (“O”) recipes (*e.g.*, Recipe O-A, Recipe O-B).

In addition to fsQCA we conducted chi-square association tests (specifically Cochran–Mantel–Haenszel tests) to evaluate significant differences in the composition of outcomes (positive, neutral, and negative) for animal and plant cases within each city condition.

C. Results

We identified 84 cases from 34 cities, diverse in terms of taxonomic group, study designs, and city conditions (Table 2.3, Table 2.4).

Case	Citation	City	Taxon	Native Status	Land Use	Biodiv sampling unit	SES sampling unit	Stratification by SES	Outcome
01X	Ackley et al. 2015	Phoenix, AZ, USA	Lizards	Native only	Mixed	Multi-parcel	Neighborhood	Not stratified	Strong Positive
02A	Avolio et al. 2015	Los Angeles, CA, USA	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
03X	Belaire et al. 2014	Chicago Metro, IL, USA	Birds	Native only	Residential only	Multi-parcel	Neighborhood	Not stratified	Weak Positive
04A	Bernholt et al. 2009	Niamey, Niger	Mixed Plants	Native only	Residential only	Single parcel	Household	Not stratified	Weak Positive
04B	Bernholt et al. 2009	Niamey, Niger	Mixed Plants	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Intermediate Positive
05Am	Beumer and Martens 2016	Maastricht, Netherlands	Mixed Plants	Mostly native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
05Ap	Beumer and Martens 2016	Phoenix, AZ, USA	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
06A	Biginmana et al. 2012	Bujumbura, Burundi	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
07X	Blicharska et al. 2017	Stockholm, Sweden	Aquatic Inverts	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
08A	Clarke et al. 2013	Los Angeles, CA, USA	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Intermediate Positive
08B	Clarke et al. 2013	Los Angeles, CA, USA	Woody Plants	Mostly non-native	Residential only	Multi-parcel	Neighborhood	Not stratified	Intermediate Positive
09A	Clarke et al. 2014	Beijing Metro, China	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
10A	Clarke and Jenerette 2015	Los Angeles, CA, USA	Mixed Plants	Mostly non-native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Strong Positive
11A	Cohen et al. 2012	Paris, France	Mixed Plants	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
12A	Conway and Bourne 2013	Toronto, Canada	Woody Plants	Mostly non-native	Residential only	Multi-parcel	Neighborhood	Not stratified	Intermediate Positive
13A	Cubino et al. 2015	Costa Brava, Spain	Mixed Plants	Native only	Residential only	Single parcel	Household	Not stratified	Strong Negative
13B	Cubino et al. 2015	Costa Brava, Spain	Mixed Plants	Non-native only	Residential only	Single parcel	Household	Not stratified	Strong Positive
13C	Cubino et al. 2015	Costa Brava, Spain	Mixed Plants	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Neutral
14X	Davis et al. 2012	Chicago City, IL, USA	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Not stratified	Neutral
15A	Eichenberg et al. 2009	Rio Claro, Brazil	Mixed Plants	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Neutral
16X	Farmer et al. 2013	Lubbock, TX, USA	Birds	Mostly native	Residential only	Multi-parcel	Household	Not stratified	Strong Positive
17X	Fuller et al. 2008	Sheffield, UK	Birds	Mostly native	Residential only	Multi-parcel	Neighborhood	Not stratified	Weak Positive
18A	Gledhill and James 2012	Halton, UK	Herbaceous Plants	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Weak Positive
18X	Gledhill and James 2012	Halton, UK	Aquatic Inverts	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
18Y	Gledhill and James 2012	Halton, UK	Amphibians	Native only	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
19X	Goddard et al. 2013	Leeds, UK	Birds	Mostly native	Residential only	Multi-parcel	Neighborhood	Stratified	Weak Positive
20A	Gonzalez-Ball et al. 2017	Heredia, Costa Rica	Mixed Plants	Native only	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
20B	Gonzalez-Ball et al. 2017	Heredia, Costa Rica	Mixed Plants	Non-native only	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
20C	Gonzalez-Ball et al. 2017	Heredia, Costa Rica	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
21A	Graca et al. 2017	Porto, Portugal	Woody Plants	Mostly native	Mixed	Multi-parcel	Neighborhood	Stratified	Weak Positive
22A	Guzelian and Nyberg 2010	Chicago Metro, IL, USA	Mixed Plants	Non-native only	Mixed	Multi-parcel	Neighborhood	Not stratified	Weak Negative
23A	Hernández and Villaseñor 2018	Santiago, Chile	Woody Plants	Native only	Mixed	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
23B	Hernández and Villaseñor 2018	Santiago, Chile	Woody Plants	Non-native only	Mixed	Multi-parcel	Neighborhood	Stratified	Neutral
23C	Hernández and Villaseñor 2018	Santiago, Chile	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
24A	Kinzig et al. 2005	Phoenix, AZ, USA	Mixed Plants	Mostly non-native	Residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
24B	Kinzig et al. 2005	Phoenix, AZ, USA	Mixed Plants	Mostly non-native	Non-residential only	Multi-parcel	Neighborhood	Stratified	Neutral
24X	Kinzig et al. 2005	Phoenix, AZ, USA	Birds	Mostly native	Residential only	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
24Y	Kinzig et al. 2005	Phoenix, AZ, USA	Birds	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
25A	Kirkpatrick et al. 2007	Hobart, Australia	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Weak Positive
26X	Leong et al. 2016	Raleigh, NC, USA	Indoor Arthropods	Native only	Residential only	Single parcel	Neighborhood	Not stratified	Strong Positive
27X	Lerman and Warren 2011	Phoenix, AZ, USA	Birds	Native only	Residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
27Y	Lerman and Warren 2011	Phoenix, AZ, USA	Birds	Non-native only	Residential only	Multi-parcel	Neighborhood	Stratified	Intermediate Negative
27Z	Lerman and Warren 2011	Phoenix, AZ, USA	Birds	Mostly native	Residential only	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
28X	Li and Wilkins 2014	Waco, TX, USA	Bats	Native only	Mixed	Multi-parcel	Neighborhood	Not stratified	Weak Positive
29X	Loss et al. 2009	Chicago Metro, IL, USA	Birds	Native only	Mixed	Multi-parcel	Neighborhood	Stratified	Strong Negative
29Y	Loss et al. 2009	Chicago Metro, IL, USA	Birds	Non-native only	Mixed	Multi-parcel	Neighborhood	Stratified	Strong Positive
29Z	Loss et al. 2009	Chicago Metro, IL, USA	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Stratified	Neutral
30X	Lowenstein et al. 2014	Chicago City, IL, USA	Pollinators	Mostly native	Mixed	Multi-parcel	Neighborhood	Not stratified	Neutral
31A	Lowenstein and Minor 2016	Chicago City, IL, USA	Mixed Plants	Native only	Residential only	Multi-parcel	Neighborhood	Stratified	Weak Positive
31B	Lowenstein and Minor 2016	Chicago City, IL, USA	Mixed Plants	Non-native only	Residential only	Multi-parcel	Neighborhood	Stratified	Neutral
31C	Lowenstein and Minor 2016	Chicago City, IL, USA	Mixed Plants	Mostly non-native	Residential only	Multi-parcel	Neighborhood	Stratified	Weak Positive
32A	Lubbe et al. 2010	Tlokwe City Municipality, South Africa	Mixed Plants	Native only	Residential only	Single parcel	Neighborhood	Stratified	Intermediate Positive
32B	Lubbe et al. 2010	Tlokwe City Municipality, South Africa	Mixed Plants	Non-native only	Residential only	Single parcel	Neighborhood	Stratified	Intermediate Positive
32C	Lubbe et al. 2010	Tlokwe City Municipality, South Africa	Mixed Plants	Mostly non-native	Residential only	Single parcel	Neighborhood	Stratified	Intermediate Positive
33X	Magle et al. 2016	Chicago Metro, IL, USA	Meso-predators	Native only	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Weak Positive
34X	Makinson et al. 2017	Sydney, Australia	Pollinators	Native only	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Weak Negative
35A	Mattsson et al. 2013	New York City, NY, USA	Mixed Plants	Mostly non-native	Residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
36A	Melendez-Ackerman et al. 2014	San Juan, Puerto Rico	Woody Plants	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Neutral
37X	Melles 2005	Vancouver, Canada	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Not stratified	Strong Positive
38X	Nilon and Huckstep 1998	Chicago Metro, IL, USA	Small Mammals	Native only	Non-residential only	Multi-parcel	Neighborhood	Stratified	Weak Positive
38Y	Nilon and Huckstep 1998	Chicago Metro, IL, USA	Small Mammals	Non-native only	Non-residential only	Multi-parcel	Neighborhood	Stratified	Strong Negative
38Z	Nilon and Huckstep 1998	Chicago Metro, IL, USA	Small Mammals	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Stratified	Intermediate Negative
39A	Pedowski et al. 2002	Campos dos Goytacazes, Brazil	Woody Plants	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Stratified	Intermediate Positive
40X	Perillo et al. 2017	Belo Horizonte, Brazil	Birds	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Strong Negative
41A	Seburanga and Zhang 2013	Kigali, Rwanda	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Weak Positive
42X	Silva et al. 2015	Valdivia, Chile	Birds	Native only	Mixed	Multi-parcel	Neighborhood	Stratified	Neutral
42Y	Silva et al. 2015	Valdivia, Chile	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Stratified	Neutral
43X	Strohbach et al. 2009	Leipzig, Germany	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Not stratified	Strong Positive
44X	Trammell and Bassett 2012	Reno, NV, USA	Birds	Native only	Mixed	Multi-parcel	Neighborhood	Not stratified	Neutral
44Y	Trammell and Bassett 2012	Reno, NV, USA	Birds	Non-native only	Mixed	Multi-parcel	Neighborhood	Not stratified	Neutral
44Z	Trammell and Bassett 2012	Reno, NV, USA	Birds	Mostly native	Mixed	Multi-parcel	Neighborhood	Not stratified	Neutral
45A	van Heezik et al. 2013	Dunedin, New Zealand	Woody Plants	Native only	Residential only	Single parcel	Household	Not stratified	Intermediate Positive
45B	van Heezik et al. 2013	Dunedin, New Zealand	Woody Plants	Non-native only	Residential only	Single parcel	Household	Not stratified	Intermediate Positive
45C	van Heezik et al. 2013	Dunedin, New Zealand	Woody Plants	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Intermediate Positive
45X	van Heezik et al. 2013	Dunedin, New Zealand	Birds	Mostly non-native	Residential only	Single parcel	Household	Not stratified	Weak Positive
46A	Walker et al. 2009	Phoenix, AZ, USA	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Strong Positive
46B	Walker et al. 2009	Phoenix, AZ, USA	Mixed Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Intermediate Positive
47A	Wang et al. 2015	Beijing City, China	Woody Plants	Mostly native	Residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
47B	Wang et al. 2015	Beijing City, China	Mixed Plants	Native only	Residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
47C	Wang et al. 2015	Beijing City, China	Herbaceous Plants	Mostly native	Residential only	Multi-parcel	Neighborhood	Stratified	Strong Positive
48A	Wang et al. 2016	Beijing City, China	Woody Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Weak Negative
48B	Wang et al. 2016	Beijing City, China	Herbaceous Plants	Mostly non-native	Mixed	Multi-parcel	Neighborhood	Not stratified	Weak Negative
49A	Zivanovic and Luck 2016	Sydney, Australia	Mixed Plants	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral
49X	Zivanovic and Luck 2016	Sydney, Australia	Birds	Mostly native	Non-residential only	Multi-parcel	Neighborhood	Not stratified	Neutral

Table 2.3. Cases considered in the meta-analysis, described by city, taxonomic group, study design, and outcome (SES-biodiversity relationship). Cities and their conditions are described in Table 2.4.

City	# of cases	Tropicality	Aridity	Density	Age	Inequality	Nat'l Development
Beijing City, China	5	temperate	ARID	DENSE	OLD	UNEQUAL	developing
Beijing Metro, China	1	temperate	ARID	sparse	OLD	UNEQUAL	developing
Belo Horizonte, Brazil	1	TROPICAL	humid	DENSE	young	UNEQUAL	developing
Bujumbura, Burundi	1	TROPICAL	ARID	sparse	young	equal	developing
Campos dos Goytacazes, Brazil	1	TROPICAL	humid	sparse	young	UNEQUAL	developing
Chicago City, IL, US	5	temperate	humid	DENSE	young	UNEQUAL	DEVELOPED
Chicago Metro, IL, US	9	temperate	humid	sparse	young	UNEQUAL	DEVELOPED
Costa Brava, Spain	3	temperate	ARID	sparse	young	equal	DEVELOPED
Dunedin, New Zealand	4	temperate	humid	sparse	young	equal	DEVELOPED
Halton, UK	3	temperate	humid	sparse	young	equal	DEVELOPED
Heredia, Costa Rica	3	TROPICAL	humid	DENSE	young	UNEQUAL	developing
Hobart, Australia	1	temperate	humid	sparse	young	equal	DEVELOPED
Kigali, Rwanda	1	TROPICAL	ARID	sparse	young	UNEQUAL	developing
Leeds, UK	1	temperate	humid	sparse	OLD	equal	DEVELOPED
Leipzig, Germany	1	temperate	humid	sparse	OLD	equal	DEVELOPED
Los Angeles, CA, US	4	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED
Lubbock, TX, US	1	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED
Maastricht, Netherlands	1	temperate	humid	sparse	OLD	equal	DEVELOPED
New York City, NY, US	1	temperate	humid	DENSE	OLD	UNEQUAL	DEVELOPED
Niamey, Niger	2	TROPICAL	ARID	sparse	young	equal	developing
Paris, France	1	temperate	humid	DENSE	OLD	equal	DEVELOPED
Phoenix, AZ, US	11	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED
Porto, Portugal	1	temperate	humid	DENSE	OLD	equal	DEVELOPED
Raleigh, NC, US	1	temperate	humid	sparse	OLD	UNEQUAL	DEVELOPED
Reno, NV, US	3	temperate	ARID	sparse	young	UNEQUAL	DEVELOPED
Rio Claro, Brazil	1	TROPICAL	humid	sparse	young	UNEQUAL	developing
San Juan, PR, US	1	TROPICAL	humid	sparse	OLD	UNEQUAL	DEVELOPED
Santiago, Chile	3	TROPICAL	ARID	DENSE	OLD	UNEQUAL	DEVELOPED
Sheffield, UK	1	temperate	humid	sparse	OLD	equal	DEVELOPED
Stockholm, Sweden	1	temperate	humid	DENSE	OLD	equal	DEVELOPED
Sydney, Australia	3	TROPICAL	humid	sparse	OLD	equal	DEVELOPED
Tlokwe City Municipality, South Africa	3	TROPICAL	ARID	sparse	young	UNEQUAL	developing
Toronto, Canada	1	temperate	humid	sparse	young	equal	DEVELOPED
Valdivia, Chile	2	temperate	humid	sparse	OLD	UNEQUAL	DEVELOPED
Vancouver, Canada	1	temperate	humid	sparse	young	equal	DEVELOPED
Waco, TX, US	1	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED

Table 2.4. Cities considered in the meta-analysis described by the conditions assessed and the number of cases within each city.

Within our 49 plant cases, 17 were purely woody plants (35%), 29 were mixed plants (59%), and 3 were purely herbaceous (6%). Cases included 8 that focused exclusively on native plants (16%) and 7 that focused on non-natives (14%). Researchers stratified sampling by SES in 25 plant cases (51%), collected SES data at the neighborhood scale in 39 cases (80%), and collected biodiversity information at the multi-parcel scale in 28 cases (57%). Six cases focused exclusively on non-residential land uses (12%) while 31 cases focused on residential land only (63%). Within our 35 animal cases, 27 were high mobility (77%) and 8 were low mobility (23%). Split by taxonomic group, 23 were bird cases (66%), 5 were mammal cases (14%), 5 were invertebrate cases (14%), and 2 were herpetofauna cases (6%). Cases included 11 that focused exclusively on native animals (31%) and 4 that focused on non-natives (11%). Researchers stratified sampling by SES in 14 animal cases (40%), collected SES data at the neighborhood scale in 33 cases (94%), and collected biodiversity information at the multi-parcel scale in 33 cases (94%). Eleven cases focused exclusively on non-residential land uses (31%) while 10 cases focused on residential land only (29%).

Case membership in different city conditions were variable (Table 2.5) with remarkably few animal cases in *DENSE* or *developing* cities.

	Tropicality	Cases	Aridity	Cases	Density	Cases	City Age	Cases	Inequality	Cases	Development	Cases
Plant	<i>TROPICAL</i>	26 (53%)	<i>ARID</i>	28 (57%)	<i>DENSE</i>	17 (35%)	<i>OLD</i>	15 (31%)	<i>UNEQUAL</i>	33 (67%)	<i>DEVELOPED</i>	31 (63%)
	<i>temperate</i>	23 (47%)	<i>humid</i>	21 (43%)	<i>sparse</i>	32 (65%)	<i>young</i>	34 (69%)	<i>equal</i>	16 (33%)	<i>developing</i>	18 (37%)
Animal	<i>TROPICAL</i>	11 (31%)	<i>ARID</i>	11 (31%)	<i>DENSE</i>	4 (11%)	<i>OLD</i>	9 (26%)	<i>UNEQUAL</i>	25 (71%)	<i>DEVELOPED</i>	34 (97%)
	<i>temperate</i>	24 (69%)	<i>humid</i>	24 (69%)	<i>sparse</i>	31 (89%)	<i>young</i>	26 (74%)	<i>equal</i>	10 (29%)	<i>developing</i>	1 (3%)

Table 2.5. Breakdown of plant and animal cases in and out of set membership in each city condition.

Most cases showed positive relationships between SES and biodiversity (53 cases or 63%). Ten cases showed negative relationships (12%) and 21 cases showed no relationship (25%). Proportions of cases showing these three types of relationships varied when considering taxonomic group, native status, land use, and city conditions.

For many of the city conditions in question, animal and plant cases showed similar proportions of positive, neutral, and negative outcomes, with some exceptions (Figure 2.1). Plant and animal cases showed different compositions of outcomes in *TROPICAL* cities (p -value = 0.0194), *DENSE* cities (p -value = 0.0621), and *young* cities (p -value = 0.0278). There were also significant associations between both outcome composition and tropicality within both plant cases (p -value = 0.0843) and animal cases (p -value = 0.0963).

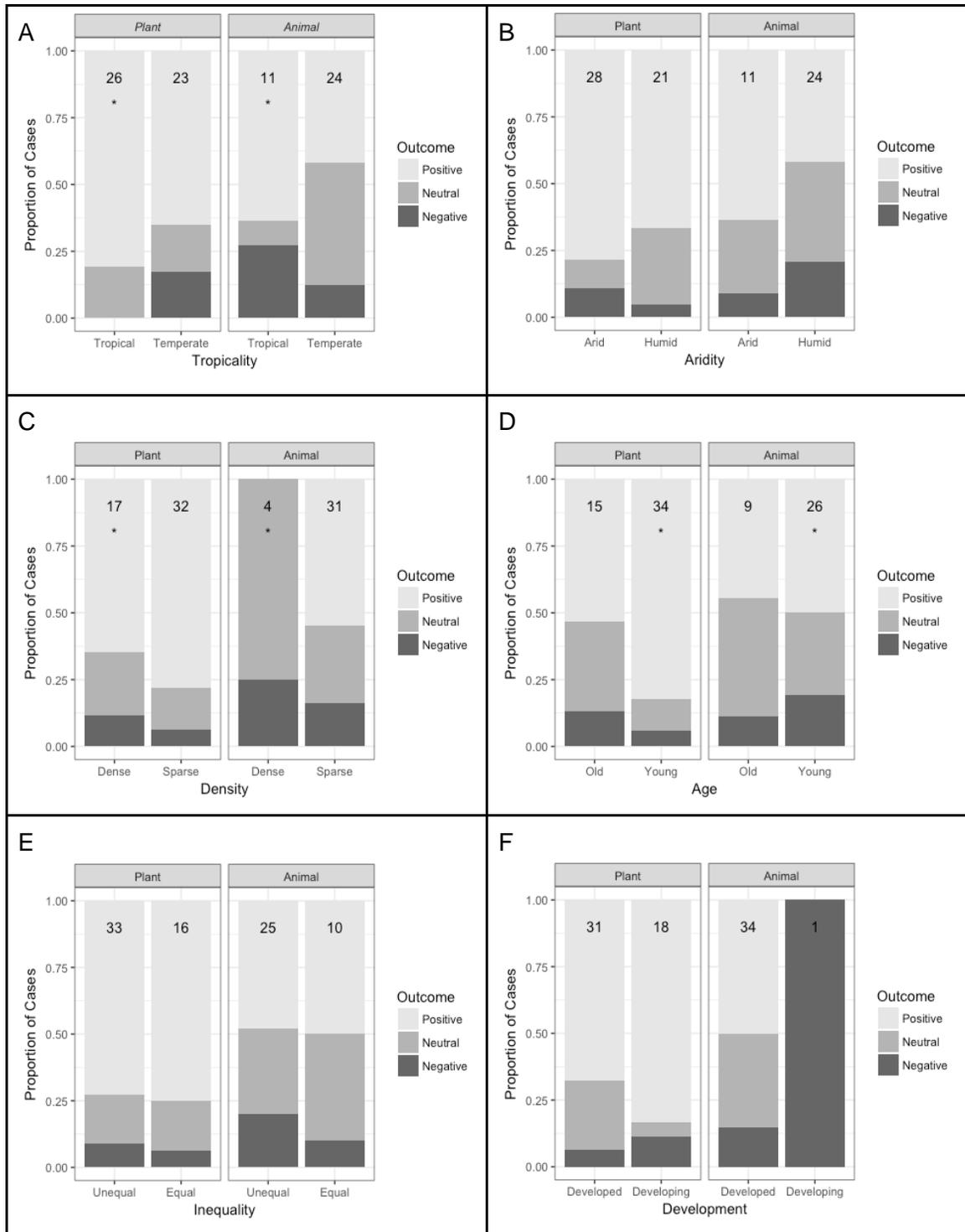


Figure 2.1. For each city condition, the proportion of plant and animal cases with positive, neutral, and negative SES-biodiversity relationships. From top left to bottom right: Tropicality, Aridity, Density, Age, Inequality, and Development. Number of cases in each taxa*city condition subset are noted at the top of each bar. Statistically significant differences (chi square test, p -value < 0.1) within a city condition but between taxonomic groups is shown with an asterisk; differences within a taxonomic group but between city conditions is shown via the italicized taxonomic group.

1. The Plant Analysis

The plant analysis yielded 39 unique combinations of conditions (Appendix H), ten of which consisted of multiple cases. Combined, positive and negative complex solutions yielded 30 recipes with high solution consistency scores (Table 2.6). Both analyses, and especially the negative analysis, had low solution coverage, signifying the presence of cases that demonstrate the outcome but were not represented by recipes. This feature is likely to be due to the coding of No Relationship cases as 0.45 in both analyses. However, the markedly higher coverage scores for the positive analysis suggest that the positive analysis, in considering Negative and No Relationship cases in the same set, is more robust in explaining outcomes compared with the negative analysis.

	Plant Analyses	
	Positive	Negative
Consistency cutoff	0.80	0.82
Solution coverage	0.74	0.32
Solution consistency	0.95	0.87

Table 2.6. fsQCA output values for the positive and negative plant analysis solutions.

Among the 30 fsQCA output recipes we identified three broad sets with shared necessary conditions and mechanisms reported by authors. Among these sets, we identified 6 subsets that reveal further unifying mechanisms and nuances among cases.

a. Set Recipe: **WOODY*CITY**

Recipe	Woodiness	Native Status	Land Use	Stratification	SES Scale	Tropicality	Aridity	Density	Age	Inequality	National Development	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
O-A	mixed	exotic	CITY	STRATIFIED	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED	NA	NA	NA	Omitted	Kinzig et al. 2005 [24B]	Phoenix
1	WOODY	exotic	CITY	not strat	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL		0.07	0.02	1.00	Positive	Walker et al. 2009 [46A], Seburanga and Zhang 2013 [41A],	Phoenix, Kigali, Los Angeles
2		exotic	CITY	not strat	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED	0.07	0.01	1.00	Positive	Walker et al. 2009 [46A, 46B], Clarke et al. 2013 [08A], Clarke and Jenerette 2015	Phoenix, Los Angeles
3	WOODY	exotic		not strat	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED	0.07	0.02	1.00	Positive	Walker et al. 2009 [46A], Clarke et al. 2013 [08A, 08B]	Phoenix, Los Angeles
4	WOODY	exotic	CITY		BROAD	TROPICAL	ARID	sparse	young	UNEQUAL	DEVELOPED	0.09	0.02	1.00	Positive	Walker et al. 2009 [46A], Avolio et al. 2015 [02A], Clarke et al. 2013 [08A]	Phoenix, Los Angeles
5	WOODY		CITY	STRATIFIED	BROAD	TROPICAL	ARID	DENSE	OLD	UNEQUAL	DEVELOPED	0.05	0.04	0.92	Positive	Hernández and Villaseñor 2018 [23A, 23B, 23C]	Santiago
6	WOODY	NATIVE	CITY	STRATIFIED	BROAD	TROPICAL	humid	sparse	young	UNEQUAL	developing	0.02	0.01	1.00	Positive	Pedlowski et al. 2002 [39A]	Campos dos Goytacazes
7	WOODY	NATIVE	CITY	STRATIFIED	BROAD	temperate	humid	DENSE	OLD	equal	DEVELOPED	0.02	0.02	1.00	Positive	Graca et al. 2017 [21A]	Porto

Table 2.7. Set recipes for **WOODY*CITY** displayed with omitted Recipe O-A.

Researchers consistently find positive relationships between SES and *WOODY* plant diversity when considering *CITY* land uses. In general, researchers note that municipalities or residents in higher SES areas intentionally increase the number of woody plant species in order to improve aesthetics or ecosystem services. At first inspection, this trend counters the hypothesis proposed by Kinzig et al. (2005) that

“perennial plant diversity in parks is largely controlled by top-down processes, including, most prominently, municipal decisions concerning landscaping and management. There may be some modest bottom-up influences reflecting individual or household choices or actions, including, for example, lobbying for particular park designs. Because the dominant influence is top down, and because these decisions are expected to be driven more by efficiency or aesthetics than by the status of different served groups, plant diversity in parks is not expected to vary with socioeconomic or cultural characteristics.”

Indeed, Kinzig et al. (2005) found no relationship between SES and perennial plant diversity in public parks [24B] (Table 2.7, Recipe O-A)³⁷. However, most cases in the *WOODY*CITY* set include non-residential land uses that are not exclusively public parks, allowing for different combinations of bottom-up and top-down drivers. Further, the *UNEQUAL* nature of almost all the included cases point to more than modest differences in bottom-up influences reflecting residential actions such as lobbying for particular park designs. Two subsets illuminate how different bottom-up and top-down forces interact under conditions of inequality.

First, in *UNEQUAL*, *ARID*, *TROPICAL* cities, *exotic WOODY* plant diversity is higher in higher SES areas across *CITY*-wide land uses (Table 2.7, Recipes 1-5). Indeed, it is common for city governments to plant exotic trees in tropical arid cities to provide shade and other ecosystem services (Walker et al. 2009 [46A, 46B], Clarke et al. 2013 [08A,

³⁷ We included Recipe O-A in this set although we coded it as a *mixed* plant case for two reasons. First, researchers sampled perennial plants, which include many woody species. Second, the recipe is on *CITY*-wide land uses, is *STRATIFIED* by SES, and is *TROPICAL* and *ARID*. As such, it does not belong in any other set.

08B], Avolio et al. 2015 [02A], Clarke and Jenerette 2015 [10A]) or as a reflection of colonial influence or dominant urban forestry practice (Seburanga and Zhang 2013 [41A], Hernández and Villaseñor 2018 [23A, 23B, 23C]). Inequality in these cities may also contribute to the SES-biodiversity gradient through greater municipal investment in tree plantings in wealthier areas, for example (e.g., Hernández and Villaseñor 2018). Further, irrigation costs in arid climates make it challenging for lower SES residents or managers to plant and maintain diverse tree communities (e.g., Avolio et al. 2015). The inclusion of recipes that are not exclusively *WOODY* CITY* suggests these mechanisms apply more broadly than to woody plants on public land; however, these included cases show smaller differences in plant diversity between different SES areas.

Second, in cities where researchers *STRATIFIED* sampling by SES, they find higher *NATIVE WOODY* plant diversity in higher SES areas across *CITY*-wide land uses due to differential lobbying power between neighborhoods (Table 2.7, Recipes 5-7). On city land such as public parks, native woody vegetation generally needs to be planted. Unlike in arid cities, however, there are lower costs associated with planting and maintaining native trees. As such, differential lobbying power and municipal priorities likely shape differences between neighborhoods, rather than cost alone, and those differences are best detected when researchers stratify their sampling by SES. Indeed, a unifying pattern among the three cities in this subset is that the municipality or residents themselves planted additional native tree species in high SES areas, due to ease of obtaining viable seeds (Pedlowski et al. 2002 [39A]), the development of new parks (Graça et al. 2017 [21A]), or the promotion of native tree species by the government Forestry Service (Hernández and Villaseñor 2018 [23A, 23B, 23C]).

b. Set Recipe: residential

Recipe	Woodiness	Native Status	Land Use	Stratification	SES Scale	Tropicality	Aridity	Density	Age	Inequality	National Development	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
8	mixed		res	STRATIFIED	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL	developing	0.07	0.02	1.00	Positive	Lubbe et al. 2010 [32A, 32B, 32C]	Tlokwe
9	mixed	exotic	res	STRATIFIED	BROAD	TROPICAL	ARID	sparse	young		developing	0.06	0.01	1.00	Positive	Lubbe et al. 2010 [32B, 32C], Bigirimana et al. 2012 [06A]	Bujumbura, Tlokwe
10	mixed	exotic	res	STRATIFIED	BROAD	temperate	ARID	sparse	OLD	UNEQUAL	developing	0.02	0.01	1.00	Positive	Clarke et al. 2014 [09A]	Beijing Metro
11	mixed	exotic	res	not strat	fine	TROPICAL	ARID	sparse	young	equal	developing	0.03	0.03	1.00	Positive	Bernholt et al. 2009 [04A, 04B] Lubbe et al. 2010 [32B, 32C], Kinzig et al. 2005 [24A]	Niamey
12	mixed	exotic	res	STRATIFIED	BROAD	TROPICAL	ARID	sparse	young	UNEQUAL		0.10	0.03	1.00	Positive	Beumer and Martens 2016 [05Ap]	Phoenix, Tlokwe
13	WOODY	exotic	res	not strat		temperate	humid	sparse	young	equal	DEVELOPED	0.08	0.02	1.00	Positive	van Heezik et al. 2013 [45B, 45C], Conway and Bourne 2013 [12A]	Dunedin, Toronto
14	WOODY		res	not strat	fine	temperate	humid	sparse	young	equal	DEVELOPED	0.08	0.02	0.89	Positive	van Heezik et al. 2013 [45A, 45B, 45C]	Dunedin
15	WOODY	exotic	res	not strat	fine	TROPICAL	humid	sparse	OLD	UNEQUAL	DEVELOPED	0.04	0.02	0.86	Positive	Melendez-Ackerman et al. 2014	San Juan
16	mixed	exotic	res	not strat	fine	temperate	ARID	sparse	young	equal	DEVELOPED	0.03	0.01	0.91	Positive	Cubino et al. 2015 [13C, 13B]	Costa Brava
17	mixed	NATIVE	res	not strat	fine	temperate	ARID	sparse	young	equal	DEVELOPED	0.06	0.06	1.00	Negative	Cubino et al. 2015 [13A]	Costa Brava
O-B	mixed	exotic	res	not strat	fine	TROPICAL	humid	sparse	young	UNEQUAL	DEVELOPED	NA	NA	NA	Omitted	Eichenberg et al. 2009 [15A]	Rio Claro
18	mixed		res	STRATIFIED	BROAD	temperate	humid	DENSE	young	UNEQUAL	DEVELOPED	0.05	0.04	0.92	Positive	Lowenstein and Minor 2016 [31A, 31B, 31C]	Chicago City
19	mixed	NATIVE	res	STRATIFIED	BROAD	temperate	humid	sparse	OLD	equal	DEVELOPED	0.04	0.02	1.00	Positive	Beumer and Martens 2016 [05Am]	Maastricht
20	mixed	exotic	res	STRATIFIED	BROAD	temperate	humid	sparse	young	equal	DEVELOPED	0.02	0.01	1.00	Positive	Kirkpatrick et al. 2007 [25A]	Hobart
21	mixed		res	STRATIFIED	BROAD	TROPICAL	humid	DENSE	young	UNEQUAL	developing	0.06	0.05	1.00	Positive	Gonzalez-Ball et al. 2017 [20A, 20B, 20C]	Heredia
22		NATIVE	res	STRATIFIED	BROAD	temperate	ARID	DENSE	OLD	UNEQUAL	developing	0.06	0.05	1.00	Positive	Wang et al. 2015 [47A, 47B, 47C]	Beijing City

Table 2.8. Set recipes for *residential* displayed with omitted Recipe O-B.

Researchers almost exclusively find positive relationships between SES and plant diversity on *residential* land. This finding upholds the hypothesis of Kinzig et al. (2005) that

“perennial plant diversity in neighborhoods is largely controlled by bottom-up processes, including, most prominently, household landscaping choices. There may be some modest top-down control exerted by city-managed plantings on public property, or by imposed agreements concerning appropriate landscaping practices, but the dominant influence is bottom up. Because of this, plant diversity in neighborhoods is expected to vary significantly with socioeconomic or cultural characteristics.”

Case authors suggest additional top-down forces related to residential segregation and housing policies that can keep plant diversity low in low SES areas and/or boost diversity in high SES areas. Two subsets illustrate different versions of these bottom-up and top-down influences in diverse city contexts.

First, in *sparse, ARID, developing* cities, *exotic mixed* plant diversity tends to be higher in higher SES areas on *residential* land (Table 2.8, Recipes 8-12). Apart from the Phoenix cases (Beumer and Martens 2016 [05Ap]; Kinzig et al. 2005 [24A]), authors explain findings with different forms of the “Hierarchy of Need” hypothesis; namely, lower SES residents cultivate a limited diversity of utilitarian plants, while higher SES

residents, freed from economic need, cultivate a greater diversity of ornamental (usually non-native) plants. Differences in plant communities between SES groups may be exacerbated by an arid climate that increases costs associated with plant maintenance. Yet other factors explain these patterns as well. In Tlokwe and Bujumbura, higher SES areas tend to have larger gardens and better soils (Bigirimana et al. 2012 [06A]; Lubbe et al. 2010 [32A, 32B, 32C]). In Beijing Metro and Niamey, higher SES areas include peri-urban sites with high diversity gardens because wealthier residents participate in nearby markets (Bernholt et al. 2009 [04A, 04B]; Clarke et al. 2014 [09A]). In Phoenix, case authors explain that differences in landscaping choices and resultant diversity of yards among neighborhoods drives the SES-biodiversity relationship. Higher SES (and higher biodiversity) neighborhoods have a greater mix of mesic and xeric yards and more trees, demanding more care and irrigation. These yards were also filled with exotic species, especially in mesic yards. Lower SES (and lower biodiversity) neighborhoods had mostly basic xeric yards that require little care. (Beumer and Martens 2016 [05Ap]; Kinzig et al. 2005 [24A]).

Second, in *humid or temperate* cities, favorable climatic conditions lower the cost of caring for and maintaining plants on *residential* land compared with arid cities (Table 2.8, Recipes 13-22). In theory, such lower costs could reduce differences in plant diversity between high and low SES groups if affordability were the only factor (as implied by both the “Hierarchy of Need” hypothesis and “Luxury Effect”). Rather, in these cities, differences in plant diversity are driven by a combination of bottom-up and top-down factors. In recipes that are *not stratified* by SES (Recipes 13-17), authors argue that bottom-up individual or community preferences drive residential planting decisions, revealed by factors such as ethnicity (Conway and Bourne 2013 [12A]), education or knowledge about plants (Melendez-Ackerman et al. 2014 [36A]; van Heezik et al. 2013

[45A]), place attachment (Cubino et al. 2015 [13A, 13B, 13C]); Melendez-Ackerman et al. 2014 [36A]; Van Heezik et al. 2013 [45B, 45C]), and home ownership (Melendez-Ackerman et al. 2014 [36A]). Notably, few if any of these factors are inherently aligned with SES. Numerous case authors in this subset also observed that larger yards or access to more space were associated with greater *exotic* plant diversity (Cubino et al. 2015 [13B, 13C]; Melendez-Ackerman et al. 2014 [36A]; van Heezik et al. 2013 [45A, 45B, 45C]), suggesting that preference must be coupled with space to actualize it and that financial ability may be a secondary factor. The fact that researchers did not stratify sampling by SES may have facilitated the detection of preference-based drivers. Indeed, in one omitted recipe and corresponding case, researchers sampled home gardens along a narrow gradient of family incomes and did not find any relation between SES and plant species richness (Table 2.8, Recipe O-B: Eichemberg et al. 2009 [15A]).

Authors of study designs that do *STRATIFY* sampling by SES suggest an additional mechanism: top-down segregation that filters residents with similar SES into neighborhoods with distinct forms, opportunities, or expectations (Recipes 18-22). Here, socioeconomic and cultural diversity may work together to shape biodiversity.

Lowenstein and Minor (2016) argue that residents use yards for social and cultural expression such that neighborhoods with high cultural diversity would also have high biodiversity, even if socioeconomic diversity is low. And indeed, in Chicago Metro, low and high SES neighborhoods that were culturally homogenous had low yard diversity while intermediate SES neighborhoods that were culturally diverse had high yard diversity (Lowenstein and Minor 2016 [30A, 30B, 30C]). In Maastricht, where cultural diversity is low across the city, low SES neighborhoods had low yard diversity while high SES neighborhoods had high yard diversity (Beumer and Martens 2016 [05Am]). In other cities, regardless of cultural diversity, segregation may simply limit opportunities to have personalized yards due to lack of available space or enforcement from public housing

agencies, especially for lower SES residents (González-Ball et al. 2017 [20A, 20B, 20C]; Kirkpatrick et al. 2007 [25A]; Wang et al. 2015 [47A, 47B, 47C]).

c. Set Recipe: *mixed*not stratified*(temperate + humid)*

Recipe	Woodiness	Native Status	Land Use	Stratification	SES Scale	Tropicality	Aridity	Density	Age	Inequality	National Development	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
23	<i>mixed</i>	<i>exotic</i>	<i>res</i>	<i>not strat</i>	BROAD	<i>temperate</i>	<i>humid</i>	DENSE	OLD	UNEQUAL	DEVELOPED	0.07	0.03	0.84	Negative	Matteson et al. 2013 [35A]	NYC
24	<i>mixed</i>	<i>exotic</i>	<i>res</i>	<i>not strat</i>	BROAD	<i>temperate</i>	<i>humid</i>	DENSE	OLD	UNEQUAL	DEVELOPED	0.03	0.02	0.81	Positive	Matteson et al. 2013 [35A]	NYC
25	<i>mixed</i>	<i>exotic</i>	CITY	<i>not strat</i>	BROAD	<i>temperate</i>	<i>humid</i>	sparse	young	UNEQUAL	DEVELOPED	0.10	0.05	0.92	Negative	Gulezian and Nyberg 2010	Chicago Metro
26		<i>exotic</i>	CITY	<i>not strat</i>	BROAD	<i>temperate</i>	ARID	DENSE	OLD	UNEQUAL	developing	0.09	0.06	1.00	Negative	Wang et al. 2016 [48A, 48B]	Beijing City
27	<i>mixed</i>	NATIVE	CITY	<i>not strat</i>	BROAD	<i>temperate</i>	<i>humid</i>	DENSE	OLD	equal	DEVELOPED	0.07	0.03	0.82	Negative	Cohen et al. 2012 [11A]	Paris
28	<i>mixed</i>	NATIVE	CITY	<i>not strat</i>	BROAD	<i>temperate</i>	<i>humid</i>	sparse	young	equal	DEVELOPED	0.03	0.02	1.00	Positive	Gledhill and James 2012 [18A]	Halton
29	<i>mixed</i>	NATIVE	CITY	<i>not strat</i>	BROAD	TROPICAL	<i>humid</i>	sparse	OLD	equal	DEVELOPED	0.02	0.00	0.85	Positive	Zivanovic and Luck 2016 [49A]	Sydney
30	<i>mixed</i>	NATIVE	CITY	<i>not strat</i>	BROAD	TROPICAL	<i>humid</i>	sparse	OLD	equal	DEVELOPED	0.05	0.01	0.85	Negative	Zivanovic and Luck 2016 [49A]	Sydney

Table 2.9. Set recipes for *mixed*not stratified*(temperate + humid)*.

Researchers do not consistently find positive relationships between SES and *mixed* plant diversity in *humid* or *temperate* cities when they do *not stratify* sampling by SES. Three unifying themes emerge from the remaining fsQCA recipes. First, in humid or temperate cities, favorable climates remove some of the differential influence of SES on landscaping decisions. Second, when researchers do not stratify their sampling by SES, the likelihood of detecting a structural or qualitative difference between SES groups diminishes. Third, some urban forms make irrelevant the theories previously discussed; namely, when residents do not have land to manipulate (more common in high density cities), we may not detect differences in plant diversity among SES groups. Two subsets illuminate how these shared features hinder the establishment or detection of SES-biodiversity relationships.

The first subset includes a type of *DENSE* city, in which upper SES residents live in high-density districts closer to the urban core with little green coverage and lower SES residents live in lower-density districts with more green areas (Table 2.9, Recipes 23-27). Cohen et al. (2012) referred to this pattern as a “Hausmann Paradox,” after Baron Hausmann, the urban planner responsible for imposing this form upon the Paris

landscape in the mid-1800s. In “Haussmann Paradox” cities, we would not expect to see positive relationships between SES and plant diversity if higher SES/higher density areas support similar or lower levels of biodiversity in their green spaces compared with lower SES/lower density areas. Cities in the included recipes are all high density and case findings meet our expectations. In Paris (21,060 persons/km²) and New York City (10,428 persons/km²), researchers found no relationship between income and floral richness (Cohen et al. 2012 [11A]; Matteson et al. 2013 [35A])³⁸. Authors in both cases suggested that the absence of such a relationship was due to two features: fewer opportunities for higher SES residents to increase floral diversity in their neighborhoods and parks and greater abundance of green spaces and community gardens in lower SES areas. In Chicago Metro (2,196 persons/km²)³⁹ and Beijing City (15,582 persons/km²), researchers found negative relationships between SES and plant diversity across city land uses. In both cities, lower SES areas tend to be further from the downtown core with more vacant land (in Chicago Metro; Gulezian and Nyberg 2010 [22A]) or green space (in Beijing City; Wang et al. 2016 [48A. 48B]). The supportive climates and similar patterns of wealth and settlement (*i.e.*, a “Haussmann Paradox”) may explain similar outcomes between these two cities. Importantly, the “Haussmann Paradox” is about SES-density relationships within a city and is more likely, but not guaranteed, to occur in denser cities. Further, researchers may be less likely to report

³⁸ fsQCA coded the Paris case [11A] as negative and the New York City case [35A] as both negative and positive. Low consistency values for these recipes (*i.e.*, 0.817053, 0.931178, 0.901751 respectively) suggest that they contribute meaningfully to our interpretation of included recipes for both analyses.

³⁹ The low density of this Chicago Metro case [22A] is a result of sampling along a transect spanning the width of Cook County, rather than just within the city boundaries. However, the City of Chicago is quite dense; as the authors state, “the lowest average presence of these 10 [plant] species occurs closest to downtown, where residents are wealthiest and available habitat (exposed soil) is rarest. Invasive presence rises just west of the wealthy downtown neighborhoods where households are poorer and available habitat increases (vacant lots, for example).”

drivers associated with a “Hausmann Paradox” when they do not stratify their sampling by SES, which is a helpful strategy for detecting neighborhood-level differences in biodiversity. Indeed, another case in Chicago Metro (Lowenstein and Minor 2016 [30A, 30B, 30C]) did stratify their sampling by SES and noticed differences in plant diversity between different SES neighborhoods.

The second subset includes cases in which researchers did not detect strong SES-plant diversity relationships due to sampling design and spatial mismatch. These cases all examined *NATIVE* plant diversity on *CITY*-wide land uses in *equal* cities (Table 2.9, Recipes 27-30). While Paris can be characterized by a “Hausmann Paradox,” authors also suggested that their focus on native plants on public land failed to capture the mechanisms most related to SES, namely those shaping exotic species in private gardens (Cohen et al. 2012 [11A]). Methodological concerns arose in Sydney, where researchers did not observe differences in park plant diversity between different SES areas, potentially due to not sampling SES at a broad enough scale to capture true differences in the degree of civic lobbying power that may differentially shape park plant diversity (Zivanovic and Luck. 2016 [49A]). Researchers in Halton (Gledhill and James 2012 [18A]) also found no relationship between house price and aquatic plant species richness. However, median house price per postcode was positively and significantly correlated with total area of private gardens and total area of green space and plant species richness increased with public green space, suggesting a potential indirect effect of SES associated with urban form. fsQCA respectively coded these three cases as negative, both negative and positive, and positive, suggesting cases membership in the set of negative or positive outcomes, even if researchers did not find strong relationships.

2. The Animal Analysis

The animal analysis yielded 26 unique combinations of conditions (see Appendix H), eight of which consisted of more than one case. Combined, positive and negative complex solutions yielded 10 recipes with high solution consistency scores (Table 2.10). Both analyses, and especially the negative analysis, had low solution coverage, signifying the presence of cases that demonstrate the outcome but were not represented by recipes. This feature is likely to be due to the coding of No Relationships cases as 0.45 in both positive and negative analyses. Like the plant analysis, the markedly higher coverage scores for the positive analysis suggest that the positive analysis, in considering Negative and No Relationship cases in the same set, is more robust in explaining outcomes compared with the negative analysis.

	Animal Analyses	
	Positive	Negative
Consistency cutoff	0.91	1.00
Solution coverage	0.64	0.21
Solution consistency	0.98	1.00

Table 2.10. fsQCA output values for the positive and negative animal analysis solutions.

Among the 10 output recipes, we identified three broad sets corresponding to mobility and native status. Within these sets we identified seven subsets with shared mechanisms and study design and city-level conditions.

a. Set Recipe: *low-mobility*

Recipe	Mobility	Native Status	Land Use	Stratification	Tropicality	Aridity	Density	Age	Inequality	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
1		NATIVE	CITY	not strat	TROPICAL	ARID	sparse	young	UNEQUAL	0.11	0.03	0.96	Positive	Li and Wilkins 2014 [28X], Ackley et al. 2015 [01X]	Phoenix, Waco
2	low-mob	NATIVE	res	not strat	temperate	humid	sparse	OLD	UNEQUAL	0.03	0.02	1.00	Positive	Leong et al. 2016 [26X]	Raleigh
O-A	low-mob	NATIVE	CITY	STRATIFIED	temperate	humid	sparse	young	UNEQUAL	NA	NA	NA	Omitted	Nilon and Huckstep 1998 [38X, 38Z]	Chicago Metro
3	low-mob	exotic	CITY	STRATIFIED	temperate	humid	sparse	young	UNEQUAL	0.07	0.07	1.00	Negative	Nilon and Huckstep 1998 Blicharska et al. 2017 [07X], Gledhill and James 2012 [18X, 18Y]	Chicago Metro Stockholm, Halton
O-B	low-mob	NATIVE	CITY	not strat	temperate	humid			equal	NA	NA	NA	Omitted		

Table 2.11. Set recipes for *low-mobility* displayed with omitted recipes O-A and O-B.

Two general patterns emerge from included and omitted fsQCA recipes (Table 2.11, Recipes 1-3, 0-A and 0-B). First, in *sparse* and *UNEQUAL* cities, higher SES areas tend to include some difficult-to-measure feature of habitat quality that promotes *NATIVE low-mobility* animal diversity (Ackley et al. 2015 [01X]; Leong et al. 2016 [26X]; Nilon and Huckstep 1998 [38X, 38Z]) while lower SES areas lack the critical habitat quality feature or are characterized by higher levels of disturbance, which in turn promotes non-native lower-mobility animal diversity (Nilon and Huckstep 1998 [38Y]). In these lower density cities, residents typically have yards, providing greater opportunity for steep economic gradients to manifests themselves in the plant assemblages. Second, in *equal* cities and especially in ponds, factors related to urban form such as the density of green spaces or buildings exert a stronger influence on low-mobility animal diversity compared with SES. More equitable distribution of green and blue spaces and in these cities may be related to the shallower degree of economic difference (Blicharska et al. 2017 [07X]; Gledhill and James 2012 [18X and 18Y]).

b. Set Recipe: *MOBILE*NATIVE*

Recipe	Mobility	Native Status	Land Use	Stratification	Tropicality	Aridity	Density	Age	Inequality	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
4	MOBILE	NATIVE	res		temperate	humid	sparse	OLD	equal	0.15	0.09	1.00	Positive	Goddard et al. 2013 [19X], Fuller et al. 2008 [17X]	Leeds, Sheffield
5	MOBILE	NATIVE			TROPICAL	ARID	sparse	young	UNEQUAL	0.23	0.14	0.97	Positive	Li and Wilkins 2014 [28X], Kinzig et al. 2005 [24X, 24Y], Lerman and Warren 2011 [27X, 27Z], Farmer et al. 2013 [16X]	Phoenix, Waco, Lubbock
6	MOBILE	NATIVE		not strat	temperate	humid	sparse	young	UNEQUAL	0.17	0.09	0.98	Positive	Belaire et al. 2014 [03X], Magle et al. 2016 [33X]	Chicago Metro
7	MOBILE	NATIVE	CITY	not strat	temperate	humid	sparse		equal	0.11	0.03	0.95	Positive	Strohbach et al. 2009 [43X], Melles 2005 [37X]	Vancouver, Leipzig
O-C	MOBILE	NATIVE	CITY				sparse			NA	NA	NA	Omitted	Makinson et al. 2017 [34X], Zvanovic and Luck 2016 [49X], Loss et al. 2009 [29X, 29Z], Silva et al. 2015 [42X, 42Y], Trammell et al. 2012 [44X, 44Z]	Sydney, Chicago Metro, Valdivia, Reno
8	MOBILE	NATIVE	CITY	not strat	TROPICAL	humid	DENSE	young	UNEQUAL	0.13	0.13	1.00	Negative	Perillo et al. 2017 [40X]	Belo Horizonte
O-D	MOBILE	NATIVE	CITY	not strat	temperate	humid	DENSE	young	UNEQUAL	NA	NA	NA	Omitted	Davis et al. 2012 [14X], Lowenstein et al. 2014 [30X]	Chicago City

Table 2.12. Set recipes for *MOBILE*NATIVE* displayed with omitted Recipes O-C and O-D.

MOBILE NATIVE animal diversity in cities can be boosted by various habitat features, driven by bottom-up or top-down factors. Three subsets of recipes differing in city

density and considered land uses demonstrate that the differing salience of these factors and if and when they align with SES.

First, in *sparse* cities when researchers consider *residential* land, residential drivers related to food resources and habitat quality (and especially mature trees) support native diversity in higher SES areas (Table 2.12, Recipes 4-6; Goddard et al. 2013 [19X]; Fuller et al. 2008 [14X]; Lerman and Warren 2011 [27X, 27Z], Kinzig et al. 2005 [24X, 24Y], Farmer et al. 2013 [16X], Li and Wilkins 2014 [28X]; Belaire et al. 2014 [03X], Magle et al. 2016 [33X]). However, some of these cases consider sites with suitable habitat nearby (e.g., transects extending from the edge of riparian forest preserves into residential neighborhoods [03X] and camera stations in sites representing “potential wildlife habitat” such as city parks, golf courses and cemeteries [33X]), suggesting that larger scale landscape context plays an important role in shaping animal diversity beyond residential actions.

Second, in *sparse* cities when researchers consider *CITY*-wide land uses, top-down drivers related to urban form and segregation shape the relationship between SES and native animal diversity (Table 2.12, Recipes 5-7). In some cities, such as Vancouver and Leipzig, segregation along ethnic or economic lines coincides with different urban forms (housing density and age) and green space quality (management and maturity) such that higher SES areas have greater native mobile animal diversity (Melles 2005 [37X], Strohbach et al. 2009 [43X]). Bottom-up drivers are still important in these cases, via lower quantity or quality of home gardens (*i.e.*, Leipzig) or lower participation in residential and community green-up efforts (*i.e.*, Vancouver) within lower SES neighborhoods. Other included cities in this subset show a similar combination of bottom-up and top-down factors shaping the SES-biodiversity relationship (Lerman and

Warren 2011 [27X, 27Z]; Kinzig et al. 2005 [24X, 24Y]; Farmer et al. 2013 [16X]; Li and Wilkins 2014 [28X]; Belaire et al. 2014 [03X]; Magle et al. 2016 [33X]). Yet, omitted recipes in Chicago Metro, Valdivia, Sydney, and Reno show that the very same features of urban form salient in included recipes do not inevitably coincide with economic or ethnic segregation (Table 2.12, Recipe O-C). Widespread high-quality habitat in the form of remnant vegetation supports bird diversity throughout cases in Valdivia and Reno, minimizing the effect of SES (Silva et al. 2015 [42X, 42Y]; Trammell and Bassett 2012 [44X, 44Z]). And in Chicago Metro and Sydney, SES similarly played a minimal role in shaping mobile animal diversity compared with factors related to urban form, such as housing density, green space availability, and undeveloped or vacant land (Loss et al. 2009 [29X, 29Z]; Zivanovic and Luck 2016 [49X]; Makinson et al. 2017 [34X]). In these cities, quality habitat or housing density did not align as distinctly with SES, at least in the ways they were measured and evaluated. Further, in some cases, researchers suggested the potential importance of interspecies interactions. In Sydney's parks, for example, the agonistic Noisy Miner (*Manorina melanocephala*) may shape bird community composition with more potency than human drivers while for bees in community gardens, the presence of specific bee-attracting plants may be independent of the SES of any garden's surrounding district (Zivanovic and Luck 2016 [49X]; Makinson et al. 2017 [34X]).

Third, cases in *DENSE* cities and that consider *CITY*-wide land uses show negative or neutral relationships between SES and native mobile animal diversity also driven primarily by top-down drivers related to urbanization, segregation, and diverse human preferences (Table 2.12, Recipe 8). In Belo Horizonte, urbanized areas are noisier, denser, wealthier, less green in terms of canopy cover, and support lower bird diversity (Perillo et al. 2017 [40X]). In Chicago City, diverse human preferences in a dense and

segregated city creates inconsistent relationships between SES and biodiversity (Table 2.12, Recipe O-D). Limited space pushes some residents to maximize floral diversity in their gardens, providing resources for insect pollinators (Lowenstein et al. 2014 [30X]) while different preferences for amenities and financial means to either increase canopy cover or choose where to live, shape differences across the city in bird diversity (Davis et al. 2012 [14X]). Cases in these dense cities demonstrate that residential drivers may be important for biodiversity (*e.g.*, where people live, gardening choices) but are subsumed or shaped by larger scale forces related to density (*e.g.*, traffic, limited yard space, *etc.*).

c. Set Recipe: *MOBILE*exotic*

Recipe	Mobility	Native Status	Land Use	Stratification	Tropicality	Aridity	Density	Age	Inequality	Raw Coverage	Unique Coverage	Consistency	Analysis	Cases	Cities
9	MOBILE	exotic	res	not strat	temperate	humid	sparse	young	equal	0.06	0.02	1.00	Positive	van Heezik et al. 2013 [45X]	Dunedin
10	MOBILE	exotic	CITY	STRATIFIED	temperate	humid	sparse	young	UNEQUAL	0.05	0.04	1.00	Positive	Loss et al. 2009 [29Y]	Chicago Metro
O-E	MOBILE	exotic				ARID	sparse	young		NA	NA	NA	Omitted	Lerman and Warren 2011 [27Y], Trammell and Bassett 2012 [44Y]	Phoenix, Reno

Table 2.13. Set recipes for *MOBILE*exotic* displayed with omitted Recipes O-E.

Mobile non-native animal diversity tends to be higher in areas with higher ornamental or exotic tree abundance and lower remnant habitat availability. The relationship between these conditions and SES differs from city to city. Included recipes demonstrate that in *sparse*, *young*, and *humid* cities, conditions supporting non-native diversity may be more common in higher SES areas (Table 2.13, Recipes 9-12; van Heezik et al. 2013 [45X]; Loss et al. 2009 [29Y]). Omitted recipes show that in *sparse*, *young*, and *ARID* cities, conditions favoring non-native diversity may be more common in lower SES areas (Table 2.13, Recipe O-E; Lerman and Warren 2011 [27Y], Trammell and Bassett 2012 [44Y]). This contrasting pattern may be driven by different cultural preferences between humid and arid cities regarding what types of vegetative communities are preferred or valued by residents with the means to attain them.

D. Discussion

To what extent does SES shape biodiversity in cities? It depends upon a combination of taxonomic and study design considerations as well as features of the city itself. Our meta-analysis illuminates some of the major combinations of conditions associated with SES-biodiversity relationships in cities and their detection. We present some unifying themes that may help researchers, activists, practitioners, and planners understand what type of relationships may exist between SES and biodiversity in their city and how they might go about measuring or addressing such relationships. Finally, we identify serious gaps in our knowledge to date concerning methodology, coverage, and generalizability and offer best practices moving forward.

1. Taxonomic Considerations

Our analysis yielded several common mechanisms through which bottom-up and top-down forces related to SES shape or fail to shape plant diversity. *WOODY* plant diversity is reliably shaped by top-down socioeconomic factors across *CITY*-wide land uses, though different mechanisms operate for *NATIVE* vs. *exotic* species in different city contexts. On *residential* land, bottom-up socioeconomic factors shape *mixed* plant diversity, though specific mechanisms are varied and include different household preferences and needs and the material ability to act on them, as well as segregation that shapes what is appropriate or possible in a given neighborhood. However, if a given city is characterized by a “Hausmann Paradox” or if researchers *do not stratify* sampling or measure the supposed drivers of plant diversity at an inappropriate scale, they may not detect any relationship between SES and biodiversity at all.

Animal diversity, on the other hand, appears to be driven by a combination of bottom-up and top-down forces that are not as reliably aligned with SES nor cleanly identified by taxonomic divisions, study designs, or city conditions. Rather, *NATIVE* animal diversity is boosted when native plants are available, human disturbance is lower, or both. *Exotic* animal diversity is boosted when non-native plants are available, human disturbance is higher, or both. In some cases, conditions favorable for diversity align with high SES areas, while in other cases, they don't. In animal diversity cases, bottom up forces are more likely to be detected when considering *residential* land uses while top down forces are more likely to be detected when considering *CITY*-wide land uses. Because animals are mobile and utilize diverse landscapes such as yards, parks, and rivers, authors generally concluded that multiple factors were important.

These findings are consistent with the framework proposed by Kinzig et al. (2005) that humans generally have direct control over plant diversity but only indirect control over animal diversity. Indeed, studies at the regional or multi-city scale further affirm this pattern (see Appendix E), with reliable associations between SES and woody plant diversity (the Eastern Cape of South Africa: Kuruner-Chitepo and Shackleton, 2011, the Pacific Northwestern US: Mills, Cunningham and Donovan, 2016) but variable associations between SES and anuran, bird, and mammal diversity (southeastern Australia: Smallbone, Luck and Wassens, 2011 and Luck, Smallbone and Sheffield, 2013, west-central Mexico: MacGregor-Fors and Schondube, 2011, Liberia: Junker et al. 2015). Yet another way to conceptualize these findings is to recognize that individual species may be more or less influenced by specific SES-mediated drivers. Studies of mammal species diversity, for example, demonstrate that the presence of a certain species or group of species might be associated with SES while other related species or species groups are not (Li and Wilkins 2014 [28X], Magle et al. 2016 [33X], and also

Goad et al. 2014, Haverland and Veech 2017). The same is true of some cultivated plant species (e.g., Seburanga et al. 2014) as well as some native specialist bird species (e.g., Lerman and Warren 2011). While measurements of alpha diversity or species richness are imprecise tools to understand these species-specific responses, they may help capture general trends in the broader biotic community and point to individual species for further investigation.

2. Study Design Considerations

The land uses examined and stratification scheme were important design considerations associated with whether or not researchers observed SES-biodiversity relationships. Relationships between SES and both plant and animal diversity were more common on *residential* land, suggesting that bottom-up drivers may be more salient in general. Importantly, plant-related mechanisms appeared to differ by climate while animal-related drivers depended on nearby suitable habitat. Nonetheless, top-down patterns across *CITY*-wide land uses were still detected, especially for *WOODY* plants and *MOBILE* animals. Researchers that *STRATIFIED* their sampling by SES were able to detect key mechanisms aligning plant diversity with SES, especially concerning differential civic lobbying power or residential segregation. *Not stratifying* by SES helped researchers notice other drivers shaping plant diversity, such as preference, housing density or a “Hausmann Paradox.” The scale of SES and biodiversity data was variable across recipes with few clear relationships with the outcome. However, spatial scale was often related to other conditions, such as taxonomic group and land uses considered. In a meta-analysis of urban forest cover and income, researchers found that studies conducted at finer spatial scales had smaller effect sizes compared to studies conducted at larger scales, either indicating that urban forest cover is driven by larger scale processes or at finer scales there was an excess of measurement error (Gerrish and

Watkins 2018). Our study suggests that SES and biodiversity measurement scales are more relevant to considerations of land use and taxa than to effect sizes or the scale of the underlying processes.

3. City Conditions

Cases with shared combinations of city conditions often shared underlying mechanisms explaining the nature of SES-biodiversity relationships.

Aridity was a critical condition in explaining many of the plant cases and some of the animal cases. In *ARID* cities, *exotic WOODY* plant diversity is often driven by municipal “luxury” investments in trees that provide ecosystem services such as shade and cooling, especially in *UNEQUAL* cities. *Exotic mixed* plant diversity is often shaped by a “Hierarchy of Need” in which wealthier residents plant a wider array of ornamental species. This mechanism is commonly invoked in *sparse* cities in *developing* countries (e.g., Clarke et al. 2014). Higher SES areas in *ARID* cities in *DEVELOPED* countries tend to feature higher *NATIVE* animal diversity and lower *exotic* animal diversity, due to the greater availability of native habitat in higher SES neighborhoods, which may be related to a general preference for native landscapes but unequal the means to attain them. Favorable climates in *humid* cities change SES-biodiversity relationships for several reasons; lower costs to maintain plants, different landscape preferences among residents, and different biological community responses to resource inputs or the plant template. Residents’ preferences and economic segregation frequently shaped *residential* plant communities in *humid* cities although there were numerous cases in which SES and plant diversity were not associated with each other, especially in *equal* cities. *Humid* cities showed a mix of patterns with regards to SES-animal diversity relationships, though in contrast to *ARID* cities, some *humid* cases featured higher *exotic*

animal diversity in high SES neighborhoods. In their meta-analysis of the effect of income on urban forest cover, Gerrish and Watkins (2018) similarly predicted that aridity and precipitation would help explain the differential influence of financial resources. Although they found that climate information did not play a role in explaining the SES-forest cover relationship, it is possible that biodiversity responds differently, especially for taxa that require fewer resource inputs (vascular plants) or that cascade trophically upward (invertebrates, birds, and mammals).

Density was a necessary condition in many of the plant and animal subsets. In *sparse* cities, residents are more likely to have space they can manipulate. With enough space, residents can convert material or financial resources into those that promote biodiversity such as plantings or bird feeders. In *DENSE* cities, less residential space suppresses such bottom-up influences; in *DENSE* cities characterized by the “Hausmann Paradox,” higher SES residents have the least space to manipulate, further reducing alignment between SES and biodiversity.

INEQUALITY, when present, can sharpen SES-biodiversity relationships, especially for *WOODY* plants in *ARID* cities or *low-mobility* terrestrial animals in *sparse* cities. *Equality*, can either dampen SES-biodiversity relationships or make them harder to detect, especially for *mixed* plants in *humid* cities or *low-mobility* aquatic animals. One general principle may be that in *equal* cities, and especially those with favorable climates or in *DEVELOPED* countries, municipal decision-makers may be able to stretch budgets further to more equitably green the city, following the hypothesis of Kinzig et al. (2005) that “perennial plant diversity in parks is largely controlled by top-down processes, including, most prominently, municipal decisions concerning landscaping and management... and is not expected to vary with socioeconomic or cultural

characteristics.” This may have been the case in Sydney, Halton, and Paris, *equal* cities where SES and biodiversity did not align with each other on *CITY*-wide land uses (Cohen et al. 2012; Gledhill and James 2012; Zivanovic and Luck 2016). It is possible that public policies favoring the equitable distribution of nature may be more common in *equal* cities. In Maastricht, Beumer and Martens (2016) observed that neighborhood differences driven by personal socioeconomics and decisions are somewhat ameliorated by such public policies; although researchers observed few private trees in the lowest SES neighborhood studied, there were many public trees. Beumer and Martens (2016) also observed that a social-housing company had carried out a project in that same neighborhood where children made nest-boxes and placed them on street trees and home walls. While these interventions may reflect Maastricht’s status as an *equal, humid, DEVELOPED* city, a similar observation was made in the *UNEQUAL* city of New York City where there are more community gardens in lower SES neighborhoods (Matteson et al. 2013). As such, economic inequality within cities may be less salient than the general character of cities’ public policies and poverty-related interventions.

Degree of national development was particularly informative for some of the *mixed* plant cases in which authors leaned on the “Hierarchy of Need” hypothesis to explain the patterns they observed (e.g., Clarke et al. 2014). However, the “Hierarchy of Need” hypothesis may not be exclusively salient in low development settings, signified by the fact that the Recipe 11 (Table 2.9) contained cities both in and out of the set of *DEVELOPED* countries (i.e., Phoenix and Tlokwe) and therefore did not include the condition *DEVELOPED*. In fact, researchers have documented food security motivations shaping plant communities in Los Angeles (Clarke and Jenerette 2015), New Orleans (Douglas and Lawrence 2011), and Portland, Oregon (McClintock et al. 2016), suggesting that the “Hierarchy of Need” hypothesis is relevant in *DEVELOPED* countries

as well as *developing* ones. Indeed, the United Nations recognizes that regardless of the degree of human development, poverty and disadvantage can be quite high, especially for ethnic minorities (Jahan 2016). One explanation for this contradiction may be that the “Hierarchy of Need” hypothesis is particularly salient in *developing ARID* cities given the higher relative cost of purchasing and irrigating ornamental species compared to *DEVELOPED ARID* cities or *developing humid* cities. Indeed, in their meta-analysis of cultivated plant lists from across the world, Kendal et al. (2012b) observed that home food production is less common in western temperate and cold climate gardens, which also tend to be of higher development status. In corroboration of this observation, Cubino et al. (2015) found that residents in Costa Brava did not primarily garden for economic reasons (e.g., obtain food or other household products). Critically, the recipe for Cubino et al. (2015) contained the same combination of necessary conditions as recipes in which the “Hierarchy of Need” was invoked as a mechanism apart from *developing*. Alternatively, the “Hierarchy of Need” hypothesis may be commonly invoked in low development settings given coinciding histories of segregation, colonialism, disenfranchisement, and participation in markets among higher SES households. These latter factors may do a better job explaining differences in diversity among SES groups. Given the similarities in the SES-residential plant diversity relationship between Phoenix and the cities of Tlokwe, Bujumbura, Beijing Metro, and Niamey, the “Hierarchy of Need” hypothesis may be misapplied.

Tropicality and city age were not critical conditions in explaining SES-biodiversity relationships. Tropicality and aridity conveyed similar information about how favorable a city’s climate was for plant growth, but aridity was generally more directly relevant. Further, almost all *ARID* cities were also *TROPICAL*, except for Beijing, Costa Brava, and Reno, which were all situated between 39° and 43° N latitude. City age was never

necessary within subsets but also never invoked as a relevant mechanism by case authors. What mattered more was within-city differences in site age.

While these summaries point to some common themes for certain taxonomic groups or in types of cities, the sheer diversity of circumstances and mechanisms through which SES and biodiversity may align challenges the notion that associations between SES and biodiversity are somehow inevitable features of urban ecosystems (Leong et al. 2018). Rather, many of the reported alignments appear coincidental or overly dependent on study design or city condition. Regardless, examining associations between SES and biodiversity where they do and don't exist remains a worthwhile pursuit to better understand both the human drivers of urban biodiversity (Aronson et al. 2016) and the socio-ecological outcomes of economic inequality. Here we present case counterpoints that illustrate the types of unifying lessons we can learn through this inquiry. Critically, each theme untangles a common assumption in the concept that human wealth, resources, or power necessarily elevates biodiversity (the "Luxury Effect").

4. Unifying Themes: Preference and Segregation

Throughout the world and across the city, individuals and communities have diverse preferences regarding biodiversity. These preferences may be related to SES, cultural norms, or feedback loops from living in high or low biodiversity settings. In Phoenix, Arizona, for example, Lerman and Warren (2011) found that residents reported higher satisfaction with bird diversity in their neighborhoods when they actually lived in neighborhoods with higher, rather than lower, avian diversity. In other settings, there may be group-level pressure to uphold a certain "ecology of prestige" by maintaining a certain symbolic yard aesthetic through planting and maintenance (Grove et al. 2006). Biodiversity isn't favored in all settings. Lubbe et al. (2010), for example, describe the

“lebala” concept among Botswana residents in Tlokwe, South Africa, in which the area surrounding the house should be devoid of vegetation to reflect tidiness and order. Kirkpatrick et al. (2007) similarly observe that many Anglo-Australians in Hobart tend to dislike having trees in their yards. The “ecology of prestige” may also promote low biodiversity if that is a symbol of a desirable social status via monoculture turf lawns (Robbins 2007). In the majority of our cases in our meta-analysis, biodiversity preference and SES aligned in accordance with the “Luxury Effect.” We suggest that this alignment is not inevitable, but rather a coincidental feature of studies that have been conducted to date.

Regardless of preferences or needs, opportunities for residents to transform material or financial resources into those promoting biodiversity can vary greatly within or between cities. There are numerous constraints that limit residents’ abilities to change their landscapes, and under the “Luxury Effect” framework we would expect these factors to be more limiting to residents of lower SES, who may have fewer resources or agency to overcome demands of space, resource inputs, or maintenance (e.g., Lubbe et al. 2010). But this is not always the case, especially when favorable climates, public policies, or space availability lowers or eliminates barriers to landscape change. Beyond residents’ yards, the “Luxury Effect” also assumes that lower SES residents will either actively or by circumstance live in settings of low environmental quality (e.g., Melles 2005, Strohbach et al. 2009). Indeed, there is a vast environmental justice literature documenting this pattern, some of which is explained by colonial legacies, institutional racism, and practices such as redlining, in which banks and insurance companies systematically denied housing loans to minority groups in US cities (Bolin et al. 2005). Other explanations include a combination of social stratification and housing filtering, wherein lower SES residents end up in neighborhoods of lower environmental quality as

higher SES and more mobile residents selectively move to more expensive, higher quality neighborhoods (Chowdhury et al. 2011). But this situation is not inevitable, especially for cities that prioritize green space provision for lower SES residents or where the residents themselves desire, attempt, and succeed in elevating their own environmental quality (e.g. Matteson et al. 2013). Further, residents may be subject to top-down municipal priorities that either favor and implement biodiversity through urban forestry programs or park maintenance practices (Hernández and Villaseñor 2018) or conversely favor and implement low biodiversity solutions like homogenous street tree plantings or green spaces consisting primarily of turf grass (Aronson et al. 2017).

Residential segregation is common throughout the world's cities and the top-down processes that separate people by race, ethnicity, or SES often result in differences in biodiversity between different groups (Roman et al. 2018). Yet economic segregation may interact with racial or cultural diversity to yield contrasting results, as seen in Chicago City and Phoenix. Researchers in both cities stratified neighborhoods by income but some of the resulting sites were diverse in terms of race and ethnicity; namely, some neighborhoods were mostly white, some were mostly non-white, and others were more diverse. In Phoenix, Kinzig et al. (2005) found highest plant species richness in neighborhoods of high income and education that were also mostly white. Authors concluded that household landscaping choices shape plant diversity and that socioeconomic resources are needed to realize those choices. In Chicago City, Lowenstein and Minor (2016) found greatest floral richness in middle-income ethnically diverse neighborhoods (with intermediate portions of Hispanic and white residents). Authors argued that residents use their yards for social and cultural expression such that neighborhood with high cultural diversity would also have high species diversity. Meanwhile, higher SES and lower SES neighborhoods tended to be more culturally

homogenous, and therefore supported lower floral diversity at the neighborhood scale. Authors therefore reported a non-linear SES-biodiversity relationship. Interestingly, in both cities, researchers reported correlations between the racial or ethnic composition and income of their study neighborhoods (percent Latino-Hispanic in Phoenix and percent white and percent black in Chicago City). Why did researchers observe a more linear SES-biodiversity relationship in Phoenix compared with Chicago City? It could be differences in how economic segregation sorts racial or ethnic groups between the two cities and the resultant outcomes in terms of yard size and quality. It may also be because in Phoenix, researchers measured perennial plants while in Chicago City, researchers measured herbaceous plants. Perennials have higher associated costs to purchase and maintain in an arid city (Shochat et al. 2008), potentially washing out the effects of social or cultural expression in ethnically diverse neighborhoods. These cases show that one of the potential outcomes of segregation is differences in biodiversity, but if economic segregation isn't necessarily racial or ethnic in character, there may still be higher biodiversity in lower or middle SES areas, but it may depend on the taxa and climate in question.

5. Opportunities for the field

While the "Luxury Effect" term is less than 20 years old, observers have noticed differences in biotic communities across the city for centuries (Leong et al. 2018). And while researchers have collectively amassed an informative body of knowledge concerning SES-biodiversity relationships in (at least) 34 individual cities, we propose four urgent opportunities for the field moving forward.

First, a key goal should be to clarify the mechanisms that shape biodiversity and are related directly SES. Most cases we assessed related SES and biodiversity but omitted

the supposed mechanisms linking the two from their analyses. Obviously, biological communities do not respond directly to human SES but rather to the absence, presence, or quality of some intermediate resource, feature, or condition connected to SES. And indeed, most case authors, when justifying their inclusion of SES variables in their analyses, acknowledged that SES was truly a proxy for other, harder to measure, features. If authors did find a relationship between SES and biodiversity, they often speculated about those unmeasured mechanisms. Moving forward, researchers should focus on these mechanisms explicitly. For some, collecting the relevant information is doable, as with the provisioning of expensive high-quality bird food or residential segregation that relegates lower SES individuals to low quality environments they cannot improve. Researchers can survey residents about bird feeding habits (e.g., Fuller et al. 2008), for example, or assess the proportion of green space in a neighborhood that is managed directly by residents or the size of residents' yards (e.g., Cubino et al. 2015). Omitting mechanisms that link SES with biodiversity may lead authors to borrow mechanisms reported by other researchers using different study designs or operating in cities with very different urban forms or development histories. Some authors may be tempted to rely on their own observations that are neither systematic nor rigorously collected. In doing so, we forego an opportunity to understand the varied drivers that shape biodiversity throughout the world's cities and therefore our ability to either address the problem of "biological poverty" where it exists or improve urban ecosystem functioning across the city (Turner et al. 2004).

Second, the cases we assessed included a wide diversity of methods that would be challenging to compare outside of the fsQCA framework. While our analysis accounted from some differences in sampling schemes (*i.e.*, stratification by SES or not) and spatial scales of SES and biodiversity data (*i.e.*, single-parcel or larger), we could not entirely

account for other differences in study design (e.g., degree of site replication, taxonomic scope), SES data types (i.e., household income versus land values), biodiversity data types (e.g., species richness versus species diversity), or statistical approaches (e.g., univariate versus multivariate versus ordered ranking). The issue of non-comparable methods is inherent to meta-analyses but is especially challenging in this context where SES data availability and biodiversity collection methods will fundamentally vary widely across countries and taxonomic groups. For example, Wang et al. (2016) noted that Chinese city dwellers were reluctant to share private data about their income and education level, unlike city dwellers in other countries. Different taxonomic groups demand different approaches as well. There are simply fewer mammal species than plant species in the world and authors of included mammal cases utilized presence/absence or occupancy modeling rather than species richness or diversity (e.g., Magle et al. 2016, Li and Wilkins 2014, Nilon and Huckstep 1998). Nonetheless, echoing Blicharska et al. (2017), “Future studies are needed to investigate in detail in what way the socioeconomic factors could influence biodiversity in terrestrial and aquatic environments in the cities. These studies should use as similar methods as possible and there is a need for comparative studies in the same geographic area.” Although such quantitative meta-analyses may obscure important non-linear relationships (e.g., in Cohen et al. 2012, Lowenstein and Minor 2016), comparable methods would inevitably be valuable for regional comparisons or those involving a small number of similar cases (e.g., aquatic invertebrates in European cities).

Third, researchers should consider a wider diversity of cities and taxonomic groups. Indeed, only 18% of available cases focused on herbaceous plants, mammals, invertebrates, or herpetofauna. Although non-native animal species are few in number, studies of exclusively non-native animal diversity in relation to SES are lacking (11% of

available cases) yet likely worthwhile. Regarding city conditions, only 19 cases occurred in *developing* cities (23%). Only four of those cities were in countries with low or medium HDI, all of which were also in Africa. The research and publication bias favoring developed countries exacerbates to the already wide knowledge gap concerning the drivers of biodiversity in developing countries (Botzat et al. 2016). Cases were also limited in age diversity, with only two cities undergoing urbanization post-1950. Yet global urban development has increased in pace since 1950, accompanied by changes in urban form and location. It is possible that these newer urban centers, primarily in Asia and Africa, show different SES-biodiversity relationships compared with those we considered in our meta-analysis (Seto et al. 2010). In addition, there were large swatches of the globe without representation in our analysis; these include the higher latitudes, northern South America, the Pacific Islands, North Africa, the Middle East, and the entire continent of Asia, apart from Beijing (Figure 2.2).

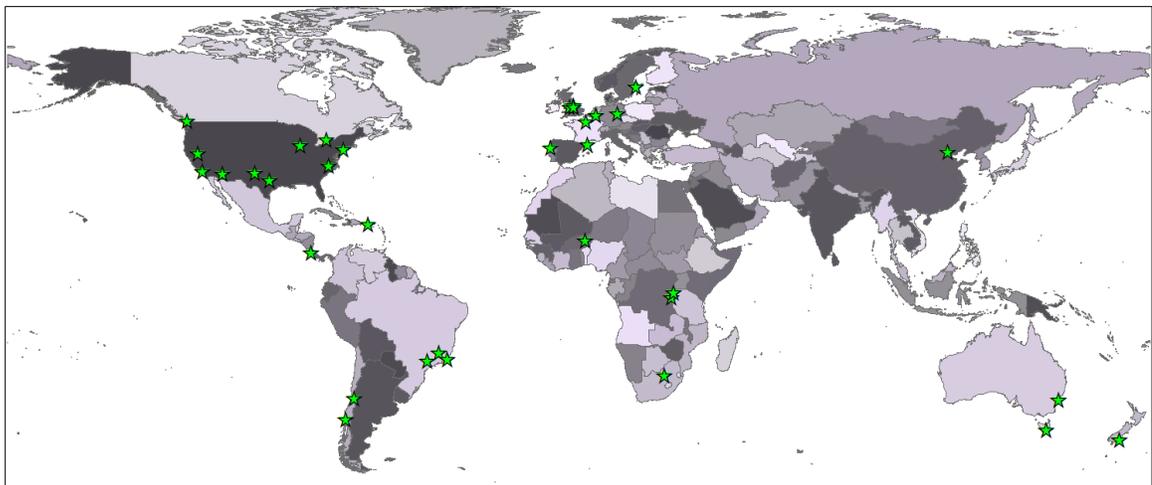


Figure 2.2. Locations of cases included in the meta-analysis, as represented by stars.

For both the plant and animal analyses, there were key combinations of conditions captured by few, if any, available cases (Table 2.14). Critically, there was only one animal case in a *developing* country city (Belo Horizonte, Brazil), and all *ARID* cases occurred in the southwestern US and were further characterized as *sparse*,

DEVELOPED, *UNEQUAL*, and *young*. Some of these coverage issues for plants and animals could be resolved by conducting analyses in cities where research has already taken place. For example, many plant cases occurred in arid cities that were *DENSE*, *developing*, *equal*, or *OLD*. Many other potential cities exist that would meet address the gaps in our current knowledge (Table 2.14).

Plant Conditions of interest	Included Cities	Potential Cities
<i>temperate, ARID</i>	Costa Brava, Beijing	Reno, NV, United States Ulaanbaatar, Mongolia Ashgabat, Turkmenistan
<i>temperate, humid, developing</i>		Kiev, Ukraine Chişinău, Moldova
<i>equal, developing</i>	Niamey, Bujumbura	Wuhan, China Kiev, Ukraine Mumbai, India
<i>equal, DENSE</i>	Paris, Porto	Stockholm, Sweden Karachi, Pakistan Mumbai, India
Animal Conditions of interest	Included Cities	Potential Cities
<i>ARID</i> in combinations with <i>DENSE, OLD, equal,</i> <i>developing</i>		Casablanca, Morocco Cairo, Egypt Karachi, Pakistan Ankara, Turkey Hermosillo, Mexico Beijing, China
<i>OLD, UNEQUAL</i>	Valdivia, Raleigh	Cape Town, South Africa San Juan, PR, United States Santiago, Chile
<i>OLD, TROPICAL</i>	Sydney	Wuhan, China San Juan, PR, United States Santiago, Chile

Table 2.14. Combinations of city conditions missing from plant and animal analyses. For some combinations of conditions, one or two cities were indeed included in the analysis. Other potential cities are suggested for future research.

Regarding study design considerations, animal cases almost exclusively utilized SES and biodiversity data collected at *BROAD* scales beyond the individual household. While animals are mobile and do move beyond parcels, it is possible that finer scale data collection could better identify bottom-up drivers related to residential decisions, as illustrated by the work of Farmer et al. 2013 [16X], van Heezik et al. 2013 [45X], and

Leong et al. 2016 [26X]. Plant cases also tended to utilize SES data at *BROAD* scales, potentially obscuring fine-scale variation in SES within neighborhoods. A final uncommon type of plant case considered exclusively non-residential land uses. While fsQCA weighs all unique combinations of conditions equally, the limited diversity of cases limits our collective understanding of how and where SES-biodiversity relationships take shape. Case in point: among our 34 cities, 20 were each only represented by one case (24% of total cases) while two cities, Phoenix and Chicago, were together represented by 25 cases (30% of total cases).

Fourth, researchers and planners would benefit from more precise characterizations of cities regarding conditions that may align socioeconomic inequality with biodiversity. It is often convenient to characterize cities by region, urban form, or history; we similarly determined membership based on these characterizations in our meta-analysis. However, we found that these characterizations were often without clear definitions or associated mechanisms. For example, previous meta-analyses have found that city age is a useful predictor of native plant species density (Aronson et al. 2014). We considered city age but struggled to clearly delineate between “old” and “young” cities based on the “relative onset of urbanization” given the varied meaning that term may have in different regions as well as data paucity in ascertaining when urbanization began. While city age may broadly capture some features of a city, researchers in our case studies were more likely to focus on within-city differences in site or neighborhood age. The same was true for density, where within-city differences were often more salient to researchers than overall density (though the latter feature was useful in characterizing the “Hausmann Paradox”). While it is true that newer cities are also more likely to have newer housing developments, especially in low density settings where land is available for development, older cities may also have new developments, as in the case of Beijing

(Wang et al. 2016). Further, the mechanisms through which site age affects species richness may depend on each city's ecoregional context and the ways in which development alters natural landscapes. For example, in Chicago Metro, newer housing developments tend to occur in previously forested or agricultural landscapes and often retain some of the remnant vegetation, thus supporting biodiversity. As these developments age and intensify, natural elements are generally replaced with housing, thus diminishing biodiversity (Loss et al. 2009). In other ecoregional contexts, neighborhoods can mature and support more biodiversity (Grove et al. 2006). Regional characterizations were also challenging to capture given that a group such as the "Latin American cities," while united by some shared features like culture, colonial history, rapid growth, and NGO-led development, may differ substantially in terms of every other city condition. Therefore, some of the mechanisms proposed by authors of cases in Latin America that may indeed be uniquely Latin American, such as the role of non-municipal green space in Valdivia (Silva et al. 2015), could not be applied to other cities in the same category if different combinations of conditions described that city. Another feature that needs further exploration is climate, especially the role of aridity, high temperatures, and low temperatures in shaping SES-biodiversity relationships. In a meta-analysis of cultivated floras, researchers found that temperature was a strong filter determining species composition, suggesting that humans have yet to overcome that barrier to cultivation (Kendal et al. 2012b). Jenerette et al. (2016) also found that minimum winter temperatures were critical in explaining urban tree biodiversity in US and Canadian cities. Like aridity, low winter temperatures pose challenges for plant communities to thrive year-to-year and may demand greater material inputs. While none of the case authors discussed the effect of cold winter temperatures as influencing their results, it is also true that only 9 out of the 34 included cities were above 45° latitude and none were beyond 60° latitude. Future work should investigate how climatic features beyond aridity

pose material constraints for SES-influenced landscape change. Other differences between cities were challenging to capture, such as zoning frameworks and cultural preferences that shape where individuals with high or low SES end up living (e.g., on the urban periphery or in the downtown core). Meanwhile, municipalities with high residential turnover may deter people from investing in their public or private green spaces, either for lack of motivation or lack of time for investments to pay off (Ramalho and Hobbs 2012). The means through which individuals obtain plants or plant or animal resources (Torres-Camacho et al. 2017) as well as the types of lawn care services available can constrict biodiversity potential but may also differ city to city (Harris et al. 2012).

6. Implications for planning and conservation

Alignment between urban biodiversity and socioeconomic inequality has material consequences for city residents, whether they are people, plants, or animals. First, residents with lower SES end up living in lower biodiversity settings, receiving fewer ecosystem services (Turner et al. 2004). There are also harder-to-measure “quality of life” benefits associated with living in high biodiversity neighborhoods that may express themselves in greater satisfaction with one’s neighborhood (e.g., Lerman and Warren 2011) or even higher home values (e.g., Farmer et al. 2013). There is experiential value as well associated with biodiversity. Interacting with nature, especially charismatic or psychologically salient elements, can inspire a sense of wonder and care for the natural world and its protection, especially for children (Louv 2005; Miller 2005). Second, alignment means that there are pockets of low biodiversity and/or unsuitable habitat throughout the city, which may challenge the persistence of certain species or biological communities (Bonnington et al. 2015; Lepczyk et al. 2017). That these pockets are socioeconomic in nature also makes them more dynamic over time and challenging for planners and ecologists to address. For example, Kirkpatrick et al. (2011) found that

increases in tree density in six eastern Australian cities between 1961 and 2006 were correlated with increases in income and education, likely driven by changing environmental attitudes and residential patterns associated with gentrification. Addressing these ecological problems may appear straightforward with the right interventions, such as targeted shrub plantings in residential yards or coordination among green spaces to improve habitat connectivity (Aronson et al. 2017; Savard et al. 2000). However, we propose that alignment is not a solvable ecological problem per se but rather a manifestation of social inequality related to differential access to material resources and public services or unequal municipal investments in different neighborhoods. Different histories of urban development will shape these inequalities in different ways and require different solutions.

We nonetheless suggest two strategies to address alignment between biodiversity and SES. Regarding bottom-up drivers, cities could work to expand opportunities for residential self-expression through cultivated plants. In cities where inequality in yard size or restrictive ordinances drive inequality in biodiversity, cities can increase the availability of non-residential green spaces such as community gardens beyond the home or reevaluate policies at the local level that restrict people's abilities to plant. Cities can also subsidize the cost of native plants or those that benefit animal specialists. Of course, cities can't force residents to bio-diversify their yards, but by empowering residents to use their yards as avenues for self or cultural expression, cities can help make *neighborhoods* diverse for all residents, cascading into positive outcomes for individual residents. For instance, Leong et al. (2016) [26X] found that indoor arthropod species richness could be explained not only by vegetation in each household's backyard but by their neighbor's gardens as well. While cumulative residential decisions at the neighborhood scale matter for animal diversity, so too does the quality of non-

residential land, be it parks, cemeteries, or remnant forest patches (McKinney 2002). It is in this realm that cities can address alignment via top-down drivers. High quality public spaces for native plant and animal diversity in cities could be strategically expanded or protected in lower SES areas. However, care should be taken to either avoid too much greening such that property values rise and original residents are displaced or to ensure that housing policies are in place to protect residents from being priced out of their neighborhoods if or when gentrification through greening occurs (Wolch et al. 2014).

City residents don't only experience biodiversity where they live. An individual that lives in a biodiversity-poor neighborhood may work in a biodiversity-rich one, or regularly visit friends or family or recreate in a different biodiversity setting and reap the benefits. As such, promoting biodiversity in non-residential green spaces throughout the city can both support rich biotic communities and provide opportunities for residents to experience and benefit from nature wherever they are.

As the global urban population grows, city planners and ecologists must look toward the future and consider how urban growth scenarios will impact both biodiversity and socioeconomic inequality (Seto et al. 2012). Cities are often located in biodiversity hotspots and at the same time responsible for habitat fragmentation, species extirpations, and ultimately biodiversity loss. As cities expand, different conservation strategies are needed depending on the nature of potential biodiversity impact and the governance capacity (*i.e.*, regulatory quality, political stability, absence of violence or terrorism) (Huang et al. 2018). Especially for peri-urban communities, informal settlements on the formal boundaries of cities, or areas with intact remnant vegetation, careful urban growth should attempt to maintain biotic communities while meeting human needs. Sometimes there will not be an ideal growth scenario (Sushinsky et al.

2017), but with a more nuanced and global understanding of how biodiversity aligns with socioeconomic inequality in cities, we can better address inequality of nature exposures and experiences now and in the future while at the same time promoting biodiversity conservation and urban sustainability (Strife and Downey 2009).

APPENDIX A ADDITIONAL METHODS INFORMATION

- Ethical Considerations

The entailed study did not contain materials or methods subject to PPRA or FERPA. The study was approved by the University of Massachusetts Institutional Review Board on 6-June-2017 (Protocol 2016-3043) and by the SPS Assessment, Research, and Accountability Department on 25-October-2016.

Parental consent was obtained via the ECOS Registration and Permission Form. This form was distributed to parents and guardians in order for their children to participate in ECOS. The first page of the packet contained information about ECOS and the second page contained details about the study. The third page asked for the following from parents or guardians:

- permission for their children to attend ECOS
- home address information for ECOS' purposes
- consent for their children to participate in the study
- a box for parents to check in order to grant permission for their address to be used in the Neighborhood Habitat Analysis

The research study only used address information in which permission for use had been granted. Registration and Permission Forms were divided by school and ECOS teachers assigned an alphanumeric code to each completed consent form from the Student Codebook (for example: WHI-K-05).

Assent was obtained during survey implementation via the Assent Form on the first page of the stapled survey packet. ECOS teachers introduced the in-class activity and explained that if students assented to UMass using their answers for research purposes, they should write their name on the assent form.

Later, ECOS teachers sorted the completed surveys into those with assent and those without. Using the student's name from the Assent Form, ECOS teachers linked consent forms with surveys. For surveys that received both assent and consent, ECOS teachers removed the assent form from the survey packet and wrote the appropriate alphanumeric code onto the new first page of the survey packet. ECOS teachers also wrote address information from the consent form into the Codebook. Mr. Kuras received completed surveys, codes, and addresses from ECOS teachers, but not name information, thus maintaining confidentiality.

Confidentiality of research participants was maintained through use of the Student Codebook. Codes de-identified participants such that individual responses could not be easily linked with participant identities by Mr. Kuras. Because it was technically possible to link responses to names using the consent forms, anonymity was not maintained. However, only ECOS teachers have access to assent and consent forms. Information derived from the neighborhood habitat analysis was reported in aggregate so as to remove risk of identifying research participants.

All consent forms, assent forms, and surveys in which consent and/or assent were not attained, were stored in a file cabinet in the ECOS building until the termination of the

study. Survey data from the completed sample was stored on a password protected computer until the termination of the study. Paper surveys were stored in the file cabinet in the ECOS building. Consent forms, assent forms, and surveys were shredded in May 2018.

Participation in the study provided minimal risk to study participants. While the questions themselves were mundane, it was possible that some participants felt minor discomfort being asked to reflect on their past experiences in nature and any perceived barriers to participating in outdoor activities. Further, since some questions asked participants to reflect on their past activities, preferences, and opportunities, it is possible that some participants compared themselves to their peers and felt jealous that they could not do as many activities as they would have liked. Participants reserved the right to only complete as much of the survey as they desired and any distressed participants could cease taking the survey and receive support from their normal classroom teacher or ECOS teacher. Survey participants were not compensated.

There were no direct benefits for study participants. However, it was reasoned that future children could benefit from knowledge produced in this study by way of improved environmental education programs in Springfield and beyond.

- Implementation

ECOS teachers administered the survey as an in-class activity during the two days that each participating school attended ECOS. ECOS teachers explained the purpose of the survey and provided an opportunity for students to give assent that their responses could be used for the research study. Students that did not assent still completed the survey but their answers were not used in the analysis. ECOS teachers read aloud the first half of the survey while students followed along. After reading the question about whether students participated in ECOS the year before, the teacher distributed the “no ECOS” pages to those that did not participate. The teacher then explained that the remainder of the survey would ask students to pick a single activity that they did at ECOS and answer questions about that chosen activity. The teacher then decided whether to continue reading the survey out loud or let the students complete it on their own. If many students were completing the “no ECOS” page, the teacher generally did not read the second half out loud since the wording was slightly different between the two versions. The teacher also decided not to read the second half out loud if he or she felt that the students could successfully complete it on their own. This flexible decision-making structure was built into the implementation process in recognition that A) each class required a different amount of support from the teacher in order to be successful and B) that in the moment, the teacher would have the best perspective on which implementation strategy would work best with each group of students.

Similarly, each teacher implemented the survey at a time during the two-day session that worked best for their particular group dynamic and lesson plan. One teacher, for example, preferred to implement her surveys at the start of the first day, as a way to refresh students’ memories about their experiences in nature and get them excited about their activities for the day. Another teacher preferred to implement her surveys at the start of the second day, once she had built more of a relationship with her students so that the survey wouldn’t feel as formal. Regardless, each teacher recorded at what time they implemented their survey and any comments or observations about how it went.

Mr. Kuras visited the ECOS teachers every week to prepare the survey materials and assist with the implementation process. Mr. Kuras also observed students completing the survey and answered their questions as a way to confirm survey validity and flag any emergent areas of concern.

- Survey Processing and Validity

Paper surveys were entered into Qualtrics by the researcher and three undergraduate research assistants. The Qualtrics input form included two “checks” for any issues to flag during input for further inspection. Within each class, surveys that were flagged in this manner and one of out every 5 surveys were re-checked for accuracy. If an input error was found on any selected survey, the two preceding and proceeding surveys were checked as well. In total, 36.5% of surveys were re-checked (133/364).

On 25 surveys, participants chose more than one answer or instead of choosing an option, they wrote something in the margins. Mr. Kuras used context clues or logic to select an answer where appropriate, or left the question blank. Questions or parts of questions that were left uncompleted were not used in the analysis.

Chosen activities were sorted by comparing responses to Q7, Q8, and Q11. In total, 305 responses fit into the three domains of SAP, SAF, and OAF, 26 responses were considered a combination of two of the above, and 33 responses were either left blank or were not among the selected domains. When no chosen activity was specified, no answer was entered unless the participant had circled only one of the six prompted activities (see Appendix C, Q7).

Activity outcome responses were originally collected through a 5-point Likert scale. Responses were used in their original form for descriptive statistics and bivariate analyses. For logistic regression, activity outcomes were collapsed into binary responses of “Yes” or “No” following the grouping scheme in Figure A.1. The “Activity Discussion” outcome was generated by taking the most affirmative value for Q12 and Q13. For example, a student that reported talking about their chosen activity “almost never” with friends but “very often” with family received a value of “Yes” for Discussion. A student that reported talking about their activity “almost never” with both friends and family received a value of “No.”

15. This past year, including the summer, **how often (if at all) have you done your chosen activity?** Choose one.

<input type="radio"/> Never	<input type="radio"/> Almost never	<input type="radio"/> Sometimes	<input type="radio"/> Often	<input type="radio"/> Very often
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12. Since ECOS, how often have you and your **friends** talked about *your activity*?

<input type="radio"/> Never	<input type="radio"/> Almost never	<input type="radio"/> Sometimes	<input type="radio"/> Often	<input type="radio"/> Very often
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13. Since ECOS, how often have you and your **family** talked about *your activity*?

<input type="radio"/> Never	<input type="radio"/> Almost never	<input type="radio"/> Sometimes	<input type="radio"/> Often	<input type="radio"/> Very often
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10. How confident do you feel about doing *your chosen activity* on your own? Choose one.

<input type="radio"/> Can't do it	<input type="radio"/> Not too sure I can do it	<input type="radio"/> Halfway certain	<input type="radio"/> Pretty sure I can do it	<input type="radio"/> Certain I can do it
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Figure A.1. Scheme for collapsing Activity Outcomes into binary responses. Solid black boxes indicate answers collapsed as “Yes” values while stenciled boxes indicate answers collapsed as “No” values.

The survey contained a number of logical checks for internal validity. For each logic check, each student was given a score of Consistent, Questionable, or Inconsistent, corresponding with 1, 2, or 3 points respectively. Surveys with multiple Questionable or Inconsistent responses (a total score of 7) were excluded from the analysis (n = 4).

Logic Check #1: In Q3, students were asked how often they did three outside activities and in Q4a, they had the opportunity to mark the statement “I don’t want to do outside activities” as True or False. Students who answered “True” for Q4a more commonly indicated that they did outdoor activities less frequently compared with those who said “False.” This means that students understood the question overall. 12 students violated this logic check and their responses were scored as Questionable. All other responses were scored as Consistent.

Logic Check #2: Responses to Q7, Q11 (both about the chosen activity), and Q8 (the place where they did the activity) were compared to determine if the responses were Consistent, Questionable, or Inconsistent. If Q7 matched Q11 and occurred in the appropriate place Q8, the survey was scored as Consistent. If [Q7 or Q11] or if Q8 was missing, or if the two chosen activities were different but occurred in the same place, the survey was scored as Questionable (e.g., WHI-C-05 with hiking/walking in the woods and catching frogs, both in the forest). If both Q7 and Q11 were missing, or if they were quite different from each other, or if the place did not align with activity at all, the survey was scored as Inconsistent (BRU-C-05 catching tadpoles in the forest, or WHI-C-04 with two chosen activities being catching fish and hiking). In essence, any survey for which it could not be ascertained with certainty which activity the participant was thinking about

when completing the survey was marked as Inconsistent. In total, 306 surveys were Consistent, 27 were Questionable, and 31 were Inconsistent.

Logic Check #3: Students were asked in Q15 how often they have done their chosen activity. First, if students chose “Never” then for Q16, they should answer with “I don’t usually do this activity.” 71 students said they Never do it but did not check “I don’t usually do it.” These responses were scored as Questionable with the exception of HOM-K-09, who didn’t check any boxes for Q16 and so was left with a score of Consistent. 65 students said they Never do their chosen and appropriately checked the box. These students received a score of Consistent. Two students chose Often or Very Often for Q15 and also selected “I don’t usually do this activity,” thus receiving a score of Inconsistent. All other students received scores of Consistent. Finally, 8 students chose “I don’t usually do this activity” and indicated that they do the activity with companions, thus receiving a score of Questionable.

Logic Check #4: Students were asked who they knew that had done their chosen activity at ECOS before (Q17). First, if students selected “No one I know has done this activity” and then responded to Q18 with details about someone specific (like a mother or brother) they knew who had done the activity before, they were given a Questionable. 4 students fit into this category. Second, if students selected “No one I know has done this activity” along with other options, they were given a Questionable. 2 students fit into this category.

Logic Check Score Summaries	Number of Surveys
Consistent across all four logic checks (4 points)	221
Questionable in only one logic check (5 points)	101
Questionable across two or Inconsistent across one logic check (6 points)	38
Multiple questionable or inconsistent responses (7 points)	4

Table A.1. Logic check scores, including explanations, and corresponding number of surveys.

- Neighborhood Habitat Analysis

Nearby Open Space: the availability of parks, conservation areas, cemeteries, and other protected greenspaces that students have access to close to home. Spatial information was obtained from MassGIS 2017 Protected and Recreational OpenSpace data layer (MassGIS 2017) and features were included if their primary purpose was recreation, conservation, recreation and conservation, historical/cultural, or Unknown (codes R, C, B, H, and X). Historical/cultural sites in this set included exclusively cemeteries and the two “Unknown” features included were the “forest park extension” and a schoolyard.

Surrounding greenness: the general amount of grass, trees, and vegetation around each student’s home, regardless of whether those features are public or private. This variable was calculated by averaging the Normalized Difference Vegetation Index (NDVI) within a 500-meter buffer of each address. NDVI essentially measures green light associated with plants and is collected at a 250-meter resolution from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. NDVI were retrieved from EarthExplorer, courtesy of the NASA EOSDIS Land Processes Distributed Active

Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, <https://earthexplorer.usgs.gov>. This analysis used NDVI collected from July 26 – August 8, 2016 (Entity ID: EMUST20160726201608085) in order to reflect the summer period in which greenness is greatest. These dates also occurred during the time period in which students were asked to reflect about their outdoor experiences.

Nearby Open Space and Surrounding Greenness capture similar information to City Habitat and Wild Habitat regarding exposure to nature. The two sets of variables were compared using model selection to assess which would better explain activity outcomes. A candidate model list was constructed, including a null model (no predictor variables), survey variables (City Habitat and Wild Habitat), spatial variables (Surrounding Greenness and Nearby Open Space), and both (Table A.2). The sample for this analysis included all surveys in which students selected one of the three chosen activities (SAP, SAF, or OAF) and had available address information (n = 157). Binomial logistic regression was used to model each activity outcome. All models were multi-level with responses nested within school Accountability and Assistance Level (AAL; see A2: Accountability and Assistance Levels). Table A.2 reports $\Delta AICc$ and model weights. For two of the three activity outcomes, survey variables and the null model outperform spatial variables. For activity discussion, all four models have roughly the same explanatory power.

Model	Formula	Repetition	Discussion	Confidence
Null	outcome ~ (1 AAL)	$\Delta AICc = 0.61$ W = 0.319	$\Delta AICc = 0.58$ W = 0.220	$\Delta AICc = 0.40$ W = 0.389
Spatial	outcome ~ open_space + surr_green + (1 AAL)	$\Delta AICc = 3.06$ W = 0.094	$\Delta AICc = 0$ W = 0.293	$\Delta AICc = 4.26$ W = 0.056
Survey	outcome ~ hab_wild + hab_city + (1 AAL)	$\Delta AICc = 0$ W = 0.433	$\Delta AICc = 0.25$ W = 0.259	$\Delta AICc = 0$ W = 0.475
Both	outcome ~ hab_wild + hab_city + open_space + surr_green + (1 AAL)	$\Delta AICc = 2.06$ W = 0.154	$\Delta AICc = 0.50$ W = 0.228	$\Delta AICc = 3.56$ W = 0.080

Table A.2. Four models were used to explain activity outcomes using spatial and survey variables as predictors. For each outcome, $\Delta AICc$ and model weight (W) are reported. Shaded cells represent models with $\Delta AICc < 2$, signifying roughly the same explanatory power.

- Accountability and Assistance Levels

Schools were grouped by overall performance relative to other schools that serve the same or similar grades in the state (as measured by the “school percentile”). Participating schools with a 2016 “school percentile” of 20% or higher were grouped together as the “high performance group” (Daniel B. Brunton School, White Street School, Frederick Harris School, and Warner School; n = 128 students) and schools with a “school percentile” lower than 20% were grouped as the “low performance group” (Homer Street School, German Gerena Community School, Hiram L. Dorman School, Indian Orchard Elementary, Mary O. Pottenger School, and Milton Bradley School; n = 232 students) Massachusetts uses the 20% threshold to determine which schools require additional technical assistance or intervention (DOE 2017).

**APPENDIX B
ADDITIONAL SURVEY QUESTIONS**

- Who did ECOS?

Roughly 90% of survey respondents participated in ECOS, either in Forest Park or at Camp Wilder (Q5). The sample size of students that did not do ECOS *and* that selected SAP, SAF, or OAF as their chosen activity was too small (n=19) to facilitate a comparison with students that did do ECOS.

Participated in 4 th grade ECOS Program at Forest Park	294 (80.8%)
Participated in 4 th grade ECOS Program at Camp Wilder	33 (09.1%)
Did not participate in ECOS at all	37 (10.1%)
Total Respondents	364 (100%)

- Chosen Activity

When asking students to select their chosen activity, the survey provided six common activities as prompts. These included catching frogs, catching fish or tadpoles, catching bugs, exploring in nature, hiking or walking in the woods, or sitting quietly in the woods (AKA the “silent sit”). Students chose an activity and wrote it down (Q7), then selected where they did their chosen activity: pond, forest, or field (Q8). On the following page, students were asked again to write their chosen activity (Q11).

Responses were classified as SAP (small animal activities in the pond) if students selected the pond and included the prompted activities of catching frogs, catching fish or tadpoles, or catching bugs. Other sorted SAP activities included “catching crawfish” (n=1) and “fishing” (n=4). SAF (small animal activities in the field or forest) responses included the prompted activities of catching frogs and catching bugs and the selection of field or forest. Other sorted SAF activities included catching toads (n=5), grasshoppers (n=1), and butterflies (n=1). The prompted activities of exploring in nature, hiking or walking in the woods, and sitting quietly in the woods, along with the selection of forest, were sorted into OAF (other activities in the forest). Additional responses in this domain included “scavenger hunt” (n=1) and “drawing” (n=1).

While 305 responses fit into these three activity domains, 26 responses were considered a combination of two of the above, and 33 responses were either left blank or were not among the selected domains. Some students chose learning-based activities such as leaf drawing (1), frog cycles (2), food web game (1), scavenger hunt (1), boat racing (1), making paper (1), and seeing deer (1). Especially among students that did not participate in the 4th grade ECOS program, many Chosen Activities were recreational and included basketball/football (3), biking (2), play (3), swimming (2), walking (1), going to the park (1), camping (1), and going to Six Flags (1). When asked where they did these activities, students referenced house/home, street, yard, pond, beach, and ocean. Some students specifically referenced parks including Mt. Tom (1), Chicopee State Park (1), and Forest Park (3).

- Discussion with Friends versus Family

Students reported that friends spoke about their chosen activity with a higher frequency than family. While the differences between these two questions were significant (Wilcoxon test $V = 11291$, $p = 0.04653$), the average values for both responses were indistinguishable (both “sometimes”). Statistical differences were likely driven by the slightly higher tendency for students to report that their family “never” talks about their chosen activity. Neither responses for discussion with friend nor family differed between chosen activities (Kruskal-Wallis $X^2 = 0.89303$, $df = 2$, $p = 0.6399$; Kruskal-Wallis $X^2 = 1.1714$, $df = 2$, $p = 0.5567$, respectfully).

APPENDIX C
THE SURVEY



Department of Environmental Conservation

**Urban Environmental Education:
Linking ecology-oriented activities in and out of school**
Assent Form

Welcome to ECOS! You're here to learn about nature and the environment. But first, we'd like to hear from you about your experiences with nature and about your memories from ECOS last year. By answering the questions in this packet, you can help us learn about what nature means to you so that we can make ECOS better for students in the future!

By asking many students the same questions, we can learn a lot about how they feel about nature and how to improve the program. This is called research and we would like to use your answers for a research study that we're doing with UMass Amherst. Everyone in your class will be answering the questions in this packet, but it is up to you if we can use your answers to learn about the program.

Your parent or guardian knows about this study and that we are asking if you would like to be part of it. This is not a test and your decision will not affect your grade. We will keep your answers private. If you have any questions at any time about the research, just raise your hand!



If you are OK being part of this study,
please write your name below.



Name _____

If you want to talk to the lead researcher, ask your teacher or email
Evan Kuras at ekuras@umass.edu.

University of Massachusetts Amherst-IRB (413) 545-3428	
Approval Date: 09/23/2016	Protocol #: 2016-3043
Valid Through: 06/07/2017	
IRB Signature: <i>Nancy C. Lovett</i>	

The questions in this packet ask about your past experiences with nature and outdoor activities. There will also be questions about your memories from ECOS last year. If you didn't do ECOS, last year, you can still complete this packet. Try your best to answer all of the questions. There are no right or wrong answers! You can skip any questions you don't want to answer. If you have any questions, raise your hand. Thanks for your help!

1. How often, if at all, do you see these animals outside where you live?
Fill in your choice for each animal.

 <p>Pigeon</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>	 <p>Snake</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>	 <p>Deer</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>
 <p>Squirrel</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>	 <p>Grasshopper</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>	 <p>Dragonfly</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>
 <p>Frog</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>		 <p>Turtle</p> <p><input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often</p>

2. Which activities did you do this past year, including the summer?
Check the boxes with the activities that you did.

- | | |
|-------------------------------------------------------------------------------|--------------------------------------------------------------------|
| <input type="checkbox"/> Hiking | <input type="checkbox"/> Going to a park |
| <input type="checkbox"/> Camping | <input type="checkbox"/> Going to a zoo or aquarium |
| <input type="checkbox"/> Fishing | <input type="checkbox"/> Swimming in a lake, pond, beach, or ocean |
| <input type="checkbox"/> Biking in the woods | <input type="checkbox"/> Taking care of indoor or outdoor plants |
| <input type="checkbox"/> Picking vegetables, fruits, or flowers from a garden | <input type="checkbox"/> None of these |
| <input type="checkbox"/> Planting trees, seeds, or plants | |



3. How often, if at all, did you do the three activities below this past year, including the summer? Fill in your choice for each activity.

Catching small animals	Collecting things from nature	Playing or exploring in nature
<input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often	<input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often	<input type="radio"/> Never <input type="radio"/> Sometimes <input type="radio"/> Often

4. Some people don't do the three activities above as much as they want. *What about you?* Circle "True" or "False" for each reason that might stop you from doing these activities.

- a. I don't want to do outside activities True False
- b. I don't have enough time True False
- c. I have no one to do them with True False
- d. I don't know where to do them True False

Places I like to do them are...

- d. Hard to get to True False
- e. Too crowded True False
- f. Not friendly True False
- g. Not safe True False
- h. Full of pests such as mosquitoes True False

5. Did you go to both days of ECOS in 4th grade last year? Choose one.

- Yes, both days
- No, only one day
- No, I didn't go to ECOS last year → Raise your hand
- No, I was in 5th grade last year → Raise your hand



Students who did ECOS answered the questions below



6. How did you like ECOS? Circle one.



7. Below are some activities that 4th graders often do during ECOS.

- Catching frogs
- Catching tadpoles or fish
- Catching bugs
- Sitting quietly in the woods
- Hiking or walking in the woods
- Exploring new places outside

On the line below, write an activity from last year that you remember well.

It can be an activity from the list above or from your memory.
The rest of this packet will ask you questions about your chosen activity.

Your chosen activity: _____

8. Where did you do your chosen activity? Choose one.

- Pond
- Field
- Forest
- Don't remember*

9. **How did you feel doing *your chosen activity*? Circle ONE OR TWO faces that represent your feelings.**



10. How confident do you feel about doing *your chosen activity* on your own?
Choose one.

- Can't do it
- Not too sure I can do it
- Halfway certain
- Pretty sure I can do it
- Certain I can do it

11. On the last page, you answered questions about an activity you remembered from 4th grade. **Write that activity again on the line below:**

Your chosen activity: _____



12. Since ECOS, how often have you and your **friends** talked about your activity?

- Never Almost never Sometimes Often Very often

13. Since ECOS, how often have you and your **family** talked about your activity?

- Never Almost never Sometimes Often Very often

14. Since ECOS, how often has your **classroom teacher** talked about your activity?

- Never Almost never Sometimes Often Very often

15. This past year, including the summer, **how often (if at all) have you done your chosen activity**? Choose one.

- Never Almost never Sometimes Often Very often

16. **Who**, if anyone, do you do your chosen activity with? Check all that apply.

- | | | |
|---------------------------------------------|----------------------------------|-----------------------------------------------------------|
| <input type="checkbox"/> Brother or sister | <input type="checkbox"/> Parent | <input type="checkbox"/> Grandparent |
| <input type="checkbox"/> Cousin or relative | <input type="checkbox"/> Friend | <input type="checkbox"/> Neighbor |
| <input type="checkbox"/> By myself | <input type="checkbox"/> Teacher | |
| <input type="checkbox"/> Other _____ | | <input type="checkbox"/> I don't usually do this activity |

17. Do you know anyone that has done your chosen activity at ECOS before? **Who**? Check all that apply.

- | | | |
|------------------------------------------------------------------------------|---------------------------------|--------------------------------------|
| <input type="checkbox"/> Brother or sister | <input type="checkbox"/> Parent | <input type="checkbox"/> Grandparent |
| <input type="checkbox"/> Cousin or relative | <input type="checkbox"/> Friend | <input type="checkbox"/> Neighbor |
| <input type="checkbox"/> Other _____ | | |
| <input type="checkbox"/> No one I know has done this activity at ECOS before | | |

18. What do people say about doing your activity at ECOS? Write on the lines below.

That's it! Thanks again for your help



Students who did not do ECOS answered the questions below

6. Which of these outdoor activities have you done before? Check all that apply.

- | | |
|----------------------------------------------------|---------------------------------------------------------|
| <input type="checkbox"/> Catching frogs | <input type="checkbox"/> Sitting quietly in the woods |
| <input type="checkbox"/> Catching tadpoles or fish | <input type="checkbox"/> Hiking or walking in the woods |
| <input type="checkbox"/> Catching bugs | <input type="checkbox"/> Exploring new places outside |



7. **On the line below, write an outdoor activity that you have done before.**

It can be an activity from the list above or from your memory.

The rest of this packet will ask you questions about your chosen activity.

Your chosen activity: _____

8. Where do you usually do your chosen activity? Write your answer below.

9. **How do you feel doing your chosen activity?** Circle **ONE OR TWO** faces that represent your feelings.



10. How confident do you feel about doing your chosen activity on your own?
Choose one.

- Can't do it Not too sure I can do it Halfway certain Pretty sure I can do it Certain I can do it

11. On the last page, you chose an outdoor activity that you have done before.
Write that activity again on the line below:

Your chosen activity: _____



12. How often have you and your **friends** talked about your activity this past year?

- Never Almost never Sometimes Often Very often

13. How often have you and your **family** talked about your activity this past year?

- Never Almost never Sometimes Often Very often

14. How often has your **classroom teacher** talked about your activity this past year?

- Never Almost never Sometimes Often Very often

15. This past year, including the summer, **how often (if at all) have you done** your chosen activity? Choose one.

- Never Almost never Sometimes Often Very often

16. **Who**, if anyone, do you do your chosen activity with? Check all that apply.

- | | | |
|---------------------------------------------|----------------------------------|------------------------------------------------------------------|
| <input type="checkbox"/> Brother or sister | <input type="checkbox"/> Parent | <input type="checkbox"/> Grandparent |
| <input type="checkbox"/> Cousin or relative | <input type="checkbox"/> Friend | <input type="checkbox"/> Neighbor |
| <input type="checkbox"/> By myself | <input type="checkbox"/> Teacher | |
| <input type="checkbox"/> Other _____ | | <input type="checkbox"/> <i>I don't usually do this activity</i> |

17. Do you know anyone that has done your chosen activity at **ECOS** before? **Who?**
Check all that apply.

- | | | |
|-------------------------------------------------------------------------------------|---------------------------------|--------------------------------------|
| <input type="checkbox"/> Brother or sister | <input type="checkbox"/> Parent | <input type="checkbox"/> Grandparent |
| <input type="checkbox"/> Cousin or relative | <input type="checkbox"/> Friend | <input type="checkbox"/> Neighbor |
| <input type="checkbox"/> Other _____ | | |
| <input type="checkbox"/> <i>No one I know has done this activity at ECOS before</i> | | |

18. What do people say about doing your activity at **ECOS**? Write on the lines below.

That's it! Thanks again for your help!



APPENDIX D
TAKE-HOME RESOURCE

Bringing ECOS home
Continuing environmental education in your backyard

My student just attended the ECOS program. What did they do there?
Every year, Springfield students pile on school buses and travel to Forest Park to attend ECOS (Environmental Center for Our Schools). In 4th and 5th grade, students explore different animal habitats, do ecological science experiments, and learn about the history of Forest Park.

What should I talk to my student about?
Ask your student what animals they saw at ECOS. Did they see any wildlife in Forest Park that they don't normally see at home? ECOS has been around since 1970 and many current Springfield parents (maybe even you!) did the program too. Share any memories you have about ECOS, or if you didn't go, tell them about experiences you had exploring outside during your childhood.



Forest Park, Springfield

What can I do to follow up on ECOS?
Go outside with your student and ask them to show you something they learned about nature. Look for animals in your yard or on your street. How are the habitats near home different from the habitats in Forest Park? If you want to branch out, there are some amazing parks, trails, nature sanctuaries, museums, and summer programs in the area. Keep reading below!

Close to or in Springfield
Forest Park (including The Zoo)
The Connecticut Riverwalk and Bikeway
Robinson State Park

Summer camps
Forest Park Summer Camp
Camp Massasoit
On the Wilder Side Summer Camp
Springfield Parks and Rec Camp at ECOS

Want to travel further?

Hiking Mt. Tom State Reservation Mount Holyoke Range State Park The Notch Visitor Center Mount Sugarloaf State Reservation	Wildlife Mass Audubon's Arcadia Wildlife Sanctuary Magic Wings Butterfly Conservatory Holyoke Dam Fishway	Programs, museums, and more! Hitchcock Center Saturday Family Science Beneski Museum of Natural History, Amherst College Gardening the Community Dinosaur Footprints
-----------------------------------------------------------------------------------------------------------------------------------------------	---------------------------------------------------------------------------------------------------------------------------	-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------



Mount Holyoke Range

Follow ECOS on Facebook:
[@springfieldforestpark](https://www.facebook.com/springfieldforestpark)

Additional information on the back

Additional Information

Close to Home

Forest Park	<u>The Zoo in Forest Park</u>	293 Sumner Ave., Springfield
	Pricing: Children (ages 12 and under): \$3.25	
	Adults: \$5 Seniors (62+): \$3.50 Military: \$3.50	
The Connecticut Riverwalk and Bikeway		Multiple entrances along CT river
Robinson State Park (\$-parking)		428 North St., Feeding Hills

Hiking

Explore miles of trails around the pioneer valley and along the Connecticut River. Explore scenic views, a picnic lunch, and look for birds, mammals, and vegetation along the way.

Mt. Tom State Reservation (\$-parking)	125 Reservation Road, Holyoke
Mount Holyoke Range State Park (Hadley, Amherst, and Belchertown)	1500 West St., Amherst
and the Notch Visitor Center	300 Sugarloaf St., Deerfield
Mount Sugarloaf State Reservation	

Wildlife

Witness nature up-close at these local spots. Observe wildlife on conservation land, view thousands of butterflies at Magic Wings indoor park, or watch fish migrate over the dam.

Mass Audubon's Arcadia Wildlife Sanctuary	127 Combs Rd., Easthampton
Magic Wings Butterfly Conservatory (\$)	281 Greenfield Rd., South Deerfield
Holyoke Dam Fishway	1 Bridge St., Holyoke

Programs, museums, and more!

Looking for something to do after school or on the weekends? Take part in science programs at the Hitchcock center, experience fossils and minerals at the Natural History Museum, learn how to plant food at a local community garden, or walk to the site of natural dinosaur tracks.

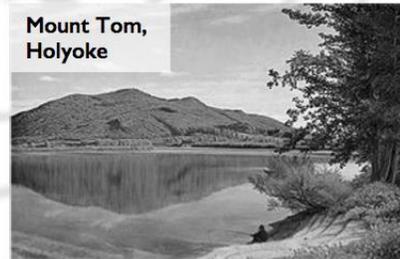
Hitchcock Center Saturday Family Science	845 West St., Amherst
Beneski Museum of Natural History, Amherst College	11 Barrett Hill Rd., Amherst
Gardening the Community	256 Hancock St., Springfield
Dinosaur Footprints	parking lot on Route 5, Holyoke

Summer camps

Experience the outdoors all summer long at these camps in Springfield! Campers will engage in a variety of activities such as swimming, hiking, arts and crafts, archery, biking, ropes courses, and much more (check websites for prices).

Camp Weber	Camp Massasoit
On the Wilder Side Summer Camp	
Springfield Parks and Rec Camp at ECOS	

Mount Tom,
Holyoke



ECOS Mission Statement

“ECOS provides outdoor environmental education for the Springfield Public Schools using Forest Park as an outdoor classroom. At ECOS, students engage in scientific inquiry through the use of science and engineering practices to develop an attitude of respect and stewardship for the natural world”

APPENDIX E
MULTI-CITY SES-BIODIVERSITY RELATIONSHIPS

Taxa (Citation)	Geography	SES-biodiv relationship	Explanation
Birds, insects, and plants combined (Hand et al. 2016)	Three New Zealand cities (Auckland, Dunedin and Wellington)	strong positive	Overall biodiversity declined with increasing neighborhood deprivation score, especially in private rather than public green spaces.
Woody plants (Kuruner- Chitepo and Shackleton 2011)	Three towns in the Eastern Cape of South Africa (Port Alfred, Grahamstown and Somerset East)	strong positive	Tree species richness was higher in central business districts and the more affluent suburbs (historically reserved for people of European descent under apartheid). Township areas (historically for people of African descent) and subsidized low- cost housing areas (developed for poor communities) had fewer tree species. Differences were driven by competing socio-economic demands for infrastructure rather than greening in lower SES areas.
Woody plants (Mills et al. 2016)	Urbanized area west of the Cascade Mountain Range in Oregon and Washington (including Eugene, Portland, Seattle, and Bellingham)	strong positive	Higher median house values were associated with greater numbers of tree species.
Frogs (Smallbone et al. 2011)	Nine towns across Victoria and South Wales in Australia	moderate positive	Frog species richness responded to increasing neighborhood vegetation cover, which was related to higher SES. Frog species richness was higher in less urbanized neighborhoods on the fringes of towns and in elevated locations, in contrast to more developed central neighborhoods with lower SES and lower elevation.
Birds (MacGregor- Fors and Schondube 2011)	Three west-central Mexican cities in Michoacán (Morelia, Uruapan, Zamora)	weak positive	Economic prosperity (housing and site quality) could affect bird species richness (specifically species that are moderately abundant) but there are other factors that drive richness more directly, such as vegetation features, human activities, and urban

			infrastructure. Green areas that may be important for birds are distributed independently in cities independent of socio-economy.
Birds (Luck et al. 2013)	Eighteen towns and cities across Victoria and South Wales in Australia	weak positive	Bird species diversity is most directly driven by vegetation cover (especially native or nectar-rich plants) and may occur in higher SES areas but that may be due in part to higher SES individuals choosing to live on the fringes of towns (peri-urban areas), which have greater vegetation cover.
Mammals (Junker et al. 2015)	Entire country of Liberia using a grid cell approach	moderate positive	Chimpanzee nest density increased with literacy rates, potentially because education can shift income generation activities away from wildlife and/or increase awareness of negative consequences of eating bushmeat. Large mammal species richness decreased with distance to market (economic and infrastructure development), potentially due to associated landscape changes such as decreased vegetation and increased access to hunting.

Table E.1. Published analyses of relationships between SES and species diversity of various taxonomic groups at the multi-city or regional scale.

APPENDIX F CASE SELECTION PROCESS

1) We searched Web of Science in February 2016 for articles or book chapters in English using the following terms:

- For SES: socio-economic* OR socioeconomic* OR income OR socio* OR social OR culture OR political ecology OR political economy OR religion OR infrastructure OR education OR attitude*
- For biodiversity: "species diversity" OR richness OR biodiversity OR bird* OR plant* OR vegetation OR avian OR species OR pollinator* OR mammal* OR amphibian* OR reptile* OR insect* OR invertebrate* OR bee* OR butterfly* OR spider* OR ant OR fish OR aquatic OR tree* OR carabid* OR primate* OR lizard* OR turtle* OR frog OR salamander* OR flora* diversity OR fauna* diversity OR flower diversity OR forest diversity OR grassland
- For cities: urban* OR city OR cities OR town* OR settlement* OR neighborhood* OR neighbourhood* OR residential OR garden* OR yard*

This search yielded 150 papers, of which we included 32 in our analysis.

2) We searched Web of Science to find articles published that cite any of the "classic papers," specifically Hope et al. 2003, Kinzig et al. 2005, Loss et al. 2009, and Lubbe et al. 2010. This search yielded 9 new papers for our analysis.

3) We read through the 41 papers selected thus far and sought references to other studies about SES-biodiversity relationships in cities that we had not yet encountered. This search yielded 8 new papers for our analysis.

APPENDIX G ADDITIONAL CALIBRATION CONSIDERATIONS AND PROCEDURES

Collecting and coding case information required additional steps and considerations not reported in the main text.

- Taxonomic Group and Study Design

Taxonomic group: We first assigned cases the categories of woody plants, mixed plants, birds, herpetofauna, mammals, or invertebrates. We then created the conditions *WOODY* and *MOBILE* to limit the number of conditions utilized.

Native status: We selected “mostly native” as our default given that multiple meta-analyses have found that the majority of plant and bird species in cities are native (52% to 97% native depending on taxonomic group and land use considered; Aronson et al. 2014, La Sorte et al. 2014, Nielsen et al. 2014). Three cases were coded as mostly non-native although authors did not specify the origin of considered species. We coded the two plant cases in Kinzig et al. (2005) [24A, 24B] as mostly non-native even though authors did not specify the native status of plants in their analysis because plants were mostly non-native in every other case from the same city. We also coded plants in Clarke et al. (2014) [09A] as mostly non-native because authors only considered “cultivated” plants in Beijing villages and noted that 80% were ornamental or edible.

Land use: We coded cases that included residential and non-residential land uses as more in than out of the set of city-wide land uses. We reasoned that SES-related drivers of biodiversity may differ substantially between residential and non-residential land uses. On non-residential land, institutions such as municipalities, industries, and schools, make decisions about biodiversity that may be more distinct and in line with institutional objectives (e.g., Zivanovic and Luck 2016). Indeed, Matteson et al. (2013) explicitly did not assess the relationship between SES and biodiversity on non-residential land “because there were no human residences in the green space transects (and thus very little variation in our measures of development intensity [which included median household income]).” As such, cases with mixed land uses may reflect a stronger influence of institutional drivers than residential ones.

Biodiversity and SES sampling units: Fully described in main text.

Stratification by SES: Fully described in main text.

- City Conditions

Tropicality: Fully described in main text.

Aridity: We used the *Global Aridity Index* from the Consultative Group for International Agriculture Research (CGIAR) Consortium for Spatial Information (Trabucco et al. 2009). The Global Aridity Index (AI) is modeled using data available from [WorldClim](#), which is based on high-resolution global geo-database (30 arc seconds or ~1km at the equator) of monthly average data for precipitation and temperature (mean, minimum, and maximum) between the years of 1950 and 2000. Similar measures have been used for other global meta-analyses of biodiversity (e.g., Dobbs et al. 2014). The AI represents

the evaporative demand of the atmosphere as calculated by Mean Annual Precipitation divided by Mean Annual potential Evapotranspiration. All values were extracted for all grid cells within a 2 km radius of each city's central point (provided by google maps) and averaged. Mean values included between 10 and 28 grid cells. Smaller numbers of grid cells were averaged for coastal cities (e.g., San Juan, Puerto Rico) while larger numbers were averaged for inland cities farther with higher latitudes (e.g., Santiago, Chile).

Age: We assessed city age based on the year the city was founded or established (Table G.1), following Hahs et al. (2009), using the reported year on Wikipedia and confirming that this date corresponded to the relative time scale at which urbanization was initiated (LaSorte 2014). For many of the older cities, these dates aligned with the establishment of a port (Porto, Portugal) or military post (Paris, France), or the granting of a charter or status that allowed for urban development (Raleigh, USA). For some cities, founding or establishment dates aligned with the arrival of a colonial regime (Valdivia, Chile and Sydney, Australia). For newer cities, many dates corresponded with incorporation or becoming a recognized capital. Some of these cities (Vancouver, Canada) were already population centers before the dates we selected, but in those situations, we could not identify an earlier official reference period that better reflected the onset of urbanization. To determine city age, we subtracted the onset year from 2010.

City	Onset Year	City Age	Operative Phrase	Text from wikipedia.com
Beijing, China	-1045	3055	Ancient Capital	"The city of Beijing has a long and rich history that dates back over 3,000 years... The first walled city in Beijing was Jicheng, the capital city of the state of Ji and was built in 1045 BC"
Belo Horizonte, Brazil	1897	113	Inaugurated	"In 1893, due to the climatic and topographic conditions, Curral Del Rey was selected...as the location for the new economical and cultural centre of the state, under the new name of "Cidade de Minas." ...Then Cidade de Minas was inaugurated finally in 1897."
Bujumbura, Burundi	1912	98	Became capital	"1912 - Usumbura becomes capital of Ruanda-Urundi."
Campos dos Goytacazes, Brazil	1835	175	City Status	"[The] village of São Salvador de Campos de Goytacazes was founded on May 29, 1677. On March 28, 1835 the village was promoted to city status."
Chicago, IL, US	1837	173	Incorporated	"The City of Chicago was incorporated on Saturday, March 4, 1837, and for several decades was the world's fastest-growing city."
Costa Brava, Spain	1950	60	Identified	"In the 1950s, the Costa Brava was identified by the Spanish government and local entrepreneurs as being suitable for substantial development as a holiday destination."
Dunedin, New Zealand	1848	162	Established	Scotland. Between 1855 and 1900 many thousands of Scots emigrated to the incorporated city."
Halton, UK	1852	158	Administration Established	"[The Borough of Halton contains Widnes and Runcorn] "Modern local government in the town of Widnes commenced with the creation of the Widnes Local Board in 1865" "Under the Runcorn Improvement Act 1852, a board of Improvement Commissioners was established to administer the civil government of the town"
Heredia, Costa Rica	1812	198	Municipality Status	"The Municipality of Heredia was founded on 19 May 1812, and in 1824, Heredia was promoted to city by Juan Rafael Mora, the first President of the Republic."
Hobart, Australia	1804	206	Founded	"Founded in 1804 as a penal colony."
Kigali, Rwanda	1962	48	Became capital	"1962 - Kigali becomes capital of independent Republic of Rwanda, population: 6,000 (estimate)...1970 - Population: 54,403 (estimate)."
Leeds, UK	1207	803	Charter for "urban development"	"The inhabitants of Leeds received their first charter, in November, 1207... [which] granted to the townspeople of Leeds only the lowest conditions needed for urban development."
Leipzig, Germany	1015	995	Documented	"Leipzig was first documented in 1015 in the chronicles of Bishop Thietmar of Merseburg as urbs Libzi... and endowed with city and market privileges in 1165 by Otto the Rich."
Los Angeles, CA, US	1835	175	Declared a city	"In 1835, the Mexican Congress declared Los Angeles a city, making it the official capital of Alta California. It was now the region's leading city."
Lubbock, TX, US	1909	101	Incorporated	"Lubbock... was incorporated on March 16, 1909. In the same year, the first railroad train arrived." 1910 - Population: 1,938.
Maastricht, Netherlands	1204	806	City Status	"[The city rights of Maastricht] developed gradually during its long history. In 1204 the city's dual authority was formalised in a treaty, with the prince-bishops of Liège and the dukes of Brabant holding joint sovereignty over the city"
New York City, NY, US	1653	357	Incorporated	"New Amsterdam was incorporated as a city on February 2, 1653"
Niamey, Niger	1926	84	Became capital	"In 1926 it became the capital of Niger, and the population gradually increased, from about 3,000 in 1930 to around 30,000 in 1960."
Paris, France	-52	2062	Became military post	"The Romans conquered the Paris Basin in 52 BC and... began extending their settlement in a more permanent way to Paris's Left Bank... It became a prosperous city with a forum, baths, temples, theatres, and an amphitheatre."
Phoenix, AZ, US	1881	129	Incorporated	"Phoenix incorporated as a city in 1881... 1880 - Population: 1,800"
Porto, Portugal	-300	2310	Developed as port	"Historic references to the city go back to the 4th century and to Roman times...300 BCE - Town strengthened and developed by the Romans... as a commercial port."
Raleigh, NC, US	1795	215	Charter granted	"Raleigh was chosen as the site of the new capital in 1788... It was officially established in 1792 as both county seat and state capital (incorporated on December 31, 1792 – charter granted January 21, 1795)... 1800 - Raleigh population is 669"
Reno, NV, US	1868	142	Founded	"Once the railroad station was established, the town of Reno officially came into being on May 9, 1868."
Rio Claro, Brazil	1827	183	Incorporated	"[Rio Claro] was incorporated as the village of São João Batista do Ribeirão Claro in 1827"
San Juan, PR, US	1521	489	Formally named	"In 1521, the newer settlement was given its formal name, Puerto Rico de San Juan Bautista."
Santiago, Chile	1541	469	Founded	"Founded in 1541 by the Spanish conquistador Pedro de Valdivia, Santiago has been the capital city of Chile since colonial times."
Sheffield, UK	1297	713	Established as a borough	"This was followed on 10 August 1297 by a charter from Lord Furnival establishing Sheffield as a free borough [Town of Sheffield]"
Stockholm, Sweden	1252	758	First mentioned/Founded	"The earliest written mention of the name Stockholm dates from 1252... during the end of the 13th century, Stockholm quickly grew to become not only the largest city in Sweden, but also the de facto Swedish political centre."
Sydney, Australia	1788	222	Settled	"[It was] 1788 when the First Fleet, which contained convicts and was led by Captain Arthur Phillip, arrived in Botany Bay to found Sydney as a penal colony... It consisted of over a thousand settlers, including 778 convicts"
Tlokwe City Municipality, South Africa	1860	150	Became "Chief City"	"In May 1860 Potchefstroom became the "chief city" of the Republic, with the capital having moved to Pretoria."
Toronto, Canada	1834	176	Incorporated	"The town was incorporated on March 6, 1834... Toronto grew rapidly in the late 19th century, the population increasing from 30,000 in 1851 to 56,000 in 1871."
Valdivia, Chile	1552	458	Founded	"Pedro de Valdivia later travelled by land to the river described by Pastene, and founded the city of Valdivia in 1552 as Santa María la Blanca de Valdivia"
Vancouver, Canada	1886	124	Incorporated	"The City of Vancouver was incorporated on 6 April 1886, the same year that the first transcontinental train arrived... Vancouver's population grew from a settlement of 1,000 people in 1881 to over 20,000 by the turn of the century and 100,000 by 1911."
Waco, TX, US	1856	154	Incorporated	"1856 - Town of Waco incorporated"

Table G.1. City Age determinations, including relevant text signifying urbanization onset.

Density: Population density was obtained to match the spatial extent of the cases rather than applying a single value to all cases in a given city (Table G.2). Cases fell into three categories:

1. Clearly articulated study area (or the formal boundary in which the study took place) and human population in that area. Example from Gonzalez-Ball et al. (2017): “The city of Heredia, with an area of 3 km², has a total population of 19,138 inhabitants (INEC 2015) and a population density of 6379.33 inhabitants/km².”
1. Clearly articulated study area (or formal boundary) but not human population. For these cases, we found human population estimates for the reported area from that country’s census website or from wikipedia. Example from Trammell and Bassett (2012): Study took place within the cities of Reno and Sparks, Nevada. Populations for both cities were summed together and divided by the total area of both cities.
2. Did not clearly articulate study area or human population, but rather presented a map of study sites. In these cases, we used the smallest comprehensive formal boundary that captured the sites and found population density for that area. Example from Makinson et al. (2017): Study took place in the Sydney metropolitan region (including the urbanized councils of Leichardt, Balmain, City of Sydney, Marrickville, Chatswood, Ryde, Ku-ring-gai, Willoughby, Ashfield and Waverley). Population density was collected for Sydney as an “urban centre/local” according to the Australian census website, which captured all the listed urbanized councils and the study area map.

When finding population data, we searched for census data most proximate in time to when the study was conducted. For studies that took place beyond the major city in the region (like in the suburbs or Toronto or the peri-urban villages of Beijing), population density estimates included the city itself as well as the relevant outlying areas.

City	Publication	Population	Area (km2)	Density (person/km2)	Boundary (year)	Source
Beijing, China	Clarke et al. 2014 [09A]	20000000	16800.0	1190.5	Municipality	Publication
Beijing, China	Wang et al. 2015 [47A]	10,440,000	670.0	15582.1	Within the 5th ring road	Publication for area + Wang et al. (2012) for population
Beijing, China	Wang et al. 2015 [47B]	10,440,000	670.0	15582.1	Within the 5th ring road	Publication for area + Wang et al. (2012) for population
Beijing, China	Wang et al. 2015 [47C]	10,440,000	670.0	15582.1	Within the 5th ring road	Publication for area + Wang et al. (2012) for population
Beijing, China	Wang et al. 2016 [48A]	10,440,000	670.0	15582.1	Within the 5th ring road	Wang et al. (2016) for area + Wang et al. (2012) for population
Beijing, China	Wang et al. 2016 [48B]	10,440,000	670.0	15582.1	Within the 5th ring road	Wang et al. (2016) for area + Wang et al. (2012) for population
Belo Horizonte, Brazil	Perillo et al. 2017 [40X]	2300000	330.0	6969.7	"city of"	Publication
Bujumbura, Burundi	Bigirimana et al. 2012 [06A]	478155	146.0	3275.0	"the city area is exceeding"	Publication
Campos dos Goytacazes, Brazil	Pedlowski et al. 2002 [39A]	463,731	n/a	115.2	"city limits" (2010)	https://cidades.ibge.gov.br/brasil/rj/campos-dos-goytacazes/panorama
Chicago, IL, USA	Belaire et al. 2014 [03X]	5,194,675	2448.4	2121.7	Cook County (2010)	https://www.census.gov/quickfacts/fact/table/cookcountyillinois,US/PSST045217
Chicago, IL, USA	Davis et al. 2012 [14X]	2500000	600.0	4166.7	"city of"	Publication
Chicago, IL, USA	Gulezian and Nyberg 2010 [22A]	5,376,741	2448.4	2196.0	Cook County (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Chicago, IL, USA	Loss et al. 2009 [29X]	6,280,902	3296.6	1905.3	Cook and DuPage County (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Chicago, IL, USA	Loss et al. 2009 [29Y]	6,280,902	3296.6	1905.3	Cook and DuPage County (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Chicago, IL, USA	Loss et al. 2009 [29Z]	6,280,902	3296.6	1905.3	Cook and DuPage County (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Chicago, IL, USA	Lowenstein et al. 2014 [30X]	2,695,598	589.6	4572.2	City boundary (2010)	https://www.census.gov/quickfacts/fact/table/chicagocityillinois,US/PSST045217
Chicago, IL, USA	Lowenstein and Minor 2016 [31A]	2,695,598	589.6	4572.2	"in and around Chicago" or "city of" (2010)	https://www.census.gov/quickfacts/fact/table/chicagocityillinois,US/PSST045217
Chicago, IL, USA	Lowenstein and Minor 2016 [31B]	2,695,598	589.6	4572.2	"in and around Chicago" or "city of" (2010)	https://www.census.gov/quickfacts/fact/table/chicagocityillinois,US/PSST045217
Chicago, IL, USA	Lowenstein and Minor 2016 [31C]	2,695,598	589.6	4572.2	"in and around Chicago" or "city of" (2010)	https://www.census.gov/quickfacts/fact/table/chicagocityillinois,US/PSST045217
Chicago, IL, USA	Magle et al. 2016 [33X]	7492621	6613.3	1133.0	Chicago Metropolitan region, specifically Cook, DuPage, Lake, Will Counties (2010)	https://www.census.gov/quickfacts/fact/table/dupagecountywillinois,US/PSST045217
Chicago, IL, USA	Nilon and Huckstep 1998 [38X]	6,021,097	3597.5	1673.7	Lake and Cook Counties (pre-1998)	Census for 2000
Chicago, IL, USA	Nilon and Huckstep 1998 [38Y]	6,021,097	3597.5	1673.7	Lake and Cook Counties (pre-1998)	Census for 2000
Chicago, IL, USA	Nilon and Huckstep 1998 [38Z]	6,021,097	3597.5	1673.7	Lake and Cook Counties (pre-1998)	Census for 2000
Costa Brava, Spain	Cubino et al. 2015 [13A]	45360	128.0	354.4	5 municipalities	Cubino et al. (2016)
Costa Brava, Spain	Cubino et al. 2015 [13B]	45360	128.0	354.4	5 municipalities	Cubino et al. (2016)
Costa Brava, Spain	Cubino et al. 2015 [13C]	45360	128.0	354.4	5 municipalities	Cubino et al. (2016)
Dunedin, New Zealand	van Heezik et al. 2013 [45A]	120000	255.0	470.6	30 suburbs or "city of"	Publication + wikipedia
Dunedin, New Zealand	van Heezik et al. 2013 [45B]	120000	255.0	470.6	30 suburbs or "city of"	Publication + wikipedia
Dunedin, New Zealand	van Heezik et al. 2013 [45C]	120000	255.0	470.6	30 suburbs or "city of"	Publication + wikipedia
Dunedin, New Zealand	van Heezik et al. 2013 [45X]	120000	255.0	470.6	30 suburbs or "city of"	Publication + wikipedia
Halton, UK	Gledhill and James 2012 [18A]	119300	91.0	1311.0	"Borough of"	Publication
Halton, UK	Gledhill and James 2012 [18X]	119300	91.0	1311.0	"Borough of"	Publication
Halton, UK	Gledhill and James 2012 [18Y]	119300	91.0	1311.0	"Borough of"	Publication
Heredia, Costa Rica	Gonzalez-Ball et al. 2017 [20A]	19,138	3.0	6379.3	"city of"	Publication
Heredia, Costa Rica	Gonzalez-Ball et al. 2017 [20B]	19,138	3.0	6379.3	"city of"	Publication
Heredia, Costa Rica	Gonzalez-Ball et al. 2017 [20C]	19,138	3.0	6379.3	"city of"	Publication
Hobart, Australia	Kirkpatrick et al. 2007 [25A]	216273	1695.5	127.6	31 Hobart suburbs or "greater Hobart" (2011)	http://stat.abs.gov.au/ttr/jsp?RegionSummary&region=6GHOB&dataset=ABS_REGIONAL_ASGS&geoconcept=REGION&datasetASGS=ABS_REGIONAL_ASGS&datasetLGA=ABS_NRP9_LGA&regionLGA=REGION&regionASGS=REGION
Kigali, Rwanda	Seburanga and Zhang 2013 [41A]	1000000	730.0	1369.9	"city of"	Publication
Leeds, UK	Goddard et al. 2013 [19X]	790000.00	550.0	1436.4	"municipality of"	Publication
Leipzig, Germany	Strohbach et al. 2009 [43X]	437,000	297.4	1469.6	"city of" (late 1990s)	Publication + wikipedia
Los Angeles, CA, USA	Avolio et al. 2015 [02A]	15018478	31222.1	481.0	Los Angeles, Orange, Riverside Counties (2010)	https://www.census.gov/quickfacts/fact/table/riversidecountycalifornia,orangecountycalifornia,losangelescountycalifornia/PSST045217
Los Angeles, CA, USA	Clarke et al. 2013 [08A]	3800000	1214.0	3130.1	"City of"	Publication
Los Angeles, CA, USA	Clarke et al. 2013 [08B]	3800000	1214.0	3130.1	"City of"	Publication
Los Angeles, CA, USA	Clarke and Jenerette 2015 [10A]	9,818,605	10509.9	934.2	Los Angeles County (2010)	https://www.census.gov/quickfacts/fact/table/riversidecountycalifornia,orangecountycalifornia,losangelescountycalifornia/PSST045217

Table G.2. Population Density of cities in the meta-analysis, including spatial extent and data sources.

City	Publication	Population	Area (km2)	Density (person/km2)	Boundary (year)	Source
Lubbock, TX, USA	Farmer et al. 2013 [16X]	229573	317	724.2	"city of"	Census for 2010
Maastricht, Netherlands	Beumer and Martens 2016 [05Am]	120000	60.6	1980.2	"city of"	Publication
New York City, NY, USA	Matteson et al. 2013 [35A]	8,175,133	784	10427.5	NYC all five boroughs (2010)	https://www.census.gov/quickfacts/fact/table/newyorkcitynewyork_US/PST045217
Niamey, Niger	Bernholt et al. 2009 [04A]	900000	239	3765.7	administrative area	Graefe et al. (2008)
Niamey, Niger	Bernholt et al. 2009 [04B]	900000	239	3765.7	administrative area	Graefe et al. (2008)
Paris, France	Cohen et al. 2012 [11A]	2211297	105	21060.0	"city of"	Publication
Phoenix, AZ, USA	Ackley et al. 2015 [01X]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Phoenix, AZ, USA	Beumer and Martens 2016 [05Ap]	1500000	1338	1121.1	"city of" (2010)	Publication
Phoenix, AZ, USA	Kinzig et al. 2005 [24A]	1,321,045	1338	987.3	"city of" (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Phoenix, AZ, USA	Kinzig et al. 2005 [24B]	1,321,045	1338	987.3	"city of" (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Phoenix, AZ, USA	Kinzig et al. 2005 [24X]	1,321,045	1338	987.3	"city of" (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Phoenix, AZ, USA	Kinzig et al. 2005 [24Y]	1,321,045	1338	987.3	"city of" (2000)	https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Phoenix, AZ, USA	Lerman and Warren 2011 [27X]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Phoenix, AZ, USA	Lerman and Warren 2011 [27Y]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Phoenix, AZ, USA	Lerman and Warren 2011 [27Z]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Phoenix, AZ, USA	Walker et al. 2009 [46A]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Phoenix, AZ, USA	Walker et al. 2009 [46B]	3000000	6400	468.8	CAP LTER	Hope et al. (2003)
Porto, Portugal	Graca et al. 2017 [21A]	237,559	41.42	5735.4	"municipal boundaries" including 7 parishes	Publication + http://worldpopulationreview.com/world-cities/porto-population/ + https://www.citypopulation.de/php/portugal-porto.php
Raleigh, NC, USA	Leong et al. 2016 [26X]	1168580	2903.9	402.4	"in and around Raleigh... 65 km radius of central Raleigh" Wake and Durham County (2010)	https://www.census.gov/quickfacts/fact/table/durhamcountynorthcarolina.wakecountynorthcarolina/PST045217
Reno, NV, USA	Trammell and Bassett 2012 [44X]	309,380	367.2	842.5	Reno city + Sparks city	Publication + wikipedia
Reno, NV, USA	Trammell and Bassett 2012 [44Y]	309,380	367.2	842.5	Reno city + Sparks city	Publication + wikipedia
Reno, NV, USA	Trammell and Bassett 2012 [44Z]	309,380	367.2	842.5	Reno city + Sparks city	Publication + wikipedia
Rio Claro, Brazil	Eichemberg et al. 2009 [15A]	168,087	498.422	337.2	"municipality of"	Publication + wikipedia
San Juan, Puerto Rico	Melendez-Ackerman et al. 2014 [36A]	n/a	n/a	3192.0	San Juan Metropolitan Area	Staudhammer et al. (2015)
Santiago, Chile	Hernández and Villaseñor 2018 [23A]	7000000	967	7238.9	urban extent of Santiago	Publication
Santiago, Chile	Hernández and Villaseñor 2018 [23B]	7000000	967	7238.9	urban extent of Santiago	Publication
Santiago, Chile	Hernández and Villaseñor 2018 [23C]	7000000	967	7238.9	urban extent of Santiago	Publication
Sheffield, UK	Fuller et al. 2008 [17X]	525,809	142.06	3701.3	"city boundary" at least 160km2 (2005)	https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationsinatesforukenglandandwalesscotlandandnorthernirelandand https://en.wikipedia.org/wiki/Sheffield
Stockholm, Sweden	Blicharska et al. 2017 [07X]	900000	188	4787.2	"City of" or "Municipality of"	Publication + wikipedia
Sydney, Australia	Makinson et al. 2017 [34X]	3,908,642	2036.6	1919.2	Sydney metropolitan region: Leichardt, Balmain, City of Sydney, Marrickville, Chatswood, Ryde, Ku-ring-gai, Willoughby, Ashfield, Waverley (2013)	http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/communityprofile/UCL1010_01?opendocument
Sydney, Australia	Zivanovic and Luck 2016 [49A]	3,908,642	2036.6	1919.2	"city of" (2013)	http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/communityprofile/UCL1010_01?opendocument
Sydney, Australia	Zivanovic and Luck 2016 [49X]	3,908,642	2036.6	1919.2	"city of" (2013)	http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/communityprofile/UCL1010_01?opendocument
Tlokwe City Municipality, South Africa	Lubbe et al. 2010 [32A]	128,353	185.4	692.3	The main districts	https://en.wikipedia.org/wiki/Potchefstroom
Tlokwe City Municipality, South Africa	Lubbe et al. 2010 [32B]	128,353	185.4	692.3	The main districts	https://en.wikipedia.org/wiki/Potchefstroom
Tlokwe City Municipality, South Africa	Lubbe et al. 2010 [32C]	128,353	185.4	692.3	The main districts	https://en.wikipedia.org/wiki/Potchefstroom
Toronto, Canada	Conway and Bourne 2013 [12A]	1159405	1254	924.6	Peel Municipality; Brampton, Bolton, Caledon, Mississauga including non-urban portion	Publication
Valdivia, Chile	Silva et al. 2015 [42X]	140000	42.39	3302.7	"city of"	Publication
Valdivia, Chile	Silva et al. 2015 [42Y]	140000	42.39	3302.7	"city of"	Publication
Vancouver, Canada	Melles 2005 [37X]	1830000	2412	758.7	Vancouver CMA including Burnaby and Coquitlam	Publication
Waco, TX, USA	Li and Wilkins 2014 [28X]	120,465	218.1	552.3	"city of"	Publication

Table G.2, *continued*. Population Density of cities in the meta-analysis, including spatial extent and data sources.

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Economic Inequality: Fuzzy set GINI Index of Income Inequality values were estimated by assessing GINI scores for each of the cities under investigation. GINI values for US and Puerto Rico cities are the values reported by the US Census Bureau, American Community Survey 2006-2010, 5-year estimates. For some cities in OECD countries (Paris, Stockholm, Vancouver, Toronto, and Santiago), GINI estimates for metropolitan areas were available from OECD.Stat (<http://stats.oecd.org/>). For other cities, we calculated the GINI Index based on data estimates for 2010 accessed from the Canback Global Income Distribution Database (C-GIDD). C-GIDD data were available for most cities directly, but for some smaller cities or cities with less data availability (e.g. Tlokwe, South Africa), we apply estimates for broader urban regions by selecting data that represents “other urban areas”, outside the most major cities, within the same state/province/metro area in the same country (e.g. “North-West Province, urban” in the South African case, which represents the case with the least-specific data availability in our sample). We downloaded C-GIDD data on income distribution by household, using preset levels that are meant to be reasonably comparative around the globe. The data estimate the number of households falling within each of ten preset income categories, which we used as the basis for calculating the GINI index. In calculating the GINI, we assumed that each household had access to the average income value within each category, except for the lowest income category where we assume the average value of \$750 (category is \$0-\$1,500) and the highest income category where we assumed average values of \$100,000 in poorer countries and \$150,000 in richer countries. The resulting GINI estimates range from 0 with complete equality (all households have the same income access) to 1 with complete concentration of wealth into a single household. To check the methodology, the team compared our GINI estimates from these various sources with other published estimates. Our estimates using C-GIDD data generally coordinated well with the country-level World Bank estimates and with the OECD.Stat and ACS city-level estimates, though we found that in richer countries the C-GIDD based estimates tend to underestimate income inequality.

National Development: We used the Human Development Index (HDI) to characterized cities according to their country’s degree of human development. We reasoned that, although individual cities may vary in their degrees of development within a country, national HDI provides a more meaningful signal about the nature of urbanization, population growth, poverty, and difference affecting that city and the processes within from a macro-scale. HDI combines three dimensions of human development using a geometric mean; life expectancy, education (knowledge), and income (standard of living). A country with an HDI close to 1 has an average life expectancy of 85, between 15 and 18 years of schooling, and a gross national income per capita of \$75,000. A country with a HDI value close to 0 has an average life expectancy close to 20, minimal schooling, and a gross national income per capita of of \$100. HDI estimates were obtained through the United Nations for the year 2010.

- The Outcome

We utilized a multi-step process to reduce bias in coding case outcomes. First, for each case, two coders identified relevant text from the publication that described the SES-biodiversity relationship in question, including effect size (or correlation coefficient, variable importance, etc.) and statistical significance where relevant and type of biodiversity measurement. Next, two members of the research team assigned codes for degree of membership (strong, intermediate, weak, or no relationship) based on the selected text. Guidelines were generated from cases with total agreement. Where there was disagreement or confusion, EK and LM sought clarifying information from the papers and returned the cases to the original coders for re-evaluation. A number of cases generated significant disagreement. These cases were sorted according to the type of challenge, including indirect relationships, non-linearity, and complex or contradictory results. A new single coder (PW, MG, SC, CN) evaluated cases in each category to determine how membership should be assigned. Following this, the research team convened to determine guidelines for challenging cases, with particular focus on cases where SES groups were compared qualitatively (not in a modeling framework), mammal cases (where presence/absence of different species or species groups were measured rather than true “diversity”), and indirect relationships. Finally, using the updated criteria for judging cases, PW and EK assigned final codes to the cases with remaining disagreement and confirmed membership for cases with initial agreement. Below we articulate our rhetorical guidelines for determining degree of membership.

Strong Relationship (fully in): There is a clear and strong relationship between SES and biodiversity. Phrases included: most effective in explaining, large increase, strong effect, strongly related, strong support, significant in the model, greater than expected by chance, and better predictor than any other variable. Other criteria: variable importance was high, R^2 was high (>0.20), and p -values were low (<0.05).

Intermediate Relationship (mostly but not fully in): There is clearly a relationship between SES and biodiversity, but enough counter-evidence, complexity, uncertainty, or missing evidence to prevent cases from full membership. There were no common phrases in this group; rather, cases that were determined to be intermediate between weak and strong were included in this set. Some cases in this group had clear differences in diversity between SES groups, but lacked statistical evidence. Others were complex or indirect but convincing nonetheless.

Weak Relationship (more or less in): There is a weak relationship between SES and biodiversity or one that is suggested by combining multiple pieces of evidence. Phrases included: weak relationship, weakly correlated, explained only a small proportion of variation. One case had $R^2 < 0.10$ but a significant p -value [46B] while another case had a higher R^2 (0.23) that was not significant [22A]. Other cases in this group had indirect effects with yard size or bird feeding, didn't fully document their evidence, had a high degree of uncertainty, or included contradictory or mixed results.

No membership (more or less out): Clearly, there is no relationship between SES and biodiversity. Phrases included: no relationship, no effect, not a good predictor, no statistically significant associations/correlations, no significant difference. Other criteria: variable did not make it into top model, variable importance ~ 0 , beta coefficient ~ 0 , p -value $\gg 0.05$. These cases also included those with contradictory results or no clear directional pattern overall.

APPENDIX H TRUTH TABLES

Woody	Native	City	Stratified	Broad_SES	Tropical	Arid	Dense	Old	Unequal	Developed	Number of Cases	Positive Analysis	Positive Consistency	Negative Analysis	Negative Consistency
0	0	0	0	0	0	1	0	0	0	1	2	1	0.91	0	0.41
0	0	0	0	0	1	0	0	0	1	0	1	0	0.77	0	0.77
0	0	0	0	0	1	1	0	0	0	0	1	1	1.00	0	0.27
0	0	0	0	1	0	0	1	1	1	1	1	1	0.81	1	0.84
0	0	0	1	1	0	0	0	0	0	1	1	1	1.00	0	0.57
0	0	0	1	1	0	0	1	0	1	1	2	1	0.89	0	0.64
0	0	0	1	1	0	1	0	1	1	0	1	1	1.00	0	0.63
0	0	0	1	1	1	0	1	0	1	0	2	1	1.00	0	0.64
0	0	0	1	1	1	1	0	0	0	0	1	1	1.00	0	0.47
0	0	0	1	1	1	1	0	0	1	0	2	1	1.00	0	0.36
0	0	0	1	1	1	1	0	0	1	1	2	1	1.00	0	0.50
0	0	1	0	1	0	0	0	0	1	1	1	0	0.75	1	0.92
0	0	1	0	1	0	1	1	1	1	0	1	0	0.50	1	1.00
0	0	1	0	1	1	1	0	0	1	1	2	1	1.00	0	0.18
0	0	1	1	1	1	1	0	0	1	1	1	0	0.75	0	0.75
0	1	0	0	0	0	1	0	0	0	1	1	0	0.37	1	1.00
0	1	0	0	0	1	1	0	0	0	0	1	1	1.00	0	0.51
0	1	0	1	1	0	0	0	1	0	1	1	1	1.00	0	0.67
0	1	0	1	1	0	0	1	0	1	1	1	1	1.00	0	0.67
0	1	0	1	1	0	1	1	1	1	0	2	1	1.00	0	0.10
0	1	0	1	1	1	0	1	0	1	0	1	1	1.00	0	0.75
0	1	0	1	1	1	1	0	0	1	0	1	1	1.00	0	0.45
0	1	1	0	1	0	0	0	0	0	1	1	1	1.00	0	0.67
0	1	1	0	1	0	0	1	1	0	1	1	0	0.79	1	0.82
0	1	1	0	1	1	0	0	1	0	1	1	1	0.85	1	0.85
1	0	0	0	0	0	0	0	0	0	1	2	1	1.00	0	0.32
1	0	0	0	0	1	0	0	1	1	1	1	1	0.86	0	0.70
1	0	0	0	1	0	0	0	0	0	1	1	1	1.00	0	0.25
1	0	0	0	1	1	1	0	0	1	1	1	1	1.00	0	0.35
1	0	1	0	1	0	1	1	1	1	0	1	0	0.50	1	1.00
1	0	1	0	1	1	1	0	0	1	0	1	1	1.00	0	0.50
1	0	1	0	1	1	1	0	0	1	1	2	1	1.00	0	0.20
1	0	1	1	1	1	1	0	0	1	1	1	1	1.00	0	0.57
1	0	1	1	1	1	1	1	1	1	1	2	1	0.88	0	0.54
1	1	0	0	0	0	0	0	0	0	1	1	1	0.80	0	0.58
1	1	0	1	1	0	1	1	1	1	0	1	1	1.00	0	0.12
1	1	1	1	1	1	0	0	1	1	0	1	1	1.00	0	0.49
1	1	1	1	1	1	1	0	0	1	0	1	1	1.00	0	0.25
1	1	1	1	1	1	1	1	1	1	1	1	1	1.00	0	0.39

Table H.1. Truth table for the plant analysis showing unique combinations of conditions, the number of cases that are members in that set of conditions, and the outcome codings and consistency values for the positive and negative analyses.

Mobile	Native	City	Stratified	Tropical	Arid	Dense	Old	Unequal	Number of Cases	Positive Analysis	Positive Consistency	Negative Analysis	Negative Consistency
0	0	1	1	0	0	0	0	1	1	0	0.15	1	1.00
0	1	0	0	0	0	0	1	1	1	1	1.00	0	0.00
0	1	1	0	0	0	0	0	0	2	0	0.68	0	0.66
0	1	1	0	0	0	1	1	0	1	0	0.76	0	0.72
0	1	1	0	1	1	0	0	1	1	1	1.00	0	0.01
0	1	1	1	0	0	0	0	1	2	0	0.61	0	0.73
1	0	0	0	0	0	0	0	0	1	1	1.00	0	0.33
1	0	0	1	1	1	0	0	1	1	0	0.68	0	0.70
1	0	1	0	0	1	0	0	1	1	0	0.84	0	0.86
1	0	1	1	0	0	0	0	1	1	1	1.00	0	0.37
1	1	0	0	0	0	0	0	1	1	1	1.00	0	0.78
1	1	0	0	0	0	0	1	0	1	1	1.00	0	0.52
1	1	0	0	1	1	0	0	1	1	1	1.00	0	0.65
1	1	0	1	0	0	0	1	0	1	1	1.00	0	0.72
1	1	0	1	1	1	0	0	1	3	1	0.97	0	0.22
1	1	1	0	0	0	0	0	0	1	1	0.93	0	0.65
1	1	1	0	0	0	0	0	1	1	1	0.97	0	0.85
1	1	1	0	0	0	1	0	1	2	0	0.83	0	0.85
1	1	1	0	0	0	0	1	0	1	1	0.93	0	0.62
1	1	1	0	0	1	0	0	1	2	0	0.81	0	0.82
1	1	1	0	1	0	1	0	1	1	0	0.62	1	1.00
1	1	1	0	1	0	0	1	0	2	0	0.79	0	0.75
1	1	1	0	1	1	0	0	1	1	1	0.95	0	0.81
1	1	1	1	0	0	0	0	1	2	0	0.42	0	0.84
1	1	1	1	0	0	0	1	1	2	0	0.66	0	0.81
1	1	1	1	1	1	0	0	1	1	1	0.91	0	0.17

Table H.2. Truth table for the animal analysis showing unique combinations of conditions, the number of cases that are members in that set of conditions, and the outcome codings and consistency values for the positive and negative analyses.

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