THESIS

THE EFFECTIVENESS OF URBAN CONSERVATION PROGRAMS FOR ENGAGING THE PUBLIC AND ENHANCING WILDLIFE HABITAT

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ABSTRACT

THE ROLE OF URBAN CONSERVATION PROGRAMS IN ENHANCING WILDLIFE HABITAT AND ENGAGING CITIZENS

The ecological and social effects of urbanization pose significant threats to global biodiversity. Habitat loss and fragmentation associated with urban development often displace native, human-sensitive species and replace them with exotic and human-adapted species. Urban residents also have limited access to natural areas, which may limit public support for conservation. Given these challenges, effectively engaging the public in conservation initiatives is increasingly important. The Nature in the City (NIC) initiative was launched in 2014 by the City of Fort Collins to create: "a connected open space network accessible to the entire community that provides a variety of experiences and functional habitat for people, plants, and wildlife." Here, I evaluated the extent to which two NIC programs achieved their goals to monitor plant and animal communities, enhance habitat for native species, and engage the public in conservation.

My first chapter focused on the NIC Biodiversity Project, a citizen science ecological monitoring program. This program recruits and trains volunteers to collect data on the distribution of birds and butterflies across Fort Collins. Specifically, I assessed the tradeoffs associated with collecting data with citizen scientists as compared to paid technicians in terms of 1) data quality, 2) cost efficiency, and 3) the effectiveness of public engagement. I found mixed results for data quality; the probability of detecting human-adapted species was similar for citizen scientists and technicians, but citizen scientists were less likely to detect human-sensitive species. Additionally, citizen scientists tended to over report the abundance of human-adapted

birds as compared to technicians. Habitat use estimates for four out of five species were comparable between data collected by citizen scientists and technicians. Citizen scientists were more cost efficient, producing more surveys and detections per paid work-hour than paid technicians. Finally, the citizen science program increased volunteers' ability to identify local wildlife and intentions to participate in similar programs but did not affect nature relatedness and self-efficacy for environmental action.

My second chapter focused on the City of Fort Collin's Certified Natural Areas (CNA) program, which encourages private landowners to engage in stewardship practices that provide habitat for native plants and animals. I assessed 1) whether the CNA program increased native vegetation cover and vegetation structural heterogeneity, 2) provided habitat for human-sensitive birds and butterflies, and 3) which site- or landscape-level factors influenced these outcomes. I compared 10 residential open spaces not enrolled in the CNA program, 10 enhanced residential open spaces enrolled in the CNA program and 12 public natural areas managed by the City of Fort Collins. Although I did not detect significant differences in the amount of native vegetation cover or structure across site types, enhanced residential open spaces and public natural areas had consistently less mowed vegetation cover than residential open spaces, which was associated with more detections of insectivorous and shrub-nesting bird species. I also detected more human-sensitive bird species in enhanced residential open spaces than residential open space and found that across all sites, native vegetation was positively related to butterfly richness. Together, these results demonstrate that although enhanced residential open spaces are not a substitute for public natural areas providing high-quality habitat for human-sensitive wildlife, even relatively simple stewardship practices, such as not mowing vegetation, can have a positive influence on bird and butterfly communities in urban neighborhoods.

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TABLE OF CONTENTS

Chapter 1 – Evaluating The Role Of Citizen Science In Ecological Research And Public Engagement: A Colorado Case Study

SUMMARY

Citizen science, the enlisting of non-professional scientists to voluntarily collect data, is a popular approach for involving the public in ecological research. In theory, the benefits of this model are two-fold and complementary: citizen science programs produce useful datasets while also engaging the public in conservation initiatives. However, in practice there may be tradeoffs regarding data quality, cost efficiency, and the effectiveness of public engagement, yet these tradeoffs are rarely quantified. Here, we compared the costs and benefits of a) employing paid technicians or b) recruiting citizen science volunteers to collect bird and butterfly data for an urban biodiversity project. We found mixed results for data quality; the probability of detecting human-adapted species was similar between technicians and citizen scientists, but citizen scientists were less likely to detect human-sensitive species. Additionally, citizen scientists tended to over report the abundance of human-adapted birds as compared to technicians. However, habitat use estimates for four out of five species were comparable between data collected by citizen scientists and technicians. We found that citizen scientists were more cost-effective, producing 1.5x more bird and 2x more butterfly surveys and detections per paid work-hour. Lastly, citizen scientists improved their ability to accurately identify local bird (16%) and butterfly (31%) species after participating in the program, and a majority of volunteers reported an increased interest in behavioral intentions to engage in conservation-related activities, such as observing wildlife (75%) and seeking more information about birds and butterflies (75%). We did not observe significant changes in attitudes, likely due to high pre-program levels of nature

relatedness and environmental efficacy among volunteers. Together, our findings suggest that citizen science can increase scientific literacy among volunteers and can produce cost-effective data of similar quality to technicians, particularly for human-adapted species. To further improve data quality, we recommend that citizen science trainings focus on the identification of human-sensitive species as well as tracking multiple individuals of the same species during surveys. To more effectively catalyze changes in attitudes as a result of participation in citizen science, programs should focus on recruiting members of the public with varied preexisting attitudes towards conservation.

INTRODUCTION

Citizen science is often presented as a "win-win" for conservation. Commonly defined as the "enlisting of non-professional scientists to voluntarily collect or process data," (Silvertown, 2009) citizen science is a model for conducting scientific research that can contribute to social and ecological goals (Dickinson et al., 2012). Citizen science programs seek to collect useful data while also engaging the public and there is evidence that some programs can achieve these goals. For example, given appropriate training, citizen science data can be as precise (Lewandowski & Specht, 2015) and more cost-effective than data collected by professionals (Gardiner et al., 2012; van der Velde et al., 2017). In addition to the role that citizen scientists can play in research, many studies have demonstrated that citizen science programs can be a highly effective avenue for educating the public on ecological issues (Bonney et al., 2016; Crall et al., 2013). Participation in these programs can also reinforce pro-environmental attitudes and strengthen social networks within communities (Chase & Levine, 2018).

Yet, citizen science also has potential limitations as a tool for collecting rigorous data efficiently, while also engaging a diverse public. For instance, the training necessary for collecting high-quality data differs depending on the task, with some protocols requiring more intensive training processes, such as in-field training sessions (Kremen et al., 2011; Newman et al., 2003), which may limit the number of willing volunteers and a program's capacity to train and manage volunteers. Studies also increasingly acknowledge that volunteers for citizen scientist projects are disproportionately white, older, affluent, well-educated, and hold strong preexisting environmental attitudes, potentially limiting opportunities to engage new communities and expand the social network of conservation (Chase & Levine, 2018).

As a result, institutions implementing citizen science programs may face tradeoffs between data quality, data collection efficiency and effective public engagement. In these cases, institutions may need to prioritize or balance their objectives to determine an appropriate level of public participation in research and monitoring. While frameworks for public participation in research exist (Shirk et al., 2012), potential tradeoffs between citizen science and other potential models (e.g., data collection by trained technicians) are rarely evaluated in quantitative terms. This lack of rigorous comparison may limit trust in citizen science among applied ecologists and conservation practitioners (Burgess et al., 2017).

Here, we present a case study on the Nature in the City (NIC) Biodiversity Project in Fort Collins, Colorado (U.S.). Like many rapidly growing cities, Fort Collins is faced with the challenge of conserving habitat and engaging an increasingly urban population (Spear et al., 2017). In response to these challenges, the City of Fort Collins adopted the NIC Initiative with the goal of protecting open space for wildlife and people. The NIC Biodiversity Project supports the initiative by monitoring birds and butterflies throughout Fort Collins with paid technicians and citizen scientists. The program's structure and its dual ecological and social goals make Fort Collins' NIC Biodiversity Project an ideal model for assessing the tradeoffs of implementing a citizen science program versus collecting data with paid technicians.

Our objective was to quantitatively compare the costs and benefits of employing paid technicians to investing in a citizen science program, with the overall goal of enhancing conservation for wildlife and people in an urban environment. Using Fort Collins' NIC Biodiversity Project, we compared these two approaches to collecting ecological data by assessing the following outcomes: data quality, cost-effectiveness, and public engagement (Table 1.1). This framework and our results could be broadly used to guide ecological monitoring programs where engaging the public in science-based decisions could help conserve open space in growing communities.

METHODS

Study site

Fort Collins is located in northern Colorado along the front range of the Rocky Mountains. The city has an estimated population of 165,080 and grew by 11.7% from 2010 to 2015 (U.S. Census Bureau). The NIC Initiative was adopted in 2015 by the City of Fort Collins with the vision of creating "a connected open space network accessible to the entire community that provides a variety of experiences and functional habitat for people, plants, and wildlife" (City of Fort Collins, 2018). As part of this initiative, the NIC Biodiversity Project is an ecological monitoring program that recruits teams of citizen scientists and paid technicians to survey for birds and butterflies in diverse types of urban green spaces throughout the city (Figure 1.1). The Fort Collins Natural Areas Department uses the data collected by this monitoring program to identify areas where habitat connectivity can be protected or restored and to inform land acquisition and management.

Technician surveys

In 2014, an initial ecological assessment of 166 urban green spaces in Fort Collins was conducted with paid technicians that surveyed for all bird and butterfly species. This assessment was repeated in 2018. Technicians surveyed birds with five-minute point counts (Ralph et al., 1995) between May 15th and June 30th. Over the course of each field season, technicians conducted three point counts at each sampling point between 06:00 and 10:00. These three surveys were conducted by at least two different trained observers. Observers recorded all bird species that were seen and heard within a 50m radius.

Technicians also surveyed each site for butterflies three times between July 1st and August 15th. They conducted Pollard walks, a common method for assessing butterfly abundance (Pollard, 1977), along two 50m transects within each site. Technicians located the start and end of each transect using GPS units. Unlike point counts, Pollard walks were not limited by time. Rather, the observer walked slowly (heel-to-toe) along each 50m transect, recording the species and abundance of all butterflies that traversed a 6m buffer in all directions around the transect. Observers recorded all butterfly species observed.

Citizen science program

From 2015 to 2018, we recruited a team of citizen scientists to survey a subset of the 166 sites, during the same monitoring period as the paid technicians. Thus, in one year (2018), paid technician and citizen science monitoring programs were run in parallel. Before each season began, we trained citizen scientists to identify 15 bird and 10 butterfly species by sight and sound in grouped classroom training events. Limiting the number of species that citizen scientists survey is a common practice for reducing variability in data quality (Freitag et al., 2016). We selected 15 bird and 10 butterfly species based on the criteria that they were relatively common in the city, easily identifiable to species, and relevant to the NIC Initiative's conservation goals (Supplemental Table 1.2). After classroom trainings were completed, citizen scientists were given in-field training on how to conduct bird and butterfly surveys based on the same survey techniques, described above, used by paid technicians. We maintained communication with participants via email to answer questions about species identification and protocols throughout the program.

We constructed pre- and post-program volunteer surveys adapted from pre-existing survey instruments (Phillips et al., 2014; Toomey & Domroese, 2013; Merenlender et al., 2016). Our surveys assessed citizen scientists' 1) ability to identify local birds and butterflies, 2) self-efficacy for environmental action, or perception of their ability to address environmental issues, 3) nature relatedness, or an individual's level of connectedness to the natural world (Nisbet et al., 2009), and 4) behavioral intentions for conservation action, or "the degree to which a person has formulated conscious plans to perform or not perform some specified future behavior" (Ajzen, 1985) (Supplemental Methods 1.1). We administered pre-program surveys to citizen scientists through Survey Gizmo (SurveyGizmo, 2018) as they signed up for the program and closed the survey before they began training (April 15th-May1st). We administered post-program surveys after citizen scientists had completed their final field surveys and closed the surveys after approximately one month (August 15th-September 15th).

Cost effectiveness

In 2018, program coordinators logged their paid-hours as they pertained to the paid technician surveys and the citizen science program. Paid-hours were categorized as pre-program, during monitoring season, or post-program. Pre-program paid-hours for technician surveys included items such as organizational meetings, hiring processes, technician training and time spent preparing for various tasks. Monitoring season paid-hours included items such as time spent conducting surveys and driving time. Post-program paid-hours included items such as data entry and post-program meetings. Citizen science pre-program paid-hours included items such as organizational meetings, volunteer recruitment, volunteer trainings and time spent preparing for various tasks. Monitoring season paid-hours included items such as time spent coordinating volunteers and driving time. Post-program paid-hours included items such as data entry, volunteer appreciation events and post-program meetings.

Statistical Analyses

Data quality – We used a false-positive occupancy model and an unpaired t-test to assess the probability of a falsely reported species and incorrect reported number of individuals, respectively. To ensure appropriate comparisons between technician and citizen science surveys, we used a subset of data to assess differences in data quality between these two approaches. Specifically, we limited our analyses to detections of the 15 bird and 10 butterfly species in 2018, when both programs were operating simultaneously, and we included only data collected at the 45 sites surveyed by both technicians and citizen scientists.

We used a false positive site occupancy model to estimate the probability that misidentifications occurred based on detection histories at all 166 sites. This technique, introduced by Miller et al. (2011), can be applied when using one ‘uncertain’ and one ‘certain’ survey method. Surveys using the ‘uncertain method’ may falsely detect a species that is absent (false positive, p_{10}), or fail to detect a species that is present (false negative). Surveys using the ‘certain method’ are assumed to have no false positives, but false negatives may still occur. For this study, we considered the technician surveys to be the certain method and the citizen scientist surveys to be the uncertain method. As such, we fixed r_{10}= 0 for occasions when technicians collected data when running these models. We used a false positive model to estimate the probability of habitat use (Ψ), the probability of a false positive detection for citizen scientists (p_{10}), the probability of a true positive detection recorded by a technician (r_{11}), and the probability of a true positive detection recorded by a citizen scientist (p_{11}). Estimates for species were excluded if their models failed to converge or yielded unrealistic estimates (ex. Ψ=1.00). For each species, we compared the estimated probability of true detection by each survey method (p_{11} vs. r_{11}). We also compared the estimated rates of false positive detections by citizen scientists (p_{10}) among species.

For the species that yielded realistic false positive models, we used a single-season occupancy modeling framework to estimate two separate habitat use probabilities with the citizen science (Ψ_{CS}) and the technician (Ψ_T) detection histories (Mackenzie & Royle, 2005). Bird models were built using all iterations of three site covariates (site area, natural habitat cover and vegetation cover within a 100m buffer) and two observational covariates (wind level and cloud cover). Butterfly models were built using all iterations of two site covariates (green space cover within a 100m buffer and shrub cover within a 100m buffer) and two observational covariates (wind level and cloud cover). These covariates and buffer distances were identified as important predictor variables based on previous analyses (J. Sushinsky, unpublished data). Models for a species were again excluded if their models failed to converge or yielded unrealistic estimates (ex. Ψ=1.00). We used Akaike's information criterion (AIC) to select models and report on models with ΔAIC values less than 2 (Burnham & Anderson, 2004). We compared top model estimates from each single season model set (Ψ_{CS} and Ψ_{T}) to probabilities estimated using combined detection histories in a false-positive occupancy modeling framework (Ψ_{CS+T}).

To compare differences in how citizen scientists and technicians reported the number of individuals at a site, we categorized all bird and butterfly detections by guild (human-sensitive vs. human-adapted species; Supplemental Table 1.2). At each site, we calculated the mean number of bird and butterfly detections reported, and we used an unpaired t-test to compare the mean number of detections among surveys throughout the season (Lewandowski & Specht, 2015). To compare the variability between datasets, we divided the citizen science standard errors by the technician standard errors.

Cost-effectiveness - We summed all paid-hours invested in the citizen science program and technician monitoring of birds and butterflies in 2018 (Supplemental Table 1.1). We then divided the total number of surveys and number of bird and butterfly detections by paid work-hours to calculate surveys per paid-hour and detections per paid-hour for each monitoring approach.

Public Engagement – We did not find an effect of survey year on volunteer ecological knowledge or attitudes (bird identification: $F(1,191)=0.04$, $p=0.84$; butterfly identification: $F(1,192=3.8$, $p=0.54$; self-efficacy for environmental action: $F(1,175=0.05$, $p=0.83$); nature relatedness: F(1,147=0.40, p=0.53). As a result, we pooled volunteer survey data from all years (2015-2018). We evaluated surveys using protocols provided by Merenlender et al (2016). We scored questions about respondents' ability to identify local birds and butterflies based on the percentage of correct answers out of five. We scored questions concerned with respondents' perceptions of their ability to address environmental issues and interest in the natural world on a 7-point Likert scale (Brossard et al. 2005). We used an unpaired t-test to compare the mean score between pre- and post-program surveys (Merenlender et al., 2016).

For the behavioral intentions questions, we found no effect of year on the proportion of respondents who expressed an increased interest in any activity (Supplemental Table 1.4); therefore, we pooled survey data from all years. We used a two-way chi-squared test to compare the proportions of answers (interest increased, decreased or stayed the same) to each question to a "standard" proportion provided by a dummy activity ("Reduce my ecological footprint") representing a pro-environmental behavior not related directly to our program (Toomey & Domroese, 2013).

To address potential post-program survey non-response bias, we used a log-linear analysis to compare key demographics of our respondents (gender, race, education, income, age and home ownership) between pre- and post-program respondents. This approach allowed us to assess if there were differences in the demographic composition of our pre- and post-program respondent groups while accounting for differences in survey responses between years (Chambers & Welsh, 1993).

RESULTS

Data quality

False positive models for eight bird and three butterfly species converged and yielded realistic estimates (Figures 2 and 3). The probability of a true positive detection was most similar between citizen scientists and technicians for human-adapted species such as American Robin (*Turdus migratorius*) (p_{11} = 0.505, ±SE=0.04, r_{11}= 0.51, ±SE=0.03), House Finch (*Haemorhous mexicanus*) (p_{11} = 0.47, ±SE=0.05, r_{11}= 0.56, ±SE=0.03) (Figure 1.2) and cabbage white (*Pieris rapae*) (p_{11} = 0.56, ±SE=0.05, r_{11}= 0.53, ±SE=0.04) (Figure 1.3). However, the probability of a true detection was higher for technicians than citizen scientists for human-sensitive species such as House Wren (*Sturnella neglecta*) (p_{11} = 0.37, ±SE=0.09, r_{11}= 0.63, ±SE=0.06) (Figure 1.2) and common checkered skipper (*Pyrgus communis*) (p_{11} = 0.31, ±SE=0.07, r_{11}= 0.50, ±SE=0.07) (Figure 1.3).

Single-season habitat use models for four bird and one butterfly species converged and yielded realistic estimates (Figure 1.4). Top model habitat use estimates were comparable, with confidence intervals overlapping when using citizen science and technician detection histories for American Robin (Ψ_{CS}=0.80, ±SE_{CS}=0.08, Ψ_{T}=0.83, ±SE_{T}=0.06), Northern Flicker (*Colaptes auratus*) (Ψ_{CS}=0.41, ±SE_{CS}=0.27, Ψ_{T}=0.23, ±SE_{T}0.07), Western Meadowlark (Ψ_{CS}=0.28, ±SE_{CS}=0.14, Ψ_{T}=0.15, ±SE_{T}0.03) and cabbage white (Ψ_{CS}=0.73, ±SE_{CS}=0.08, Ψ_{T}=0.69,±SE_{T}=0.08) (Figure 1.4). For one species, Red-winged Blackbird (*Agelaius phoeniceus*), top model habitat use estimates were higher when using citizen science detection histories and confidence intervals did not overlap (Ψ_{CS}=0.74, ±SE_{CS}=0.17, Ψ_{T}=0.46,±SE_{T}=0.04).

The covariates included in top model sets were different for only one out of the five species (Supplemental Table 1.5).

Citizen scientists reported a similar number of detections for human-sensitive bird species as paid technicians, but they reported 1.4x more detections of human-adapted bird species ($t(72) = 2.4$, p-value = 0.02) (Figure 1.5). The number of bird detections was less variable in technician datasets, with the standard error for technician-collected data being 1.3x smaller for human-sensitive species and 1.7x smaller for human-adapted species than the citizen science dataset (Figure 1.5). We did not observe a significant difference in detections of human-adapted species of butterflies ($t(245) = 1.4$, p-value = 0.15) or human-sensitive butterflies ($t(240) = -1.0$, p-value = 0.3). The standard error for technician-collected butterfly data was 1.4x smaller for human-adapted species and 1.3x smaller for all butterflies, but 1.1x larger for human-sensitive species.

Cost-effectiveness

The citizen science program was a more cost-effective model for collecting bird and butterfly data than technician monitoring both in terms of surveys per paid-hour and detections per paid-hour (Figure 1.6). Citizen scientists produced 1.5x more bird surveys and 1.5x more bird detections per paid-hour than technicians. This difference was even stronger for butterfly monitoring, as citizen scientists produced 2.2x as many surveys and reported 2.4x more detections per paid-hour.

Public engagement

Out of a mean of 39 (± 13) citizen scientists per year, we received responses from 33 (± 14) respondents (M=84%±7 response rate) for the pre-program survey and 18 (± 4.4) respondents for the post-program survey (47%±18 response rate). The demographic characteristics of the pre- and post-program survey respondent groups did not differ (Supplemental table 1.6).

On average, respondents exhibited a 16% increase in their ability to accurately identify five local birds between their pre-program (M=3.6±0.21) and post-program (M=4.4±0.13) surveys ($t(192)=-3.8$, $p<.01$) (Figure 1.7). This effect was even larger for butterfly identification, as respondents increased their scores by 31% out of five species (pre-program: M=2.0±0.28, post-program: M=3.6±0.15) ($t(1,186)=-6.9$, $p<.01$). We did not observe an effect of participating in the program on self-efficacy for environmental action ($t(146)=1.4$, $p=0.15$) or nature relatedness ($t(147)=-1.1$, $p=0.26$) (Figure 1.7).

Respondents reported increased interests in spending time viewing birds and butterflies ($X^2(2)=49$, $p<0.01$), seeking additional information about birds and butterflies ($X^2(2)=43$, $p<0.01$), volunteering for another citizen science program ($X^2(2)= 19$, $p<0.01$), volunteering for the Nature in the City biodiversity project in future years ($X^2(2)= 37$, $p<0.01$), getting involved with the Nature in the City initiative ($X^2(2)=13$, $p=0.01$), sharing knowledge of birds or butterflies with friends or family members ($X^2(2)=29$, $p<0.01$), visiting open space areas in Fort Collins ($X^2(2)=17$, $p<0.01$) and protecting or restoring wildlife habitat throughout Fort Collins ($X^2(2)=8.5$, $p=0.02$) (Figure 1.8). However, we did not observe an effect of participation on interests in protecting or restoring wildlife habitat on the respondent's property ($X^2(2)=5.9$, $p=0.05$) or contributing to a wildlife conservation organization ($X^2(2)=2.3$, $p=0.32$) (Figure 1.8).

DISCUSSION

Recruiting volunteers has the potential to engage the public in conservation while also providing useful datasets for researchers. However, using a citizen science program instead of traditional data collection by paid technicians may involve tradeoffs among data quality, cost-effectiveness, and public engagement. We quantified those tradeoffs in the context of an urban biodiversity project designed to inform land conservation and development decisions. We found that citizen scientists had similar probabilities of detecting human-adapted species but were less likely to detect human-sensitive species. Additionally, we found that the citizen science model was more cost-effective, with more surveys completed per paid work-hour. Finally, although volunteers increased their ability to identify local birds and butterflies, they did not report a higher likelihood of engaging in conservation actions following participation in the program.

Questions about the quality of data collected by citizen scientists is of growing concern and research interest (Lewandowski & Specht, 2015). Our citizen science dataset yielded bird and butterfly habitat use estimates that were comparable to those generated by the technician dataset. Yet, there were a number of notable differences between the citizen science and technician datasets that could have important implications for those planning to use these data to make conservation decisions. For example, habitat use estimates based on technician data were considerably less variable than citizen scientists for some species, suggesting that technician detection histories were more consistent, and their estimates are more certain than citizen scientists (Miller, 2005). Additionally, while the probability of a true detection was similar between citizen scientists (p_{11}) and technicians (r_{11}) for human-adapted species, human-sensitive species were less likely to be detected correctly by citizen scientists. This could either be the result of volunteers failing to correctly identify human-sensitive bird species once detected or failing to detect these species altogether. Consistent with the latter explanation, Kelling et al (2015) found differences citizen science in bird detections and identification rates for particularly cryptic or difficult-to-identify species. This finding is not surprising, given that citizen scientists are less likely to have experience with observing and identifying human-sensitive species. Further, citizen scientists tended to over-report the number of human-adapted species when compared to technicians, which could affect estimates of population sizes, community evenness and species dominance. Still, despite these differences in detection rates and abundance estimates, citizen scientists produced datasets that estimated habitat use values comparable, albeit with less confidence, to technician datasets for four out of the five species we analyzed. These results adds to a growing body of literature supporting the assertion that citizen scientists can produce similar datasets to those produced by professional scientists (Kosmala et al., 2016; Lewandowski & Specht, 2015; Meentemeyer et al., 2015; Theobald et al., 2015).

We found that the citizen science model was substantially more cost-effective than hiring technicians. This is consistent with Van der Veld et al. (2018), who showed that volunteers were more efficient at completing surveys for marine debris than researchers. Although false detections are likely inflating the citizen science detections per paid-hour estimates, citizen scientists still produced more surveys per paid-hour than technicians. We note that cost-effectiveness is likely a function of citizen science group size and the time spent on training, and thus is likely to vary among programs. However, for this particular program, even if we doubled training time in the field to focus on reducing false positives and improve data quality, the citizen science model would still produce 1.1x more bird and 1.7x more butterfly surveys than the technician model.

We demonstrated that citizen science can be a highly effective tool for advancing scientific literacy and conservation education (Brossard et al. 2005, Crall et al. 2013). Our program was successful in increasing both the ability of citizen scientists to identify birds and butterflies, and the volunteers' intention to engage in some conservation behaviors, such as observing and learning more about wildlife (Crall et al., 2016; Toomey & Domroese, 2013). While these findings are encouraging, they are limited to behavioral intentions, which do not consistently predict lasting behavioral change (Webb & Sheeran, 2006). Moreover, the activities with the strongest increases in interest ("Spend time observing wildlife" and "Seek additional information about birds and butterflies") were more closely related to increasing individual scientific literacy, whereas interest in activities that directly relate to conservation action ("Contribute to a wildlife conservation organization" and "Protect or restore wildlife habitat on my own property") did not increase. We did not observe changes in nature relatedness or self-efficacy for environmental action (Chase and Levine 2018). We suspect, and the data support, that this is due to our volunteers starting the program with already high levels of nature relatedness and self-efficacy for environmental action (Figure 1.7).

There were several dimensions of our study that may limit our inference and could serve as important areas for future inquiry on this topic. Like many other studies assessing citizen science data quality in ecological monitoring, we were limited in our ability to compare citizen scientists' observations to a "true" value (Lewandowski & Specht, 2015). However, we demonstrate that it is possible to partially overcome this limitation by using a false positive occupancy modelling framework to better understand how differences between citizen scientist and paid technician datasets may ultimately affect the information used by decision-makers. However, it is important to note that this approach to variable selection was not exhaustive, and this may have contributed to model uncertainty. Further, because we only focused on one program, our ability to assess cost-effectiveness as a function of program structure was limited. We anticipate that program cost-effectiveness tradeoffs may be a function of program size and the intensity of required volunteer training and suspect that long-term programs may receive more pay off for their initial investment in training citizen scientists. We suggest that future studies quantify these relationships to better understand the critical points (e.g., mean group size, hours of training) at which one approach becomes more cost-effective than another. Lastly, it was beyond the scope of our study to evaluate how our program affected citizen scientists' long-term behaviors related to conservation. Future studies should monitor the activities of citizen scientists beyond the time scale of the program to better understand whether participation truly increases pro-conservation behaviors and whether those behavioral changes persist over time (Toomey & Domroese, 2013).

We offer several recommendations for how to improve citizen science programs to achieve conservation goals. First, we suggest that trainings focus on anticipated or observed problems with data collection. For example, given that citizen scientists may have struggled to detect and correctly report human-sensitive species, we suggest that classroom and in-field trainings focus on detecting and identifying these species. Similarly, given the over reporting of human-adapted species that we observed among citizen scientists, we recommend that training also focus on tracking multiple individuals of the same species during surveys to reduce errors associated with double counting. We additionally suggest that both of these challenges could be addressed by pairing new volunteers with experienced citizen scientists or by organizing regular wildlife-viewing trips in small groups to practice field methods. We do acknowledge that investing a substantial amount of time and resources to intensify training may offset cost effectiveness. However, we contend that this initial investment is likely to pay off, particularly for large scale, long-term programs that have high citizen scientist retention rates between seasons. Still, we recognize that the ability to identify human-sensitive species may be a challenge for new volunteers with limited experience. Hiring technicians may be particularly advantageous for short-term projects for which determining the distribution or abundance of human-sensitive species is a priority.

If a major goal of a given program is to affect public attitudes regarding conservation and environmental action, recruitment should focus on reaching members of the public who may not necessarily have preexisting positive attitudes towards conservation. Citizen science programs that do not recruit a diverse volunteer group that is representative of the broader community are limited in their ability to change public attitudes (Lukyanenko et al., 2016). To this end, some have argued that citizen science recruitment must engage communities that are typically underrepresented in conservation research and decision-making (Chase & Levine 2018). If influencing public attitudes is a major goal of a citizen science program, then we suggest that active recruitment should extend beyond advertising through word of mouth or contacting past volunteers to focus on reaching potential volunteers who are not yet part of these networks.

CONCLUSION

Citizen science is a promising tool for collecting large datasets to inform major environmental challenges, while also engaging the public in the scientific enterprise. However, recognizing and understanding the tradeoffs associated with citizen science is critical to evaluating whether this approach to data collection will meet program objectives. Here, we quantified these tradeoffs by comparing the costs and benefits of paid technicians relative to citizen scientists in collecting data to inform the conservation of urban open space. We found that these two approaches resulted in similar data quality, although citizen scientists may under-detect human-sensitive species and over-report human-adapted species. Despite this shortcoming, coordinating citizen scientists was more cost-effective than employing technicians, and participating in the program increased the scientific literacy of volunteers. We hope that our findings and this framework can be used to help other organizations make strategic decisions about if and how to integrate citizen science into their programs. Despite some tradeoffs in data quality, engaging the public in data collection has strong potential to broaden the constituency for nature and improve organizations' capacity to make evidence-based conservation decisions.

Tables/Figures

Table 1.1. Summary of three outcomes that were evaluated when assessing the tradeoffs between monitoring wildlife through a citizen science program and hiring technicians. Each outcome (left) is associated with a number of quantifiable metrics (right), which were measured and compared between both models for collecting ecological data.

Outcome	Metrics
Data quality	• The probability that a reported detection is "true" as estimated in a false-positive occupancy framework • Differences in estimates of habitat use in models constructed using technician versus citizen science data • Differences in important covariates in models constructed using technician versus citizen science data • Number and standard error of detections of human-sensitive and human-adapted species
Cost-effectiveness	• Number of surveys per paid-hour • Number of detections per paid-hour
Public engagement	• Changes in ecological knowledge • Changes in nature relatedness and self-efficacy for environmental action • Changes in interest level in behaviors related to conservation

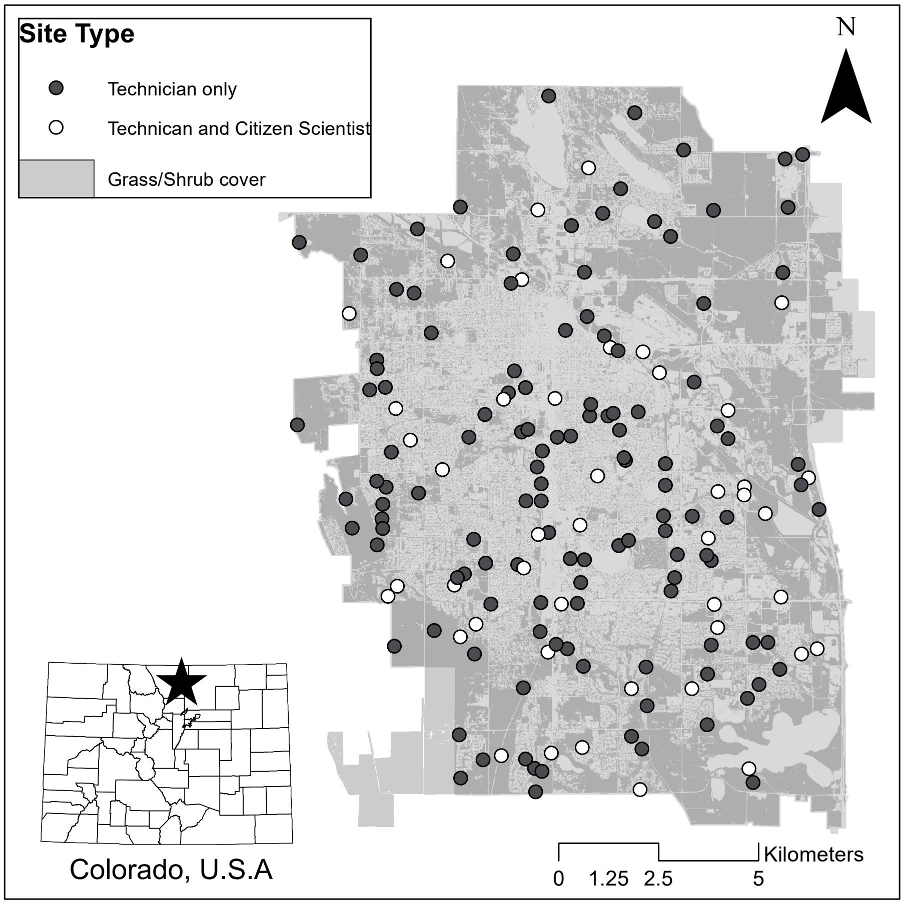

Figure 1.1. The City of Fort Collins (Colorado, U.S.) Growth Management Area with the location of bird and butterfly sites surveyed by technicians and citizen scientists in 2018. Sites surveyed only by technicians are represented by grey circles (n=121) and sites surveyed by both technicians and citizen scientists are represented by black circles (n=45).

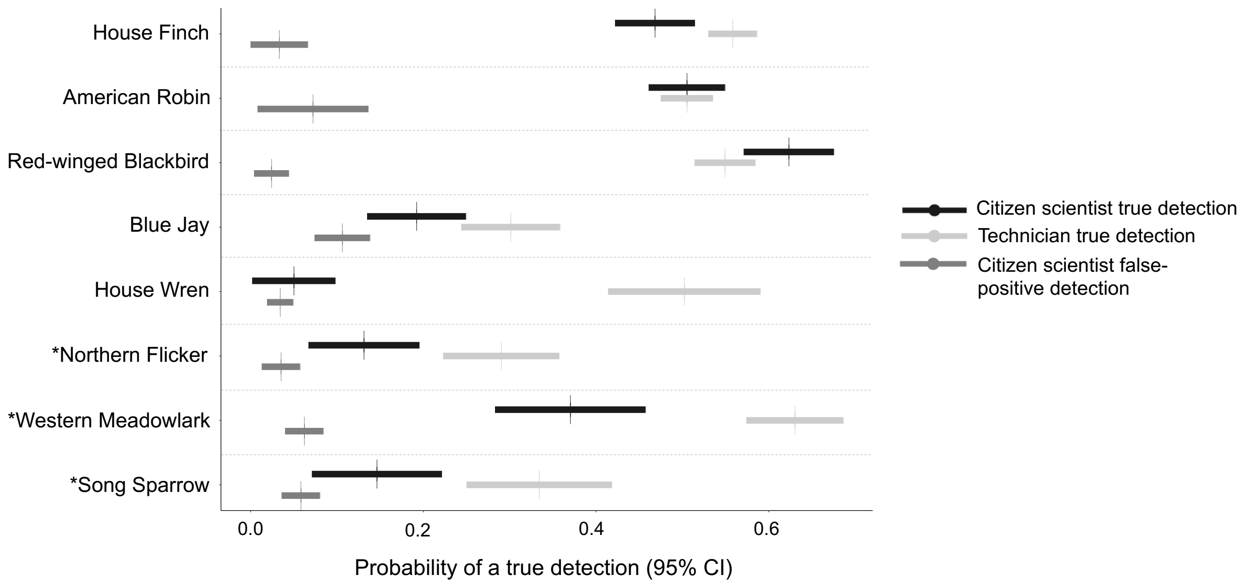

Figure 1.2. Estimates (±CI) of the probability that a reported detection is "true" for both citizen scientists (p_{11}) and paid technicians (r_{11}) as estimated by false-positive occupancy models for eight bird species. House finch, American Robin, Red-winged Blackbird, Blue Jay and House Wren are human-adapted species, whereas Northern Flicker, Western Meadowlark and Song Sparrow are human-sensitive species (indicated with asterisks).

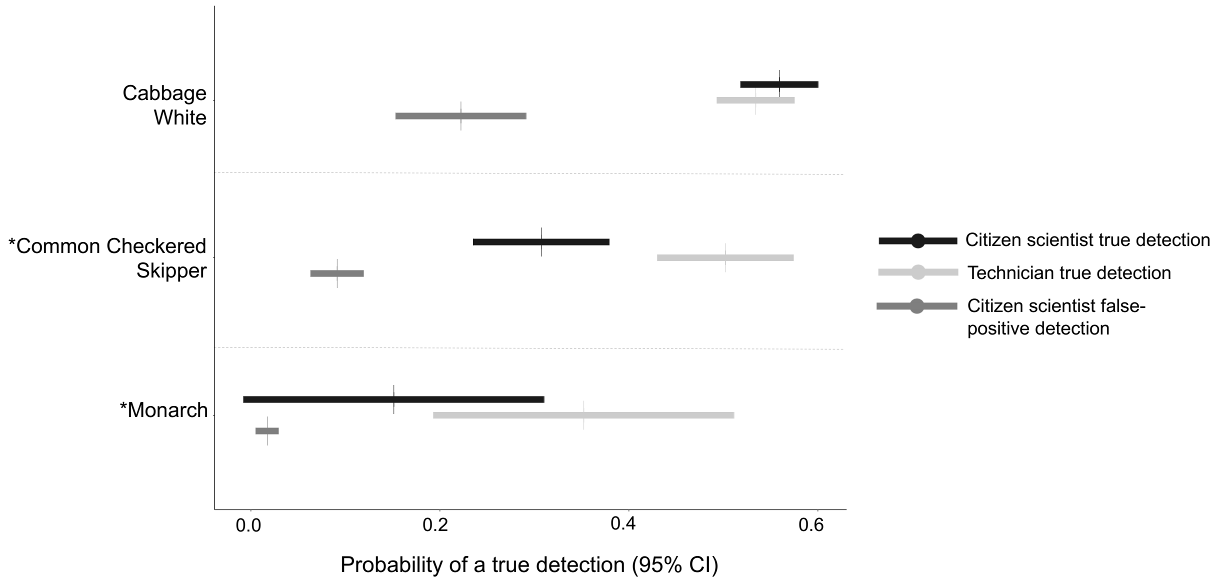

Figure 1.3. Estimates (±SE) of the probability that a reported detection is "true" for both citizen scientists (p_{11}) and paid technicians (r_{11}) as estimated by false-positive occupancy models for three butterfly species. Cabbage white is a human-adapted species, whereas common checkered skipper and monarch are human-sensitive species (indicated with asterisks).

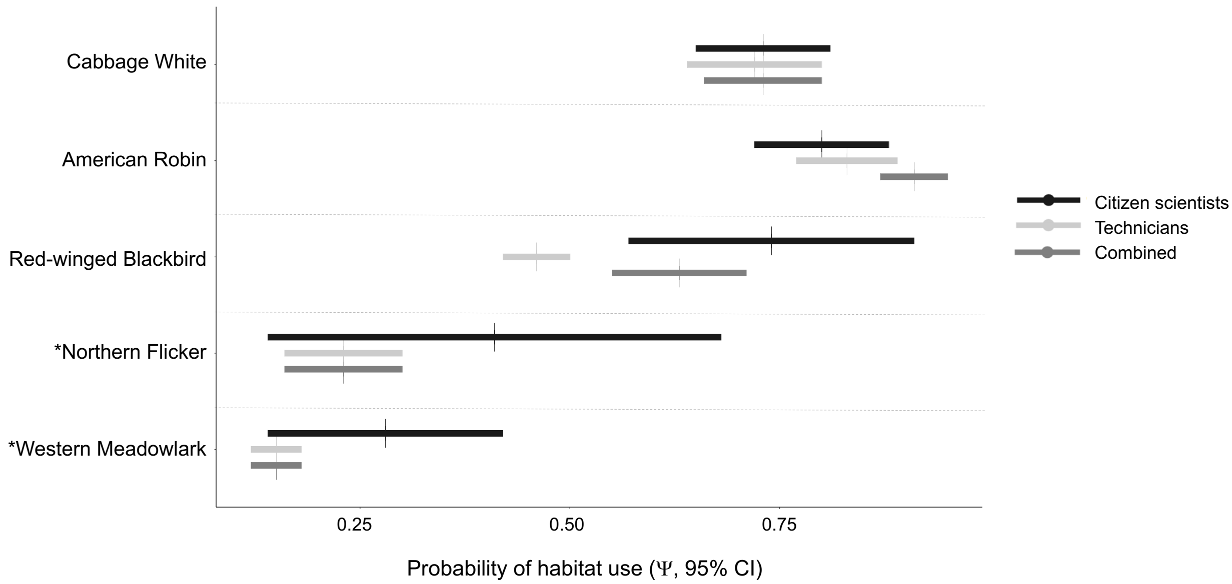

Figure 1.4. Habitat use (Ψ) estimates (±95% CI) for four bird species and one butterfly species using a citizen science dataset in a single season occupancy modeling framework, a technician dataset in a single season occupancy modeling framework and a combined dataset in a false-positive occupancy modeling framework. Cabbage white, American Robin and Red-winged Blackbird are human-adapted species, whereas Northern Flicker and Western Meadowlark are human-sensitive species (as indicated with asterisks).

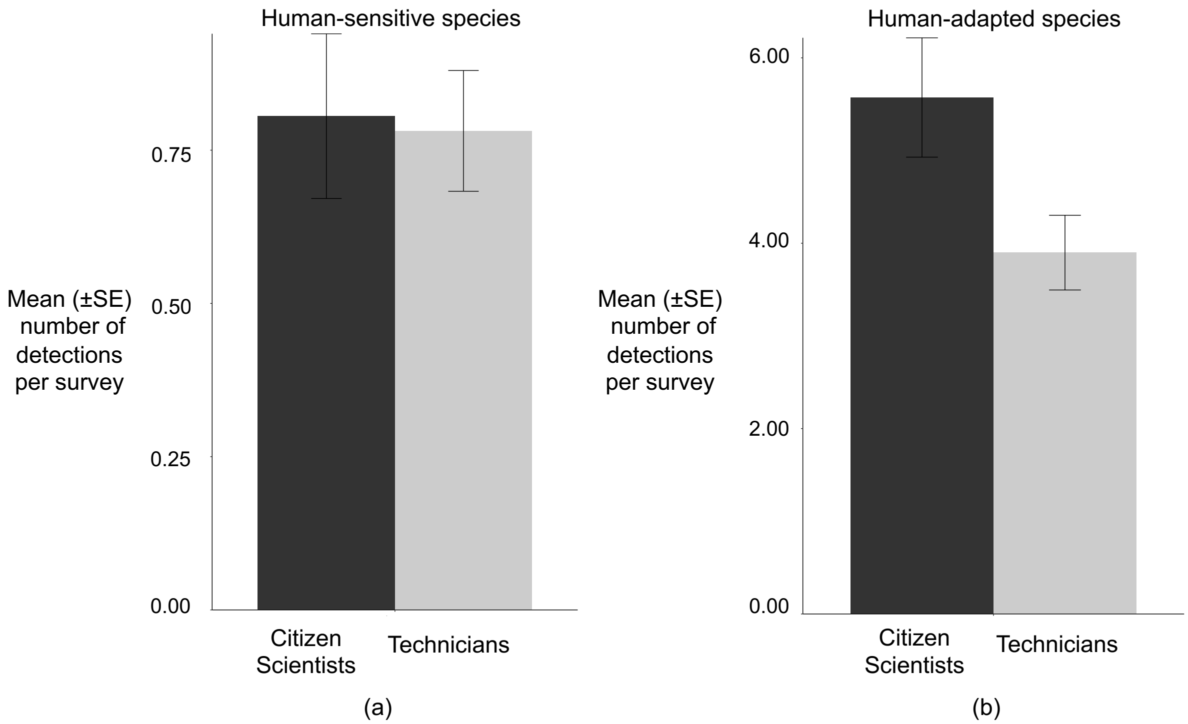

Figure 1.5. Mean (±SE) number of detections of human-sensitive (a) and human-adapted (b) bird species as reported by citizen scientists and technicians at urban open space sites (n=45) in Fort Collins, Colorado.

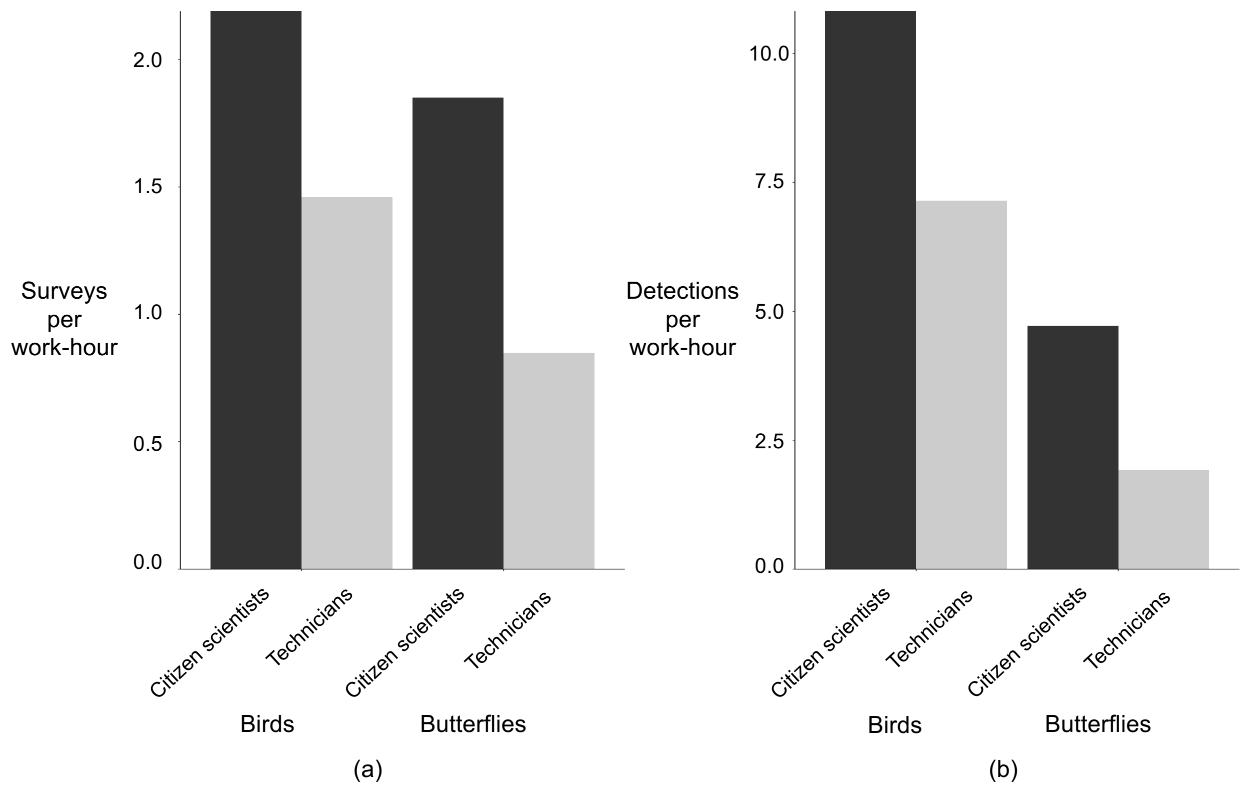

Figure 1.6. The number of bird and butterfly surveys (a) and detections (b) per paid work-hour produced by monitoring with a citizen science program and with paid technicians.

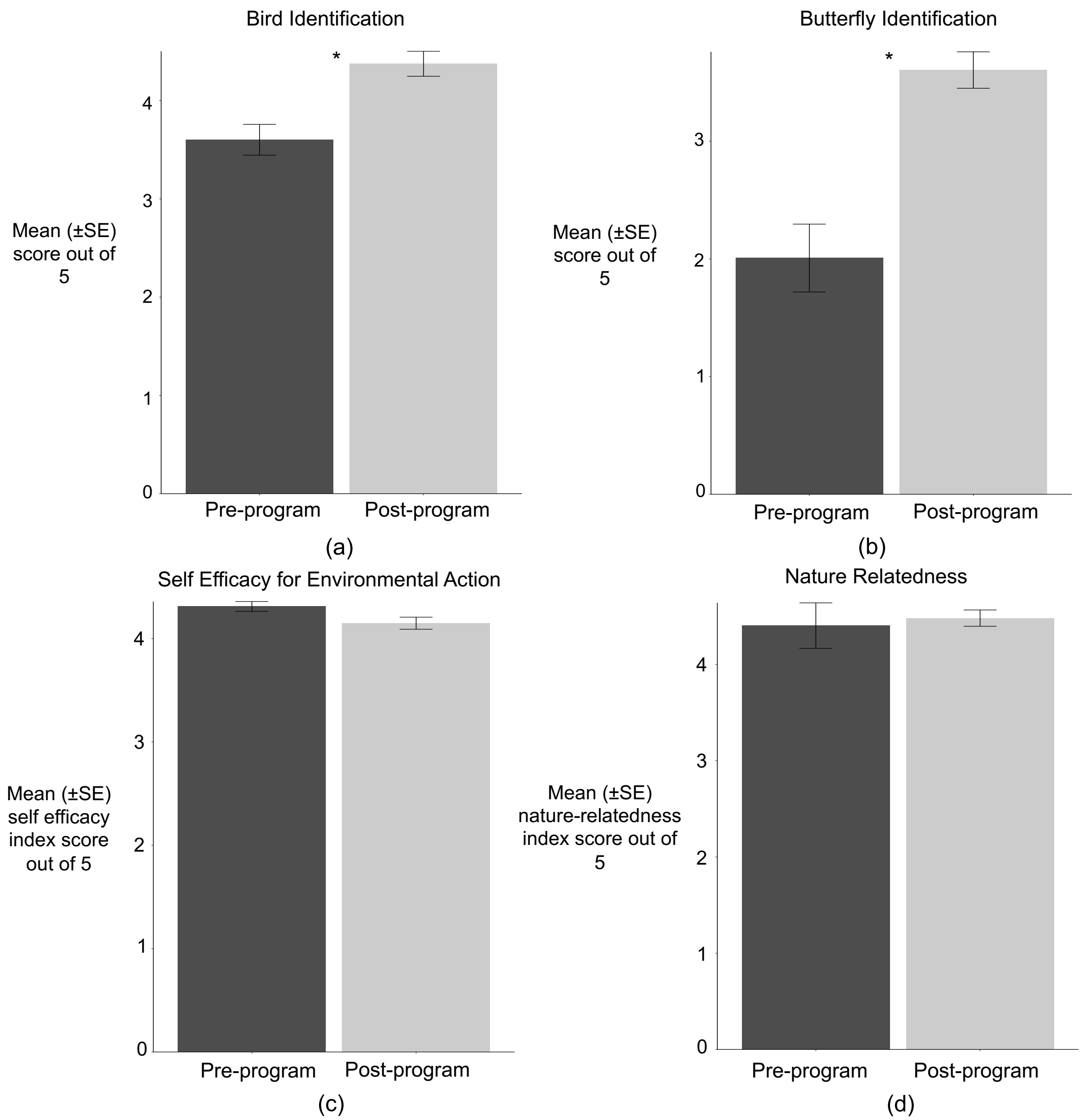

Figure 1.7. A comparison of respondents' ability to identify local birds (a) and local butterflies (b), self efficacy for environmental action (c), and nature relatedness (d) before and after participating in the Nature in the City Biodiversity Project. For bird and butterfly identification, respondents were asked to identify five bird and five butterfly species based on pictures given in a survey. For attitudinal scores, respondents were asked to agree (5) or disagree (1) with statements regarding their ability to address environmental issues and their relationship to the natural world. Scores are reported as mean (±SE) number of correct answers out of five. An asterisk (*) is used to denote a significant difference.

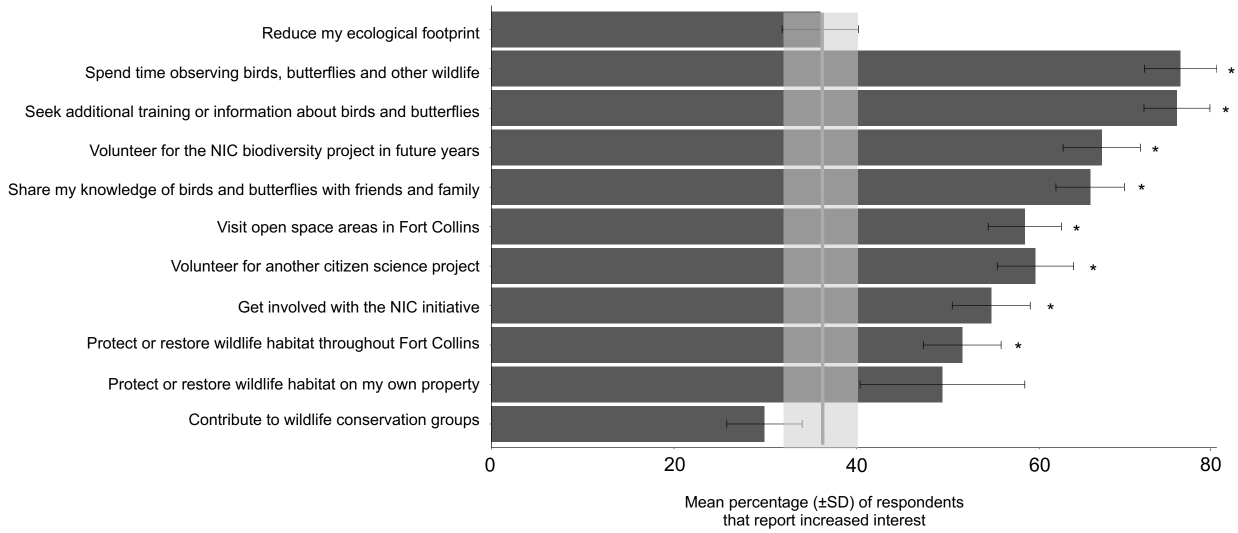

Figure 1.8. The mean (±SD) percentage of respondents each year (n=4) who reported an increased interest in each activity after participating in the citizen science program. "Reduce my ecological footprint" was treated as a dummy question and the light grey line represents the "standard" interest increase, to which all other proportions were compared. An asterisk (*) indicates that a statistically significant proportion of respondents reported an increased interest in this activity.

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Chapter 2 - The Efficacy Of Urban Habitat Enhancement Programs For Promoting Native Plant And Human-Sensitive Animal Communities

SUMMARY

Urbanization presents both social and ecological challenges for protecting biodiversity. Urban development drives habitat loss and degradation and often leads to extirpation of native and specialist species. Additionally, the mass migration of people to urban centers is creating a growing disconnect from nature, which could affect future support for wildlife conservation. Urban habitat enhancement programs focus on engaging the public to protect or improve the quality of habitat for native species within the urban matrix. These programs are increasingly common, yet their effectiveness is rarely evaluated. Here, we assessed an urban habitat enhancement program in Fort Collins, Colorado (U.S.) by comparing plant, bird, and butterfly communities in sites enrolled in this program (enhanced residential open spaces (EROS)), relative to ecological communities in uncertified residential open spaces (ROS), and city-owned public natural areas (PNA). Our objectives were to evaluate: 1) whether the enhancement program increased native vegetation cover and vegetation structural heterogeneity in EROS relative to other site types, 2) whether the program provided habitat for native, human-sensitive bird and butterfly species, and 3) the relative importance of site- and landscape-level factors in achieving these outcomes. Although we did not detect significant differences in the amount of native vegetation cover or vegetation structure across site types, EROS and PNA had consistently less mowed vegetation cover than ROS sites, which were associated with more detections of insectivorous and shrub-nesting bird species. Additionally, we detected more

human-sensitive bird species in EROS than ROS and found that native vegetation across all sites was positively associated with butterfly richness. Although small, enhanced sites are not a substitute for large protected areas in regard to habitat quality for human-sensitive wildlife, even relatively simple stewardship practices, such as not mowing vegetation, can positively influence bird and butterfly communities in urban neighborhoods.

INTRODUCTION

Urbanization poses novel challenges and opportunities for biodiversity conservation (Sanderson et al., 2018). Residential and commercial development is a major driver of habitat loss and fragmentation (Güneralp & Seto, 2013; Liu et al., 2016) and the effects of these land cover changes on ecological communities are complex and often context dependent. While species richness may increase at moderate levels of urbanization for many taxa (McKinney, 2008), native, human-sensitive species are often negatively affected by development and are displaced by exotic and human-adapted species (Chace & Walsh, 2006). As urban sprawl encroaches into undeveloped areas, identifying effective pathways to provide habitat for native, human-sensitive species within the urban matrix has emerged as a priority for protecting global biodiversity.

The social repercussions of urbanization are also increasingly recognized as a significant threat to biodiversity (Dietsch et al., 2016). With 68% of the world's population predicted to live in cities by 2050 (United Nations, 2018), public access to nature is becoming increasingly limited (Kowarik, 2018). Because experiences with nature are deeply tied to public interest in protecting biodiversity (Prévot et al., 2018), the large-scale migration of people into cities could have a detrimental effect on public support for conservation (Miller, 2005). To appeal to a growing demographic of urban stakeholders, effective strategies are needed for encouraging urban-dwellers to engage with local urban green space.

Urban habitat enhancement programs are a model for engaging the local community in the conservation and recovery of habitat for native plants and animals. As part of a larger cultural shift towards community-based conservation (Alexander et al., 2016), these programs engage the public in managing patches of the urban landscape for native species (Adams, 2005). The government agencies and non-governmental organizations that run these programs typically offer some combination of monetary incentives (e.g., tax incentives or funding for habitat enhancement), professional guidance or assistance developing management plans, and public recognition (e.g., signage or online showcasing) to participants in return for planting and managing native vegetation (Goddard et al., 2010). For example, the Audubon Rockies' Habitat Heroes program (http://rockies.audubon.org/habitat-hero), which seeks to promote bird-friendly gardening practices, provides participants with native wildflower seeds, books on planting native gardens, official Audubon Society signage and a chance to be featured in the High Country Gardens catalog. Another program, the Texas Urban Conservation Project (https://npsot.org/wp), which is funded by the U.S. Department of Agriculture, provides participants with direct funding and a curated strategy for planting urban pollinator gardens. While the specific incentives and types of institutional support of a given program may vary, the consistent goal is to encourage the public to protect or restore native habitat. In theory, this model addresses conservation challenges associated with urbanization by both sustaining and enhancing habitat for native plants and wildlife in an urban landscape and providing urban residents with opportunities to connect with urban green space.

Urban habitat enhancement programs often operate under the assumption that restoring or maintaining native vegetation at a site will protect native, human-sensitive birds and butterflies. However, research on interactions among vegetation, birds, and butterflies suggests that relationships are complex and often influenced by factors at multiple spatial scales. Within a single property, there is certainly evidence that native plants support more diverse communities of native birds (Daniels & Kirkpatrick, 2006; Lerman & Warren, 2011) and butterflies (Burghardt et al., 2009; Matteson & Langellotto, 2010). However, the size of a site has been shown to play a role in determining its assemblage of bird and butterfly species (Goddard et al., 2017; Xie et al., 2016). Further, at larger scales within an urban matrix, a given site's ability to provide habitat for native birds and butterflies may be masked by landscape-level factors, such as the dominant vegetation of a neighborhood or the amount of impervious surface surrounding that site (Goddard et al., 2017; Matteson & Langellotto, 2011). As such, successful habitat enhancement must understand and account for the site-level (area within a property's boundaries) and landscape-level (area surrounding a property) factors that influence biodiversity. Evaluating habitat enhancement programs and understanding what factors are most strongly tied to human-sensitive species diversity could help to ensure that resources are being used efficiently and effectively, given limited funding for conservation action.

For the purposes of this study, we focused on a specific urban habitat enhancement program and assessed its ability to provide habitat for native, human-sensitive birds and butterflies in Fort Collins, Colorado. The Certified Natural Areas (CNA) program was adopted by the Fort Collins Natural Areas Department in 1997 in response to rapid urban development. The purpose of this voluntary program is to encourage "site management practices that focus on protecting, restoring, and enhancing native animal and plant communities". To qualify for this program, these private properties, hereafter referred to as enhanced residential open spaces (EROS), must be at least 0.1 ha in area, be located within City's Growth Management Area (GMA), and have existing or potential wildlife habitat use (City of Fort Collins, 2015). Most EROS are residential lands owned in common by homeowner's associations (63%), whereas over one-third (37%) are institutional open space owned by private businesses (Manci, 2017). Given the program's focus on protecting native species within the context of a rapidly urbanizing area, the CNA program faces challenges that are common to many urban enhancement programs and presents an opportunity for a timely and useful case study.

Our objective was to use lessons learned from the CNA program to evaluate the potential strengths and limitations of urban habitat enhancement through public engagement. Specifically, we compared ecological communities (plants, birds and butterflies) in EROS to uncertified residential open spaces (ROS) and city-owned public natural areas (PNA) to assess 1) the extent to which this program met its objective of increasing native plant cover and structural heterogeneity, 2) whether the program provides habitat for native, human-sensitive birds and butterflies, and 3) the influence of site and landscape-level factors in achieving these goals. We predicted that EROS, similar to PNA, would be characterized by higher native plant cover and structural heterogeneity and more native, human-sensitive bird and butterfly species relative to uncertified ROS. However, we also predicted that the presence of native, human-sensitive species may be heavily influenced by site-level factors, such as site area and the amount of grass/shrub cover surrounding a given site.

METHODS

Study area

We conducted this study in Fort Collins, Colorado (U.S.A.). Fort Collins sits at an elevation of 1,524m with annual temperatures ranging from -7° to 30°C and an average annual precipitation of 40.8 cm (National Oceanic and Atmospheric Administration). The population of Fort Collins was 165,080 in 2018 and grew by 11.7% from 2010 to 2015 (U.S. Census Bureau). Larimer County, which includes Fort Collins, is expected to grow from 330,000 to over 540,000 by the year 2050 (Colorado Department of Local Affairs, 2017).

Study Design and Site Selection

We surveyed for birds and butterflies at three site types: ROS, EROS, and PNA. Site types were defined by ownership and management. ROS were privately-owned common areas within residential neighborhoods and managed by homeowners' associations that were not enrolled in the Certified Natural Areas (i.e., habitat enhancement) program. EROS were privately-owned common areas within residential neighborhoods and managed by homeowners' associations that were enrolled in the CNA program. PNA were open space areas that were owned and managed by the City of Fort Collins Natural Areas Department to provide wildlife habitat and recreation opportunities for local residents and visitors. We chose these three site types to represent a gradient of different management techniques for public and private land. We assumed that PNAs represented relatively high-quality habitat within the urban matrix, as these parcels are explicitly managed for wildlife. We assumed that ROS represented the status quo for residential parcels, as they are not actively managed for wildlife, and thus serve as an appropriate baseline comparison for EROS, which are enrolled in the CNA program. We expected that EROS would be intermediate to the two other site sites because they shared characteristics with both ROS (small site area and residential) and PNA (managed for native plant and animal communities).

We selected 10 ROS, 10 EROS and 12 PNA for a total of 32 study sites (Figure 2.1). While selecting sites, we assessed potential differences between site types other than the site- and landscape-level covariates of interest to ensure meaningful comparisons. We used a one-way analysis of variance (ANOVA) and an unpaired t-test to compare seven covariates (site area, distance to GMA, distance to water, canopy cover, disturbed habitat cover, property value and mean neighborhood age) to test for differences among site types. While we did not find significant differences between site types for most of these metrics (Table 1), one exception was that PNA were on average 8.7x larger than EROS ($F(2)=5.66$, $p=0.02$) and 9.2x larger than ROS ($F(2)=5.66$, $p=0.02$). Due to this finding, we accounted for site area in subsequent analyses.

Vegetation cover and composition

We characterized plant community structure and composition at all sites from mid-June through mid-August in 2018. From June 15th to July 1st, we sampled vegetation cover and vegetation structure. We selected sampling points at each site that were at least 150m away from one another and located such that a 100m radius around each point was contained entirely within a single site type. We surveyed vegetation within a 20m radius of the sampling point and divided the survey area into four quadrants, separated by the cardinal directions. Within each quadrant, we visually estimated the percentage of ground cover (<5cm) that was composed of bare ground, forbs, mowed vegetation, unmowed vegetation, impervious surface cover, litter, mud, shrub, tree and water. At the understory (1m), midstory (4m) and overstory (>6m) levels, we visually estimated the percentage of grass, shrub and tree cover (Burghardt et al., 2009).

From July 2nd to August 15th, we sampled vegetation composition and floral activity. We collected data on vegetation composition and floral activity along two Pollard walk transects at each site. We sampled the percent cover of each species within 1m^2 quadrats at 15m, 30m and 45m, starting on the right side of the transect and alternating for each count (Daubenmire, 1966). Additionally, during each butterfly survey, we recorded the species and approximate number of florets for each plant species that was flowering within the Pollard walk buffer area to estimate nectar availability.

Bird surveys

We surveyed birds using point counts (Ralph et al., 1995) between May 15th and June 30th in 2017 and 2018. We conducted three point counts at each site's sampling point throughout each field season. We conducted point counts between 06:00 and 10:00 and each count lasted five minutes. We recorded all the birds that were seen and heard within a 50m radius. In addition to recording the species and abundance of all detected birds, each observer noted the method of detection for each observation and approximate cloud cover and wind speed before each point count (Ralph et al., 1995). We did not conduct point counts in any amount of precipitation.

Butterfly surveys

We surveyed butterflies three times between July 1st and August 15th in 2017 and 2018. We conducted Pollard walks, a common method for assessing butterfly composition and abundance (Pollard, 1977), along two 50m transects within each of the 32 sites. We located the start and end of each transect using GPS units. Unlike point counts, Pollard walks were not limited by time. Rather, the observer walked slowly (heel-to-toe) along each 50m transect, recording the species and abundance of all butterflies that traversed a 6m buffer in all directions around the transect. Similar to point counts, we recorded cloud cover and approximate wind speed before Pollard walks. We did not conduct Pollard walks if cloud cover exceeded 50%, if wind speeds exceeded 8 mph or in any amount of precipitation, as these weather conditions may negatively impact detection probability (Dennis & Sparks, 2006; Reim et al., 2018).

Bird and Butterfly Guilds

We categorized bird species based on their native status (native or non-native), sensitivity to human development (human-sensitive or human-adapted), nesting strategy (tree, cavity, shrub or ground) and diet (omnivore, granivore, insectivore). We used the definition provided by Farr et al. (2017) to characterize human-sensitive and human-adapted species. We based our sensitivity categorizations on previous studies that assessed avian responses to human development (Aronson. et al., 2014; Blair, 1996; Chace & Walsh, 2006; Crooks et al., 2004; Eakin et al., 2015; Farr et al., 2017; Mangan et al., 2017; Odell & Knight, 2001; Oliver et al., 2011). In the few cases when there were discrepancies between sources, we based our classification on the study that was most ecologically similar to our study area. We used a combination of these studies and Cornell Lab of Ornithology's All About Birds guide to classify birds as native or non-native and to identify diet and nesting strategy (https://www.allaboutbirds.org/guide) for all species. The results of our categorizations are summarized for all detected bird species (Supplemental Table 2.1).

We categorized butterfly species based on their native status (native or non-native), sensitivity to human development (human-sensitive or human-adapted), nectar dependence (high or low), and vagility, or ability to move throughout a habitat (1=low vagility:4=high vagility). Similar to our bird categorizations, we consulted literature that has evaluated butterfly responses to human development to determine species-specific sensitivity (Blair & Launer, 1997; Chu & Jones, 2011; Clark, Reed, & Chew, 2007; Matteson & Langellotto, 2010; Nelson & Nelson, 2001). We used the field guide “Butterflies of the Colorado Front Range” to identify butterfly species as native or non-native (Chu & Jones, 2011). The results of the classification process are summarized for butterfly species (Supplemental Table 2.2).

Site- and landscape-level covariates

For the purposes of this study, we considered site-level covariates to be habitat characteristics within the property boundaries of each site and landscape-level covariates to be habitat characteristics of the area surrounding the site. Additionally, we excluded PNA from these comparisons due to the strong difference in site area, which could confound our calculation. Additionally, we were primarily interested in how EROS compared to ROS, which are similar in size and because ROS represent the baseline (unenhanced) alternative to sites that are enrolled in the CNA program.

We collected site-level covariates in two different categories. First, we used a subset of the covariates we collected in the field at the scale of the sampling area. Specifically, we used the data we collected on the percentage of mowed vegetation, vegetation structural heterogeneity, native cover, and floral activity during plant sampling at each site. Using these data, we calculated the mean percentage of vegetation that was mowed, the mean percentage of native vegetation, and the mean floral activity at each site. We calculated an index of vegetation structural heterogeneity with a Shannon-Weiner index, using the percent cover of vegetation at each of the four strata (ground, understory, midstory and overstory) defined above (Sekercioglu, 2002). Secondly, we used a dataset provided by the Urban Ecology Lab at Colorado State University (unpublished data, McHale 2018) to calculate the percentages of canopy cover, bare soil cover, grass/shrub cover, water, buildings and impervious surface in ArcGIS (ESRI 2011. ArcGIS Desktop: Release 10.5). Additionally, we calculated site area for ROS and EROS based on parcel boundaries.

We calculated landscape-level covariates on the area surrounding each property using the dataset provided by the Urban Ecology Lab at Colorado State University in ArcGIS. Specifically, we calculated the percentages of canopy cover, bare soil cover, grass/shrub cover, water, buildings and impervious surface within 100m, 300m, 500m and 1000m buffers that surrounded but did not include each property. This range of buffers was chosen to account for the variability in home range sizes across our observed species list and falls within the range of buffers used by similar studies that assessed bird and butterfly habitat selection in an urban setting (Matteson & Langellotto, 2010; Xie et al., 2016).

Data analysis

We used a one-way analysis of variance (ANOVA) to assess differences in the amount of mowed vegetation and vegetation structural heterogeneity across site types and Tukey's Honest Significant Methods to assess the significance of pairwise comparisons between site types. We used a permutational multivariate analysis of variance (PERMANOVA) with Bray-Curtis similarity percentages to determine whether the mean percent cover of native vegetation differed across site types. Due to multiple sites having no native vegetation, we introduced a "dummy" species which had a value of 1 for all sites (Clarke et al., 2006). We estimated native vegetation species richness at each site using an asymptotic approach in R package SpadeR (Chao & Chiu, 2016).

For each site, we estimated bird and butterfly species richness for each year using an asymptotic approach (Chao & Chiu, 2016) and calculated the mean number of detections for each site per visit. For birds, we calculated the mean proportions of native species, human-sensitive species, tree-nesters, shrub-nesters, cavity-nesters, ground-nesters, granivores, insectivores, omnivores, both in terms of the number of total detections and total species per visit. For butterflies, we calculated the mean proportions of native species, human-sensitive species, nectar dependence and the mean vagility in terms of the number of total detections and total species. We used a two-way analysis of variance (ANOVA) to assess differences in species richness and the proportion of detections for each guild among site types and years and Tukey's Honest Significant Methods to assess the significance of pairwise comparisons between site types. Lastly, we conducted a post-hoc power analysis to evaluate our ability to detect potential differences among sites, given the high levels of variability that we observed.

We used a PERMANOVA with Bray-Curtis similarity to determine whether or not the relative proportion of land cover characteristics differed between ROS and EROS within the site boundaries and the 100m, 300m, 500m and 1000m buffers around each site. We used a combination of multiple and beta regression analyses to assess relationships between site- and landscape-level variables to influencing bird and butterfly communities. We built multiple regression models using species richness as the response variable for both birds and butterflies and mean vagility of detected butterflies. For birds, we built beta regression models using the proportion of bird detections in each of the following guilds as response variables: native species, human-sensitive species, cavity-nesting species, shrub-nesting species, tree-nesting species, ground-nesting species, insectivores, omnivores, and granivores. For butterflies, we built beta regression models using the proportion of butterfly detections in each of the following guilds as response variables: native species, human-sensitive species and the nectar-dependent species.

Before building our models, we tested for collinearity among site- and landscape-level covariates using Spearman's correlation coefficient and excluded any variables with a correlation greater than 0.7 in the same model set (Farr et al., 2017). This led to the exclusion of bare soil cover, water, and impervious surface cover. Thus, at the site level, our models included site area, native cover, percentage of mowed vegetation, vegetation structural heterogeneity, floral activity, and the percentage of canopy cover, grass/shrub cover and building cover within the site boundaries as predictor variables (Table 2). At the landscape level, our models included the percentage of canopy cover, grass/shrub cover and building cover within the buffers (100m, 300m, 500m and 1000m) surrounding each site (Table 2). We used a stepwise approach to model building. First, we built univariate models for each landscape-level predictor variable and tested for the best supported scale. We then built model sets that included single factor linear relationships of each site-level factor and landscape-level factor at the best supported scale. We calculated Akaike's information criterion adjusted for small sample size (AICc) to rank and compare models (Burnham & Anderson, 2004) and examined the regression coefficients to determine the direction and strength of each site- and landscape-level factor.

RESULTS

Vegetation cover and composition

We detected a total of 46 native plant species at our 32 sites. Native plant richness differed among site types ($F(2)=3.98$, $p=0.03$), with the mean richness at PNA being 7.5x higher than at ROS ($p=0.03$) (Figure 2.2). However, the percentage of native cover ($R^2= 0.09$, $p=0.78$) (Figure 2.2) and mean floral activity ($F(2)=0.93$, $p=0.41$) did not differ among site types. The amount of mowed vegetation varied among site types ($F(2)=14.4$, $p<0.01$) (Figure 2.3). EROS had a mean of 2.7x less mowed vegetation than ROS ($p<0.01$) and PNA had a mean of 30x less than ROS ($p<0.01$). Vegetation structural heterogeneity did not differ among site types ($F(2)=0.03$, $p=0.97$).

Bird and Butterfly Diversity

We detected a total of 64 bird species and 18 butterfly species across all sites and years. Bird species richness differed among site types ($F(2)=3.4$, $p=0.05$), with PNA ($M=17\pm6$) having 1.4x more species than ROS ($M=12\pm4$) ($p=0.03$) (Figure 2.4). Bird richness at EROS fell in between the other two site types ($M=14\pm4$). The mean number of bird detections per visit did not differ among site types ($F(2)=1.95$, $p=0.16$). Neither bird richness nor the number of bird detections varied across years. Butterfly species richness did not differ among site types ($F(2)=2.9$, $p=.06$). The mean number of butterfly detections per visit did not differ among site types ($F(2)=1.7$, $p=0.08$) (Figure 2.5); however, we detected 2.4x more butterflies in 2017 than in 2018 ($F(2)=10.1$, $p<0.01$).

The effect of year was not significant for birds, so we pooled the survey data from both years. Additionally, the proportions of total detections and proportions of total species were correlated (Supplemental Table 2.3), so we only report the proportions of total detections as our response variable to minimize redundancy. The proportions of human-sensitive and ground-nesting species detections were highest at PNA, lowest at ROS, and intermediate at EROS (human sensitive: $F(2)=9.1, p<0.01$, ground-nesting species: $F(2)=8.4, p<0.01$). The proportions of human-sensitive species detections were 2.2x higher at EROS than ROS ($p=0.05$) and 3.1x higher at PNA than at ROS ($p<0.01$). The proportions of ground-nesting species detections at PNA were 7x higher than at ROS ($p<0.01$). The proportions of insectivores were similar at PNA and EROS, but lower at ROS than the other two site types ($p<0.01$). In contrast, the proportions of omnivores and tree-nesting species detections were highest at ROS (omnivores: $F(2)=4.1$, $p=0.02$, tree-nesting species: $F(2)=15.6, p<0.01$). The proportions of omnivorous species detections at ROS were 1.6x higher than at EROS ($p=0.03$) and PNA ($p=0.04$). The proportions of tree-nesting species detections at ROS were 1.7x higher than at EROS ($p<0.01$) and 2.2x higher than at PNA ($p<0.01$). Lastly, we detected the highest proportion of shrub-nesting species at EROS ($F(2)=7.5, p<0.01$). The proportions of shrub-nesting species detections were 3x higher at EROS than at ROS ($p<0.01$) and 2.3x higher than at PNA ($p=0.01$) (Figure 2.6; Supplemental Table 2.4).

Although butterfly richness and abundance differed between years ($F(2)=10.1$, $p<0.01$), we pooled data because trends between years were consistent. Additionally, similar to birds, the proportion of total detections and proportion of total species for butterfly guilds were correlated (Supplemental Table 2.3), so we report the proportions of total detections as our response variable to minimize redundancy. The proportions of native and human-sensitive species detections did not differ among site types (Figure 2.7). The proportions of nectar-dependent species detections were similar at EROS and ROS, but 0.7x higher at PNA. The mean vagility of detected species was similar at EROS and ROS but 1.2x lower at PNA ($p=0.05$) (Figure 2.7; Supplemental Table 2.5).

We conducted a post-hoc power analysis to evaluate our ability to detect potential differences among sites, given the high levels of variability that we observed. The power analyses estimated that a sample size of 195 sites was necessary to detect a small effect size ($f=0.1$), 156 sites were necessary to detect a medium effect size ($f=0.25$) and 60 sites were necessary to detect a large effect size ($f=0.4$) for the ANOVAs that we conducted on plant, bird and butterfly communities.

Site- and landscape-level variable relationships with bird and butterfly guilds

Within the site area, the relative composition of land cover did not differ between ROS and EROS ($R^2= 0.12$, $p=0.10$). Within the 100m and 300m buffers surrounding but not including each site, the relative composition of land cover differed between EROS and ROS (100m: $R^2= 0.16$, $p=0.03$; 300m: $R^2= 0.15$, $p=0.04$), with EROS being surrounded by more grass/shrub cover but less canopy cover. In contrast, within the 500m and 1000m buffers, the relative composition of land cover did not differ between EROS and ROS (500m: $R^2= 0.13$, $p=0.07$; 1000m: $R^2= 0.05$, $p=0.35$).

None of the five top multiple regression models ($\Delta AICc<2.0$) evaluating the relationship between bird species richness and site- and landscape-level factors yielded significant relationships (Supplemental Table 2.6). For butterflies, one of the two top multiple regression models evaluating the relationship between species richness and site- and landscape-level factors yielded a significant relationship. Butterfly richness was positively correlated with the percentage of native plant cover (ß= 2.82, SE=1.385, $p=0.04$) (Supplemental Table 2.7).

Of the 14 top beta regression models evaluating the relationship between the proportion of detections for each bird guild and site- and landscape-level factors, 10 yielded significant relationships (Figure 2.8). The percentage of mowed vegetation was negatively correlated with the proportions of detections of shrub-nesting species (ß = -1.02, SE=0.24, $p<0.01$) and insectivores (ß = -0.62, SE=0.14, $p<0.01$), but positively correlated with the proportions of detections of granivores (ß = -0.48, SE=0.17, $p<0.01$) and tree-nesting species (ß = 0.56, SE=0.20, $p<0.01$). The percentage of native plant cover was positively correlated with the proportion ground-nesting species detections (ß = 1.03, SE=0.21, $p<0.01$). Site area (ß = 0.31, SE=0.13, p=0.01) and the percentage of grass/shrub cover within the site boundaries (ß = 0.30, SE=0.15, p=0.04) were positively correlated with the proportion of omnivore detections. Canopy cover at a 1000m buffer surrounding the site was positively correlated with the proportion of human-sensitive (ß = 0.37, SE=0.15, p=0.01; Supplemental Table 2.6).

Of the 11 top beta regression models evaluating the relationship between the proportion of detections for different butterfly guilds and site- and landscape-level factors, two yielded significant relationships (Figure 2.9). Site area was positively correlated with the proportion of nectar-dependent species detections (ß = 0.46, SE=0.22, p=0.04). Building cover at a 100m buffer surrounding the site was negatively correlated with the proportion of native species detections (ß = -0.50, SE=0.20, p=0.01; Supplemental Table 2.8).

DISCUSSION

In a rapidly urbanizing world, understanding the factors that influence the effectiveness of urban conservation programs has important implications for protecting biodiversity as well as increasing public support for conservation. It has been estimated that residential lawns comprise

70-75% of urban green space worldwide (Ignatieva et al., 2015). Urban habitat enhancement programs have the potential to transform these spaces into habitat for native, human-sensitive species that are often extirpated from human-dominated areas. We evaluated one such program and found that the program did not increase native vegetation cover relative to comparable residential land, but stewardship by private landowners did effectively reduced the amount of mowed vegetation and provided benefits to some bird and butterfly species.

We found that EROS, which were private residential open spaces enrolled in the habitat enhancement program, had less mowed vegetation than unenrolled residential space, and the reduction of mowed grass cover was positively related to the number of shrub-nesting and insectivorous bird detections (Figure 2.9). This finding is consistent with many previous studies demonstrating that residential land management practices such as leaving lawns unmowed and allowing leaf litter to accumulate provide habitat for urban-sensitive, native species (Goddard et al., 2017). For example, Lerman and Warren (2011) demonstrated that residential landscapes that more closely resemble the native ecosystem are effective at providing habitat for human-sensitive species. Similarly, Jasmani et al., (2017) found that intensively managed urban parks with frequent mowing regimes were associated with lower bird diversity than relatively unmanaged parks. Our findings add to a growing body of evidence which suggests that even subtle management practices, such as not mowing open space adjacent to homes, can have substantial positive effects on local human-sensitive wildlife species.

Contrary to our predictions, although PNA had the highest native plant richness, we did not observe higher richness or percent cover of native plants in EROS relative to ROS (Figure 2.3). Still, we found that native plant cover was positively correlated with detections of ground-nesting bird species and overall butterfly richness (Figures 8 and 9). As is common in many urban systems, the richness and abundance of native vegetation was highly variable (Threlfall et al., 2016). EROS ranged from sites with over 60% native cover to sites with no native vegetation at all (Figure 2.3). This high variability within site types could be caused by varying degrees of disturbance, inconsistent management across sites, limited enforcement of program guidelines, or differences in land use history (Goddard et al., 2017). Consequently, the degree to which stewardship on residential land is effective in achieving conservation objectives may be dependent on the social capital invested in a project as well as the ecological context of a patch within the surrounding landscape (Goddard et al., 2013).

We found that the relative abundance of birds in various foraging and nesting guild differed across types of urban green space. Most notably, we detected more human-sensitive species at EROS than ROS and human-sensitive species were positively correlated with the amount of canopy cover surrounding a site. Further, the proportion of bird detections in multiple guilds at EROS was often intermediate between the other two site types. For example, similar to PNA, the bird community we detected in EROS had a greater proportion of insectivores; yet, similar to ROS, EROS had a greater proportion of granivores (Figure 2.6). In some cases, EROS provided unique habitats; we detected more shrub-nesting species in EROS than either of the other two site types (Figure 2.6). These results are consistent with previous studies in urban areas, which have found that different types of urban green space may provide suitable habitat for distinct species assemblages (Gallo et al., 2017). Similarly, our findings parallel those of Chong et al. (2014), by demonstrating that relatively natural urban green spaces can house more diverse wildlife communities than cultivated, mowed lawns.

Native vegetation cover and butterfly species richness were positively correlated, which is a particularly encouraging outcome as this habitat characteristic can be addressed through on-site management (Figure 2.9). These results are consistent with a growing body of research that suggests that many pollinators will respond to site-level variables (Majewska & Altizer, 2018) and, more specifically, that butterfly diversity is positively related with native vegetation (Burghardt et al., 2009; Matteson & Langellotto, 2010). In contrast to birds, native butterflies did not constitute a high proportion of our detections. For both years that we surveyed, one invasive butterfly, the cabbage white, was by far the most dominant species across all site types. However, we did find that the mean vagility of detected species was significantly lower in PNA than both EROS and ROS (Figure 2.7). This is consistent with Olivier et al (2016), who found that, in altered landscape, species with limited mobility relied upon larger patches of high-quality habitat. This may suggest that larger sites of intact habitat may serve as refugia for butterfly species that are less able to move throughout the urban matrix.

We found evidence that birds and butterflies may be selecting habitat based on a mix of both site- and landscape-level variables. For example, for birds we detected fewer shrub-nesting species at mowed sites and canopy cover within 1000m around a site was positively correlated with all human-sensitive species (Figure 2.8). For butterflies, site area was positively correlated with the proportion of nectar-dependent species detections and building cover within 100m buffer around a site was negatively correlated with native species detections (Figure 2.9). It is likely that the scale at which wildlife selects habitat is species-specific, as suggested by McCaffrey & Mannan (2012). As such, some human-sensitive species will benefit from habitat enhancement, whereas others will require large-scale conservation effort (Goddard et al., 2017). Thus, effective management for human-sensitive species across various guilds must address landcover on multiple scales.

Our study design was limited in its ability to address some aspects of the relationship between urban habitat enhancement and bird and butterfly communities. For example, although we attempted to estimate habitat use of individual bird and butterfly species in an occupancy modelling framework (Miller et al., 2011), the detection histories for human-sensitive species did not provide enough power for models to converge. This limited our ability to account for missed detections during surveys, and we suspect that human-sensitive species may be underrepresented in our dataset and analyses. Additionally, consistent with established trends (Thomas, 1991), butterfly detections were highly variable between years. With just two years of ecological monitoring, our ability to determine relationships between butterfly community composition and site types may have been limited. Lastly, our survey effort was restricted to the existing 19 EROS sites, which is less than the estimated sample size (n=60) required to detect a large effect (f=0.4) on the proportion of native vegetation, birds and butterflies across site types.

To foster effective residential stewardship for native vegetation, we recommend that the program provide participants with adequate resources and guidance for successful stewardship. Additionally, regular monitoring of vegetation composition, enforcement of certification standards, and increased incentives for maintaining native plant communities could encourage improved habitat enhancement and build a stronger community of urban stewards (Goddard et al., 2013). At the landscape-level, we suggest that urban habitat enhancement programs coordinate with other initiatives for strategic land protection and targeted land acquisition. Similarly, we suggest that programs could cluster sites to create larger and more connected networks of habitat within the urban matrix (McCaffrey & Mannan, 2012). To achieve this, we recommend that programs understand how green space is distributed throughout a city's landscape and prioritize areas for conservation or restoration.

Urban habitat enhancement programs provide a model for engaging the local community in the conservation and recovery of habitat for native plants and animals. However, to our knowledge, the ability for these programs to provide habitat for native, human-sensitive species within the urban matrix has rarely been evaluated. Here, we surveyed the plant, bird and butterfly communities of sites enrolled in one such program and compared them to comparable sites that were not enrolled in the program. Although we found little evidence to suggest that the program was successful at increasing native plant cover or vegetation structure, we did find that these sites had less mowed vegetation compared to similar unenrolled sites. Further, we found that more cover of unmowed vegetation provided benefits to insectivorous and shrub-nesting bird species. We suggest that urban habitat enhancement does have the potential to benefit human-sensitive wildlife. We hope that our study can serve as a model for assessing the effectiveness of similar programs and help guide the development and implementation of new initiatives to enhance private urban natural areas for biodiversity and people.

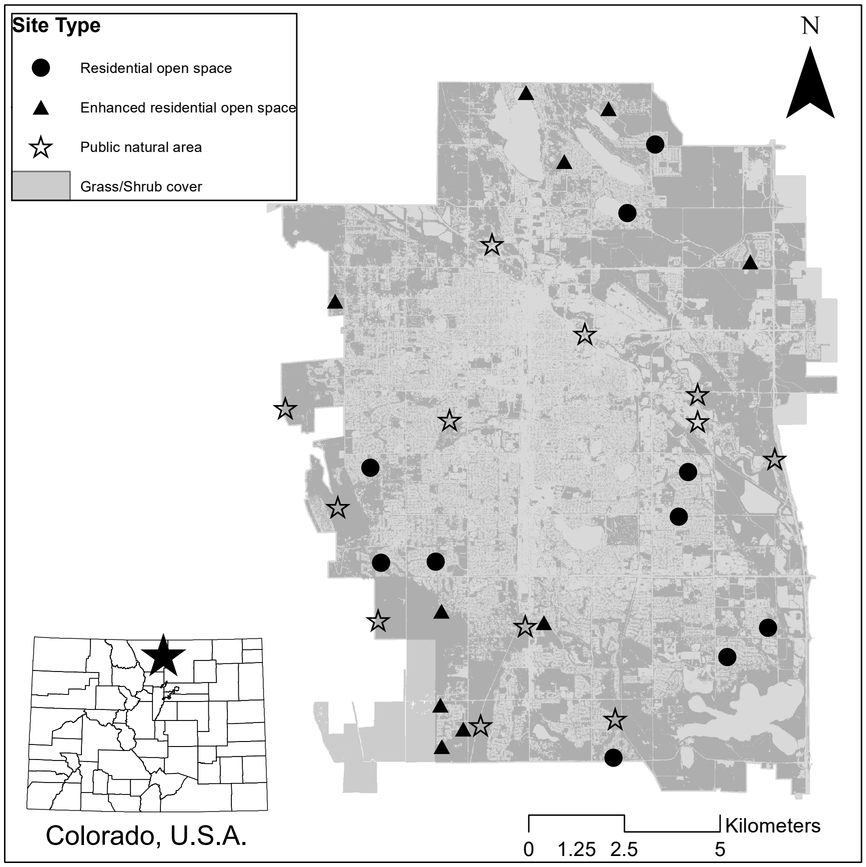

Figure 2.1. The City of Fort Collins Growth Management Area with the location of study sites represented as different shapes. Residential open spaces (ROS) are sites that are privately owned and managed but not enrolled in the Certified Natural Areas Program. Enhanced residential open spaces (EROS) are privately owned and managed and are enrolled in the Certified Natural Areas Program. Public natural areas (PNA) are owned and managed by the City of Fort Collins Natural Areas Program for wildlife and public recreation.

Table 2.1. The mean values of various variables (area, distance to Growth Management Area, distance to water, canopy cover, shrub cover and disturbed habitat cover) that may influence bird and butterfly habitat use and their associated standard error for 10 residential open spaces (ROS), 10 enhanced residential open spaces (EROS) and 12 public natural areas (PNA) in Fort Collins, Colorado. One-way analysis of variances (ANOVAs) were used to determine if there were significant differences between sites.

Variable	ROS	EROS	PNA
Area (ha)	7.38 (±5.10)	7.71 (±2.28)	67.5 (±22.4)*
Distance to GMA (m)	1472 (±306)	919 (±285)	1577 (±421)
Distance to water (m)	135 (±50.9)	151 (±53.6)	220 (±71.8)
Canopy cover	15.0 (±4.88)	10.0 (±5.57)	10.0 (±4.13)
Shrub cover	7.00 (±2.30)	7.00 (±3.82)	11.0 (±5.01)
Disturbed habitat cover	56.0 (±14.0)	56.0 (±11.0)	64.0 (±10.0)
Mean price($/ft^2)	214 (±15)	220 (±19)	
Mean Neighborhood Age (years)	25 (±3)	29 (±4)	

*denotes a significant difference ($p<0.05$)

Table 2.2. Summary of the site- and landscape-level variables used in multiple regressions to assess the relationship between the proportion of bird and butterfly species detections at a given site and the characteristics of that site.

Variable	Description (units)
Site-level variables	
SITE_AREA	Total area of the site (km^2)
NATIVE_COVER	Percentage of surveyed vegetation that was native (%)
PERCENT_MOWED	Percentage of surveyed vegetation that was mowed (%)
[a]INDEX_VEG_HETERO	Diversity of vegetation cover at ground (5cm), understory (1m), midstory (4m) and overstory (>6m) levels
[b]FLORAL_ACTIVITY	Mean number of open florets along Pollard Walk transect
CANOPY_COVER_site	Percentage of tree cover within the site area (%)
GRASS_SHRUB_site	Percentage of grass and shrub cover within the site area (%)
BUILDING_COVER_site	Percentage of building cover within the site area (%)
*Landscape-level variables	
CANOPY_COVER_buffer	Percentage of tree cover in the surrounding landscape at various buffer distances (%)
GRASS_SHRUB_buffer	Percentage of grass and shrub cover in the surrounding landscape at various buffer distances (%)
BUILDING_COVER_buffer	Percentage of building cover in the surrounding landscape at various buffer distances (%)

*Landscape-level variables were taken at 100m, 300m, 500m and 1000m buffer radii.

[a] Variable only used in bird models

[b] Variable only used in butterfly models

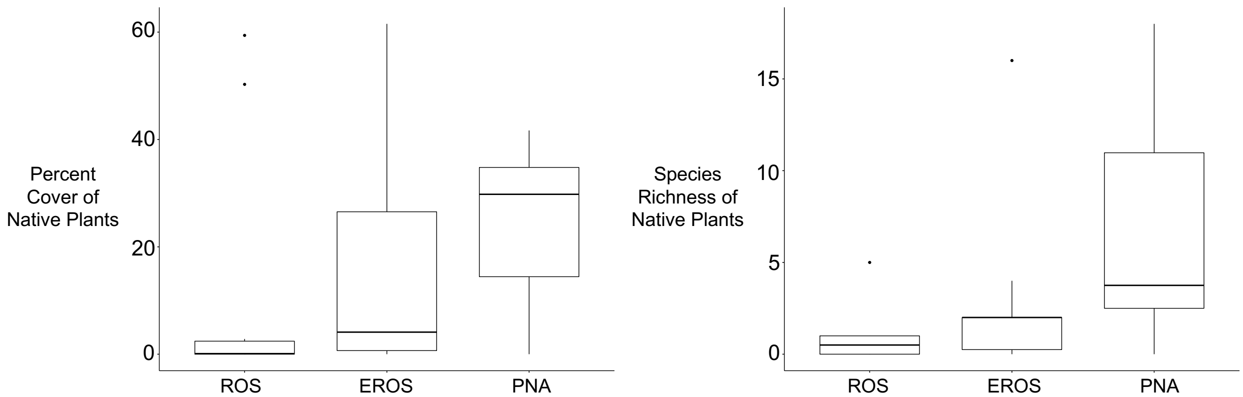

Figure 2.3. The mean (±SE) percentage of native cover and richness of native plant species (±SE) at residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10) and public natural areas (PNA, n=12) across Fort Collins, CO.

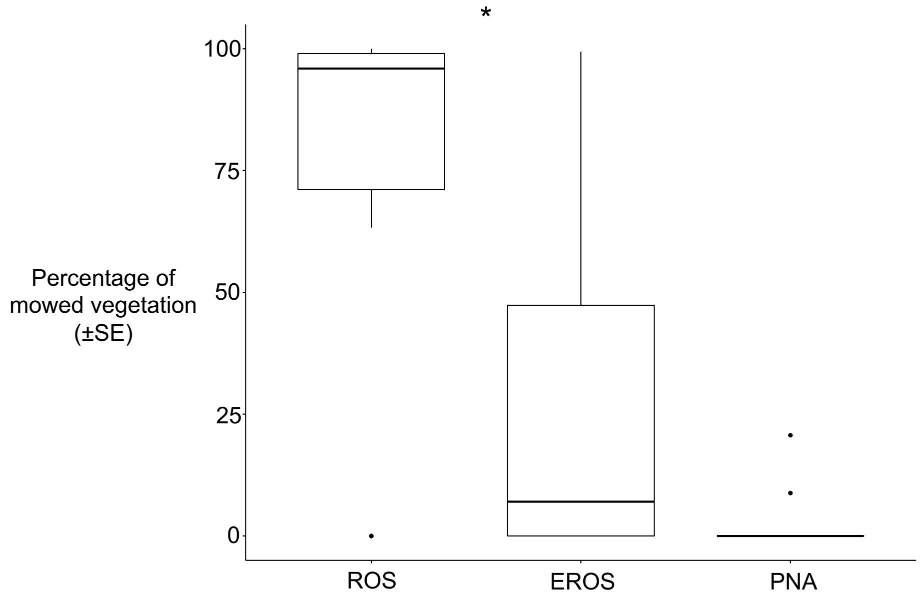

Figure 2.3. The mean (±SE) percentage of mowed vegetation at residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10), and public natural areas (PNA, n=12) across Fort Collins, CO. An asterisk (*) is used to denote a significant difference (p<0.05) between two site types.

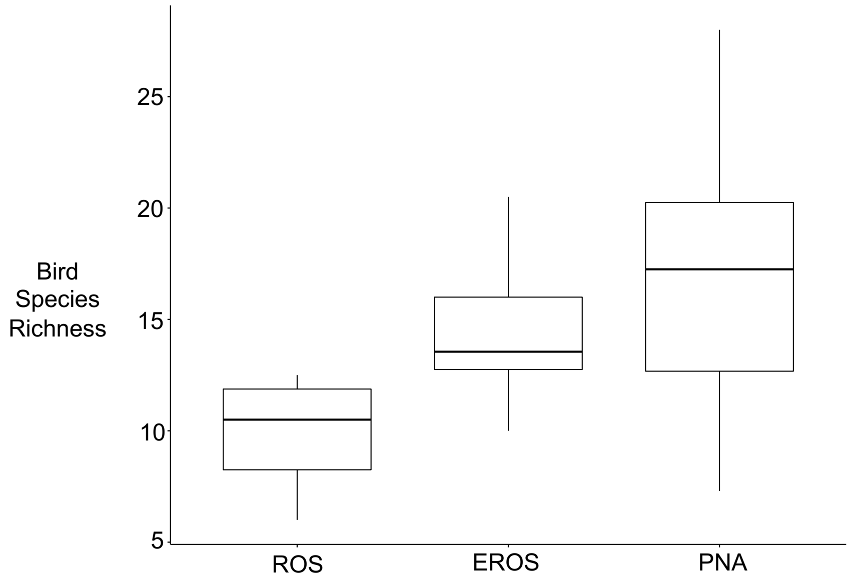

Figure 2.4. The mean (±SE) estimated species richness for birds at residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10), and public natural area (PNA, n=12) across Fort Collins, Colorado pooled between two field seasons (2017 and 2018).

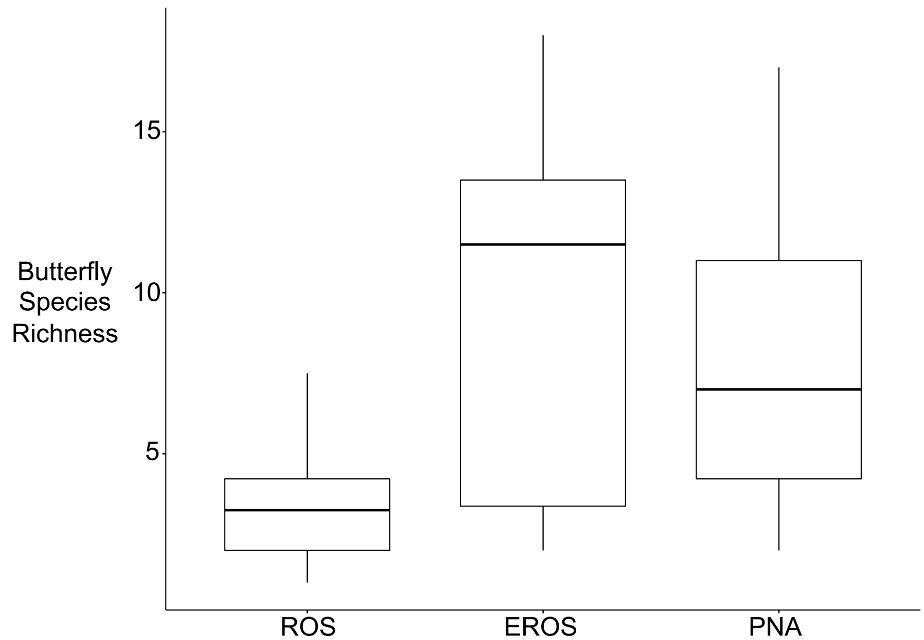

Figure 2.5. The mean (±SE) estimated species richness for butterflies at residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10) and public natural areas (PNA, n=12), across Fort Collins, Colorado over two summers (2017 and 2018).

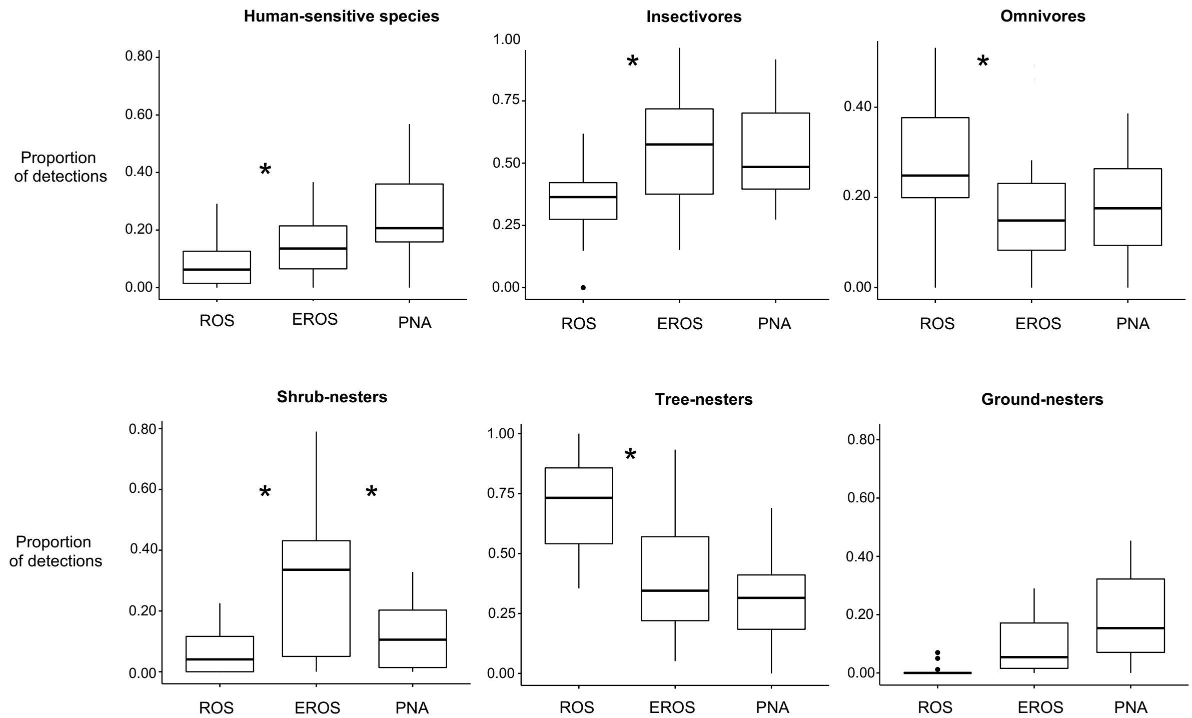

Figure 2.6. The mean (±SD) proportion of total detections of various bird guilds calculated per visit to residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10), and public natural areas (PNA, n=12). An asterisk (*) is used to denote a significant difference ($p<0.05$) between two site types.

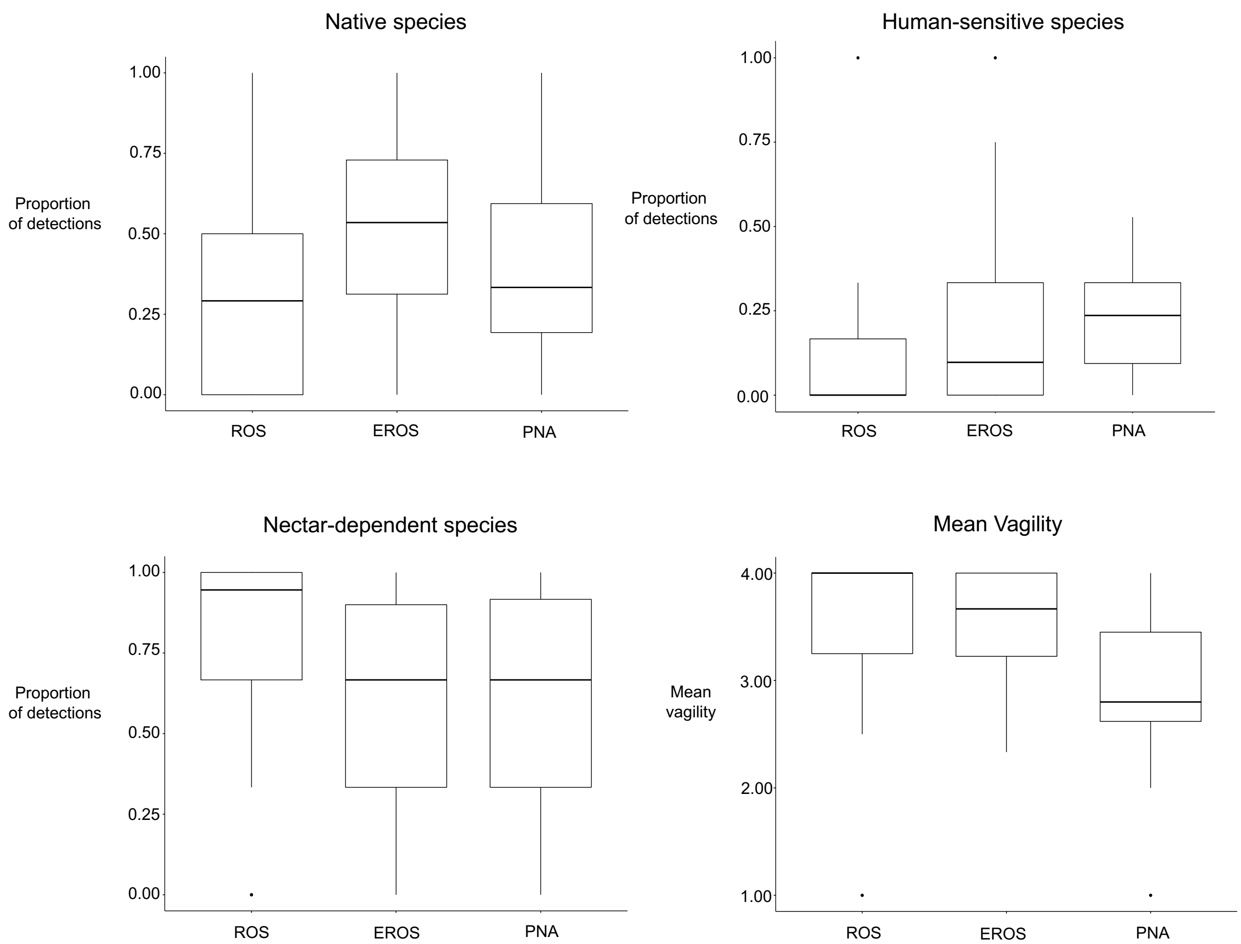

Figure 2.7. The mean (±SE) proportion of total detections for various butterfly guilds calculated per visit to residential open spaces (ROS, n=10), enhanced residential open spaces (EROS, n=10), and public natural areas (PNA, n=12).

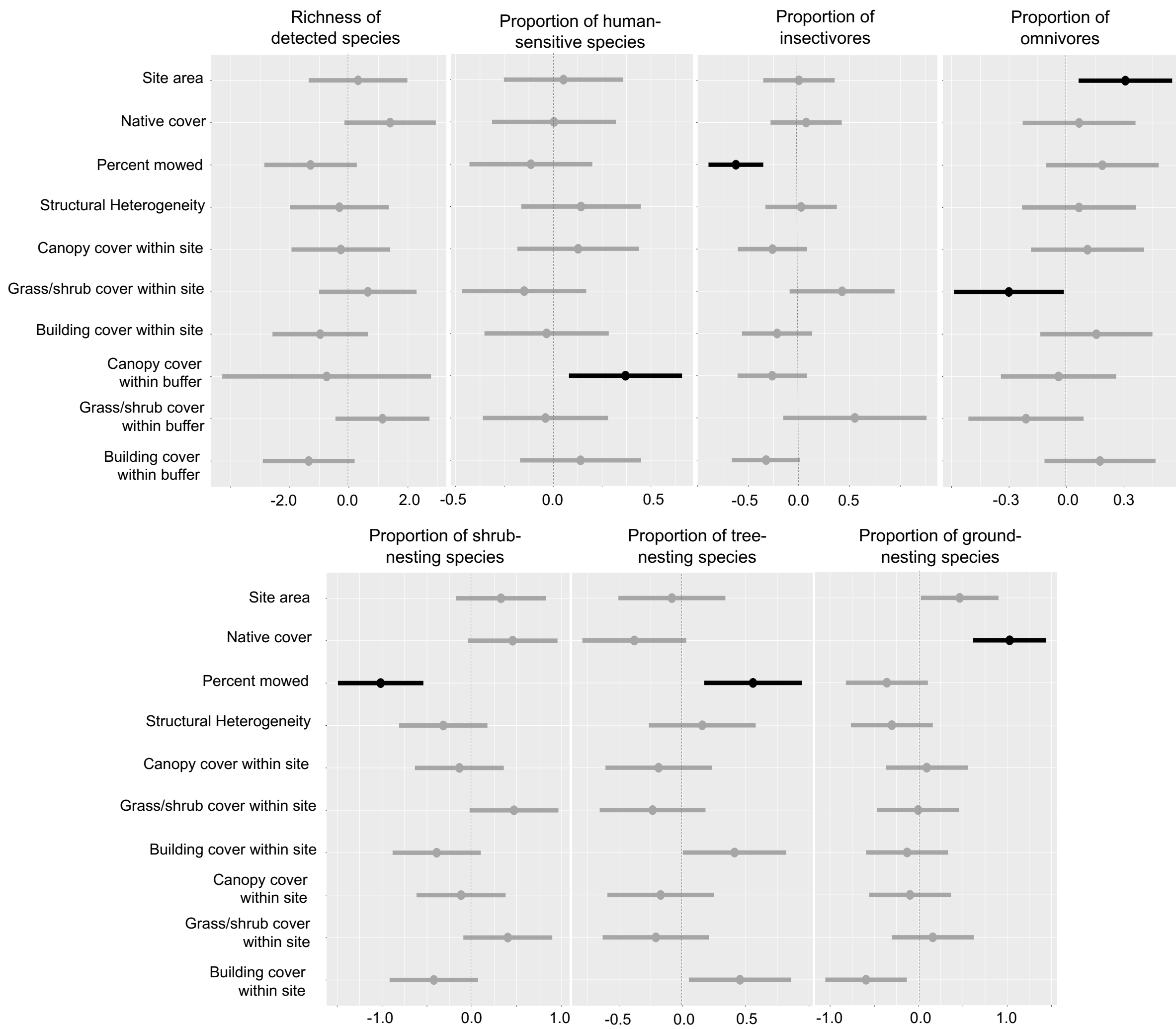

Figure 2.8. A summary of the standardized coefficients from top beta regression models between site and landscape-level habitat covariates and four bird community response variables. Beta (ß) values are represented by dots and standard errors are represented by whiskers. Significant relationships with predictor values are represented in black and non-significant relationships are represented in grey.

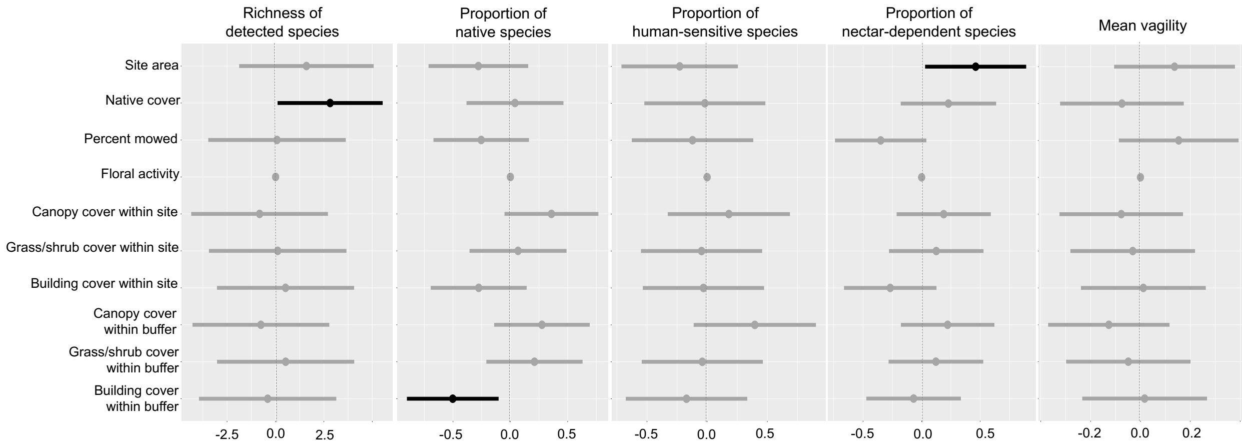

Figure 2.9. A summary of the standardized coefficients from top beta regression models between habitat covariates and butterfly communities. Beta (ß) values are represented by dots and standard errors are represented by whiskers. Significant relationships with predictor values are represented in black and non-significant relationships are represented in grey.

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APPENDICES

Supplemental Methods 1. Questions included in the pre- and post-program survey instrument, which was used to determine citizen scientists' 1) ecological knowledge, 2) nature relatedness and self-efficacy for environmental action, and 3) behavioral intentions related to conservation before and after participating in the Nature in the City Biodiversity Project.

Pre-program survey instrument questions

1. Please select a four-digit personal identification (PIN) that will be easy to recall for future surveys:
2. In which part of the City do you live?
3. In which part of the City do you work? If more than one location, please select the option where you spend the most time.
4. Do you own or rent your residence?
5. What is your gender?
6. What is your race?
7. What is your level of education (highest degree received)?
8. What is your household income?
9. What is your age?
10. Why would you like to participate in the Nature in the City Biodiversity Project this summer? Please select up to three items below that match your reasons, or feel free to add another. (Volunteer in the community, Participate in scientific study, Help to conserve nature in Fort Collins, Spend time with friends and family, Learn about conservation issues, Spend time observing wildlife, Meet others with similar interests, Spend time outside, Learn more about local plants and animals, Other)
11. The following statements are about your interest in the natural world. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)
12. The following statements are about how you feel about yourself as a scientist. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)
13. The following statements are about how you feel about your ability to address environmental issues. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)
14. What is your level of familiarity with the Nature in the City initiative? (Not at all familiar-Extremely familiar)
15. What is your level of familiarity with open spaces in the City of Fort Collins? (Not at all familiar-Extremely familiar)
16. What is your level of experience with conducting scientific field research? (Not at all-experienced-Extremely experienced)
17. How would you rate your knowledge of bird species in the Fort Collins area? (Poor-Excellent)
18. If you know them, please identify the following bird species. Otherwise, select "I don't know."

19. How would you rate your knowledge of butterfly species in the Fort Collins area? (Poor-Excellent)
20. If you know them, please identify the following butterfly species. Otherwise, select "I don't know."

Post-program survey instrument questions

1. Please enter the four-digit personal identification number (PIN) that you selected during the first, pre-program survey. (If you can't remember your PIN, or if you did not take the first survey, please enter 0000.)
2. What did you enjoy most about participating in the Nature in the City biodiversity project? Please check all items that apply, and feel free to add any others. (Meeting others with similar interests, Helping to conserve nature in Fort Collins, Spending time outside, Volunteering in the community, Spending time with friends and family, Spending time observing wildlife, Learning about local plants and animals, Learning about conservation issues, Participate in scientific study, Other)
3. In which of the following activities did you participate? Please check all items that apply. (Classroom training session, Bird survey training, Bird survey on my own, Butterfly survey training, Butterfly survey on my own)
4. How would you rate the quality of various program activities and resources? (Poor-Excellent)
5. What are your suggestions for how we could improve the program for future years?
6. What is your level of familiarity with the Nature in the City initiative? (Not at all familiar-Extremely familiar)
7. What is your level of familiarity with open space areas in the City of Fort Collins? (Not at all familiar-Extremely familiar)
8. What is your level of experience with conducting scientific field research? (Not at all-experienced-Extremely experienced)
9. How would you rate your knowledge of bird species in the Fort Collins area? (Poor-Excellent)
10. If you know them, please identify the following bird species. Otherwise, select "I don't know."
11. How would you rate your knowledge of butterfly species in the Fort Collins area? (Poor-Excellent)
12. If you know them, please identify the following butterfly species. Otherwise, select "I don't know."
13. The following statements are about your interest in the natural world. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)
14. The following statements are about how you feel about yourself as a scientist. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)
15. The following statements are about how you feel about your ability to address environmental issues. Please indicate how much you disagree or agree with each of the following statements. (Strongly disagree-Strongly agree)

16. As a result of participating in the Nature in the City biodiversity project, how did your interest in doing the following activities change? Please indicate whether your interest decreased, increased or stayed the same.
17. How likely are you to participate in the Nature in the City biodiversity project in future years?
18. How likely are you to recommend that others participate in the Nature in the City biodiversity project in future years? (Not at all likely-Extremely likely)
19. Is there anything else you would like to tell us about your experience?

Supplemental Table 1.1. Summary of surveys produced, and detections reported as compared to the number of paid-hours allocated to a citizen science and a technician monitoring program. Paid-hours, surveys and detections are presented for bird monitoring, butterfly monitoring and program totals.

	Citizen Science program			**Technician monitoring**		
	Total	Bird monitoring	Butterfly monitoring	Total	Bird monitoring	Butterfly Monitoring
Work-hours	187.5	86.25	101.25	727.5	364.5	363
Surveys produced	367	189	187	841	531	310
Surveys/work-hour	*2.00*	*2.19*	*1.85*	*1.16*	*1.46*	*0.85*
Detections reported	1412	934	478	3304	2603	701
Detections/work-hour	*7.53*	*10.82*	*4.72*	*4.54*	*7.14*	*1.93*

Supplemental Table 1.2: A list of the bird and butterfly indicator species that citizen scientists were trained to identify for the Nature in the City Biodiversity Project. Species are organized alphabetically by common name and into human-adapted and human-sensitive guilds. References that justify guild placement are provided.

Bird Species	Reference	Butterfly Species	Reference
Human-adapted species			
American Robin (*Turdus Migratorius*)	Odell et al., 2003 Farr et al., 2017	Cabbage White (*Pieris rapae*)	Matteson & Langellotto, 2010 Chu & Jones, 2011
Barn Swallow (*Hirundo rustica*)	Chace & Walsh, 2006 Aronson et al., 2014 Farr et al., 2017	Checkered White (Pontia pr*otodice*)	Nelson & Nelson, 2001 Chu & Jones, 2011
Blue Jay (*Cyanocitta cristata*)	Chace & Walsh, 2006 Farr et al., 2017	Clouded Sulphur (*Colias philodice*)	Nelson & Nelson, 2001 Chu & Jones, 2011
Common Grackle (*Quiscalus quiscula*)	Farr et al., 2017	Orange Sulphur (*Colias eurytheme*)	Nelson & Nelson, 2001 Chu & Jones, 2011
House Finch (*Haemorhous Mexicanus*)	Mangan et al., 2016	Painted Lady (*Vanessa cardui*)	Nelson & Nelson, 2001 Chu & Jones, 2011
House Wren (*Troglodytes aedon*)	Chace & Walsh, 2006 Farr et al., 2017		
Red-winged Blackbird (*Agelaius phoeniceus*)	Chace & Walsh, 2006 Farr et al., 2017		
Human-sensitive			
American Goldfinch (*Spinus tristis*)	Farr et al., 2017	Common Checkered Skipper (*Pyrgus communis*)	Matteson & Langellotto, 2010 Chu & Jones, 2011 Nelson & Nelson, 2001
Black-capped Chickadee (*Poecile Atricapillus*)	(Odell, Theobald, & Knight, 2003b) Farr et al., 2017	Monarch (*Danaus plexippus*)	Janet R. & Stephen R., 2011
Downy Woodpecker (*Picoides Pubescens*)	Mangan et al., 2016	Reakirt's Blue (*Hemiargus isola*)	Nelson & Nelson, 2001 Janet R. & Stephen R., 2011
Northern Flicker (*Colaptes auratus*)	Farr et al., 2017	Taxiles Skipper (*Poanes taxiles*)	Nelson & Nelson, 2001 Janet R. & Stephen R., 2011
Song Sparrow (*Melospiza melodia*)	Chace & Walsh, 2006 Farr et al., 2017	Viceroy (*Limenitis archippus*)	Nelson & Nelson, 2001
Western Kingbird (*Tyrannus verticalis*)	Odell et al. 2003 Farr et al., 2017		
Western Meadowlark (*Sturnella neglecta*)	Farr et al., 2017		
Yellow Warbler (*Setophaga petechia*)	Chace & Walsh, 2006 Farr et al., 2017		

Supplemental Table 1.3. False positive occupancy model estimates from the top models for each of species. Species are organized by taxon (bird vs. butterfly) and guilds (human-adapted vs. human-sensitive).

Guild	Species	Probability of citizen science false positive detection (p_{10})(±SE)	Probability of true citizen science detection (p_{11})(±SE)	Probability of true technician detection (r_{11})(±SE)
		Birds		
Human-adapted	American Robin (*Turdus Migratorius*)	0.072 (0.064)	0.505 (0.044)	0.505 (0.030)
Human-adapted	Blue Jay (*Cyanocitta cristata*)	0.106 (0.032)	0.192 (0.057)	0.301 (0.057)
Human-adapted	House Finch (*Haemorhous Mexicanus*)	0.033 (0.033)	0.468 (0.046)	0.558 (0.028)
Human-adapted	House Wren (*Troglodytes aedon*)	0.034 (0.015)	0.0499 (0.048)	0.502 (0.088)
Human-adapted	Red-winged Blackbird (*Agelaius phoeniceus*)	0.024 (0.020)	0.623 (0.052)	0.549 (0.035)
Human-sensitive	Northern Flicker (*Colaptes auratus*)	0.035 (0.022)	0.131 (0.064)	0.290 (0.067)
Human-sensitive	Song Sparrow (*Melospiza melodia*)	0.058 (0.022)	0.146 (0.075)	0.334 (0.084)
Human-sensitive	Western Meadowlark (*Sturnella neglecta*)	0.062 (0.022)	0.370 (0.087)	0.630 (0.056)
		Butterflies		
Human-adapted	Cabbage White (*Pieris rapae*)	0.222 (0.069)	0.559 (0.050)	0.534 (0.041)
Human-sensitive	Common Checkered Skipper (*Pyrgus communis*)	0.091 (0.028)	0.307 (0.072)	0.502 (0.072)
Human-sensitive	Monarch (*Danaus plexippus*)	0.017 (0.012)	0.151 (0.096)	0.352 (0.159)

Supplemental Table 1.4. A summary of log-linear analyses, which were used to assess potential effect of year (n=4) on the proportion of respondents who reported an increased interest in engaging in conservation activities. Respondents were asked to whether their interest "increased," "decreased," or "stayed the same" as a result of participating in the Nature in the City Biodiversity Project.

Volunteering for another citizen science project			
	G^2	df	p
Proportion of "increased" responses ~ year	4.2	6	0.66
Volunteering for the Nature in the City biodiversity project in future years			
	G^2	df	p
Proportion of "increased" responses ~ year	6.3	6	0.39
Spending time observing birds, butterflies or other wildlife			
	G^2	df	p
Proportion of "increased" responses ~ year	3.6	6	0.74
Getting involved with the Nature in the City initiative			
	G^2	df	P
Proportion of "increased" responses ~ year	5.1	6	0.53
Seeking additional training or information about birds or butterflies			
	G^2	df	P
Proportion of "increased" responses ~ year	0.44	6	0.99
Sharing my knowledge of birds or butterflies with friends or family members			
	G^2	df	P
Proportion of "increased" responses ~ year	3.4	6	0.75
Visiting open space areas in Fort Collins			
	G^2	df	P
Proportion of "increased" responses ~ year	3.4	6	0.75
Protecting or restoring wildlife habitat throughout Fort Collins			
	G^2	df	P
Proportion of "increased" responses ~ year	5.1	6	0.53
Sharing my knowledge of birds or butterflies with friends or family members			
	G^2	df	P
Proportion of "increased" responses ~ year	3.4	6	0.75
Contributing to wildlife conservation groups			
	G^2	df	P
Proportion of "increased" responses ~ year	4.4	6	0.62

Supplemental Table 1.5. Single-season occupancy model components for all models with a ΔAIC < 2.00 and top model estimates of Ψ for bird and butterfly species that yielded consistent, realistic models using citizen science and technician data. Top model names, and the covariates that they include, are listed for each species.

Species	Top models$_{CS}$	Ψ_{CS} (±SE)	Top models$_{T}$	Ψ_{T} (±SE)
American Robin (*Turdus migratorius*)	Ψ(.)p(.) Ψ(natural_habitat_300m)p(.)	0.80 (0.08)	Ψ(natural_habitat_300m)p(.) Ψ(site_area+naural_habitat_300m)p(.)}	0.83 (0.06)
Red-winged Blackbird (*Agelaius phoeniceus*)	Ψ (natural_habitat_300m)p(.)	0.74 (0.17)	Ψ (natural_habitat_300m)p(.)}	0.46 (0.04)
Northern Flicker (*Colaptes auratus*)	Ψ(.)p(.) Ψ(site_area)p(.) Ψ(natural_habitat_300m)p(.)	0.41 (0.27)	Ψ(site_area)p(veg_cover_500m) Ψ(site_area)p(.)	0.23 (0.07)
Western Meadowlark (*Sturnella neglecta*)	Ψ(site_area)p(wind+sky) Ψ(.)p(wind+sky)	0.28 (0.140)	Ψ(natural_habitat_300m)p(.)	0.15 (0.03)
Cabbage White (*Pieris rapae*)	Ψ(.)p(.) Ψ(shrub_cover_100m)p(.) Ψ(greenspace_cov_100m)p(.) Ψ(shrub_cover_100m +greenspace_cov_300m)p(.)	0.73 (0.08)	Ψ(shrub_cover_100m)p(.) Ψ(shrub_cover_100m +greenspace_cov_300m)p(.)	0.72 (0.08)

Supplemental Table 1.6: A summary of log-linear analyses, which were used to assess potential differences in the demographics of pre- and post-program survey respondents across four years. Participants in the Nature in the City Biodiversity Project completed a pre-program survey and a sub-sample of participants completed a post-program survey. Demographics of pre-program survey respondents and post-program survey respondents were compared while accounting for differences between years.

Home ownership			
	G^2	df	p
Response (Rent or own) ~ Pre vs. Post	0.84	1	0.36
Gender			
	G^2	df	p
Response (Male or non-male) ~ Pre vs. Post	0.92	2	0.63
Race			
	G^2	df	p
Response (Caucasian or non-Caucasian) ~ Pre vs. Post	0.22	1	0.64
Education			
	G^2	df	P
Response (1-12th grade or less; 6-Post-graduate) ~ Pre vs. Post	3.4	4	0.49
Income			
	G^2	df	p
Response (1-<$21,999;5-$150,000 to $249,999) ~ Pre vs. Post	7.8	4	0.10
Age			
	G^2	df	p
Response (1-18 to 24;6-65 to 74) ~ Pre vs. Post	4.3	4	0.37

Supplemental Table 2.1. Bird species detected in Fort Collins categorized into guilds (native/non-native and human-sensitive/human-adapted), feeding strategy (omnivore, granivore, carnivore, insectivore and nectarivore), and nesting strategy (tree-nester, shrub-nester, cavity-nester, burrower, ground-nester, floating-nester and building-nester).

Common Name	Scientific Name	Native/Non-Native	Human-sensitive/adapted	Feeding strategy*	Nesting Strategy*
American Crow	*Corvus brachyrhynchos*	Native	Human-adapted[5,6]	Omnivore	Tree
American Goldfinch	*Spinus tristis*	Native	Human-sensitive[5,6]	Granivore	Shrub
American Kestrel	*Falco sparverius*	Native	Human-adapted[5,6]	Carnivore	Cavity
American Robin	*Turdus migratorius*	Native	Human-adapted[5,6]	Insectivore	Tree
American White Pelican	*Pelecanus erythrorhynchs*	Native	Human-adapted[9]	Carnivore	Ground
American Tree Sparrow	*Spizelloides arborea*	Native	Human-sensitive[8]	Granivore	Ground
Barn Swallow	*Hirundo rustica*	Native	Human-adapted[5,6]	Insectivore	Building
Black-billed Magpie	*Pica hudsonia*	Native	Human-adapted[5,6]	Omnivore	Tree
Black-capped chickadee	*Poecile atricapillus*	Native	Human-sensitive[5,6,7]	Insectivore	Cavity
Black-crowned Night Heron	*Nycticorax nycticorax*	Native	Human-adapted[9]	Carnivore	Tree
Belted Kingfisher	*Megaceryle alcyon*	Native	Human-adapted[5,6]	Carnivore	Burrow
Blue Grosbeak	*Passerina caerulea*	Native	Human-sensitive[5,6]	Insectivore	Shrub
Blue Jay	*Cyanocitta cristata*	Native	Human-adapted[5,6]	Omnivore	Tree
Brewer's Blackbird	*Euphagus cyanocephalus*	Native	Human-adapted[5,6]	Omnivore	Tree
Broad-tailed hummingbird	*Selasphorus platycercus*	Native	Human-adapted[6,]	Nectarivore	Shrub

Brown-headed Cowbird	*Molothrus ater*	Native	Human-adapted[5,6]	Granivore	Tree
Bullock's Oriole	*Icterus bullocki*	Native	Human-adapted[5,6]	Insectivore	Tree
Canada Goose	*Branta canadensis*	Native	Human-adapted[6]	Granivore	Ground
Clark's Grebe	*Aechmophorus clarkii*	Native		Carnivore	Floating
Common Grackle	*Quiscalus quiscula*	Native	Human-adapted[5]	Omnivore	Tree
Common Nighthawk	*Chordeiles minor*	Native	Human-adapted[6]	Insectivore	Ground
Common Raven	*Corvus corax*	Native	Human-adapted[5,6]	Omnivore	Cliff
Common Yellowthroat	*Geothlypis trichas*	Native	Human-adapted[5]	Insectivore	Shrub
Cooper's Hawk	*Accipiter cooperii*	Native	Human-adapted[3,5,6]	Carnivore	Tree
Downy Woodpecker	*Picoides pubescens*	Native	Human-sensitive[6]	Insectivore	Cavity
Eurasian Collared Dove	*Streptopelia decaocto*	Non-Native	Human-adapted[5,6]	Granivore	Tree
European Starling	*Sturnus vulgaris*	Non-Native	Human-adapted[1,5,6]	Insectivore	Cavity
Great Blue Heron	*Ardea herodias*	Native	Human-adapted[9]	Carnivore	Tree
Great Horned Owl	*Bubo virginianus*	Native	Human-adapted[3]	Carnivore	Tree
Grasshopper Sparrow	*Ammodramus savannarum*	Native	Human-sensitive[4]	Insectivore	Ground
Hairy Woodpecker	*Leuconotopicus villosus*	Native	Human-adapted[6]	Insectivore	Cavity
House Finch	*Haemorhous mexicanus*	Native	Human-adapted[5,6]	Granivore	Tree
Horned Lark	*Eremophila alpestris*	Native	Human-sensitive[4]	Granivore	Ground
House Sparrow	*Passer domesticus*	Non-Native	Human-adapted[1,5,6]	Granivore	Cavity
House Wren	*Troglodytes aedon*	Native	Human-adapted[5,6]	Insectivore	Cavity
Killdeer	*Charadrius vociferus*	Native	Human-adapted[6]	Insectivore	Ground
Lesser Goldfinch	*Spinus psaltria*	Native	Human-sensitive[4,5,6]	Granivore	Tree
Mallard	*Anas platyrhyncho*	Native	Human-adapted[2,6,7]	Omnivore	Ground

Mourning Dove	*Zenaida macroura*	Native	Human-adapted[5,6]	Granivore	Tree
Northern Flicker	*Colaptes auratus*	Native	Human-adapted[5,6]	Insectivore	Cavity
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	Native	Human-adapted[5,5]	Insectivore	Cliff
Prairie Falcon	*Falco mexicanus*	Native	Human-sensitive[3]	Carnivore	Cliff
Red-tailed Hawk	*Buteo jamaicensis*	Native	Human-adapted[3,6]	Carnivore	Tree
Red-winged Blackbird	*Agelaius phoeniceus*	Native	Human-adapted[6,5]	Insectivore	Shrub
Rock Pigeon	*Columba livia*	Non-Native	Human-adapted[1,6]	Granivore	Building
Say's Phoebe	*Sayornis saya*	Native	Human-sensitive[6]	Insectivore	Building
Savannah Sparrow	*Passerculus sandwichensis*	Native	Human-sensitive[5]	Insectivore	Ground
Song Sparrow	*Melospiza melodia*	Native	Human-sensitive[3,5]	Insectivore	Ground
Spotted Sandpiper	*Actitis macularius*	Native	Human-sensitive[9]	Invertivore	Ground
Spotted Towhee	*Pipilo maculatus*	Native	Human-sensitive[7,5]	Insectivore	Ground
Swainson's Hawk	*Buteo swainsoni*	Native	Human-adapted[3]	Carnivore	Tree
Tree Swallow	*Tachycineta bicolor*	Native	Human-adapted[3,5]	Insectivore	Cavity
Vesper Sparrow	*Pooecetes gramineus*	Native	Human-sensitive[5]	Insectivore	Ground
Violet Green Swallow	*Tachycineta thalassina*	Native	Human-adapted[6]	Insectivore	Cavity
Virginia's Warbler	*Oreothlypis virginiae*	Native	Human-sensitive[5]	Insectivore	Ground
Western Kingbird	*Tyrannus verticalis*	Native	Human-sensitive[5,6,7]	Insectivore	Tree
Western Meadowlark	*Sturnella neglecta*	Native	Human-sensitive[5,6]	Insectivore	Ground
Western Wood-Pewee	*Contopus sordidulus*	Native	Human-sensitive[6]	Insectivore	Tree
White-breasted Nuthatch	*Sitta carolinensis*	Native	Human-sensitive[5]	Insectivore	Cavity
Wilson's Snipe	*Gallinago delicata*	Native	Human-sensitive[9]	Invertivore	Ground
Wood Duck	*Aix sponsa*	Native	Human-adapted[9]	Insectivore	Cavity

Yellow Warbler	*Setophaga petechia*	Native	Human-sensitive[3,5,6]	Insectivore	Shrub
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	Native	Human-sensitive[9]	Insectivore	Shrub
Yellow-rumped Warbler	*Setophaga coronata*	Native	Human-adapted[6]	Insectivore	Tree

*The Cornell Lab of Ornithology Online Bird Guide was consulted to determine the diet and nesting strategy for each species

S2 References

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Supplemental Table 2.2. Butterfly species detected in Fort Collins categorized into guilds (native/non-native and human-sensitive/human-adapted), vagility (1-4), and nectar dependence (0 and 1). If sources were not found to categorize a species, that cell was left blank.

Scientific Name	Common Name	Native/Non-native	Human-adapted/sensitive	Vagility*	Nectar dependence*
Colias sp.	Sulphurs	Native	Human-adapted[2,5]	4	1
Cercyonis pegala	Common Woodnymph	Native	Human-sensitive[2,4]	2	1
Danaus plexippus	Monarch	Native	Human-sensitive[5]	4	1
Euptoieta claudia	Variegated Fritillary	Native		4	1
Limenitis archippus	Viceroy	Native	Human-sensitive[3]	2	0
Papilio polyxenes	Black Swallowtail	Native	Human-adapted[3]	3	1
Papilio sp.	Swallowtails	Native		3	1
Pholisora catullus	Common Sootywing	Native		1	1
Phyciodes sp.	Crescents	Native	Human-adapted	2	1
Polyommatini sp.	Blues	Native	Human-sensitive	1	
Pieris rapae	Cabbage White	Non-native	Human-adapted[2,4]	4	1
Piruna pirus	Russet Skipperling	Native			
Poanes taxiles	Taxiles Skipper	Native	Human-sensitive[5]	1	1
Polites peckius	Peck's Skipper	Native	Human-adapted[3]	1	1
Pontia protodice	Checkered White	Native	Human-adapted[2,5]	4	1
Pyrgus communis	Common Checkered Skipper	Native	Human-sensitive[2,5]	4	1
Speyeria aphrodite	Aphrodite fritillary	Native		2	1
Vanessa cardui	Painted Lady	Native	Human-adapted[2,5]	4	0

*Vagility was reported in meters and categorized by degrees of magnitude:
1: 10^1
2: 10^2

3: 10^3
4: $>10^3$
Nectar dependence was measured as the relative proportion that nectar contributes to an adult's diet:
0: low
1: high

S3 References

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Supplemental Table 2.3. A summary of linear regression models and associated R^2 values evaluating the relationship between the proportion of detections and the proportion of the number of species for birds and butterflies that we detected in Fort Collins, Colorado.

Model	R^2
Birds	
Prop. sensitive species by detections ~ Prop. sensitive species by richness	0.93
Prop. native species by detections ~ Prop. native species by richness	0.89
Prop. granivore species by detections ~ Prop. granivore species by richness	0.91
Prop. insectivore species by detections ~ Prop. insectivore species by richness	0.86
Prop. omnivore species by detections ~ Prop. omnivore species by richness	0.89
Prop. carnivore species by detections ~ Prop. carnivore species by richness	0.88
Prop. tree-nesting species by detections ~ Prop. tree-nesting species by richness	0.95
Prop. shrub-nesting species by detections ~ Prop. shrub-nesting species by richness	
Prop. cavity-nesting species by detections ~ Prop. cavity-nesting species by richness	0.76
Prop. ground-nesting species by detections ~ Prop. ground-nesting species by richness	
	0.94
	0.85
Butterflies	
Prop. sensitive species by detections ~ Prop. sensitive species by richness	0.13
Prop. native species by detections ~ Prop. native species by richness	0.27
Prop. nectar-dependent species by detections ~ Prop. nectar-dependent species by richness	0.90

Supplemental Table 2.4. Summary statistics, ANOVA statistics and Tukey's Honest Significant Methods pairwise statistics for the proportion of various bird guilds detected across residential open spaces (ROSs, n=10), enhanced residential open space (EROSs, n=10), and public natural areas (PNAs, n=12) across Fort Collins, Colorado.

Guild	Residential open space (Mean, ±SD)	Enhanced residential open space (Mean, ±SD)	Public natural area (Mean, ±SD)	ANOVA statistics	Pairwise comparisons
Human-sensitive species	0.09, ±0.10	0.20, ±0.12	0.28, ±0.21	(F(2)=9.1,p<0.01)*	ROS-EROS: p=0.05* EROS-PNA: p=0.23 ROS-PNA: p<0.01*
Native species	0.94, ±0.10	0.92, ±0.06	0.94, ±0.10	(F(2)=3.2,p=0.89)	ROS-EROS: p=0.85 EROS-PNA: p=0.81 ROS-PNA: p=0.99
Granivores	0.29, ±0.13	0.25, ±0.22	0.12, ±0.10	(F(2)=5.7, p=0.01)*	ROS-EROS: p=0.76 EROS-PNA: p=0.05* ROS-PNA: p=0.01*
Insectivores	0.35, ±0.12	0.56, ±0.23	0.55, ±0.18	(F(2)=6.9, p<0.01)*	ROS-EROS: p<0.01* EROS-PNA: p=0.99 ROS-PNA: p<0.01*
Omnivores	0.27, ±0.10	0.17, ±0.13	0.18, ±0.10	(F(2)=4.1, p=0.02)*	ROS-EROS: p=0.03* EROS-PNA: p=0.97 ROS-PNA: p=0.04*
Tree-nesters	0.67, ±0.23	0.40, ±0.23	0.31, ±0.14	(F(2)=15.6,p<0.01)*	ROS-EROS: p<0.01* EROS-PNA: p=0.32 ROS-PNA: p<0.01*
Shrub-nesters	0.10, ±0.10	0.29, ±0.25	0.12, ±0.08	(F(2)=7.5,p<0.01)*	ROS-EROS: p<0.01* EROS-PNA: p=0.01* ROS-PNA: p=0.87
Cavity-nesters	0.08, ±0.06	0.10, ±0.10	0.15, ±0.14	(F(2)=1.1, p=0.33)	ROS-EROS: p=0.91 EROS-PNA: p=0.57 ROS-PNA: p=0.32
Ground-nesters	0.03, ±0.03	0.11, ±0.10	0.21, ±0.18	(F(2)=8.4,p<0.01)*	ROS-EROS: p=0.20 EROS-PNA: p=0.08 ROS-PNA: p<0.01*

*denotes a statistical significance (p<0.05)

Supplemental Table 2.5. Summary statistics, ANOVA statistics and Tukey's Honest Significant Methods pairwise statistics for the proportion of various butterfly guilds detected across residential open spaces (ROSs, n=10), enhanced residential open space (EROSs, n=10), and public natural areas (PNAs, n=12) across Fort Collins, Colorado.

Guild	Residential open space (Mean, ±SE)	Enhanced residential open space (Mean, ±SE)	Public natural area (Mean, ±SE)	ANOVA statistics	Pairwise comparisons
Human-sensitive species	0.13, ±0.05	0.20, ±0.09	0.22, ±0.04	(F(2)=0.89, p=0.41)	ROS-EROS: p=0.64 EROS-PNA: p=0.92 ROS-PNA: p=0.39
Native species	0.33, ±0.21	0.50, ±0.27	0.37, ±0.20	(F(2)=1.7, p=0.20)	ROS-EROS: p=0.14 EROS-PNA: p=0.28 ROS-PNA: p=0.87
Nectar-dependent species	0.60, ±0.13	0.63, ±0.27	0.78, ±0.22	(F(2)=2.7, p=0.08)	ROS-EROS: p=0.93 EROS-PNA: p=0.19 ROS-PNA: p=0.09
Mean vagility	3.6, ±0.61	3.5, ±0.50	3.01, ±0.55	(F(2)=3.9, p=0.03)*	ROS-EROS: p=0.99 EROS-PNA: p=0.06 ROS-PNA: p=0.05*

*denotes a statistical significance (p<0.05)

Supplemental Table 2.6. Best supported regression models (ΔAICc<2.0) for bird species richness and various guilds in relation to site- and landscape-level predictor variables. The AICc values, ΔAICc values, residual deviance, regression coefficient estimates and standard errors are shown for each model.

Model	AICc	ΔAIC	Std. Regression Coefficients (SE)	Pseudo-R^2
Species Richness				
NATIVE_COVER	111.55	0	1.40 (0.79)	0.101
BUILDING_1000m	111.75	0.19	-1.36 (0.80)	0.092
% MOWED	112.03	0.48	-1.30 (0.80)	0.079
GRASS/SHRUB_100m	112.69	1.14	1.13 (0.81)	0.048
BUILDING_site	113.28	1.73	-0.97 (0.82)	0.020
Proportion of native species				
CANCOV_site	-94.86	0	0.33 (0.23)	0.101
CANCOV_300m	-93.97	0.90	0.23 (0.23)	0.060
GRASS/SHRUB_site	-93.96	0.90	-0.23 (0.23)	0.051
GRASS/SHRUB_1000m	-93.85	1.01	0.22 (0.23)	0.050
Proportion of human-sensitive				
CANCOV_1000m*	-47.70	0	0.37 (0.15)	0.185
Proportion of cavity-nesting species				
GRASS/SHRUB_500m*	-83.00	0	-0.83 (0.22)	0.59
CANCOV_300m*	-81.80	1.20	0.85 (0.22)	0.42
Proportion of shrub-nesting				
% MOWED*	-58.24	0	-1.02 (0.24)	0.374
Proportion of tree-nesting species				
% MOWED*	-02.69	0	0.56 (0.20)	0.310
Proportion of ground-nesting species				
NATIVE_COVER*	-143.7	0	1.03 (0.21)	0.282
Proportion of insectivores				
% MOWED*	-16.29	0	-0.62 (0.14)	0.517
Proportion of omnivores				
SITE_AREA*	-27.68	0	0.31 (0.13)	0.170
GRASS/SHRUB_site*	-27.15	0.53	0.30 (0.15)	0.167
Proportion of granivores				
% MOWED*	-16.85	0	0.48 (0.17)	0.282

*denotes a statistically significant relationship (p<0.05)

Supplemental Table 2.7. Best supported regression models (ΔAICc<2.0) for butterfly species richness, proportion of native species detections, proportion of nectar dependent species detections and mean vagility in relation to site- and landscape-level predictor variables. The AICc values, ΔAICc values, residual deviance, regression coefficient estimates and standard errors are shown for each model.

Model	AICc	ΔAIC	Regression Coefficients (SE)	R^2
Species Richness				
NATIVE_COVER*	140.74	0	2.82 (1.39)	0.138
FLORAL_ACTIVITY	141.60	1.12	0.01 (0.004)	0.111
Proportion of native species				
BUILD_100m*	-2.22	0	-0.50 (0.20)	0.255
Proportion of human-sensitive species				
CANCOV_1000m	-138.91	0	0.40 (0.26)	0.112
SITE_AREA	-137.79	1.12	-0.23 (0.25)	0.092
CANCOV_site	-137.30	1.61	0.18 (0.26)	0.035
BUILD_300m	-137.11	1.80	-0.17 (0.26)	0.017
% MOWED	-136.95	1.96	-0.12 (0.26)	0.011
Proportion of nectar-dependent species				
SITE_AREA*	-3.77	0	0.46 (0.22)	0.150
% MOWED	-2.83	0.94	-0.35 (0.20)	0.111
BUILD_site	-1.88	1.89	-0.27 (0.20)	0.083
Mean vagility				
% MOWED	57.40	0	0.15 (0.12)	0.028
SITE_AREA	58.34	0.36	0.14 (0.12)	0.011

*denotes a statistically significant relationship ($p<0.05$)