The Impacts of Urbanization on Birds in the San Francisco East Bay

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ABSTRACT

Around the globe, urbanization has changed wildlife habitats and affected species in a variety of ways. Few previous studies have explored the impacts of urbanization on avian communities along the coastlines. In this study, I focus on the urbanization gradient along the San Francisco East Bay and explore the relationships between land cover variables and the avian community. Specifically, my study aims to answer two questions: (1) how does the amount of living vegetation affect the abundance and species richness of birds across the urbanization gradient at San Francisco East Bay? and (2) how does the percentage of impervious surface affect the birds across this urbanization gradient? To answer these questions, I used remote sensing data and surveyed birds at three study sites. A linear mixed-effect model failed to show any significant impacts of the amount of living vegetation (p-value = 0.4368) and impervious surface (p-value = 0.9046) on the bird species richness. It also failed to show any significant impacts of the amount of living vegetation (p-value = 0.3995) and impervious surface (p-value = 0.3928) on the bird abundance. However, further analyses using non-metric multidimensional scaling did reveal the differences among the communities at the three study sites at the species level. Overall, this study provided important information in terms of the spatial and temporal scale of studies on this subject. It also revealed certain limitations of collecting data with point counts and indicated the possibility of using other datasets in addition to point count data in future studies.

KEYWORDS

Wildlife ecology, land cover, landscape ecology, species richness, abundance

INTRODUCTION

Urbanization has transformed wildlife habitats around the globe over the past several centuries. It often leads to the formation of urbanization gradients, which extend from heavily developed urban centers to the margins of cities (McDonnell and Hahs 2008). Along these gradients, changes in the landscape affect wildlife in a variety of ways. In urbanized areas, the percentage of impervious surface drastically increases, reducing and fragmenting habitat. Open spaces in residential and commercial areas tend to have less shrub and more grasses and herbs; urbanization causes structural simplification and thus decreases habitat quality of vegetation (Marzluff and Ewing 2001, Mckinney 2008). Additionally, urbanization removes native plant species and imports nonnative species through landscaping and horticultural activities (Mckinney 2008). These changes in vegetation threaten the survival of wildlife that relies on specific plant species for food and nesting sites. Other human activities, including traffic and pollution, further degrade remaining wildlife habitat (Mckinney 2008). As a result, 275 wildlife species in the United States alone had been listed as threatened or endangered due to urbanization by August 1994 (Czech et al. 2000).

Birds are vulnerable to the impacts of disturbances and changes in their habitats caused by urbanization. Bird species richness, community structure, and other population parameters are closely related to the abundance and types of vegetation in cities (Ciach and Fröhlich 2016, Sandström et al. 2006). In the city of Valencia, Spain, larger parks led to higher bird species richness (Murgui 2009). In addition, human activities influence the distribution of birds. Road noise emission disrupted the vocal communication among birds and led to a decrease in overwintering birds in Kraków, Poland (Ciach and Fröhlich 2016). Increased traffic reduced the species richness of birds in Mexico City (Ciach and Fröhlich 2016). Other causes related to human activities, such as collisions with cars, predation by companion animals (pets), and collisions with buildings also led to decrease in bird population in urbanized habitats (Cusa et al. 2015). Finally, because bird species have distinct breeding, migratory, and foraging behaviors, their needs for resources shape their distribution in urbanized habitats. Overall, studies have revealed that vegetation and disturbances, together with species' requirements for resources at different times of the year, impede or enhance the survival of birds in urbanized habitats. Nonetheless, gaps still exist in our understanding of the impacts of urbanization on birds.

Though previous studies have investigated the impacts of urbanization on avian communities, they focused on only a subset of landscapes and species. Since most studies focused on birds in inland urbanization gradients, there is a need for further research on birds residing along urban coastlines. Waterbirds rely on a unique set of habitats and resources to survive (Stralberg et al. 2010). Thus, the impacts of urbanization on these species may be different from impacts on inland birds. In addition, researchers have seldom used the land cover variables of normalized vegetation index (NDVI) and the impervious surface to characterize landscapes in their studies. NDVI assesses the availability of green photosynthetic vegetation and often serves as a proxy for bird habitat quality (McKinnon et al. 2015). The percentage of impervious surface indicates the level of human alteration of landscapes and the availability of soil for vegetation growth (Sarkar Chaudhuri et al. 2017). Both variables can be conveniently extracted from satellite images.

In this study, I focused on the urbanization gradient at the San Francisco East Bay to address this lack of research on avian communities along coastal urbanization gradients. I examine the impacts of urbanization on the abundance and species richness of birds across this urbanization gradient. Specifically, I seek to answer these two questions: first, how does the amount of living vegetation affect the total abundance of birds and the overall species richness across this urbanization gradient? Second, how does the percentage of impervious surface affect the total abundance of birds and the overall species richness across this urbanization gradient? I hypothesize that bird abundance and species richness are positively correlated with the amount of living vegetation and negatively correlated with the percentage of impervious surface. To test this hypothesis, I surveyed birds at three different sites along the urbanization gradient at San Francisco East Bay and calculated NDVI as well as the percentage of impervious surface from classified satellite images.

METHODS

Study site

I investigated bird communities at three study sites with varying levels of urbanization (Figure 1). The first study site, McLaughlin Eastshore State Park (Figure 2), extends along the east shore of San Francisco Bay north of the Bay Bridge. Although it was previously a landfill, the park has undergone comprehensive restoration since the 1980s and is now the least urbanized study site among the three (Krieger 2017). There are a variety of habitat types in the park, including seasonal wetlands and coastal prairies. As a result, the park is home to a diverse collection of birds, including inland birds and seabirds. House finches, California towhees, and European starlings are a few species commonly found at the park.

Figure 1. Eastshore State Park, Aquatic Park, and the Northern Half of Emeryville (from top to bottom)

Figure 2. Eastshore State Park

The second study site, Aquatic Park (Figure 3), is a moderately urbanized site located in Southwest Berkeley. Encompassing 64.8 acres of habitat for water birds, the park provides shelter to many water bird species including American coots and Gadwalls (Avocet Research Associates 2005). However, the park is exposed to more human impacts. The heavy traffic on the Highway 580 corridor and the railroad traffic are consistent sources of loud noise on either side of the park. Within the park, watercraft such as kayaks and rowing shells are in use throughout the year and disturb bird species (Avocet Research Associates 2005).

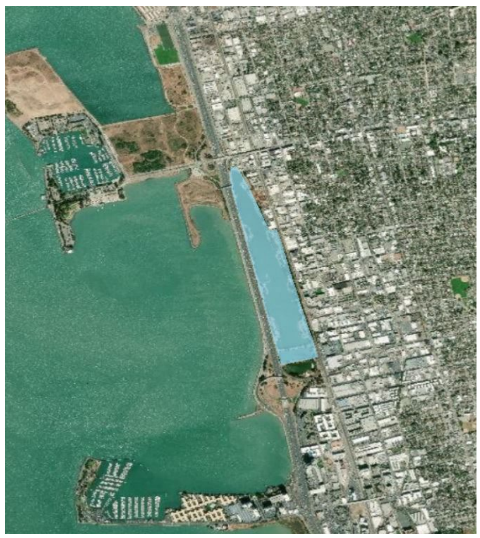

Figure 3. Aquatic Park

The third study site is an area within Emeryville extending from the northern limit of the city to Powell Street (Figure 4). Highly urbanized, this area comprises various land uses, including medium to high-density residential neighborhoods, heavy industrial areas, and parks (City of Emeryville n.d.). a large variety of human infrastructures are found in this part of Emeryville, including markets, hotels, and a cinema. Within this study site, the vegetation available to wildlife mostly consists of shrubs, grass, and decorative trees (City of Emeryville 2009).

Figure 4. Study Site in Emeryville

Data collection

Bird Survey

To obtain the abundance and species richness of birds along the urbanization gradient, I surveyed birds at the three study sites. Within each study site, I used systematic sampling to choose six survey locations (Gregory et al. 2004). First, I divided each study site into thirty equal-sized grid squares and numbered the grids from one to thirty. Then, for every study site, I selected a random number using a random number generator. Finally, I selected the grids with every 5th number starting from the previously selected number to choose the survey locations (Figure 5) (Gregory et al. 2004).

Figure 5. Survey locations

To survey birds at these selected locations, I performed unlimited-radius point counts and recorded the species I could see or hear regardless of their distance from the survey locations. To capture the seasonal variations in the bird populations, I conducted point counts on every Sunday morning from June to mid-November. Each time, I started my survey around sunrise and surveyed the study sites in a randomly selected order (Lynch 1995). Within each study site, I divided the survey locations into three groups of locations that were closest to each other. I conducted point counts at each group of survey locations in a randomly selected order with a count period of five minutes per location. Before I started the point count, I estimated the level of traffic noise and counted the number of people I saw. During the count period, I recorded the occurrences of birds by visual sightings and listening to their calls. To avoid repeatedly counting one moving individual, I recorded the occurrences of multiple individuals of the same species only if they showed up as a group (Buskirk and McDonald 1995).

Land Cover Data

To quantify the amount of living vegetation and impervious surface, I derived NDVI and the percentage of impervious surface at my survey locations from satellite images. For NDVI, I obtained the Landsat Surface Reflectance-derived NDVI product from USGS. For the percentage of impervious surface, I obtained the latest imagery from the National Agriculture Imagery Program that was taken in 2016 and performed supervised classification using ArcGIS Pro. Finally, I created a circular buffer around every survey location in ArcMap (Figure 6). Since the sizes of the study sites varied, the size of the buffer was half of the distance between its center and the nearest survey location. Within the circular buffer, I extracted the average NDVI and the percentage of impervious surface in ArcMap.

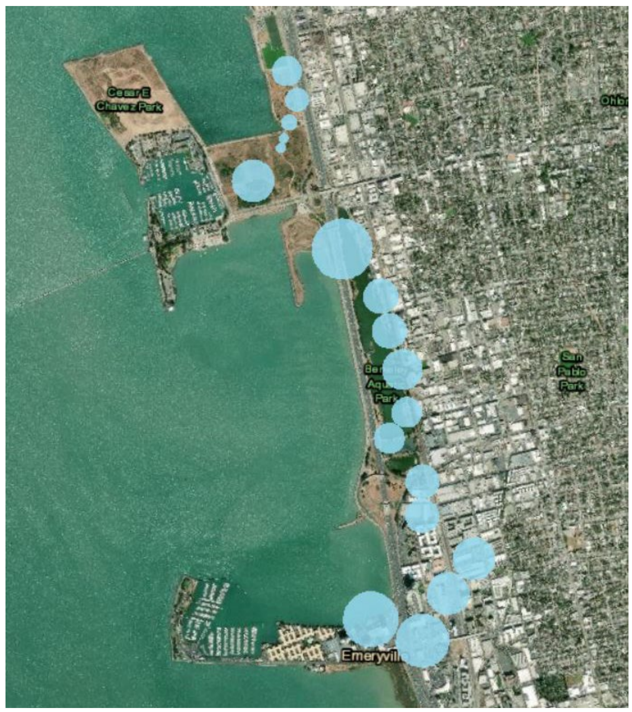

Figure 6. The buffer around survey locations

Data analysis

To examine the relationship between the diversity and abundance of birds and the land cover variables, I used linear mixed effect models through the 'nlme' package in R studio (Pinheiro et al. 2013, RStudio Team 2016). I started by removing species whose occurrences were less than 10% of the total number of bird occurrences. As a result, I excluded the influence of species that were rare due to reasons other than urbanization. Next, I built the linear mixed effect regression models with land cover variables as fixed variables and human presence, traffic noise, and the study site as random variables. For dependent variables, I calculated the Shannon diversity index, the total number of species observed, and the median abundance of birds at each survey location. To capture the seasonal variation in the data due to the arrival of migratory birds, I built two separate models for each of these three response variables, one for data collected before the end of August, and the other one for data collected after the start of September. I compared the regression coefficients and R-squared values of these models to determine if the correlations were strong and to see if the models fit the data well.

RESULTS

Data summaries

Bird survey

In total, I observed 41 species at 18 survey locations across 3 study sites. After removing observations with a certainty level less than 70% and species that had been only observed once, 30 species remained (Table 1). During the first study period from June 1st to the end of August, Emeryville had the highest species richness (17) while the Eastshore State Park had the lowest of (13). During the second study period from September 1st to the end of December, Eastshore State Park had the highest species richness (46) while Emeryville and Aquatic Park both had a species richness of 14. As for the number of individual birds, during the first study period, the highest median abundance was 91 observed at the Aquatic Park and the lowest median abundance was 45.5 observed at the Eastshore State Park. During the second study period, the highest median abundance was 114 observed at the Aquatic Park and the lowest median abundance was 54.5 observed at the Eastshore State Park.

During both study periods, the number of species observed at each visit went through modest changes at Aquatic Park and Eastshore State Park (Figure 7). However, at Emeryville, the number of species observed dropped suddenly before September and slowly rose back to the original level around November. The number of individual birds observed at each visit at gradually decreases for Aquatic Park and Emeryville during the first study period and increased greatly starting around early September (Figure 8). For Eastshore State Park, the number of birds observed peaked during early September, decreased until October, and rose again afterward.

Table 1. Species observed at the three study sites

Species	Common.name	Scientific.name	Number of Occurrences	Percentage of Occurrences
American Coot	American Coot	Fulica americana	202	20.59123344
American Crow	American Crow	Corvus brachyrhynchos	171	17.43119266
American White Pelican	American White Pelican	Pelecanus erythrorhynchos	39	3.975535168
Anna's Hummingbird	Anna's Hummingbird	Calypte anna	14	1.427115189
Barn Swallow	Barn Swallow	Hirundo rustica	4	0.407747197
Black-chinned Hummingbird	Black-chinned Hummingbird	Archilochus alexandri	4	0.407747197
Black-crowned Night Heron	Black-crowned Night Heron	Nycticorax nycticorax	2	0.203873598
Brewer's Blackbird	Brewer's Blackbird	Euphagus cyanocephalus	67	6.829765545
Bushtit	Bushtit	Psaltriparus minimus	4	0.407747197
California Gull	California Gull	Larus californicus	19	1.936799185
California Towhee	California Towhee	Kieneria crissalis	25	2.54841998
Dark-eyed Junco	Dark-eyed Junco	Junco hyemalis	23	2.344546381
Double-crested Cormorant	Double-crested Cormorant	Nannopterum auritus	16	1.630988787
Great Egret	Great Egret	Ardea alba	5	0.509683996
House Finch	House Finch	Haemorhous mexicanus	71	7.237512742
House Sparrow	House Sparrow	Passer domesticus	10	1.019367992
Mallard	Mallard	Anas platyrhynchos	68	6.931702345
Mourning Dove	Mourning Dove	Zenaida macroura	5	0.509683996
Red-shouldered Hawk	Red-shouldered Hawk	Buteo lineatus	2	0.203873598
Rock Pigeon	Rock Pigeon	Columba livia	56	5.708460754
Snowy Egret	Snowy Egret	Egretta thula	22	2.242609582
Song Sparrow	Song Sparrow	Melospiza melodia	4	0.407747197
Western Gull	Western Gull	Larus occidentalis	148	15.08664628

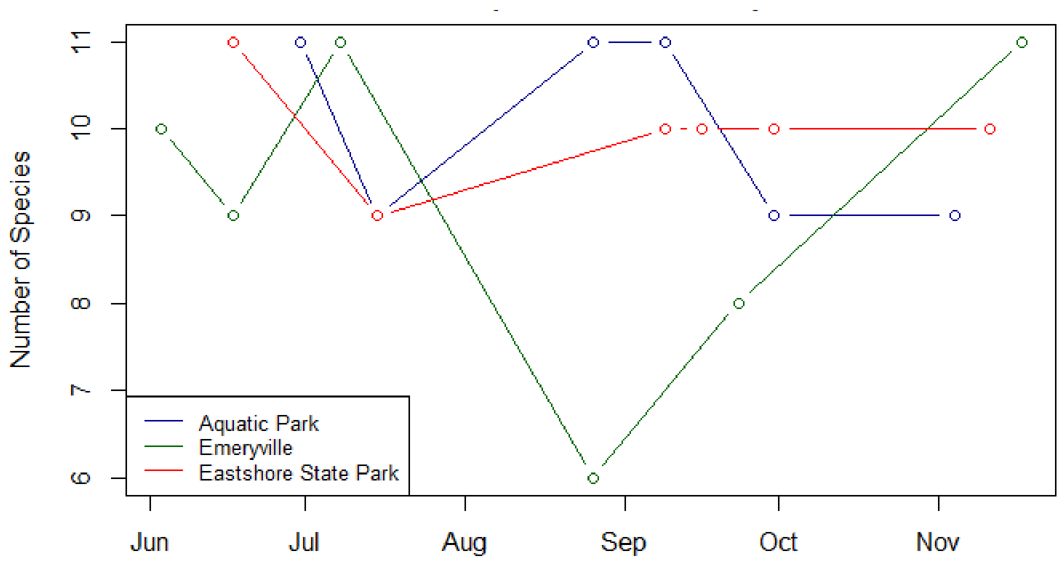

Figure 7. Number of species observed at each visit

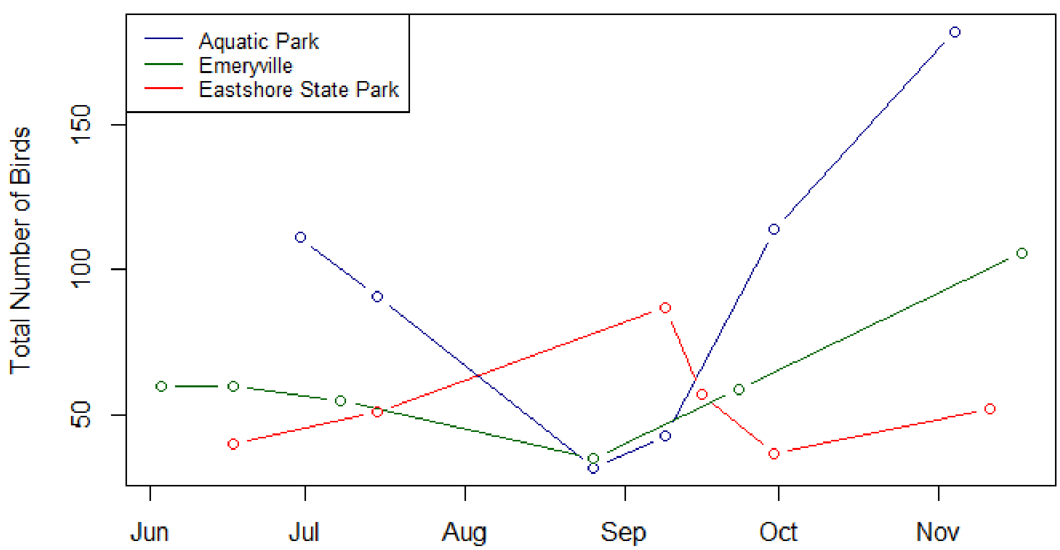

Figure 8. Number of individual birds observed at each visit

Land cover data: NDVI

I extracted NDVI from 13 satellite images in total. Throughout the period, the average NDVI at Emeryville was lower than the NDVI at the Eastshore State Park and slightly lower than the NDVI at the Aquatic Park. Although the average NDVI at the Eastshore State Park was the highest among the three from June to early November, during late November it became slightly lower than the average NDVI at the Aquatic Park. In addition, the average NDVI at Emeryville and the Eastshore State Park went through little change from June to December while the NDVI at the Aquatic Park increased at the end of my study period (Figure 9).

During the first study period, the median NDVI among survey locations across the study period was the highest in Eastshore State Park and the lowest in the Aquatic Park (Figure 10). During the second study period, the median NDVI among survey locations across the study period was still the highest in Eastshore State Park and the lowest in the Aquatic Park (Figure11).

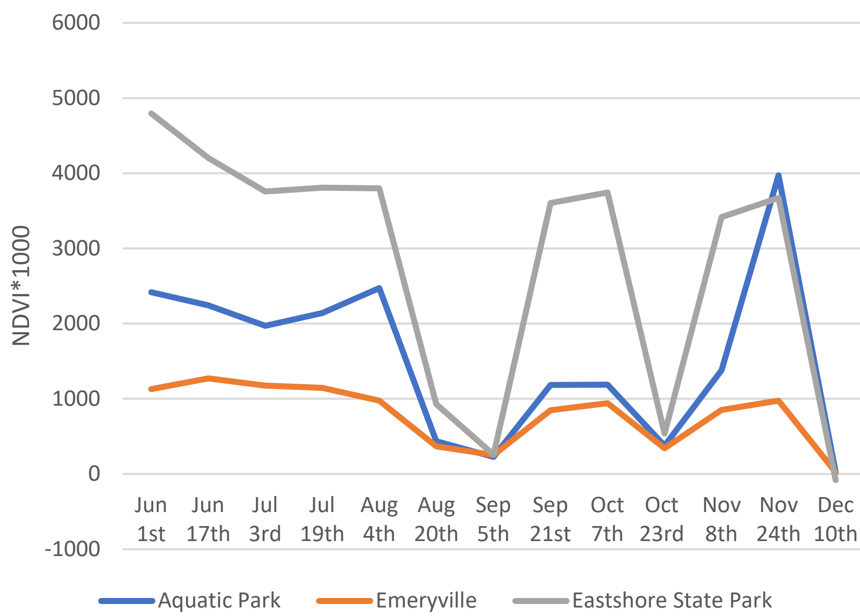

Figure 9. Average NDVI for study sites

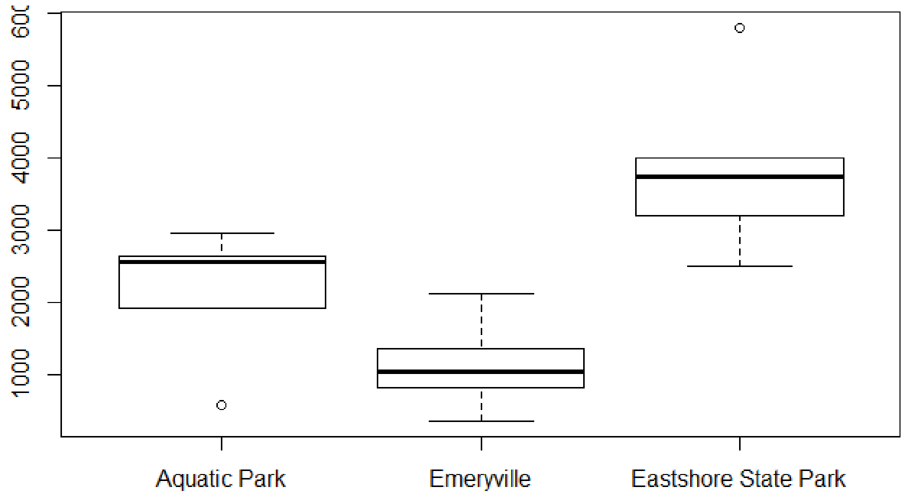

Figure 10. The distribution of median NDVI at study sites before the end of August

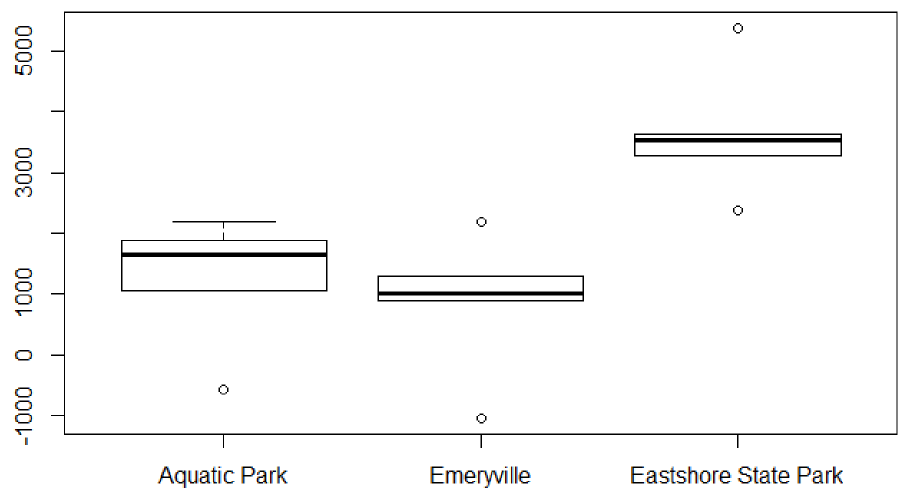

Figure 11. The distribution of median NDVI at study sites after the start of September

Land cover data: percentage of impervious surface

Emeryville had the highest percentage of the impervious surface while the Eastshore State Park had the lowest percentage of impervious surface (Figure 12). The median percentage of the impervious surface among the survey locations at Emeryville, 0.83, was significantly higher than that of the Eastshore State Park, 0.02 and that of the Aquatic Park, 0.42. However, Eastshore State

Park had the largest range of the percentage of impervious surface across its survey locations, 0.412, while the Aquatic Park had the smallest, 0.26.

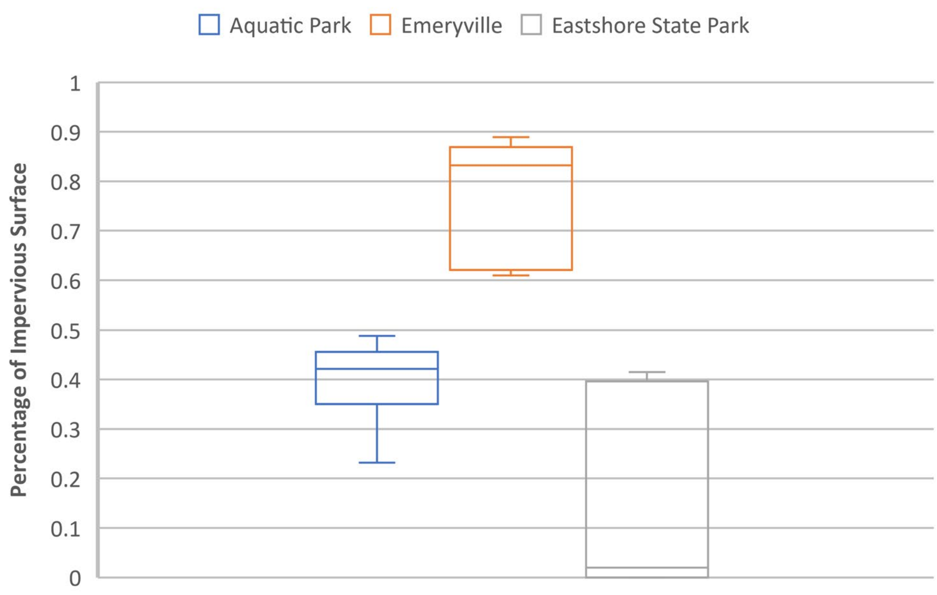

Figure 12. The percentage of impervious surface at study sites

Data analysis

Species richness

For the first linear mixed-effect model built from data collected before the end of August, the p-value was 0.4368 for the fixed variable median NDVI and 0.9046 for the fixed variable percentage of impervious surface. These high p-values show that the model was not statistically significant. For the second linear mixed-effect model built from data collected after the start of September, the p-value was 0.5963 for median NDVI and 0.0928 for the percentage of impervious surface, indicating again that the model was not statistically significant.

Abundance

For the first linear mixed-effect model built from data collected before the end of August, the p-value was as high as 0.3995 for the fixed variable median NDVI and 0.3928 for the fixed variable percentage of impervious surface. These high p-values show that the model was not statistically significant. For the second linear mixed-effect model built from data collected after the start of September, the p-value was 0.5811 for median NDVI and 0.6430 for the percentage of impervious surface, indicating again that the model was not statistically significant.

Shannon Diversity Index

For the first linear mixed-effect model built from data collected before the end of August, the p-value was 0.5052 for the fixed variable median NDVI and 0.8966 for the fixed variable percentage of impervious surface. These high p-values show that the model was not statistically significant. For the second linear mixed-effect model built from data collected after the start of September, the p-value was 0.7652 for median NDVI and 0.2850 for the percentage of impervious surface, indicating again that the model was not statistically significant.

DISCUSSION

For the species richness, abundance, and Shannon diversity index calculated from the avian community data, the linear mixed-effect models failed to demonstrate any significant correlation between these variables and the median NDVI for both study periods. The models also failed to show any correlations between these variables and the percentage of impervious surface for the two study periods. These results did not indicate any significant impacts of the amount of living vegetation and the percentage of impervious surface on the local bird community at San Francisco East Bay. These results generally contradicted the findings of most previous studies carried out in other parts of the world (Mckinney et al. 2010, Latta et al. 2013, Minor and Urban 2010).

Impacts of the amount of living vegetation

My results did not indicate that the amount of living vegetation influence the avian diversity and abundance at my three study sites. However, previous studies have shown strong impacts of the vegetation attributes, including the percentage of tree cover and shrub species richness, on avian species richness and abundance (Luther et al. 2008). Researchers have found urban green space with more native tree species and higher species richness can even reduce the negative impacts of urbanization on birds and lead to the higher functional richness of birds (Pena et al. 2017). In addition, other studies have revealed the influence of vegetation characteristics, such as surrounding woody vegetation cover and the existence of native forests, on bird community composition at multiple scales (Dale 2018, Ikin et al. 2014).

One thing to note is that most previous studies focused on vegetation characteristics that were different from NDVI, which reflects the amount of living vegetation (Rousseau et al. 2015). The other studies often used variables that measured a very specific aspect of the vegetation, including hollow bearing tree density and existing vegetation height (Ikin et al. 2014, Stephens et al. 2016). While previous studies indicated that these distinct vegetation characteristics played a role in shaping bird communities, my results did not show any impact of the amount of living vegetation on avian diversity and abundance at San Francisco East Bay. This outcome may indicate that the quality and diversity of the vegetation in urbanized areas play a more important role than the quantity of vegetation in shaping the local avian communities.

Impacts of the percentage of impervious surface

My results did not indicate any influence of the percentage of impervious surface on the avian diversity and abundance at my three study sites. In general, research has revealed a negative influence of impervious surface on bird richness and relative abundance (Silva et al. 2015). Specifically, researchers discovered that impervious surface negatively impacted the abundance of intolerant species, forest species, insectivorous species (Lussier et al. 2006). However, there was a study whose results indicated a positive impact of impervious surface on the abundance of birds in winter (Tzortzakaki et al. 2018). My results showed that birds at San Francisco East Bay may not respond to the difference in the percentage of impervious surface. However, since only a limited number of studies have examined the relationship between impervious surface and avian community, the contradicting outcomes of my research and previous studies indicate a need for further studies on the impact of this land cover variable.

Differences among avian communities at species-level

Although the linear mixed-effect models failed to show any significant relationships between the land cover variables and the bird communities at the three study sites, further analyses using non-metric multidimensional scaling (NMDS) revealed there were some differences among the three communities at the species level. For data collected before the end of August (Figure 13), the species composition at the Aquatic Park and Emeryville were quite different from each other. In addition, most birds observed at these two sites occurred at the Eastshore State Park. For data collected after the start of September, there was quite a lot of overlap between the species composition between the Emeryville and the Eastshore State Park (Figure 14). Many species observed at these two sites also occurred at the Aquatic Park.

One thing to note was that the abundance of several species contributed to the separation among the three sites. For example, the abundance of the species American white pelican after the start of September contributed to the separation between the Aquatic Park and the two other sites along the MDS 1 axis. The abundance of Brewer's blackbird also led to the separation between Aquatic and the two other sites along the MDS 2 axis. According to the results of the NMDS analyses, it is possible that analyses at species level may reveal more about the impacts of land cover variables on species compositions. These differences in the avian communities at species level revealed the possible impacts of land cover variables other than NDVI and the percentage of impervious surface. The water body in the Aquatic Park, for example, may have attracted the American white pelicans while the anthropogenic food sources in Emeryville may have led to the high abundance of Brewer's blackbird (Galbraith et al. 2015, Schneider and Griesser 2009).

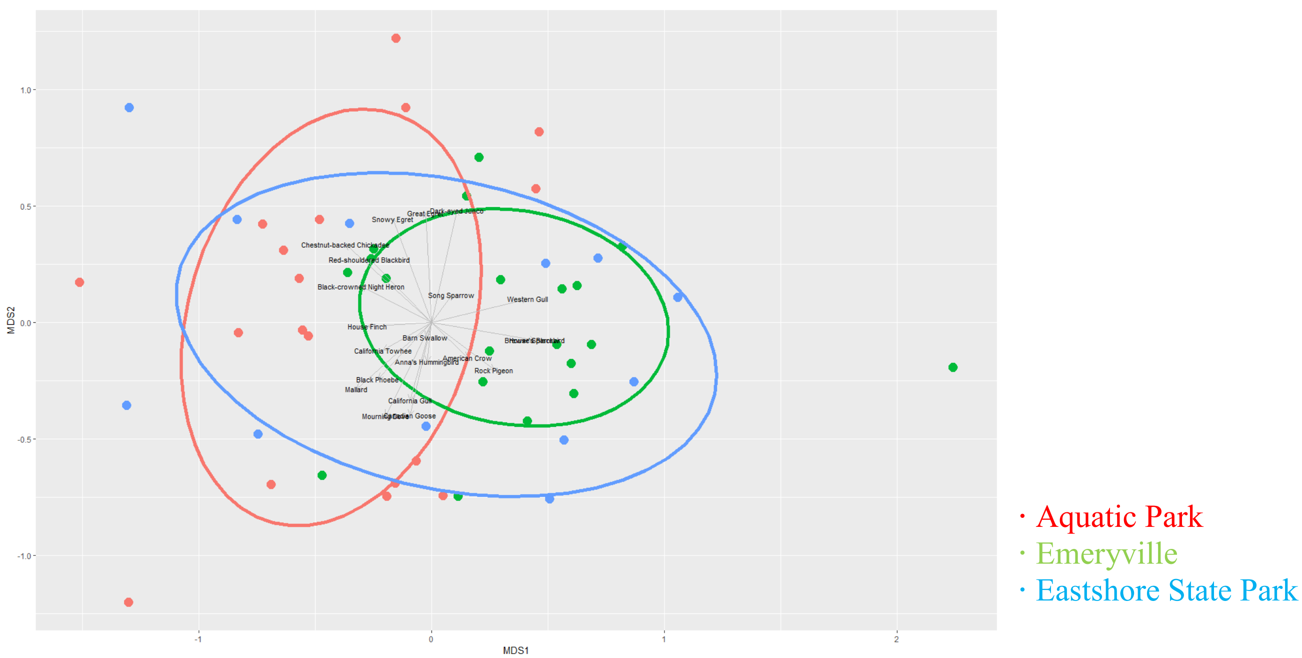

Figure 13. NMDS plot for data collected before the end of August

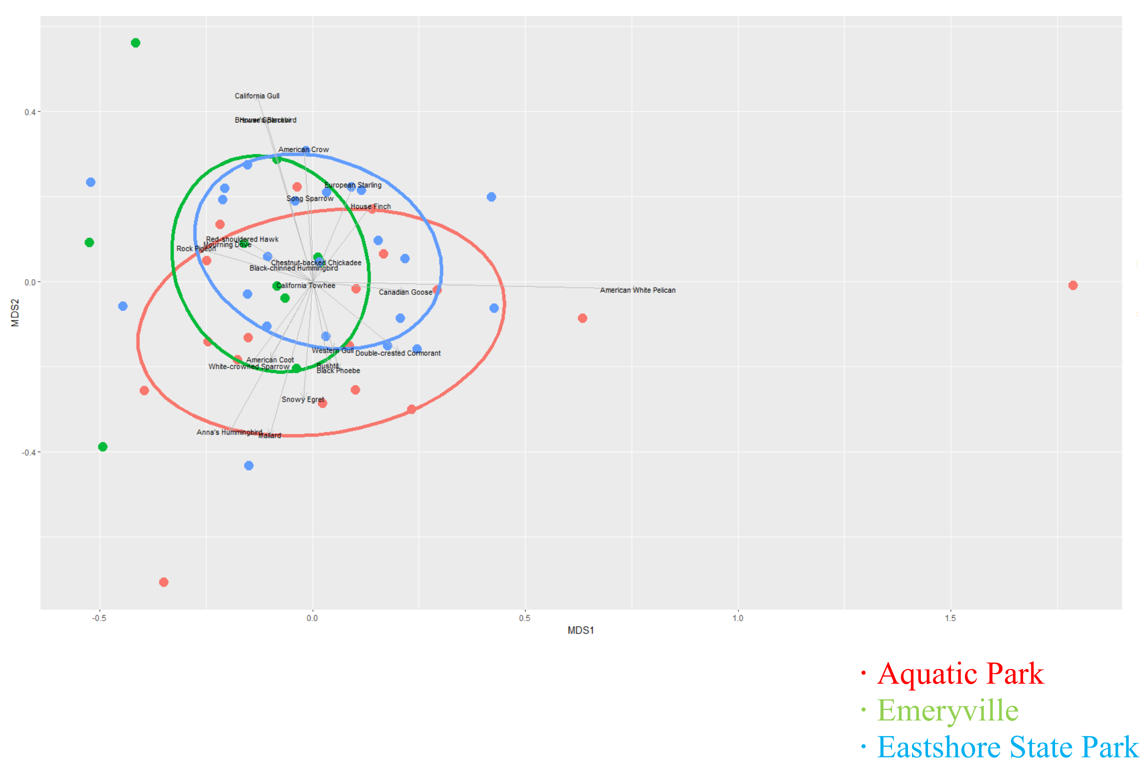

Figure 13. NMDS plot for data collected after the start of September

Limitations and future directions

A major limitation of my study is that the limited number of my survey locations may have failed to represent the species occurring at the three study sites. Most previous studies used data collected by point counts at a relatively large number of survey locations (Luther et al. 2008, Silva et al. 2015).

Another limitation is the element of time. Time plays an important role in the impacts of surrounding land cover on the species composition of avian community at my study sites. Studies with longer time frames can often capture the changes in the species composition over time (Midway et al. 2015). Since the Eastshore State Park has experienced restoration and thus considerable changes in the amount and types of habitats present in the park, it is possible that the local community is still going through changes and has not yet reached its steady state (Krieger 2017). Thus, a study with a longer time frame that tracks the changes in species composition over years may better capture the responses of birds to the amount of living vegetation as well as NDVI.

Another explanation could be that the impacts of other land cover characteristics, such as water, have masked the influences of NDVI and impervious surface on the avian diversity and abundance. For example, since studies have revealed a negative correlation between the avian species richness and the distance to water bodies, the enclosed water body in the Aquatic Park may have attracted a high number of species (Schneider and Griesser 2009). Other vegetation characteristics, including volume of understory vegetation or amount of a certain plant species, can also have relatively strong impacts on the species composition of birds and hid the influences of NDVI and impervious surface (Ikin et al. 2014, Powell and Steidl 2015).

Finally, the distance among my study sites may be too small for the birds to demonstrate different responses to the land cover variable at the three sites. The scales at which most previous studies were carried out were much broader than mine (Matthies et al. 2017, Moreno-rueda and Pizarro 2009). At the scale of my study, birds may just disregard the differences in the amount of living vegetation and impervious surface and move across the three sites frequently.

Broader implications

In conclusion, my results failed to reveal that the species composition of birds at San Francisco East Bay were impacted by the amount of living vegetation and impervious surface at a local scale. The study provided useful lessons regarding the appropriate scale and time frame for future studies. Specifically, it suggested that both temporal and spatial scale of a study may have huge impacts on the outcomes of the study. Thus, it is important to identify the right scale at which the studied pattern occur in future studies. In addition, this study shows that a limited number of survey locations potentially affects the quality of data collected through point counts. In the future, it may be worth using other datasets, for example, the online database eBird, along with point count data in such studies. Finally, I believe there is still a need for further studies on the avian community along the urbanization gradient at San Francisco East Bay to conserve birds in their urban habitats.

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