Bird Community Assemblage and Distribution in a Tropical, Urban Ecosystem of Puerto Rico

Authors: Wolff, Patrick J., DeGregorio, Brett A., Rodriguez-Cruz, Victor, Mulero-Oliveras, Eneilis, and Sperry, Jinelle H.

Source: Tropical Conservation Science, 11(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1940082918754777

Research Article

Bird Community Assemblage and Distribution in a Tropical, Urban Ecosystem of Puerto Rico

Tropical Conservation Science
Volume 11: 1–10

DOI: 10.1177/1940082918754777
journals.sagepub.com/home/trc
SAGE

Patrick J. Wolff[1], Brett A. DeGregorio[1], Victor Rodriguez-Cruz[2], Eneilis Mulero-Oliveras[3], and Jinelle H. Sperry[1]

Abstract

Urbanization has profound effects on the presence and distribution of wildlife species. Although numerous studies have been conducted to inform our understanding of the effects of urbanization on wildlife, studies of urban wildlife communities in the tropics are especially rare. Here, we investigated the bird community assemblage and distribution at an urban military installation, Fort Buchanan, located within the San Juan Metropolitan Area on the Caribbean island of Puerto Rico. Using fixed-radius point count surveys and opportunistic encounters, we documented over 1,700 individual birds of 60 avian species across three sampling periods in March, April, and October 2016 (84 surveys over 12 total sampling days). The species occurring at the highest densities in this urban environment were Bananaquit (*Coereba flaveola*: 4.58 birds/ha), Antillean Grackle (*Quiscalus niger*: 3.64 birds/ha), Zenaida Dove (*Zenaida aurita*: 2.25 birds/ha), and White-winged Dove (*Zenaida asiatica*: 2.12 birds/ha). The birds occurring in the lowest densities were one native, imperiled duck species (*Dendrocygna arborea*), and several neotropical migrants. Most species were not randomly distributed throughout the site but were instead correlated with particular landscape features or habitat types. For instance, migratory warblers were mostly found in remnant forest patches, while Zenaida Doves were associated with open, grassy areas. As human populations continue to expand and urbanization spreads, it will become increasingly important to conserve critical, but often overlooked wildlife habitat—especially forest patches for migratory birds—within urban ecosystems.

Keywords

distance sampling, habitat use, neotropical migrants, Puerto Rico, urbanization

Introduction

Urbanization is likely the single most important driver of wildlife extinction during this century (Czech & Krausman, 1997). The processes associated with urbanization have profound effects on the presence and distribution of wildlife species and their habitats (Buxton & Benson, 2016; Hamer & McDonnell, 2010; Ordeñana et al., 2010). As more and more of the earth's surface is converted to human-dominated, urban environments, it becomes critical to understand how urban wildlife communities are structured and how wildlife species occupy urban habitats. Birds are one of the more visible and easily studied taxa occurring in cities worldwide (Magle, Hunt, Vernon, & Crooks, 2012; Suarez-Rubio & Thomlinson, 2009; Suarez-Rubio et al., 2016). Much of the research to date has suggested that bird communities are negatively impacted by urbanization (Beissinger & Osborne, 1982; Franz, Cappalatti, & Barros, 2010; Sorace & Gustin, 2010; Suarez-Rubio, Renner, & Leimgruber, 2011; Sol, González-Lagos, Moreira, Maspons, & Lapiedra, 2014). In response, many ecologists and conservationists have increased focus on urban

[1]US Army Engineer Research and Development Center, Champaign, IL, USA
[2]Sol Solutions, LLC, Scottsdale, AZ, USA
[3]Biology Department, Recinto Universitario de Mayaguez Universidad de Puerto Rico, Mayaguez, Puerto Rico

Received 2 October 2017; Revised 18 December 2017; Accepted 18 December 2017

Corresponding Author:
Patrick J. Wolff, US Army Engineer Research and Development Center, 2902 Newmark Dr., Champaign, IL 61822, USA.
Email: patrick.j.wolff@usace.army.mil

bird communities within the last two decades (e.g., Buxton & Benson, 2015; MacGregor-Fors and Escobar-Ibáñez, 2017; Marzluff, 2001). These studies of urban bird communities have been important for informing policy, planning, and management.

Despite the increasing emphasis on urban wildlife, studies of urban bird communities in the tropics are uncommon compared to temperate regions (MacGregor-Fors, 2007). In a review of more than 100 urban bird studies (Marzluff, 2001), only six occurred in the tropics, and this lack of tropical urban bird studies was cited as one of the primary gaps in our understanding of the effects of urbanization on wildlife. In recent years, there has been increased effort to fill this gap (MacGregor-Fors and Escobar-Ibáñez, 2017) and to draw attention to under-recognized research in the tropics (Ortega-Álvarez & MacGregor-Fors, 2011a). Given the rapidly increasing human populations and urbanization in tropical areas (UN-Habitat, 2013; World Resources Institute, 1996), and the rich biodiversity native to tropical regions, more studies are needed to better understand how bird communities are structured and persist in tropical urban areas. Here, we report on the occurrence, habitat associations, and density of bird species at a site in a rapidly developing tropical urban metropolis, San Juan, Puerto Rico.

Puerto Rico is similar to most Caribbean islands in that it was severely deforested for agriculture and other land uses during the 19th century (Aide & Grau, 2004), leading to extinctions of a large number of avifaunal species (Brash, 1987). Although an economic shift from agriculture to small industry in the mid-20th century allowed the recovery of some secondary forest (Aide, Zimmerman, Pascarella, Rivera, & Marcano-Vega, 2000), these forests are now threatened by a rapidly growing human population, with an estimated 11% of the island composed of urban land use (Martinuzzi, Gould, & González, 2007). The San Juan Metropolitan Area, located on the north shore, is one of the most sprawling urbanized areas on the island. Despite the city's expanding footprint, the region still contains pockets of natural habitat interspersed throughout the urban landscape and supports diverse communities of native and exotic wildlife (Acevedo & Aide, 2008; Acevedo & Restrepo, 2008). Even small patches of forest within an urban matrix can be home to diverse and complex bird communities consisting of endemic, migratory, and exotic species (Acevedo & Aide, 2008). Numerous studies have been conducted on the avian communities in the forests of southern (e.g., Faaborg, Arendt, & Kaiser, 1984; Faaborg, Dugger, & Arendt, 2007) and eastern (e.g., Wunderle, Diaz, Velazquez, & Scharrón, 1987) Puerto Rico, but the urban areas in and around San Juan have received little attention. Here, we investigate the bird community assemblage and distribution at an urban military installation, Fort Buchanan, located within the San Juan Metropolitan Area. Specifically, our goals were to (a) document the bird species occurring on this urban installation, (b) estimate the density of native and exotic species on the installation, and (c) investigate the habitat associations of species on the installation.

Methods

Study Site

Fort Buchanan is a U.S. Army installation established in 1923 and consists of approximately 746 ha. The installation is located in Guaynabo, within the sprawl of greater metropolitan San Juan along the northern coast of Puerto Rico (Figure 1). Although the San Juan area overall has a very high human population density (3,190 people/km^2; United States Census Bureau, 2016), Fort Buchanan's population is relatively sparse (715 people/km^2), concentrated primarily within urban land cover (Figure 1). The installation is almost entirely surrounded by residential, commercial, and industrial areas and is primarily developed with urban infrastructure and a golf course. It also contains approximately 70 ha of secondary forest in different stages of natural regeneration, which remained similar throughout our study (>99% tropical semievergreen forest, <1% seasonal swamp forest; Dial Cordy and Associates Inc., 2003). These forests are highly fragmented, typically located on karst hills, and are isolated from one another by development. Monthly mean temperatures vary little throughout the year (23–27°C; Dial Cordy and Associates Inc, 2003), but San Juan experiences significant seasonal variation in precipitation (mean monthly rainfall, May–November = 87.8 mm; December–April = 52.1 mm).

The matrix separating forest patches on Fort Buchanan contains residential and school areas with lawns and landscape trees such as African Tulip Tree (*Spathodea campanulata*), Queen-of-flowers (*Lagerstroemia speciosa*), Flamboyant-tree (*Delonix regia*), Coconut (*Cocos nucifera*), Silk-cotton Tree (*Ceiba pentandra*), and Mango (*Mangifera indica*). Away from residential areas, the installation is primarily used for commercial and industrial purposes and contains extensive impervious surface. El Toro creek runs through the installation, although the stream channel is completely encased in concrete to control flooding. There are two ponds on the installation. One is 3.2 ha, centrally located, surrounded by a thin strip of riparian forest, and categorized as a Critical Wildlife Area by the Puerto Rico Department of Natural and Environmental Resources (Ventosa-Febles, Camacho-Rodríguez, Chabert-Llompart, Sustache-Sustache, & Dávila-Casanova, 2005). The other is a small golf course pond (<1 ha) ringed by herbaceous vegetation and manicured lawn.

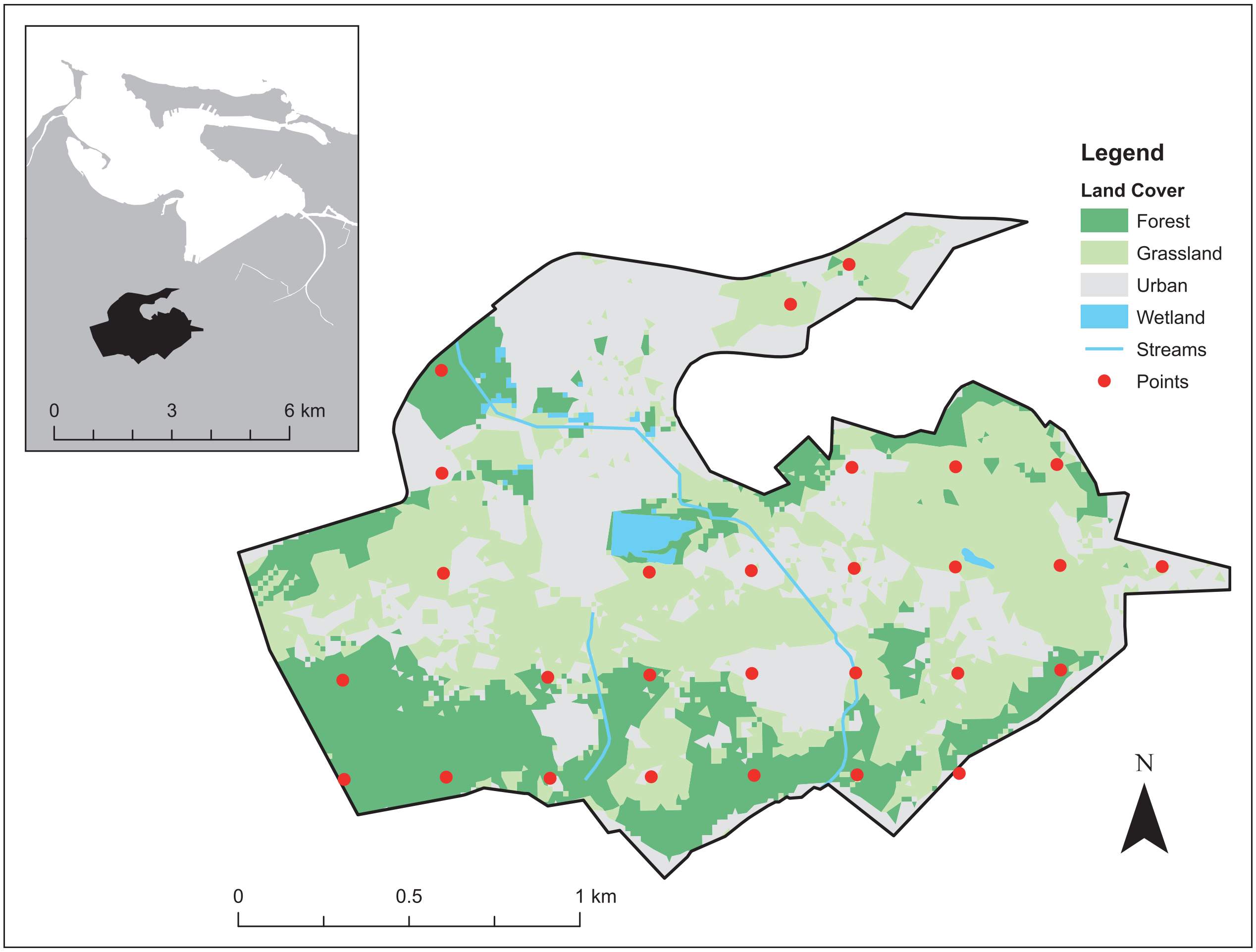

Figure 1. Locations of 28 avian survey points where fixed-radius point counts were conducted in March, April, and October 2016 at Fort Buchanan, Puerto Rico (18°24′45″N, 66°07′19″W). Point locations were determined by placing a uniform grid over the installation. Missing points were due to restricted access. Inset: location of Fort Buchanan within the San Juan Metropolitan Area.

Bird Surveys

To document all of the bird species occurring on the installation, we conducted fixed-radius point count surveys during 14 to 19 March, 18 to 20 April, and 25 to 27 October, 2016. We conducted surveys to coincide with spring migration (March), resident bird breeding season (April), and fall migration (October). We initiated point counts within 30 min of sunrise and completed all surveys before 10:00 to coincide with periods of peak bird activity. We surveyed each point for 5 minutes, during which every bird detected by sight or sound was recorded. We identified each bird to the species level and recorded its distance from the point center, classified into distance intervals: 0 to 50 m, 50 to 100 m, 100 to 200 m, or flyover. At all points, we recorded categorical indices of precipitation and wind speed (factors potentially affecting detectability), and surveys were not conducted during times of significant precipitation or wind.

During each of the three survey periods, we conducted surveys at 28 point count locations (Figure 1). We determined survey locations by creating a uniform grid over the installation boundaries using a GIS (ArcMap 10.2: ESRI Inc. Redlands, CA, USA). Thus, surveys occurred in all available land cover types and each habitat type was sampled in proportion to its availability. Although we made an effort to systematically survey the entire spatial extent of the installation, there were some gaps in coverage in the north and west portions of the installation due to limited accessibility in these areas. We spaced point count stations 300 m apart to reduce the possibility of *double-counting* individual birds at adjacent points but to provide the best coverage of the installation.

In addition to our standardized survey protocol, we also recorded the location and habitat use of all birds encountered opportunistically. This included birds encountered while establishing point count locations, traveling between points, or in the course of other field research within the survey periods. While data from these encounters were not used to calculate species density, they were used to augment our species list for the installation and to explore habitat associations of particular species.

Bird Density Estimation and Habitat Associations

For analyses, we excluded observations >100 m ($n = 208$) from point center or birds documented flying over the point ($n = 368$). Thus, observations were binned into two distance intervals (0–50 m and 50–100 m). We estimated individual densities for species with >20 detections or that were detected at >5 points. Some uncommon, but ecologically similar species were grouped for analyses due to small individual sample sizes. These included *migratory warblers* (Black-and-White Warbler [*Mniotilta varia*], Blackpoll Warbler [*Setophaga striata*], Hooded Warbler [*Setophaga citrina*], Northern Parula [*Parula americana*], and Prairie Warbler [*Setophaga discolor*]) and *waterbirds* (Great Egret [*Ardea alba*], Green Heron [*Butorides virescens*], Pied-billed Grebe [*Podilymbus podiceps*], Common Gallinule [*Gallinula galeata*], Spotted Sandpiper [*Actitis macularius*], Killdeer [*Charadrius vociferous*], and Wilson's Snipe [*Gallinago delicate*]). As an additional analysis, we also calculated pooled densities of resident exotic birds (9 species) and resident native birds (25 species). Note that the Common Gallinule and Pied-billed Grebe are resident native species, but were included only in the waterbird group. All other waterbirds included in the analysis were migratory species. We did not estimate densities for feral, domestic species (Chicken [*Gallus gallus*], Muscovy Duck [*Cairina moschata*], and White Cockatoo [*Cacatua alba*]).

For species that met these criteria, we estimated density and examined habitat associations using a hierarchical distance sampling framework (Kery & Royle, 2016). We used the package *unmarked*, function gdistsamp (Fiske & Chandler, 2011) in program R (R Core Team, 2015) to fit density models to point count data, accounting for imperfect detection. This function is based on the multinomial observation model for binned distance sampling data (Chandler, Royle, & King, 2011). For each species, we first tested the fit of both the Poisson and negative binomial detection functions, and chose the better of the two based on Akaike's Information Criterion (AIC; Burnham & Anderson, 2002). Second, we tested the effects of detection covariates (see next section) on detection probability (p). Third, we examined the influence of six habitat covariates on density (λ; see next section). Availability (φ) was kept constant (intercept-only) for all models. We developed a candidate set of 14 models for density, which contained models that tested each density covariate separately, and additive combinations of uncorrelated covariates. We used a maximum of one covariate for p and two covariates for λ in a single model to avoid overparameterization. We identified the best model using AIC (all models with $\Delta\text{AIC} < 2$ were considered competitive), and used this model to predict average density in birds/ha at Fort Buchanan. We used a parametric bootstrap with 100 simulations to test goodness of fit of our chosen models with error sums-of-squares, chi-square, and Freeman–Tukey fit statistics (Kery & Royle, 2016).

Detection and Density Covariates

We tested the effects of Julian date, time (minutes after sunrise), and wind (categorical: none or light) on detection probability (p). Because there was no precipitation during 82 surveys, and light precipitation occurred during the other two, we excluded this covariate from analyses. We examined the influence of six habitat covariates for their effect on density: four land cover types (forest, grassland, urban, and wetland), distance from water (m), and distance from forest edge (m). Urban land cover comprised impervious surfaces and buildings. To quantify land cover, we calculated the area of each cover type within a 100 -m buffer of each point. All density covariates were measured in ArcMap and standardized as suggested by Kery and Royle (2016).

Results

Species Occurrence and Density

A total of 60 avian species were detected across Fort Buchanan during the study period (Table 1), 49 of which were detected during point count surveys (1,760 individuals). We observed more species during spring migration (49) and fall migration (46) than during the resident bird breeding season (38). Of species only opportunistically detected ($n = 11$), three were residents, three were migrants, and five were residents for which individuals also migrate to Puerto Rico. Thirty-seven species were observed less than 10 times, and no migratory species was detected more than six times. Notably, we observed a pair of West Indian Whistling-Ducks (*Dendrocygna arborea*) in April, a native, imperiled species with an estimated Puerto Rican population of fewer than 100 individuals (Nytch, Hunter, Núñez-Garcia, Fury, & Quiñones, 2015).

Of species detected during point count surveys, we estimated density for 13 species and four groups of species (Table 2) based on a total of 1,085 individuals. For some species and groups, the best model for density was the null model because the inclusion of habitat covariates did not substantially improve model fit based on AIC. Resident native species occurred at the highest density (17.26 birds/ha; Table 2), followed by resident exotics (1.92 birds/ha), waterbirds (1.30 birds/ha), and migratory warblers (0.45 birds/ha). The most common resident natives were the Bananaquit (*Coereba flaveola,*

Table 1. Species Detected at Fort Buchanan During Point Count Surveys And Opportunistically Encountered.

Scientific name	Common name	Native or exotic and conservation status	Residency status	Number of detections
Cairina moschata	Muscovy Duck	Exotic	R	13
Dendrocygna arborea	West Indian Whistling-Duck	Native[1]	R	0
Gallus gallus	Chicken	Exotic	R	3
Podilymbus podiceps	Pied-billed Grebe	Native	R	3
Ardea alba	Great Egret	Native	Both	1
Ardea herodias	Great Blue Heron	Native	Both	0
Butorides virescens	Green Heron	Native	Both	5
Egretta caerulea	Little Blue Heron	Native	Both	0
Egretta thula	Snowy Egret	Native	Both	0
Egretta tricolor	Tricolored Heron	Native	Both	0
Nycticorax nycticorax	Black-crowned Night-Heron	Native	R	0
Pandion haliaetus	Osprey	Native	M	0
Buteo jamaicensis	Red-tailed Hawk	Native[5]	R	0
Gallinula galeata	Common Gallinule	Native	R	21
Charadrius vociferus	Killdeer	Native	Both	5
Actitis macularius	Spotted Sandpiper	Native	M	3
Gallinago delicata	Wilson's Snipe	Native	M	2
Columba livia	Rock Pigeon	Exotic	R	18
Columbina passerina	Common Ground-Dove	Exotic	R	11
Patagioenas leucocephala	White-crowned Pigeon	Native	R	11
Patagioenas squamosa	Scaly-naped Pigeon	Native[2]	R	61
Zenaida asiatica	White-winged Dove	Native[4]	R	154
Zenaida aurita	Zenaida Dove	Native[2]	R	136
Zenaida macroura	Mourning Dove	Native[4]	R	2
Coccyzus minor	Mangrove Cuckoo	Native[1]	R	7
Crotophaga ani	Smooth-billed Ani	Native	R	14
Anthracothorax dominicus	Antillean Mango	Native[1]	R	3
Anthracothorax viridis	Green Mango	Native[2]	R	4
Melanerpes portoricensis	Puerto Rican Woodpecker	Native[2]	R	28
Falco columbarius	Merlin	Native	M	0
Falco sparverius	American Kestrel	Native[4]	Both	0
Ara ararauna	Blue-and-yellow Macaw	Exotic	R	3
Brotogeris versicolurus	White-winged Parakeet	Exotic	R	386
Myiopsitta monachus	Monk Parakeet	Exotic	R	15
Cacatua alba	White Cockatoo	Exotic	R	3
Myiarchus antillarum	Puerto Rican Flycatcher	Native[2]	R	11
Tyrannus dominicensis	Gray Kingbird	Native[2]	R	107
Vireo altiloquus	Black-whiskered Vireo	Native[2]	R	3
Petrochelidon fulva	Cave Swallow	Native	R	10
Pronge dominicensis	Caribbean Martin	Native[2]	R	1
Turdus plumbeus	Red-legged Thrush	Native[2]	R	50
Margarops fuscatus	Pearly-eyed Thrasher	Native[4]	R	75
Mimus polyglottos	Northern Mockingbird	Native	R	43
Mniotilta varia	Black-and-White Warbler	Native[4]	M	2
Parkesia motacilla	Louisiana Waterthrush	Native[1]	M	0

(continued)

Table 1. Continued

Scientific name	Common name	Native or exotic and conservation status	Residency status	Number of detections
Parula americana	Northern Parula	Native[2]	M	1
Setophaga adelaidae	Adelaide's Warbler	Native[1]	R	1
Setophaga citrina	Hooded Warbler	Native	M	1
Setophaga discolor	Prairie Warbler	Native[1]	M	2
Setophaga striata	Blackpoll Warbler	Native	M	6
Coereba flaveola	Bananaquit	Native[4]	R	192
Sicalis flaveola	Saffron Finch	Exotic	R	39
Spindalis portoricensis	Puerto Rican Spindalis	Native[2]	R	4
Tiaris bicolor	Black-faced Grassquit	Native	R	28
Icterus icterus	Venezuelan Troupial	Exotic	R	3
Icterus portoticensis	Puerto Rican Oriole	Native[1]	R	3
Molothrus bonariensis	Shiny Cowbird	Exotic	R	6
Quiscalus niger	Antillean Grackle	Exotic	R	242
Passer domesticus	House Sparrow	Exotic	R	3
Lonchura cucullata	Bronze Mannikin	Exotic	R	15
Total 60				1,760

Note. Each species was identified as either a native species or exotic species. Superscripts refer to conservation statuses assigned to each species defined by Nytch et al. (2015). Residency status refers to migratory (M), resident (R), or both (i.e., if the species is present year-round, but individuals also migrate to Puerto Rico). Detections refers to the number of individuals detected during point count surveys (detections = 0 for species that were only opportunistically encountered).

Table 2. Estimated Bird Densities, With Standard Errors, of 13 Species and 4 Species Groups on Fort Buchanan.

Scientific name	Common name	Density (birds/ha)	*SE*	Model: Detection (p)	Model: Density (λ)
Coereba flaveola	Bananaquit	4.58	0.63	.	Grassland (−)
Quiscalus niger	Antillean Grackle	3.64	1.16	Wind (−)	Forest (−)
Zenaida aurita	Zenaida Dove	2.25	0.54	Wind (+)	Grassland (+)
Zenaida asiatica	White-winged Dove	2.12	1.16	.	Wetland (+) + DistEdge (−)
Margarops fuscatus	Pearly-eyed Thrasher	1.15	0.27	Julian (−)	.
Tyrannus dominicensis	Gray Kingbird	1.04	0.23	.	.
Turdus plumbeus	Red-legged Thrush	0.97	0.24	.	.
Brotogeris versicolurus	White-winged Parakeet	0.91	0.67	Julian (+)	Forest (−), DistWater (−)
Sicalis flaveola	Saffron Finch	0.89	0.52	Time (+)	.
Tiaris bicolor	Black-faced Grassquit	0.77	0.51	.	Grassland (+) + DistEdge (−)
Melanerpes portoricensis	Puerto Rican Woodpecker	0.38	0.19	.	DistWater (+)
Mimus polyglottos	Northern Mockingbird	0.30	0.12	.	Wetland (−) + DistWater (+)
Patagioenas squamosa	Scaly-naped Pigeon	0.24	0.11	.	.
	Group				
	Resident native	17.26	1.32	.	.
	Resident exotic	1.92	0.64	Time (+)	Forest (−)
	Waterbirds	1.30	0.70	.	DistWater (−) + DistEdge (+)
	Migratory warblers	0.45	0.29	.	.

Note. Densities were estimated from the best-fit model for each species/group. Covariates from the best-fit model that influenced detection (p) and density (λ) are listed, with ± indicating the direction of the covariate's relationship to p or λ. If no covariates are listed (.) then the best-fit model was the null (intercept-only) model. Models were fit using the negative binomial detection function, except for Bananaquit and Northern Mockingbird (Poisson).

4.58 birds/ha) and Antillean Grackle (*Quiscalus niger*, 3.64 birds/ha). The White-winged Parakeet (*Brotogeris versicolurus*, 0.91 birds/ha) and Saffron Finch (*Sicalis flaveola*, 0.89 birds/ha) were the most common resident exotics.

Habitat Associations

Our best model for each species indicated which covariates were most influential on detection and density (Table 2). For example, our ability to detect White-winged Parakeets increased from March to October (Julian: $\beta = 0.006$, $SE = 0.002$), and density was related negatively to forest cover ($\beta = -1.69$, $SE = 0.776$) and distance from water ($\beta = -1.47$, $SE = 0.589$). For cases in which the null model was the best model, we inferred habitat associations from competitive models. For example, density of migratory warblers was estimated from the null model, but competitive models showed density was related positively to forest cover ($\beta = 0.63$, $SE = 0.444$) and distance from water ($\beta = 0.77$, $SE = 0.427$), and related negatively to urban land cover ($\beta = -0.60$, $SE = 0.497$). Similarly, competitive models for resident natives showed density was related positively to wetland cover ($\beta = 0.10$, $SE = 0.062$), grassland cover ($\beta = 0.12$, $SE = 0.072$), and distance from forest edge ($\beta = 0.10$, $SE = 0.065$), and related negatively to forest cover ($\beta = -0.12$, $SE = 0.070$). As would be expected, waterbird density was highest near water (DistWater: $\beta = -1.07$, $SE = 0.384$) and farther from forest edge (DistEdge: $\beta = 1.55$, $SE = 0.337$). The two open water-bodies at Fort Buchanan were located away from forest edge, within a primarily urban and grassland matrix (Figure 1). Density of resident exotics was highest outside of forest ($\beta = -0.88$, $SE = 0.299$).

Discussion

Despite its small size, highly modified landscape, and location within the greater San Juan Metropolitan area, we documented a diverse bird community on Fort Buchanan. In contrast to the frequently reported trend for urban areas to be dominated by a few, often introduced species (Blair, 1996; Ortega-Álvarez & MacGregor-Fors, 2009), we found a diverse community dominated by urban- and suburban-adapted native species. We documented many endemic resident species (e.g., Adelaide's Warbler [*Setophaga adelaidae*]), resident species (e.g., Bananaquit), and neotropical migrants (e.g., Hooded Warbler [*Setophaga citrina*]) across the installation. While on average, cities may support more native species than exotics (Aronson et al., 2014), urban areas often host high densities of exotics such as House Sparrows (*Passer domesticus*; MacGregor-Fors, Quesada, Lee, & Yeh, 2017) and Rock Pigeons (*Columba livia*; Beissinger & Osborne, 1982; Greene, 1984). While both species occurred on Fort Buchanan, they were in limited numbers and primary found near commercial and urbanized areas of the installation. In fact, native species occurred in substantially higher densities (17.26 birds/ha) than exotic species (1.92 birds/ha). Across Puerto Rico, endemic species typically are more abundant in forests, while exotic species are more abundant in open and disturbed habitats (Acevedo & Restrepo, 2008).

Many of the species we detected on the installation are of regional conservation concern. In 2015, the U.S. Fish and Wildlife Service, Atlantic Joint Venture, and Caribbean Landscape Conservation Cooperative published conservation rankings for Puerto Rican avian species based on population declines, threats, distribution, and population size (Nytch et al., 2015). We detected 8 Tier 1 species and 11 Tier 2 species, both groups that are thought to be declining and are in need of management or additional stewardship (Nytch et al., 2015). Two of these species, the Puerto Rican Flycatcher (*Myiarchus antillarum*) and White-crowned Pigeon (*Patagioenas leucocephala*), have experienced population declines elsewhere on the island (Faaborg, Dugger, Arendt, Woodworth, & Baltz, 1997; Wiley, 1979) but were detected relatively often during our surveys (>10 points), further highlighting the potential importance of these habitat patches for species conservation. Future research should explore how these species are using the installation (i.e., species-specific relationships to patch size and structure *sensu* Suarez-Rubio and Thomlinson, 2009) and if it provides adequate habitat for breeding.

Although we detected a large number of species on the installation, they were not evenly distributed across the different available habitats. Migratory warblers were most often encountered in fragmented forest patches and were negatively associated with urbanized habitat. Small forest fragments have been cited as important habitat for communities of neotropical migrant birds, especially when large forest patches are rare or absent (Petit, Petit, Christian, & Powell, 1999; Estrada & Coates-Estrada, 2005). Specifically in Puerto Rico's urban zone, Acevedo and Aide (2008) documented 39 avian species across three forest types, and Suarez-Rubio and Thomlinson (2009) documented 54 species in forest patches of varying size and structure in the San Juan metropolitan area. Many of the 60 species observed in this study rely upon forested habitat, further emphasizing the significance of forest fragments for the conservation of resident and migrant birds, and the important role Fort Buchanan plays in providing such habitat. Similar to many other Department of Defense installations, encroachment and development outside the fence line strengthen the importance of undeveloped habitat for wildlife species on the installation. Even though Fort Buchanan falls within a major urban metropolitan area, efforts should be made to conserve these remaining forest fragments for migratory birds and other wildlife.

Conversely, we found that many of the resident native birds were associated with developed areas of the installation. These *native-adapters* follow a well-established trend of attaining high densities in suburban areas with many tree plantings (Ikin, Knight, Lindenmayer, Fischer, & Manning, 2013). Species such as the Pearly-eyed Thrasher (*Margarops fuscatus*), Red-legged Thrush (*Turdus plumbeus*), and Zenaida Dove (*Zenaida aurita*) were most frequently encountered in residential areas with grassy lawns and ornamental trees. The most common species on the installation was the native Antillean Grackle, which was often seen in large numbers in open grassy areas such as residential lawns and sport fields. These areas may provide an abundance of food from ornamental plantings and easy foraging for insects in the manicured lawn areas (Eiserer, 1980). Manicured areas can often support high densities of particular bird species but typically do not promote diversity (Chong et al., 2014). Although densities might be high in such areas, reproductive rates and performance can be lower than birds living in more natural settings (Balogh, Ryder, & Marra, 2011). In addition, urban areas pose other risks such as predation by domestic cats (van Heezik, Smyth, Adams, & Gordon, 2010).

Although we had no significant positive habitat associations for exotic species, they were negatively associated with forest patches. The most frequently encountered exotic species was the White-winged Parakeet, which was often seen flying overhead in large numbers and roosting in large fruit trees near residential or commercial areas. As urbanization expands and forested patches decline, exotic species are likely to become even more common and widespread. Recent studies have documented avian biological invasions in tropical and subtropical regions (e.g., Lim, Sodhi, Brook, & Soh, 2003; MacGregor-Fors et al., 2017), demonstrating that avian communities invaded by exotics can have lower species richness, but greater abundances, than uninvaded communities (Ortega-Álvarez & MacGregor-Fors, 2009). Further, factors influencing the density of exotics vary among urban land uses (MacGregor-Fors et al., 2017; Ortega-Álvarez & MacGregor-Fors, 2011b). For example, in a neotropical Mexican city, avian species richness was the highest in large urban greenspaces with low management and low human activity (MacGregor-Fors et al., 2016). To maintain diverse avian communities in San Juan, it will be critical to prioritize the conservation of native forests undergoing natural regeneration.

The limitations of this study should be noted. We conducted sampling for a total of 12 days across three sampling periods, and thus could not capture the full suite of species that used the installation throughout the year. In an attempt to detect the most species, we timed the surveys in March and October to coincide with peak migration; however, it is likely that some species that use Fort Buchanan were not encountered during our surveys. Long-term studies are needed to understand the impact of urbanization on birds (Escobar-Ibáñez & MacGregor-Fors, 2016). The development of a long-term study at Fort Buchanan would help to gain a more complete understanding of avifaunal occurrence and density on the installation. In addition, survey methods other than fixed-radius point counts may provide additional information or improve density estimations. For example, variable-radius point counts (Reynolds, Scott, & Nussbaum, 1980) accommodate a wide range of species with detectability varying by habitat. Alternatively, expanding our fixed-radius point counts to include exact distance measurements or additional distance categories would yield more accurate detection functions and density estimates (Buckland, Rexstad, Marques, & Oedekoven, 2015).

Implications for Conservation

Our results show that a diverse avian community, dominated by native species, can exist within a heavily urbanized matrix with groups of species separating based on habitat. Many of the native resident birds appear to be *urban adapters* (McKinney, 2002) and occur in high densities in residential areas, whereas the neotropical migrant songbirds are almost exclusively restricted to fragmented forest patches. This work highlights the importance of forested habitats within this tropical, urban ecosystem for the conservation of migratory songbirds. On Fort Buchanan, small forest fragments can serve as corridors between larger habitat patches in the surrounding landscape (Suarez-Rubio and Thomlinson, 2009; MacGregor-Fors & Ortega-Álvarez, 2011). Two such patches are Julio Enrique Monagas National Park and Las Cucharillas Marsh, Critical Wildlife Areas (Ventosa-Febles et al., 2005) located approximately 30 m and 550 m outside of Fort Buchanan's boundary, respectively. In addition, given the isolation of forest patches by grassland and urban land cover within Fort Buchanan, the scattered woody vegetation and shrubs that connect these forest patches can reduce the effects of forest fragmentation (Fernandez-Juricic, 2000). Even within urban matrices, small forest patches can have value for birds and present a habitat comprised more native species than exotic species, which tend to flourish in urbanized habitats. Management actions should conserve these forest patches and restore native vegetation, and research should focus on the reproductive success of native birds in these patches. As critical wildlife habitats are threatened by urban development, careful planning and collaboration across stakeholders will be required to create livable cities for both humans and wildlife.

As San Juan grows, it can look to cities such as Melbourne (Australia), Chicago (United States), and Querétaro (Mexico) as models that successfully incorporate urban ecology into city planning (McDonnell & MacGregor-Fors, 2016).

Acknowledgments

We thank S. Bologna and two anonymous reviewers, whose comments improved this manuscript.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was funded by the Fort Buchanan Environmental Division.

References

Aide, T. M., & Grau, H. R. (2004). Globalization, migration, and Latin American ecosystems. *Science*, *24*, 1915–1916.

Aide, M., Zimmerman, J., Pascarella, J., Rivera, L., & Marcano-Vega, H. (2000). Forest regeneration in a chronosequence of tropical abandoned pastures: Implications for restoration ecology. *Restoration Ecology*, *8*, 328–338.

Acevedo, M. A., & Aide, T. M. (2008). Bird community dynamics and habitat associations in Karst, Mangrove and Pterocarpus forest fragments in an urban zone in Puerto Rico. *Caribbean Journal of Science*, *44*, 402–416.

Acevedo, M. A., & Restrepo, C. (2008). Land-cover and land-use change and its contribution to the large-scale organization of Puerto Rico's bird assemblages. *Diversity and Distributions*, *14*, 114–122.

Aronson, M. F. J., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A., ... Winter, M. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B, 281*, 1–8, doi: 10.1098/rspb.2013.3330.

Balogh, A. L., Ryder, T. B., & Marra, P. P. (2011). Population demography of Gray Catbirds in the suburban matrix: Sources, sinks and domestic cats. *Journal of Ornithology*, *152*(3): 717–726.

Beissinger, S. R., & Osborne, D. R. (1982). Effects of urbanization on avian community organization. *Condor*, *84*, 75–83.

Blair, R.B. (1996). Land use and avian species diversity along an urban gradient. Ecological Applications, *6*, 506–519.

Brash, A. R. (1987). The history of avian extinction and forest conversion on Puerto Rico. *Biological Conservation*, *39*, 97–111.

Buckland, S. T., Rexstad, E. A., Marques, T. A., & Oedekoven, C. S. (2015). *Distance sampling: Methods and applications*. Cham, Switzerland: Springer.

Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multi-model inference: A practical information-theoretic approach*. New York, NY: Springer-Verlag.

Buxton, V. L., & Benson, T. J. (2015). Do natural areas in urban landscapes support successful reproduction by a group of conservation priority birds? *Animal Conservation*, *18*, 471–479.

Buxton, V. L., & Benson, T. J. (2016). Conservation-priority grassland bird response to urban landcover and habitat fragmentation. *Urban Ecosystems*, *19*, 599–613.

Chandler, R. B., Royle, J. A., & King, D. I. (2011). Inference about density and temporary emigration in unmarked populations. *Ecology*, *92*, 1429–1435.

Chong, K. Y., Teo, S., Kurukulasuriya, B., Chung, Y. F., Rajathurai, S., & Tan, H. T. W. (2014). Not all green is as good: Different effects of the natural and cultivated components of urban vegetation on bird and butterfly diversity. *Biological Conservation*, *171*, 299–309.

Czech, B., & Krausman, P. R. (1997). Distribution and causation of species endangerment in the United States. *Science*, *277*, 1116–1167.

Dial Cordy and Associates Inc. (2003, June 19). *Final plant community and soil survey for Fort Buchanan Army Base, Guaynabo, Puerto Rico* (Prepared for US Army Corps of Engineers).

Eiserer, L. A. (1980). Effects of grass length and mowing on foraging behavior of the American Robin (*Turdus migratorius*). *The Auk*, *97*, 576–580.

Escobar-Ibáñez, J. F., & MacGregor-Fors, I. (2016). Peeking into the past to plan the future: Assessing bird species richness in a neotropical city. *Urban Ecosystems*, *19*(2): 657–667.

Estrada, A., & Coates-Estrada, R. (2005). Diversity of neotropical migratory landbird species assemblages in forest fragments and man-made vegetation in Los Tuxtlas, Mexico. *Biodiversity and Conservation*, *14*, 1719–1734.

Faaborg, J., Arendt, W. J., & Kaiser, M. S. (1984). Rainfall correlates of bird population fluctuations in a Puerto Rican dry forest: A nine year study. *Wilson Bulletin*, *96*, 575–593.

Faaborg, J., Dugger, K. M., Arendt, W. J., Woodworth, B. L., & Baltz, M. E. (1997). Population declines of the Puerto Rican vireo in Guánica Forest. *Wilson Bulletin*, *109*, 195–202.

Faaborg, J., Dugger, K. M., & Arendt, W. J. (2007). Long term variation in the winter resident bird community of Guánica Forest, Puerto Rico: Lessons for measuring and monitoring species richness. *Journal of Field Ornithology*, *78*, 1–9.

Fernandez-Juricic, E. (2000). Avifaunal use of wooded streets in an urban landscape. *Conservation Biology*, *14*(2): 513–521.

Fiske, I., & Chandler, R. (2011). Unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software*, *43*(10): 1–23.

Franz, I., Cappalatti, L., & Barros, M. P. (2010). Bird community in a forest patch isolated by the urban matrix at the Sinos River basin, Rio Grande do Sul State, Brazil, with comments on the possible local defaunation. *Brazilian Journal of Biology*, *70*(4): 1137–1148.

Greene, R. J. (1984). Native and exotic birds in a suburban habitat. *Wildlife Research*, *11*, 181–190.

Hamer, A. J., & McDonnell, M. J. (2010). The response of herpetofauna to urbanization: Inferring patterns of persistence from wildlife databases. *Austral Ecology*, *35*, 568–580.

Ikin, K., Knight, E., Lindenmayer, D. B., Fischer, J., & Manning, A. D. (2013). The influence of native versus exotic streetscape vegetation on the spatial distribution of birds in suburbs and reserves. *Diversity and Distributions*, *19*, 294–306.

Kery, M., & Royle, J. A. (2016). *Applied hierarchical modeling in ecology: Analysis of distribution, abundance and species richness in R and BUGS. Volume 1: Prelude and static models*. London, England: Academic Press.

Lim, H. C., Sodhi, N. S., Brook, B. W., & Soh, M. C. K. (2003). Undesirable aliens: Factors determining the distribution of three invasive bird species in Singapore. *Journal of Tropical Ecology*, *19*, 685–695.

MacGregor-Fors, I. (2007). Relation between habitat attributes and bird richness in a western Mexico suburb. *Landscape and Urban Planning*, *84*(1): 92–98.

MacGregor-Fors, I., Escobar, F., Rueda-Hernández, R., Avendaño-Reyes, S., Baena, M. L., Bandala, V. M., ... Utrera-Barrillas, E. (2016). City ''green'' contributions: The role of urban greenspaces as reservoirs for biodiversity. *Forests*, *7*, 146.

MacGregor-Fors, I., & Escobar-Ibáñez, J. (2017). *Avian ecology in Latin American cityscapes*. New York, NY: Springer.

MacGregor-Fors, I., & Ortega-Álvarez, R. (2011). Fading from the forest: Bird community shifts related to urban park site-specific and landscape traits. *Urban Forestry & Urban Greening*, *10*(3): 239–246.

MacGregor-Fors, I., Quesada, J., Lee, J. G-H., & Yeh, P. J. (2017). Space invaders: House Sparrow densities along three urban-agricultural landscapes. *Avian Conservation and Ecology, 12*(2), doi:10.5751/ACE-01082-120211.

Magle, S. B., Hunt, V. M., Vernon, M., & Crooks, K. R. (2012). Urban wildlife research: Past, present, and future. *Biological Conservation*, *155*, 23–32.

Martinuzzi, S., Gould, W. A., & González, O. M. (2007). Land development, land use, and urban sprawl in Puerto Rico integrating remote sensing and population census data. *Landscape and Urban Planning*, *79*, 288–297.

Marzluff, J. M. (2001). Worldwide urbanization and its effects on birds. In J. M. Marzluff, R. Bowman, & Donnelly (Eds.), *Avian ecology and conservation in an urbanizing world* (pp. 19–47). New York, NY: Springer.

McDonnell, M. J., & MacGregor-Fors, I. (2016). The ecological future of cities. *Science*, *352*, 936–938.

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *Bioscience*, *52*, 883–890.

Nytch, C. J., Hunter, W. C., Núñez-García, F., Fury, C., & Quiñones, M. (2015). Avian conservation planning priorities for Puerto Rico and the US Virgin Islands.

Ordeñana, M. A., Crooks, K. R., Boydston, E. E., Fisher, R. N., Lyren, L. M., Siudyla, S., ... Miles, A. K. (2010). Effects of urbanization on carnivore species distribution and richness. *Journal of Mammalogy*, *91*, 1322–1331.

Ortega-Álvarez, R., & MacGregor-Fors, I. (2009). Living in the big city: Effects of urban land-use on bird community structure, diversity, and composition. *Landscape and Urban Planning*, *90*, 189–195.

Ortega-Álvarez, R., & MacGregor-Fors, I. (2011a). Spreading the word: The ecology of urban birds outside the United States, Canada, and Western Europe. *The Auk*, *128*(2): 415–418.

Ortega-Álvarez, R., & MacGregor-Fors, I. (2011b). Conociendo al gorrión casero: Varación en las abundancies de *Passer domesticus* en diferentes tipos de uso de suelo de la Ciudad de México [Getting to know the house sparrow: variation in abundances of *Passer domesticus* in different land use types of Mexico City]. *El canto del Centozontle*, *2*, 15–28.

Petit, L. J., Petit, D. R., Christian, D. G., & Powell, H. D. W. (1999). Bird communities of natural and modified habitats in Panama. *Ecography*, *22*, 292–304.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org/.

Reynolds, R. T., Scott, J. M., & Nussbaum, R. A. (1980). A variable circular-plot method for estimating bird numbers. *Condor*, *82*, 309–313.

Sol, D., González-Lagos, C., Moreira, D., Maspons, J., & Lapiedra, O. (2014). Urbanisation tolerance and the loss of avian diversity. *Ecology Letters*, *17*(8): 942–950.

Sorace, A., & Gustin, M. (2010). Bird species of conservation concern along urban gradients in Italy. *Biodiversity and Conservation*, *19*, 205–221.

Suarez-Rubio, M., & Thomlinson, J. R. (2009). Landscape and patch-level factors influence bird communities in an urbanized tropical island. *Biological Conservation*, *142*, 1311–1321.

Suarez-Rubio, M., Renner, S. C., & Leimgruber, P. (2011). Influence of exurban development on bird species richness and diversity. *Journal of Ornithology*, *152*, 461–471.

Suarez-Rubio, M., Aung, T., Oo, S. S., Shwe, N. M., Hlaing, N. M., Naing, K. M., ... Renner, S. C. (2016). Nonbreeding bird communities along an urban–rural gradient of a tropical city in central Myanmar. *Tropical Conservation Science*, *9*, 1–9.

UN-Habitat. (2013). *State of the world's cities 2012/2013: Prosperity of cities*. New York, NY: United Nations Human Settlement Program.

United States Census Bureau. (2016). QuickFacts: San Juan Municipio, Puerto Rico. Retrieved from https://www.census.gov/quickfacts/fact/table/sanjuanmunicipiopuertorico/

van Heezik, Y., Smyth, A., Adams, A., & Gordon, J. (2010). Do domestic cats impose an unsustainable harvest on urban bird populations? *Biological Conservation*, *143*, 121–130.

Ventosa-Febles, E., Camacho-Rodríguez, M., Chabert-Llompart, J. L., Sustache-Sustache, J., & Dávila-Casanova, D. (2005). *Puerto Rico critical wildlife areas*. San Juan, Puerto Rico: Puerto Rico Department of Natural and Environmental Resources, Terrestrial Resources Division.

World Resources Institute. (1996). World resources 1996-97: The urban environment (400 pp.). Oxford, England: Oxford University Press.

Wiley, J. W. (1979). The white-crowned pigeon in Puerto Rico: Status, distribution and movements. *Journal of Wildlife Management*, *43*, 402–413.

Wunderle, J. M., Diaz, A., Velazquez, I., & Scharrón, R. (1987). Forest opening and the distribution of understory birds in a Puerto Rican rainforest. *Wilson Bulletin*, *99*, 22–37.