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Relationship of bird richness, abundance and assemblage to the built environment in a small island tropical urban setting: a Suva, Fiji case study

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Abstract

There have been few studies investigating the relationship between the built environment and the status of bird distributions in small island tropical urban areas. We present a study investigating the relationship between bird species richness, abundance and assemblage to the built environment in Suva, Fiji. Field surveys were taken at 54 randomly selected sites throughout the city, stratified by three building density classes and the central business district (CBD). At each site bird counts were recorded, along with environmental data such as average building height, within a 150 m radius. Land-use information was obtained from screen digitized high-resolution satellite imagery within the same radius. Distance to undeveloped patches of land within the urban area was calculated using a GIS. Analysis of the effects of the built environment was carried out for all species, and for exotic and native species separately. Abundance of exotics was significantly higher in the central business district (CBD) than all other urban density classes, and significantly higher than natives in all other density classes. We found a negative relationship between native species richness and distance to undeveloped patches, but no relationship for exotics. Species assemblage was not related to urban density class. We conclude that the status of native and exotic bird species in Suva is similar to what has been found in urban areas in temperate climates, and conservation efforts should focus on minimizing the amount of heavily urbanized "core areas" and protecting undeveloped areas of forested vegetation to improve bird biodiversity in small tropical islands cities.

Keywords Built environment · Avian ecology · Tropical oceanic islands · Urbanization · Urban planning · Urban vegetation

Introduction

While many studies have investigated the relationship between urbanization and the composition and distribution of avifauna in urban areas, most have been in relatively large cities in temperate climates (examples include van Heezik et al. 2008; Murgui 2009; Pellissier et al. 2012; Latta et al. 2013; Meffert and Dziock 2013; Dale 2018). The unequal balance toward studies in large urban centers in temperate climates is also evident in several meta-analyses of urban bird ecology (see for example Clergeau et al. 2001; Chace and Walsh 2006; McKinney 2008). Chace and Walsh (2006) and

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Marzluff (2001) highlight a need for more urban bird studies in tropical regions of the world, partly because of higher biodiversity expected in the tropics (Suarez-Rubio and Thomlinson 2009; Reis et al. 2012). The effect of urbanization on avifauna is of particular interest as birds are recognized as indicators of overall biological diversity (Schulze et al. 2004) and in developing countries may act as an indicator of sustainable development (United Nations 2008).

Urbanization affects biodiversity by replacing natural habitat with built structures often leading to a more homogenized landscape (Blair 2001; MacGregor-Fors et al. 2013; Beardsley et al. 2009). A common finding among studies of bird distribution in urban environments is a decrease in species richness in relation to increased urbanization (Chace and Walsh 2006; McKinney 2008; Murgui 2009; Latta et al. 2013; MacGregor-Fors et al. 2013). Evidence also suggests a positive relationship between species richness and green space such as parks and urban gardens (Melles et al. 2003; Chamberlain et al. 2007; Murgui 2009; Latta et al. 2013; Chaiyarat et al. 2018) and tree cover (Rolando et al. 1997; MacGregor-Fors et al. 2013). Vegetation on, or around, buildings has been shown to be related to urban bird composition (Deng and Jim 2007; Belcher et al. 2018), as has the size, height and variability of building height (MacGregor-Fors and Schondube 2011; Pellissier et al. 2012). Other factors include habitat type and food resources (Lim et al. 2003; Lerman and Warren 2011), noise (Fontana et al. 2011; Proppe et al. 2013) and light pollution (Ciach and Fröhlich 2007).

Highly urbanized environments tend to favor introduced (exotic) species (Clavero et al. 2009). Of 54 bird species studied by Suarez-Rubio and Thomlinson (2009) in San Juan, Puerto Rico, native species were more sensitive to landscape factors such as patch size, urbanization and canopy texture (vertical homogeneity) than exotic species. Human-modified environments and anthropomorphic activities have been shown to be correlated with undesirable exotic species in Singapore (Lim et al. 2003). Although the mechanisms by which exotic species interact and compete with native species are not clearly understood (Gurevitch and Padilla 2004; Didham et al. 2007; Roberson et al. 2013 (but see: Shochat et al. 2010)), there is evidence that exotic species fill unique ecological roles (Rodriguez 2006) and negatively impact native bird species (Baker et al. 2014), particularly in island environments (Clavero et al. 2009).

Recent avifauna studies in tropical and subtropical urban areas include Reis et al. (2012) in Palmas, Brazil; Fontana et al. (2011) in Porto Alegre, Brazil; Ortega-Álvarez and MacGregor-Fors (2009) in Mexico City; Chaiyarat et al. (2018) in Bangkok, Thailand; Belcher et al. (2018) in Singapore; and Suarez-Rubio and Thomlinson (2009) in San Juan, Puerto Rico. The San Juan study (Suarez-Rubio and Thomlinson 2009) is one of few examining avifauna composition and distribution on an urbanized tropical island. Islands may be considered unique because of the effects of insular biogeography and the relationship between species diversity, island size, and isolation (MacArthur and Wilson 1967; MacGregor-Fors et al. 2013).

Little research has been done on the distribution of avifauna in urban areas of small Pacific island countries, and there are few published studies of the birds of Suva, Fiji. The earliest study is that of Gorman (1972) who recorded 21 bird species, 14 of which were classified as native. Gorman (1972) concluded that the small number of species in the Suva urban and suburban area was not likely a consequence of competition among species, but was what would be expected from a small oceanic island with limited avifauna. Other ornithological publications related to birds of Suva are reports on the monitoring of shorebirds on the Suva Lagoon mudflats (Watling 2005) and state of the birds in Fiji (Watling 2013).

The aim of this paper is to examine the relationship of urbanization to bird biodiversity in a small island tropical urban setting. Given that remote small island urban environments are particularly susceptible to the effects of exotic bird species on native diversity (Clavero et al. 2009), we focus on two hypotheses: 1) that exotic species abundance is higher in areas of greater urbanization, and 2) that native species richness is lower in areas of greater urbanization.

Study area

Viti Levu, Fiji's largest and most populated island lies approximately 18° south latitude and 177° east longitude with a land area of approximately 10,400 km^2 (Fig. 1b). The eastern side of the island experiences heavy rain, particularly during the cyclone season, while the leeward side is considerably dryer due to orographic lifting (Fiji Bureau of Statistics 2015). Suva City, located on a peninsula on southeast Viti Levu, is the nation's capital and primary center for administrative, industrial and commercial activities. The city is approximately 26.88 km^2 in size, comprising the entire peninsula, and as of the most recent census had a population of 85,691 (Fiji Bureau of Statistics 2007). The peninsula receives an average of 3023 mm of rainfall annually (Fiji Bureau of Statistics 2015). Land uses include commercial, administrative, industrial, recreational, mangrove reserve, and residential. At the heart of Suva City is the central business district (CBD), a commercial and institutional hub adjacent to Fiji's largest sea port facility. Beyond the city boundaries are other towns making up the Greater Suva Urban Area which has a population of approximately 172,399 (Fiji Bureau of Statistics 2007). Approximately 10 km north of Suva City are the Colo-i-Suva Forest Park and Savura Forest Reserve, both of which are well forested and contain a high level of native biodiversity. A total of 34 species of birds can be found in the Savura Forest Reserve of which 24 are native (Birdlife International 2006). The study area for the present research was limited to the Suva City boundary which coincides with Suva Peninsula (Fig. 1a).

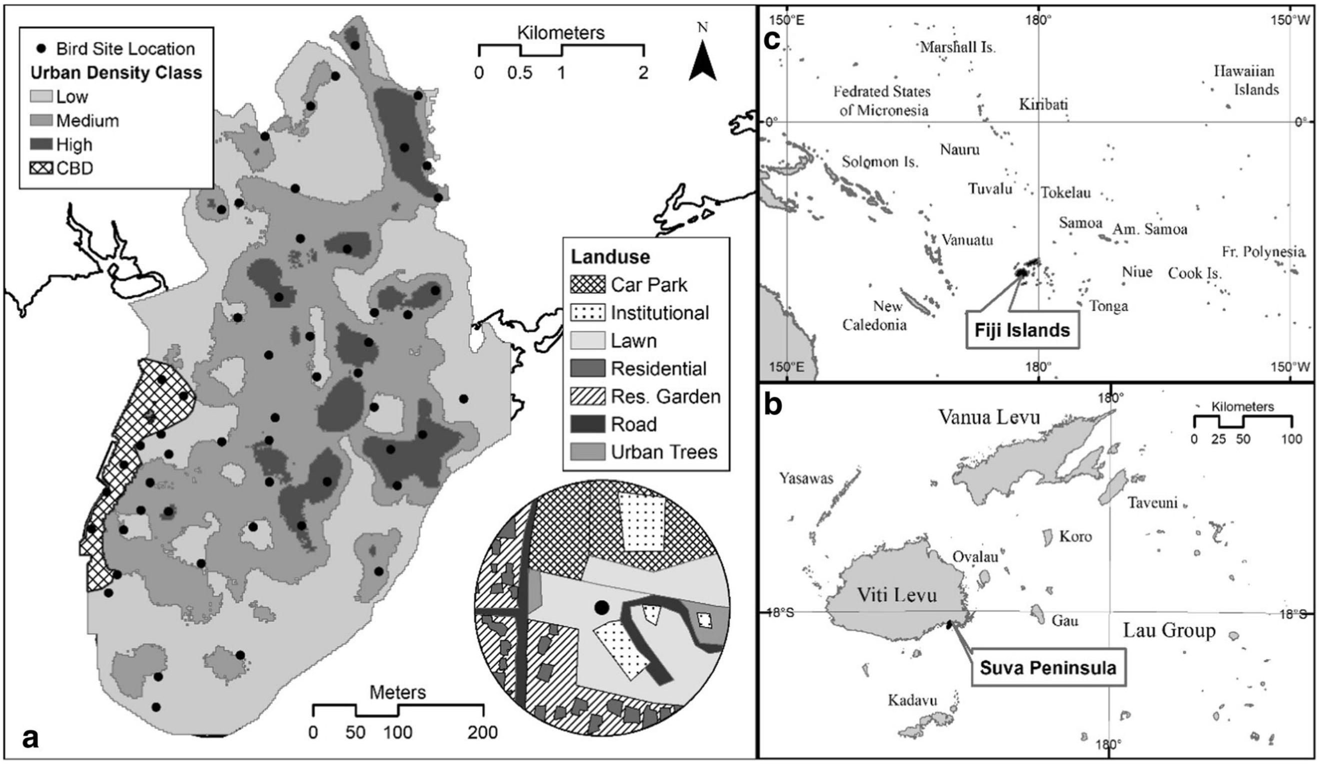


Fig. 1 (**a**) Urban density classes within the Suva City study area and an example of land use digitized within 150 m of a bird sample site. (**b**) Suva City in relation to the Fiji Islands and (**c**) the Fiji Islands within the context of other Pacific island countries

Methods

Sampling and land-use mapping

Urban density classes were created using a geographic information system (GIS) (ArcGIS 10.1). This was carried out by 1) creating a point GIS dataset of all buildings in the study area via visual interpretation of a high resolution satellite image (2009 GeoEye image), 2) using a kernel density function to create a building density surface, and then 3) reclassifying the density surface into classes: Low density (0–6 buildings/ha), medium density (7–9 buildings/ha) and high density (10–24 buildings/ha). Because the central business district (CBD) is significantly different in building size, shape and density from the rest of the study area, it was delineated as a separate urban density class via visual interpretation of the satellite imagery. Sample sites for the field survey were selected using the GIS by a stratified random approach, with a minimum distance of 300 m between sites. The number of sites selected for each urban class was roughly proportional to the size of the urban class area. A total of 54 sites were identified, 17 in both the low and medium density classes, eight in the high density class, and 12 in the CBD class (Fig. 1). To capture information about land use for each site, a 150 m buffer was created around each site and land use was visually interpreted from the satellite image within the 300 m circle (Fig. 1). Fifteen land-use classes were interpreted and digitized (Table 1). These were later collapsed to four classes for data analysis: built environment, open vegetation, all other vegetation, and water. To assess distance from undeveloped (largely forested) patches within the urban matrix, undeveloped areas larger than four

Table 1 List of land uses visually interpreted and digitized within 150 m of each site

Land use	Reclassified
Car Park	Built Environment (BuiltEnvHa)
Commercial	
Industrial	
Institutional	
Residential	
Road	
Walkways	
Lawn (residential & institutional)	Open Vegetation (VEG1Ha)
Playing field	
Residential garden	All other vegetation (VEG2Ha)
Natural trees & shrubs	
Urban trees	
Residential trees & shrubs	
Ruderal (shrubs)	
Water	Water

hectares were visual interpreted and screen digitized at a scale of 1:20,000. Straight-line (Euclidean) distance was calculated from each site to the nearest undeveloped area using the GIS.

Field survey

Field surveys were conducted from 27 November 2013 to 9 January 2014 using variable radius point counts (Raman 2003). Observations were made with Bushnell Power 8 × 30 binoculars and through identification of bird calls. Point counts were carried out in the morning between 06:20 and 10:20 and multiple sites visited during this time. Twelve minutes were spent at each of the sites. The first two minutes were spent setting up environmental monitoring equipment and allowing birds to recover from the effects of any disturbance; the next five minutes were used to conduct the bird counts, and the final five minutes used to collect readings from the environmental monitoring equipment. During each bird count the following were recorded: species name, and number of birds observed.

Physical and biological measurements were recorded. An environmeter (Kestrel 4000) was used to measure temperature, wind speed, and humidity, while a range finder (NEWCON OPTIK LRM 1200) was used to measure average building and tree height. A GPS receiver (GARMIN GPS72H) was used to navigate to the site and record location and elevation. A sound meter application (Sound Meter by Smart Tools Co.) was installed on a smart phone and used to record average, maximum and minimum sound levels (dB) over the course of the five minute surveys. In addition, a record of vegetation types was made for each site.

Data analysis

Statistical tests (Wilcoxon rank-sum test, simple linear regression, Spearman's rank correlation) and graphical plots were carried out using the R software v 3.3.2 (R Core Team 2018). Univariate statistical tests and plots were created based on a classification of species into either a 'native' or 'exotic' group.

Multivariate data analysis was conducted using PRIMER-6 v6.116 and PERMANOVA+ v1.0.6. Biological data (i.e. species abundance) were transformed using a $\text{Log}(X + 1)$ transformation to balance contributions of common and rare species (Clarke and Warwick 2001). Preparatory to clustering and ordination, a Bray-Curtis similarity matrix was created for the species data. Environmental data (i.e. sound levels, average building height, average tree height, temperature, wind speed, humidity, elevation above sea level, and land-use) were maintained in a PRIMER table though not all variables were used as some were correlated or conceptually provided redundant information.

Non-metric Multi-Dimensional Scaling (nMDS) was used to create an ordination plot of the species data. Default settings of 25 restarts, a minimum stress of 0.01, and Kruskal stress formula set to 1 were used. Non-metric Multi-Dimensional Scaling attempts to project ranked species similarity to 2 dimensional space, thus portraying sites more similar to one another as closer together in the 2-D plot (Lattin et al. 2013). How well nMDS ordination succeeds is measured by its stress value (Clarke and Warwick 2001). Analysis of Similarity (ANOSIM) was used to test for differences among the four urban density classes based on the bird community Bray-Curtis similarity matrix. ANOSIM is analogous to ANOVA (Analysis of Variance) but based on permutation/randomization tests thereby avoiding many of the assumptions (e.g. normality) of traditional parametric models (Clarke and Gorley 2006). A one-way ANOSIM was conducted using urban density class as the factor with the maximum number of permutations set to the default of 999. Hierarchical agglomerative clustering (CLUSTER) was used to group species abundance data into groups nested within clusters. Clusters based on site similarity were represented with a dendrogram and superimposed on the nMDS plot.

To evaluate the relationship between species similarity and environmental variables, a distance-based linear model (DistLM in PERMANOVA+) was used. Using the similarity matrix as the dependent variable, DistLM performs a linear regression on one or more explanatory variables (e.g. average building height) using a permutations-based algorithm (Clarke and Gorley 2006). For the DistLM, a step-wise selection procedure was used with AICc as the selection criterion with the default number of permutations.

Results

Presence, abundance and richness

Over the course of the survey a total of 1114 individuals comprising 18 bird species were detected. Of these, 12 were native (six endemic) and six were exotic species (Table 2). Species presence, measured by the proportion of sites where species were detected, can be thought of as how common it was that a species was encountered. The two most commonly encountered species for the high, medium and low density classes were *Pycnonotus cafer* (Red-vented bulbul) and *Acridotheres tristis* (Common myna) (Fig. 2). In the CBD the two most commonly encountered species were *Acridotheres tristis* and *Columba liva* (Rock dove) which was found in 15% of the CBD sites (Fig. 2).

Species richness, measured by the number of species obseved at each site was similar for all urban density classes (Wilcoxon rank-sum test, $\alpha = 0.05$), except for the CBD, which had lower native richness than the low urban density

Table 2 List of bird species recorded with native/exotic status and abbreviation using Six-letter (Scientific Name) alpha codes after the American Ornithologist Society (AOS) taxonomy

Species	Abbrev	Common Name	Status
Accipiter rufitorques	ACCRUF	Fiji goshawk	Native*
Acridotheres spp	ACRSPP	Common myna	Exotic
Aerodramus spodiopygius	AERSPO	White-rumped swiftlet	Native*
Amandava amandava	AMAAMA	Red avadavat	Exotic
Ardea novaehollandiae	ARDNOV	White-faced heron	Exotic
Artamus mentalis	ARTMEN	Fiji woodswallow	Native*
Circus approximans	CIRAPP	Swamp harrier	Native
Columba livia	COLLIV	Rock dove	Exotic
Egretta sacra	EGRSAC	Pacific reef heron	Native
Erythrura pealii	ERYTHR	Fiji parrotfinch	Native*
Foulehaio carunculata	FOUCAR	Polynes. wattled honeyeater	Native
Fregata ariel	FREARI	Lesser figatebird	Native
Myiagra vanikorensis	MYIVAN	Vanikoro flycatcher	Native
Myzomela jugularis	MYZJUG	Sulpher-breasted myzomela	Native*
Phigys solitarius	PHISOL	Collared lory	Native*
Pycnonotus cafer	PYCCAF	Red-vented bulbul	Exotic
Streptopelia chinensis	STRCHI	Spotted dove	Exotic
Zosterops lateralis	ZOSLAT	Silvereye	Native

Species denoted with * are endemic

class (W = 147.5, $p = 0.04$) and lower richness for exotics than the medium density class (W = 152, $p = 0.02$; Fig. 3a). Species abundance (total number of individuals) was significantly different between exotics and natives ($\alpha = 0.05$) for all urban density classes (Fig. 3b). Species abundance in the CBD was significantly lower for natives and higher for exotics,

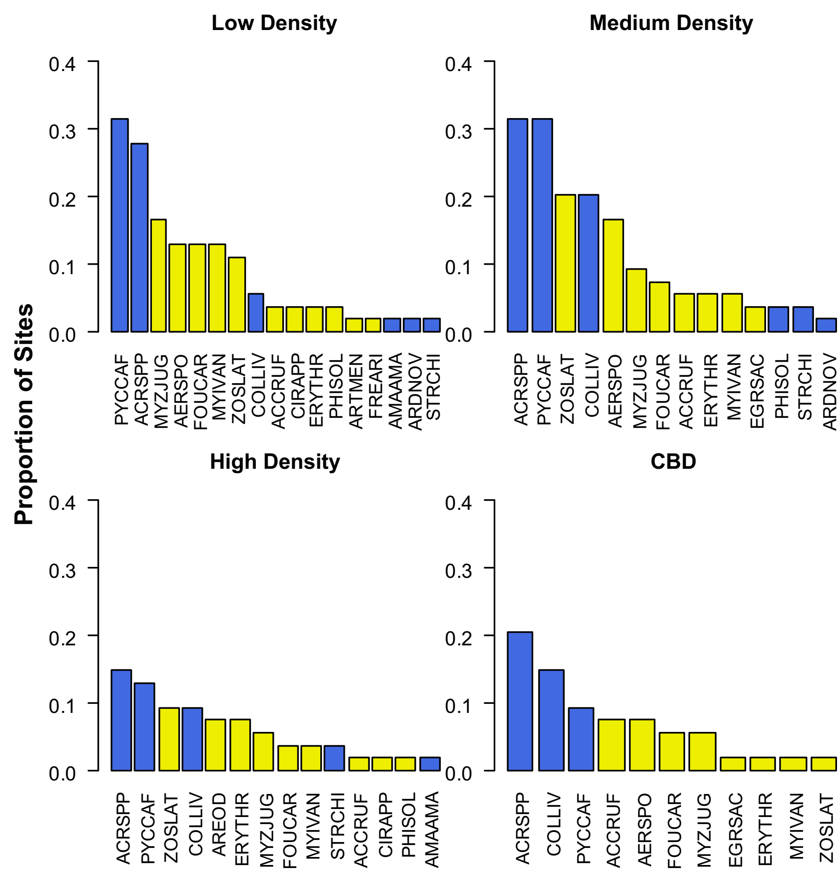


Fig. 2 Brid presence for each urban density class measured by proportion of sites where a bird species was recorded. See Table 2 for scientific name abbreviations

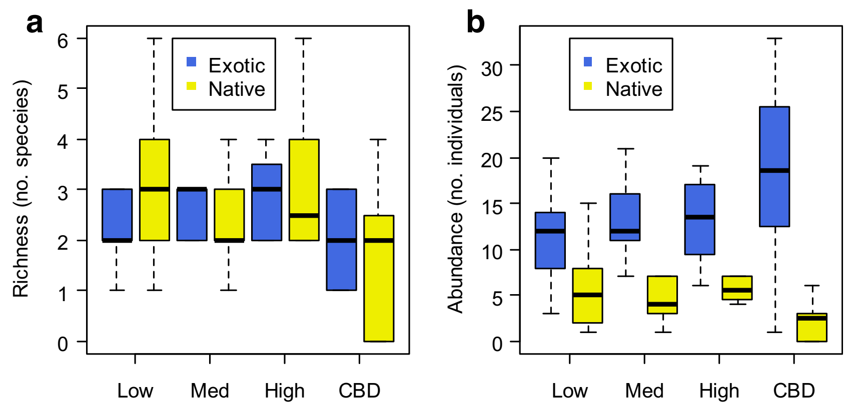


Fig. 3 Comparison of exotic and native (**a**) bird richness and (**b**) abundance for each urban density class

compared to all other urban density classes ($\alpha = 0.05$; Fig. 3b). A geographical representation of the spatial distribution of exotic and native richness and abundance is provided by Fig. 4a, b.

The relationship of distance to the nearest undeveloped patch of land (Fig. 4) for richness and abundance is presented by the scatter plots in Fig. 5a–d. Native richness decreases with distance from undeveloped areas (Spearman's rank correlation, rho = −0.380, $p = 0.004$) whereas for exotics there is no relationship. Species abundance increases with distance for exotics (rho = 0.256, $p = 0.062$) and decreases for natives (rho = −0.265, $p = 0.052$; Fig. 5a–d).

Species similarity groupings

An nMDS 2-D plot depicting sample site similarity based on the Bray-Curtis matrix of species similarity suggests that specie assemblages are not sorting into discrete groups (Fig. 6), and in particular, that the groups have little relation to the four urban density classes. In Fig. 6 each site is symbolized based on its urban density class. If bird assemblages were unique to urban classes we would expect some evidence of clustering and separation by urban class. The nMDS visualization offers little to suggest differentiation of bird assemblages associated with urban class, with

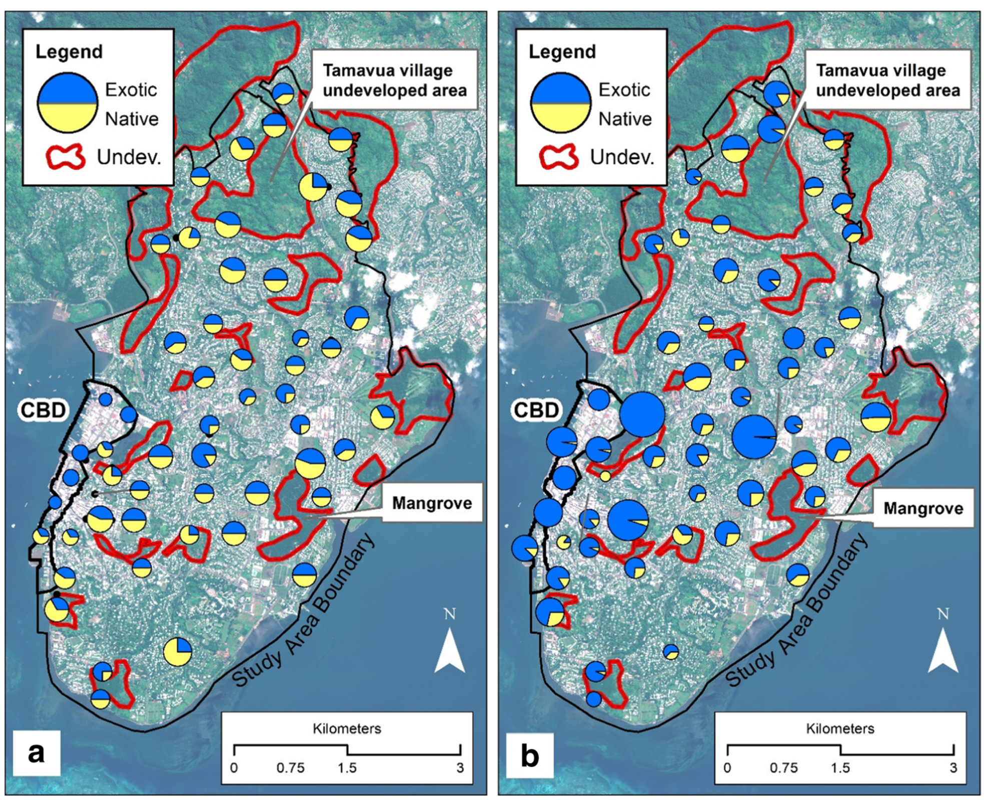


Fig. 4 Spatial distribution of (**a**) species richness and (**b**) abundance, and undeveloped areas greater than 4 ha in size. Size of symbol indicates the sum of exotics and natives combined

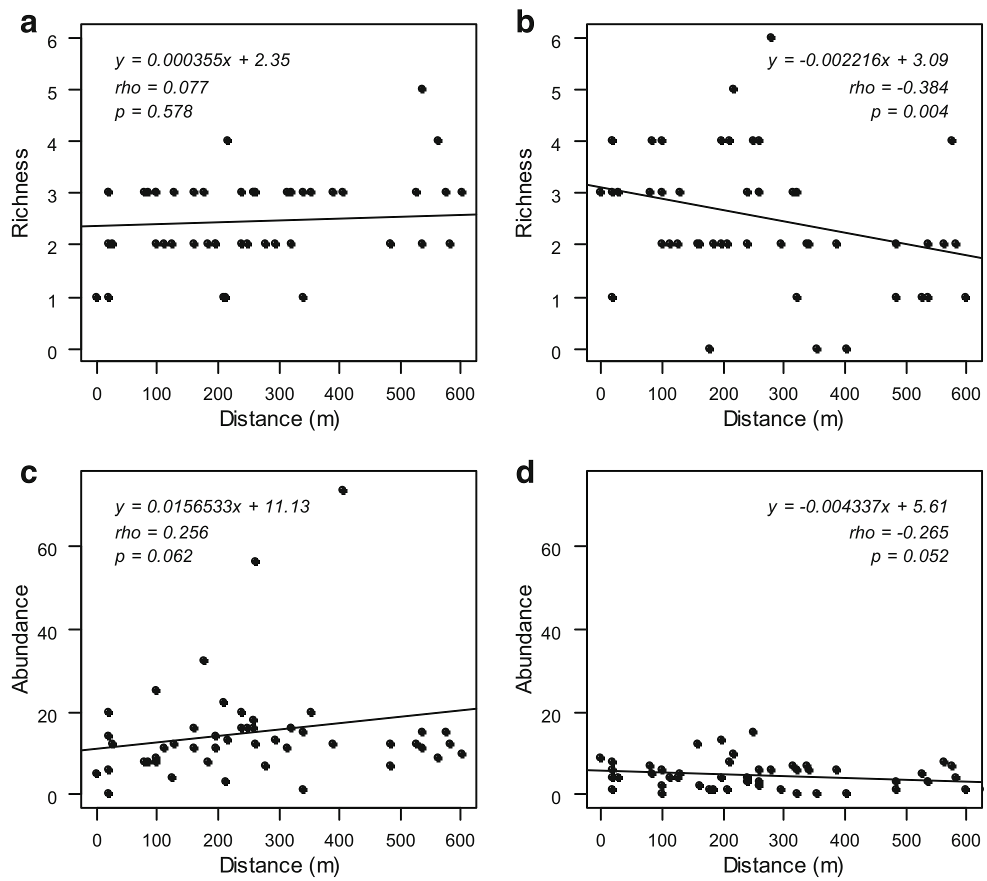


Fig. 5 Relationship of distance to undeveloped areas for (**a**) exotic species richness, (**b**) native species richness, (**c**) exotic species abundance, and (**d**) native species abundance

perhaps the exception of some separation in the CBD sites. Results from the ANOSIM test suggest the same. The Global R statistic for ANOSIM was 0.134 with two permuted statistics greater than the Global R. While significant at $\alpha = 0.05$, the Global R statistic suggests very little difference in species assemblages for the four urban density classes. With a stress value of 0.23, adequacy of the nMDS plot as a visualization of the sample site similarities must be viewed with caution (Clarke and Warwick 2001). Clarke and Warwick (2001) recommend cross-checking potentially ambiguous nMDS visualizations with another grouping technique, such as cluster analysis. Ellipses in Fig. 6 are cluster groups at a 55% Bray-Curtis species similarity threshold from a cluster analysis (Fig. 7). Cluster analysis confirms considerable overlap among the groups with the exception of some separation in the CBD group (Figs. 6 and 7).

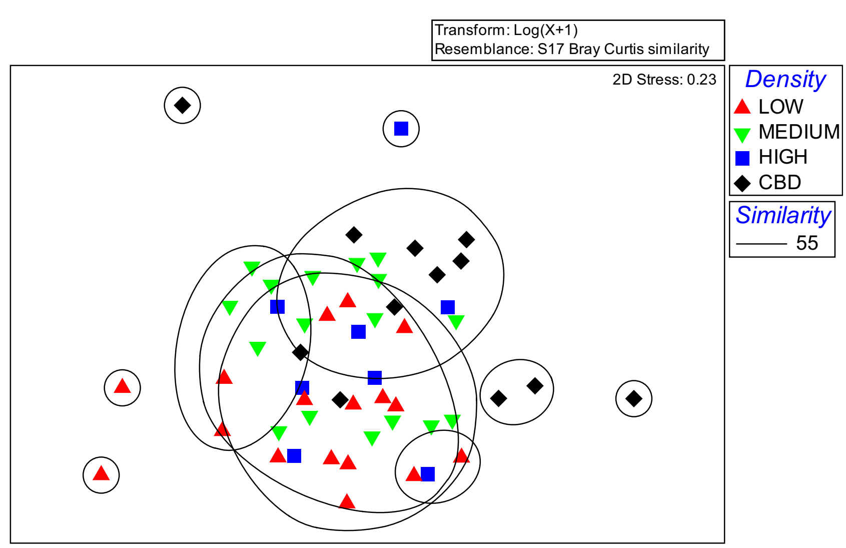
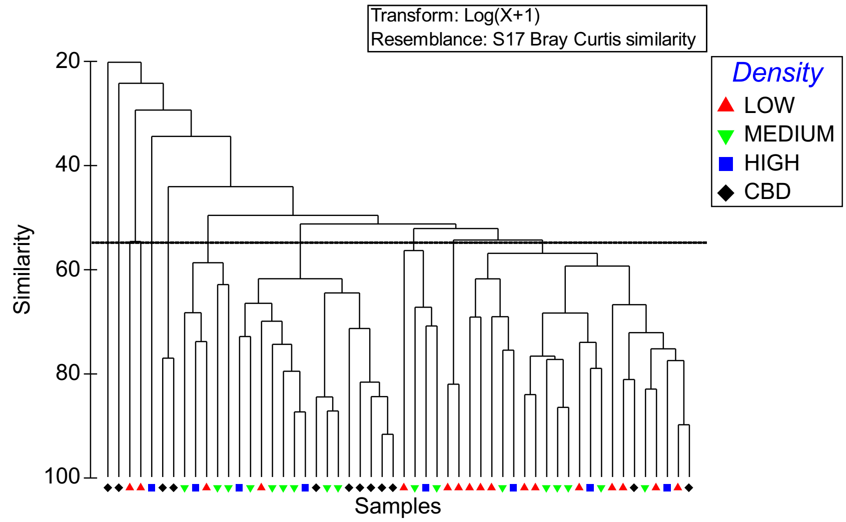


Fig. 6 Non-Metric Multidemensional Scaling (nMDS) 2-D plot depicting ranked similarities of sites from the Bray-Curtis similarity matrix. Ellipses represent cluster groups (bird assemblages based on Bray-Curtis similarity) at 55% similiarty threshold (Fig. 7)

Fig. 7 Hierarchical agglomerative clustering dendrogram with horizontal line marking 55% similiarity threshold



Species similarity and relationships with environment

The distance-based linear model (DistLM performed in PERMANOVA+) provides an indication of how well species similarity relates to multiple environmental variables. Of the six explanatory variables used in the final model, *average tree height*, *avereage building height*, and *average ambient sound* were recorded in the field. The other three, *built environment (ha)*, *open vegetation (ha)* and *building density* were obtained from the GIS data. Of the six explanatory variables, *built environment (ha)* and *average building height* have a statistically significant relationship with species similarity ($\alpha = 0.05$) (Table 3). *Average tree height* and *average ambient sound* are related to species similarity ($\alpha = 0.10$) (Table 3). It is worth noting that *all other vegetation* (Table 1) was removed from the model because it is highly correlated with *built environment (ha)*, and that *open vegetation* (i.e. VEG1Ha "playing fields and lawn" Table 1), while left in the model, is not related to species similarity ($p = 0.446$) (Table 3).

Output from DistLM's step-wise analysis evaluates explanatory variables based on their goodness-of-fit (R^2) and model parsimony (AICc). Table 4 provides best model solutions for each number of variables. The most parsimonious model includes only the variable *built environment (ha)* (R^2 0.10). The next best model includes *avereage tree height* (R^2 0.14), and the third best model includes *open vegetation* (R^2 0.17). The results suggest that the environmental variables explain some, but not a large amount of variation in species similarity, with *built environment (ha)* the strongest predictor. This is conveyed visually with an nMDS plot showing the amount of built environment land use in hectares for each site represented by symbol size (Fig. 8).

Discussion

While our results do not reveal significant differences in richness and abundance among the low, medium and high urban density classes, bird composition in the central business district (CBD) follows a markedly different pattern from the rest of the city. Species richness, for both native and exotic species in the CBD is lower (Figs. 3a and 4a) and abundance of exotics is considerably higher, while lower for natives (Figs. 3b and 4b). Not only is overall species richness lower in the CBD but the three most abundant species are exotics, whereas in the other urban density classes only the first two most abundant species are exotics (Fig. 2). When examining the site data for natural groups based on species similarity (Bray-Curtis matrix), the nMDS plot

Table 3 Distance-based linear model (DistLM) results

No.	Variable	SS(trace)	Pseudo-F	*P* value
1	AveTreeHt	2664.4	1.9242	0.069
2	AveBldHt	3099.5	2.252	0.049
3	AveAmbSound(dB)	2670.9	1.929	0.076
4	BuiltEnvHa	7656.4	5.9413	0.001
5	VEG1Ha	1370.1	0.972	0.446
6	BldDens	2065.6	1.4795	0.179

Table 4 Distance-based linear model (DistLM) step-wise results showing six best model selections based on AICc and R^2

AICc	R^2	RSS	No.Vars	Selections
388.91	0.10	67,012	1	4
389.07	0.14	64,476	2	1,4
389.43	0.17	62,158	3	1,4,5
389.83	0.20	59,853	4	1,4–6
390.41	0.23	57,724	5	1,3–6
392.03	0.24	56,639	6	All

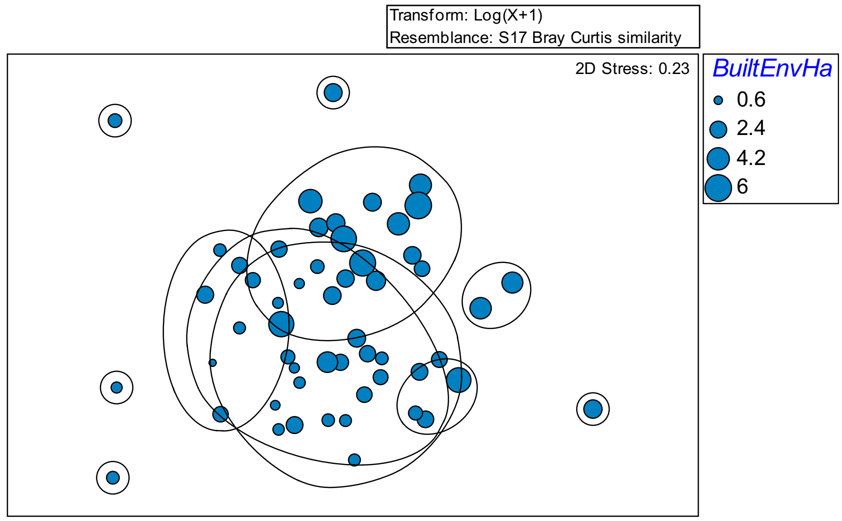


Fig. 8 Non-Metric Multidemensional Scaling (nMDS) 2-D plot showing the amount of 'Built Environment' land uses in hectares for each site (compare to Fig. 6). Ellipses represent cluster groups (bird assemblages based on Bray-Curtis similarity) at 55% similiarty threshold (Fig. 7)

reveals little differentiation among the three urban density classes, but some separation of the CBD (Fig. 6).

Lower species richness and higher abundance of exotics in the "urban core" have been observed by others (Chace and Walsh 2006; Latta et al. 2013) and structural simplification of vegetation and a reduction of habitat are the most plausible explanations (McKinney 2008). However, less vegetation and more built structures in the urban core may provide only a partial explanation. The type and size of structures may also be important. MacGregor-Fors and Schondube (2011) found that building heights were positively related to bird abundance in urban areas, and Pellissier et al. (2012) found abundance was related to the extent building heights varied. The distance-based linear regression (Tables 3 and 4) using environmental variables indicates a significant relationship ($\alpha = 0.05$) between species similarity and *average building height* and *built environment (ha)* suggesting that the bird species assemblages are "sorting" themselves along these variables (Fig. 8).

In a meta-study of urbanization and species richness McKinney (2008) notes that extreme urbanization is almost always correlated with decreased species richness, but in some cases (30% for avifauna) moderate urbanization is associated with higher species richness. Our study suggests that outside the CBD species richness is slightly higher (Fig. 3a), however across different urban density classes there is no difference in richness, and there is no relationship between species similarity and building density ($p = 0.179$; Table 3). Previous studies have shown building density to be an important variable explaining bird composition in urban areas (Blair 2004; Chace and Walsh 2006; Ikin et al. 2013), and it is worth examining why it did not reveal itself as important in this study. In Suva the CBD is markedly different from the rest of the city and can be characterized as nearly homogeneous built structures dominated by buildings and very little vegetation (Fig. 4). The remainder of the city is more heterogeneous with a greater mix of vegetation and different land uses. The lack of differentiation of bird richness and abundance by urban density class may be explained by insufficient distinction among the three density classes we used, and therefore the outcome of our analysis may be a result of how urban density was measured. A related explanation might be that the geographic extent of the study was limited to within the city boundary, and therefore the geographic scale of analysis was relatively focused rather than broad-ranging. Had we collected data beyond the city boundary we may have found a decrease in species richness in peri-urban areas outside Suva City, demonstrative of the intermediate disturbance hypothesis noted by others (Chace and Walsh 2006; McKinney 2008). Finally, the geography of Suva as a peninsula city, with water on three sides, might influence the relative homogeneity of richness and abundance, given the broader urban gradient only extends in one direction.

As in other studies (MacGregor-Fors and Schondube 2011; Ikin et al. 2013; Latta et al. 2013) our study indicates a relationship exists between species composition and distance to undeveloped vegetated areas (Fig. 5). The largest open green space in the study area is an undeveloped tract of land owned by the Tamavua village that is mostly forested (Fig. 4). Higher species richness surrounding the Tamavua village undeveloped area may be explained by vegetative structure and foraging opportunities offered by this large vegetated space. Fitzsimons et al. (2011) found that urban remnant vegetation plays an important role in supporting bird abundance and diversity, and that bird diversity is positively correlated with remnant size. In our study area the second largest undeveloped area is an inland mangrove estuary on the eastern side of the peninsula. As with the Tamavua village undeveloped area, native species richness is notably higher at the sample sites near the mangrove forest (Fig. 4a). The natural habitat of many of the native species observed in this study (e.g. *Myzomela jugularis* (Sulpher-breasted myzomela), *Foulehaio carunculata* (Polynesian wattled honeyeater)) is mangrove forest or lowland coastal forests, so finding high native species richness (and relatively high abundance) near one of the last remnant mangrove forests is not surprising.

In terms of overall species composition, 18 species were recorded in the Suva City study area, of which 12 were native and six were exotic. This is similar to what was recorded 45 years ago by Gorman (1972) who recorded 21 species, 14 of which were native and seven exotic. Ours was not a comparative study so differences may be attributed to methods; however, it is worth noting that the ratio of natives to exotics remains the same. Gorman (1972) observed one exotic (*Padda orizivora* (Java sparrow)) we did not observe, and recorded six natives not observed in this study. We observed six natives not observed in 1972. It would be interesting to examine the habitat requirements and behavior of these species in relation to changes in Suva's urban environment over the last 45 years, but that must be left to another study.

Conclusion

Looking forward, this study offers useful insight for urban planning in Suva, and possibly other urban environments on small tropical islands. Small tropical islands (especially remote oceanic islands) by their nature have lower bird diversity than mainland tropical urban areas (Gorman 1972), and therefore might be more susceptible to local extinctions (Didham et al. 2007; Clavero et al. 2009). While we did not find significant variation in bird richness, abundance and assemblage across urban density classes, we found the CBD to have significantly lower overall richness and higher abundance of exotics. We also found that undeveloped areas appear to play an important role in supporting native species and overall bird diversity. In Suva, the mangrove forest area identified as being a probable refuge for native birds is currently under threat of development. From Fig. 4a it is apparent that two of the most important refuges for native birds in Suva are the mangrove forest and the Tamavua village undeveloped area. Both of these areas, and possibly to some extent other undeveloped remnants on the peninsula, should be protected to maintain and improve biodiversity in Suva.

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