

**Distribution, diversity, abundance, and richness of  
Grenadian terrestrial birds, including endemic and  
restricted-range species.**

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A Thesis

Submitted to the Faculty of Graduate Studies in Partial Fulfillment of the Requirements for the  
Degree of Master of Natural Resources Management

Natural Resources Institute

University of Manitoba

Winnipeg, Manitoba

Spring 2020

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## ABSTRACT

The conservation status of Grenadian terrestrial birds is not fully understood because there has been no comprehensive study surveying all land bird species across the extent of Grenada. Currently, Grenada is experiencing rapid anthropogenic development and habitat alteration that may be affecting the conservation status of endemic, restricted-range, and native land bird species. To examine the impacts of anthropogenic habitat alteration on terrestrial birds and to identify bird species and bird habitat of conservation concern in Grenada, I collected baseline data on the distribution, diversity, and abundance of Grenada's resident land birds by applying both single and dependent double-observer point count surveys across 54 field sites. At field sites, I conducted eight five-minute point-count surveys within a 25-meter radius with each point count plot separated by 100-meters. Percentage habitat type and land use were also recorded within each 25-meters point count plot. I used the program DOBSERV to calculate each species perceptibility, Shannon diversity index to evaluate species diversity, and General Linear Models (GLMs) to analyze the distribution and abundance of Grenada's resident land birds. Higher densities of most species were found in anthropogenic cultivated and secondary grasslands, while lower densities generally occurred in cloud and secondary forests. Nonetheless, even the natural cloud and secondary forests with lower species densities were selected for by some species of conservation concern, such as the regional endemic Lesser Antillean Tanager and all nectarivores. Additionally, all nectarivores and a granivore avoided urban habitats. My overall results emphasize the importance of maintaining a habitat mosaic of natural and anthropogenic habitat types within Grenada. This information can inform habitat management decisions and conservation strategies, which will aid in the conservation of the land birds of Grenada and other Caribbean islands that have similar species and habitat requirements.

## ACKNOWLEDGEMENTS

I am genuinely grateful to my advisors, Dr. Miyako Warrington and Dr. Nicola Koper, for their tremendous support and patience, a vast wealth of statistical and ecological information, and remarkable editorial skills. I am also sincerely grateful to my committee members: Dr. Andrew Horn and Dr. Kevin Fraser for sharing their research knowledge and providing remarkable insights.

I am truly thankful to my field interns: Aleanna Williams, Lizda Sookram, and Robyn Brown for their hard work during the data collection period. I also am equally thankful to my research volunteers: Quincy Augustine, Udy Fedrick, and Amonie Holas for their hard work and dedication during the data collection period.

I am sincerely thankful to Denzel and the Adams family for their hospitality and providing me with free boarding on Carriacou during data collection. I am also sincerely thankful to Richard Phillip and the fishermen on Ronde island for providing me with free boarding during data collection. My data collection of the remote islands would not have been possible without safe passage via small fishing boats. As such, I am sincerely thankful to my dad, Richard Williams, for providing me with his boat to make data collection on the remote islands possible.

I would like to thank the University of Manitoba, Natural Sciences and Engineering Research Council (NSERC), St. George's University, Neotropical Bird Club (NBC) - Conservation Award, and Birds Caribbean - David S. Lee Fund for the Conservation of Caribbean Birds for providing the funding that made this project possible. I also thank Mr. Anthony Jeremiah and the Ministry of Fisheries for granting permission to collect data in Grenada's National Parks.

I am very thankful to everyone who is a part of and collaborating with the Koper lab, especially Dr. Warrington, for the much-needed support and R program training.

Lastly, I am infinitely thankful to my family especially my mom, Theresa Williams, and my partner, Lisa, for their tremendous support throughout my academic career, and to my cousin, Earl, for his unwavering support and advice. I am also genuinely thankful to Durdana and her family, Harrison and his family, Pam and Jim, and Steven and his family for their support.

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## Chapter 1.0 INTRODUCTION

### 1.1 Background:

Grenada is a tropical island located in the Southern Caribbean. The island of Grenada has relatively low terrestrial avian species richness and is host to approximately 35 recorded species of terrestrial resident birds (see literature review) including the critically endangered Grenada Dove (*Leptotila wellsi*), the endangered Grenada Hook-billed Kite (*Chondrohierax uncinatus mirus*), and the near endemic Lesser Antillean Tanager (*Tangara cucullata*) and Grenada Flycatcher (*Myiarchus nugator*) (Bangs, 1907; Lack & Lack, 1973; Bierregaard, 1994; Thorstrom, & McQueen, 2008; Rusk, 2009; The IUCN Red List of Threatened Species [IUCN], 2017). Additionally, Grenada is purported to be home to four avian species (Scaly-breasted Thrasher, *Margarops fuscus*; Brown Trembler, *Cinclocerthia ruficauda*; Purple-throated Carib, *Eulampis jugularis*; Antillean Euphonia, *Euphonia musica*) whose ranges are restricted to the Lesser Antilles and are of unknown conservation status (Rusk, 2008). However, there are no known comprehensive studies surveying all terrestrial avian species across the extent of the entire tri-island state of Grenada. This means that for some endemic and restricted-range species, such as the Grenada Flycatcher and Lesser Antillean Tanager, very little is known about their true conservation status.

Previous avian studies in Grenada have employed both visual and acoustic means of identification by using transects, but these studies focused only on particular species such as Bananaquit (*Coereba flaveola*) (Wunderle, 1981; Wunderle, 1983; MacColl & Stevenson, 2003), the Grenada Hook-billed Kite (Blockstein, 1991; Thorstrom et al., 2001; Thorstrom and Mcqueen, 2008), and the Grenada Dove (Blockstein, 1988; Rusk, 2008; Rivera-Milán et al., 2015). Furthermore, other documentation of Grenada's avifauna includes past natural history sighting by Groome (1970), Lack and Lack (1973), and citizen science bird sightings on eBird. Although these

data present a general understanding of the avifauna in Grenada, they were conducted many decades ago, were not conducted using random sampling, and sample location may be influenced by observer bias. Additionally, population size, densities, and distribution of entire groups of terrestrial birds on Grenada have not been examined to date.

## **1.2 Problem Statement:**

Grenada is experiencing rapid economic developmental changes and habitat conversion that may be affecting the conservation status of the island's avifauna species. For example, extensive anthropogenic changes have greatly diminished the island mangroves, which provide essential nesting, roosting, and feeding habitat for a variety of Grenada's passerines and marine birds (Rusk, 2009). In 2003, the Levera wetland, the largest remaining mangrove wetland in Grenada, was mostly destroyed for development (Rusk, 2009). Although the Levera mangrove was established in 2012 as the only RAMSAR site (a wetland of international importance) in Grenada, a major hotel development project started in 2016 that is resulting in further loss and degradation of the mangrove (Levera Trading Co., 2016). Development in Grenada has also converted many forested areas into cultivated lands (Henderson & Berg, 2006) and to date, the effects of this development on Grenada's wildlife are largely unknown.

Many previous studies have revealed how colonization and urbanization can lead to the loss of island biodiversity. For example, in the Hawaiian archipelago, a catastrophic wave of extinction followed the arrival of humans (Boyer, 2008). Hawaiian terrestrial birds disappeared as colonists intensified agricultural practices including clearing forests, raising domestic animals, and cultivating crops (Steadman, 1995). Approximately 56 species of terrestrial birds from the five largest Hawaiian Islands (Maui, Molokai, Oahu, Hawaii, and Kauai) went extinct since the arrival of the Europeans in the 18<sup>th</sup> century (Boyer, 2008), and numerous authors documented that these

extinctions were the result of human activities (Duncan, Blackburn, & Worthy, 2002; Roff, & Roff, 2003; Duncan, & Blackburn, 2004; Boyer, 2008). Similarly, other island ecosystems such as Madagascar (Allnutt, 2008) and Mauritius (Quammen, 2012) have experienced biodiversity loss because of colonization and urbanization.

To help us avoid future loss of terrestrial species in Grenada, we need baseline data to serve as a foundation for monitoring changes in avian abundance and distribution, and to quantify effects of ecological changes such as land use types and vegetation structure. Baseline data will be of great importance considering that the conservation status, risk of extinction and population trends of most resident terrestrial avifauna in Grenada is unknown (see Table 1).

### **1.3 Project Significance:**

To identify any birds or bird habitats that are of conservation concern, I needed to obtain baseline data for the distribution and habitat use of Grenadian birds with a keen focus on the endemic and restricted-range species. This can inform the Grenadian government of potentially important bird areas that need protection. Additionally, baseline information can inform the habitat requirement for similar species across the Caribbean.

Information on Grenada's land bird abundance and distribution are essential in developing management plans for existing protected areas such as the Grand Etang National Park and Mount Hartman Dove Sanctuary. This research is of great importance because the population trend of all terrestrial avian species in Grenada except the Grenada Dove and the Grenada Hook-billed Kite, which have decreasing population trends, are unknown (see Table 1) (IUCN, 2017; Campbell, 2019). Additionally, conservation status of only two terrestrial avian species in Grenada are known, the endangered Grenada Hook-Billed and the critically endangered Grenada dove (IUCN, 2017; Campbell, 2019). Although the IUCN (2017) has listed the status of many Grenadian avian

terrestrial species as ‘Least Concern’ throughout their geographic range, this has not been informed by scientific surveys determining population sizes, densities or distribution. Furthermore, anthropogenic habitat alteration may be influencing the conservation status of Grenadian avifauna, and as such, this study present baseline information that can be used to assess the future population trends of Grenada’s terrestrial birds which will aid in bird conservation and management decisions.

#### **1.4 Objectives:**

The main goal of this study was to identify the distribution, diversity, and abundance of Grenadian land birds across the extent of Grenada, focusing on endemic and restricted-range terrestrial species, and to identify how anthropogenic habitat degradation and land use has affected the composition of avian communities. The underlying objectives of this study included:

1. Comparing the diversity and richness of all land bird species across the extent of the state of Grenada and the other surveyed Grenadine islands.
2. Determining the habitat preferences of key focal (restricted range) and endemic species.
3. Examining the relationship between human activity and economic development and avian species distribution, diversity, and abundance.
4. Identifying any Grenadian land bird or land bird’s habitat of conservation concern.

The long-term goal I hope this study will inspire to set up a bird monitoring program in Grenada for the conservation of Grenada’s resident land birds.

#### **1.5 Research Hypothesis and Prediction:**

If there are no effects of anthropogenic habitat alteration (habitat degradation and land use) on Grenadian resident land birds’ distribution, diversity, and abundance, then across the entire island of Grenada, there will be no statistically significant difference between the distribution,

diversity, and abundance of Grenadian resident land birds relative to habitat degradation and land use.

If there are effects of anthropogenic habitat alteration on Grenadian resident land birds' distribution, diversity, and abundance, then land-use areas associated with heavy human use (example urban areas) in Grenada will be associated with a change in the distribution, diversity, and abundance of particular Grenadian avian species. I predicted that anthropogenic effects on the distribution and abundance of affected species will mainly be seen in habitat specialists. I also predicted that areas of human activity and development will be correlated with a change in the diversity of avian communities. Specifically, areas of built communities and cities would have fewer habitat specialist species as opposed to undisturbed habitat (Lancaster & Rees, 1979).

#### **1.6 Limitations:**

The main limitation of my work is that I measured bird abundance but not nesting success or other measures of reproductive productivity such as breeding productivity including clutch size, nesting mortality, and length of nest cycle. Although other measures of productivity are typical of this kind of survey, species could occupy a habitat without breeding there, and this alters the interpretation of bird observations.

Another limitation was the variation in seasonal breeding activities. Bird activities such as mating displays and vocalizations and nest buildings are most conspicuous during their breeding seasons. To get a proper estimate of Grenada's land birds, I strategically chose to collect data during the wet/rainy season, which corresponds with the breeding season for most land birds (The World Bank Group, 2017).

A different limitation of this study was the weather conditions during the wet or breeding field season in Grenada. During periods of rainfall, the activities and vocalizations of many land

birds decreased because some species may have been less likely to fly for extended periods during showers and it would require more energy for them to vocalize and overcome the noisy environment that the rain created. To mitigate this weather limitation and increase the validity of my data, I cancelled surveys during periods of heavy rains or strong wind > 20 km per hour. If surveys for a particular field site was cancelled due to weather, I sampled those sites at a later date ( $n = 6$  out of 54 field sites) to standardize my field method and to yield better estimates of species abundance at those sites (Ralph et al. 1995).

I conducted surveys using both the dependent double-observer and single-observer survey methods (as explained in the methods). The double-observer survey method was employed throughout the field season. The double-observer method of data collection not only decreased weather induced limitations but also increased the validity of my data, because two observers are more likely to detect and identify a bird as opposed to a single observer. My perceptibility as the single observer was generally high and had a mean value of 84%. As such, I also conducted single observer surveys. A more detailed explanation of how the double-observer survey method increased the validity of my data is discussed in the methods chapter.

Another limitation of this study was any potential disturbance from human activities. Human activities such as noise pollution from car traffic and motorcycling (Sastre, Ponce, Palacín, Martín, & Alonso, 2009) and light pollution (Miller, 2006) can decrease the abundance and detectability of bird species. To minimize the effect of human disturbance, I collected data at dawn when human activities tend to be lowest on Grenada. I also collected data at dusk as previous research on the detectability of Grenada's land birds found that some species were more likely to be detected in evenings compared to mornings (Bergen, 2020).

## **Chapter 2.0 LITERATURE REVIEW**

### **2.1 Importance of Baseline Surveys for Estimating Population Trends:**

Baseline surveys have been widely employed to gain ancillary and biological data needed to investigate environmental change (e.g. ecological cycles such as forest fires and climate change) and environmental impacts of a variety of human activities (Stofan & Grant, 1978). A baseline study of a population builds a foundation of information with a specified degree of accuracy toward which change can be measured (Russell & Harshbarger, 2003). Baseline surveys are important because they allow researchers to quantify critical parameters such as population trends over time (Russell & Harshbarger, 2003). When conducting avian studies, baseline surveys allow researchers to understand how avian species react to natural or human-caused environmental changes, and how environmental changes affects avian species' fitness (Stofan & Grant, 1978; Russell & Harshbarger, 2003). As such, it is important to conduct avian baseline studies to establish data that can be used to measure how species react to environmental changes.

In Grenada, the population trend of upland terrestrial avian species, as opposed to sea and wetland bird species (Wunderle, 2008), is not well known. In fact, the only known population trends of the 35 recorded (Lack and Lack, 1973; Rusk, 2009) resident terrestrial land birds in Grenada is that of critically endangered Grenada Dove (IUCN, 2017) and the endangered Grenada Hook-billed Kite (Thorstrom et al., 2008; Campbell, 2019), both of which have declining population trends as a result of land-use change (Ruck, 2009; Campbell, 2019). Such information indicates that other species might also have declining population trends. As the terrestrial ecosystem in Grenada is rapidly changing through anthropogenic activities accommodating agriculture and tourism development (Lack and Lack, 1973; Rusk, 2009), my thesis research focused specifically on resident terrestrial birds in order to quantify the effects of anthropogenic

environmental change on the terrestrial avian population by producing the first baseline data on Grenada's terrestrial avian species.

## **2.2 Factors Influencing Birds' Habitat Selection:**

Habitat selection is defined as a stratified process of behavioral responses that may result in the unequal use of habitats to influence fitness and survival of individuals (Hutto 1985; Block & Brennan 1993; Jones, 2001). The factors that influence avian species' habitat selection also influence the abundance and distribution of avian species in an ecosystem. Such factors include, but are not limited to, both direct and indirect predator avoidance (Verdolin, 2006; Cresswell, 2008; Dinkins et al., 2012; Dinkins, Conover, Kirol, Beck, & Frey, 2014), nest predation (Morton, 2005; Marzluff et al., 2007), both intraspecific and interspecific competition (Svardson, 1949; Cody, 1985; Martin, 1993; Petit & Petit, 1996), and disturbance (Cody, 1985).

Predator avoidance: Predator avoidance behaviours influence habitat selection directly by the avoidance of visual or physical encounters with predators or indirectly by reducing the use of unsafe habitats (i.e. avoiding habitats associated with higher predation risks) (Verdolin, 2006; Cresswell, 2008; Dinkins et al., 2012; Dinkins et al., 2014). An animal's perceived risk of predation influences both the direct and indirect mechanisms of predator avoidance (Cresswell 2008, Martin and Briskie, 2009). For instance, Greater Sage-Grouse (*Centrocercus urophasianus*) utilized habitat with lower densities of avian predators (Dinkins et al., 2012), suggesting that the possible mechanism for this behavioral pattern was direct predator avoidance. However, this pattern could also be explained as the avoidance of habitats correlated with high predator densities, such as habitat containing anthropogenic features such as power lines and oil and gas structures (Dinkins et al., 2012). Anthropogenic features can also be used as nest structures or perches for avian predators (Dinkins et al., 2012). Several studies have found that avian predators use areas

around power lines for foraging and power lines for nesting or perching (Prather & Messmer, 2010; Slater & Smith, 2010; Coates et al., 2014; Howe et al., 2014; Dinkins et al., 2014) demonstrating that avoidance of anthropogenic features can indirectly influence prey species habitat selection.

Nest predation: The influence of nest predation on overall habitat selection by avian species is complex (Marzluff et al., 2007). Research has shown that avian prey species may select less preferred (lower quality) nesting habitat to decrease chances of nest predation and to increase their nesting success (Morton, 2005; Marzluff et al., 2007). Such habitat selection decisions, however, can have far-reaching consequences. The Ovenbird (*Seiurus aurocapillus*) is a classic example of an area sensitive and forest interior songbird (Gibbs & Faaborg, 1990; Freemark & Collins, 1992) that selected habitat of poorer quality due to increased nest predation in the preferred higher quality habitat (Morton, 2005; Marzluff et al., 2007). Due to increased nest predation by the eastern chipmunks (*Tamias striatus*), Ovenbirds resorted to nesting at forest edges where eastern chipmunks are absent (Morton, 2005); however, by selecting habitat to avoid nest predation, the Ovenbirds inadvertently exposed itself to the negative effects of edges predation where reproductive success was much lower (Morton, 2005; Marzluff et al., 2007). The ecological term to describe this situation is an ecological trap (Morton, 2005). Settling in ecological traps and ignoring predator occurrence may be increasingly common in a world dominated by human where indirect and direct actions of people increase predator occurrences without grossly changing other cues that birds used to select habitat (Marzluff et al., 2007).

Competition: There are many hypotheses examining the relationship between competition and avian habitat selection, including the ideal free and ideal dominance distribution theories (Fretwell & Lucas, 1970). All individuals in an ideal free distribution are assumed to be free or equally capable of settling in all habitats (Petit & Petit, 1996). When preferred habitat begins to

fill to some critical density, newly arriving individuals refrain from settling in preferred habitat and choose to settle in a less suitable, yet less crowded habitat where their fitness will be greater than or equal to their fitness had they decided to settle in the high-density habitat (Petit & Petit, 1996). In contrast, an ideal dominance distribution comes about when individuals have different competitive capabilities (Petit & Petit, 1996). In such a model, subdominant individuals are excluded from preferred habitats through territorial behaviours of dominant individuals, thus, forcing subdominant individuals into less suitable habitats (Petit & Petit, 1996). The territorial behaviour of the dominant individual in the preferred habitat serves to prevent high individual densities that will decrease the dominant individuals' fitness (Petit & Petit, 1996). Both the ideal free and ideal dominance distribution theories are based on specific assumptions. The ideal free distribution theory assumptions are that: 1) all individuals are equally able to settle in all habitats and 2) within a habitat type, all individuals have the same expected reproductive success (Fretwell & Lucas, 1970; Petit & Petit, 1996). On the other hand, the main assumption of the ideal dominance distribution theory is that some individuals are more capable than others to settle in any given habitat (Fretwell & Lucas, 1970; Petit & Petit, 1996). The general assumption of both the ideal free and ideal dominance distribution theory are that 1) at high population densities, fitness is lower by some mechanism such as risk of predation or increased competition for food, and 2) birds behave "ideally" when faced with a choice of habitat (that is, under the influence of natural selection), thus, selecting a habitat that will maximize their fitness (Fretwell & Lucas, 1970; Petit & Petit, 1996).

Before conducting any avian study that examines the abundance and distribution of species, it is important to understand how competition influences the habitat selection of bird species so that proper interpretation can be drawn from the field data. As my thesis is focused on the

distribution, diversity, and abundance of avian species across the tri-island state of Grenada, it was important to consider different distribution theories and their associated assumptions in order to understand why bird species may select particular habit types across Grenada.

Habitat disturbance: Habitat disturbance or anthropogenic alteration of avian habitats such as habitat fragmentation (Stratford & Stouffer, 1999; Laurance et al., 2011) and habitat loss (Durães, Carrasco, Smith, & Karubian, 2013) can influence species habitat selection by forcing animals to select less preferred habitat to increase their chances of survival. Fragmentation of habitat decreases the abundance and richness of forest-interior species (Stratford & Stouffer, 1999; Laurance et al., 2011). Such species select alternative habitat to avoid the negative effects (such as increased risk of predation (Yahner & Scott, 1988)) that can result in fragmented habitat. Terrestrial avian species, especially habitat specialists, often avoid selecting anthropogenically disturbed habitats (Stouffer & Bierregaard, 1995; Stratford & Stouffer, 1999; Ferraz et al., 2007; Laurance et al., 2011; Durães et al., 2013). Human-induced habitat loss through clear cutting and fragmentation can influence the overall abundance of understory avian species by forcing them to select alternative but potentially predation-prone habitats (Durães et al., 2013). Additionally, habitat fragmentation from human activities increases forest edge effects on avian species. Forest interior species select habitat away from introduced forest edge, and their abundance and richness decreased when forest edges were introduced in the landscape (Ribeiro & Penido, 2015).

### **2.3 Impact of Human Activity on Avian Communities:**

Human activities can have adverse negative effects on the overall fitness and habitat use of avian communities (Phillips, Nol, Burke & Dunford, 2005; Vickery et al., 2001). Human activities such as urbanization, farming or agricultural intensification and practices, and forestry practices can increase avian nest parasitism (Phillips et al., 2005), increase the risk of avifauna extinction

(especially in developing countries), decrease extent of foraging and breeding habitat (Vickery et al., 2001; Green, Cornell, Scharlemann & Balmford, 2005), and alter bird species abundance and richness (Moorman & Guynn, 2001; Sekercioglu, 2002).

Urbanization: Urbanization is one of the world's leading causes of species loss (Czech et al. 2000; DeStefano & DeGraaf 2003). Therefore, it is essential to understand how urbanization affects avian communities so bird conservation techniques can mitigate the effects of urbanization. Urbanization can impact avian communities by reducing the density of many native species, especially habitat specialists, and alternatively, by increasing the density of some well-adapted avian species (Clergeau, Savard, Mennechez, & Falardeau, 1998; Germaine, Rosenstock, Schweinsburg, & Richardson, 1998; Savard, Clergeau, & Mennechez, 2000), some of which may be invasive (McKinney, 2002). The abundance and diversity of habitat specialists tend to decline in habitat fragments adjacent to exurban development (development occurring outside of city limits) despite the availability of apparently suitable habitat (Phillips et al., 2005). Simultaneously, the diversity and density of habitat generalist species, including nest predators such as Brown-headed Cowbirds (*Molothrus ater*), tend to increase (Kluza, Griffin, & DeGraaf, 2000; Mancke & Gavin, 2000; Phillips et al., 2005). A study conducted in Ontario, Canada on the impacts of low density, exurban housing developments on the breeding of Wood Thrushes (*Hylocichla mustelina*) revealed that urbanization directly influenced the abundance of Wood Thrushes (Phillips et al., 2005). The study showed that Wood Thrushes experience significantly higher rates of nest parasitism by Brown-headed Cowbirds when breeding in woodlots with embedded houses (houses that penetrate the border of the forest) than when breeding in undeveloped woodlots (houses greater than 100 m away from forest edge) or woodlots with adjacent houses (houses less than 100 m away from forest edge) (Phillips et al., 2005). Consequently, the increase in nest predation in

developed woodlots resulted in significant reductions in seasonal productivity (Phillips et al., 2005).

Agriculture: Agriculture can have profound negative effects on bird communities globally, and with world food demand expected to increase more than twofold by 2050 (Bongaarts, 1996; Tilman, Cassman, Matson, Naylor, & Polasky, 2002), the effects of farming on avian communities are expected to intensify (Green et al., 2005). Multiple data sources indicate that the effects of farming and agriculture on wild nature, especially bird communities, is now greatest in developing countries (Green et al., 2005). To understand the significant threat that farming posed on wild nature, Green et al. (2005) used and analyzed data from Birdlife International World Bird Database and revealed the problems faced by all 1923 species of globally near-threatened and threatened birds. The data indicated that farming (including agricultural intensification and conversion of forest to farmland) is the single most significant threat to bird species listed as threatened (totaling to 37% of threats), and threatened species in developing countries are higher than those in developed countries (40% or 1039 species and 24% or 225 species respectively) (Green et al., 2005). For near-threatened species in developing and developed countries, the scale of the threat posed by farming is greater (totaling to 57% or 687 species and 33% or 95 species respectively) than those of threatened species (Green et al., 2005). As it is possible that these near-threatened species may become threatened in the future, this means that farming is a growing threat to avifauna (Green et al., 2005). In general, bird communities tended to avoid using farmlands as nesting habitat, and instead, used a much higher proportion of forested habitat compared to farmlands (Best, Freemark, Dinsmore, & Camp, 1995). As such, avian communities were typically found to be much more abundant in forested habitats than in farmlands (Best et al., 1995). This is

not surprising considering that agricultural intensification and practices decrease bird foraging and breeding habitat (Vickery et al., 2001).

Forestry practices: Changes in plant species structure and composition (Brokaw, 1985; Phillips & Shure, 1990; Moorman & Guynn, 2001), resource availability (Levey, 1998; Moorman & Guynn, 2001), and microclimate (Phillips & Shure, 1990; Moorman & Guynn, 2001) following canopy gap creation from forestry practices can alter avian habitat use. Creating group selection openings (human-made canopy gaps) can increase the habitat use and abundance of habitat generalist field-edge species such as the Brown-headed Cowbird (Moorman & Guynn, 2001). Alternatively, forest interior or specialist species tend to avoid group-selection opening, and these species are more abundant in and utilize closed-canopy forested habitats (Moorman & Guynn, 2001). Şekercioglu (2002) found that avian species richness and abundance of both forest generalist and forest-dependent birds were highest in forested (unlogged or lightly logged) areas, indicating that many avian species may be using habitat with few human disturbances. As such, it is essential to understand how human activities such as forestry practices affect avian habitat use when studying their distribution and composition.

#### **2.4 Habitat Selection and Seasonality:**

Avian species are known to select different habitats because of seasonal changes throughout the year or their annual cycle (Rice, Anderson, & Ohmart, 1980; Brandt & Cresswell, 2008; Santangeli & Cardillo, 2012). In tropical regions, passerine species are observed selecting different habitat during the dry and rainy season (Karr & Freemark, 1983; Brandt & Cresswell, 2008). Often, passerine species select habitats with a larger home range during the dry season as opposed to the rainy season (Brandt & Cresswell, 2008), because there is less available food and water resources during the dry season (Brandt & Cresswell, 2008). Similar patterns of habitat

selection were observed during passerine species non-breeding (dry) and breeding (wet) seasons (Santangeli & Cardillo, 2012). It is important to understand how seasonal changes such as dry and wet seasons influence passerine habitat use and selection to understand how ambient environmental factors affect avian species distribution and abundance.

## **2.5 Conservation of Island Species:**

Avian conservation, especially on islands, is essential to the long-term existence of many restricted-range and endemic bird species. However, research efforts tend to be focused more on mainland species in comparison to island species (Brooks, Collar, Green, Marsden, & Pain, 2008). Conservation of island avifauna is important because island birds are more susceptible to extinction than mainland species (De Lima, Bird, & Barlow, 2011), partly because many island species have a very small geographic range, which is a good indicator of species' risk of extinction (Trevino, Skibieli, Karels, & Dobson, 2007; Gaston & Fuller, 2009). For instance, there are 116 known avian extinctions among restricted-range island species, which represents 86.6% of all avifauna extinctions; this percentage of extinction is over 40 times higher than other avian species indicating that restricted range species are indeed more prone to extinction (Johnson & Stattersfield, 1990; Stattersfield, Crosby, Long, & Wege, 2005). In fact, the total number of restricted-range avian extinctions is possibly much higher than previously estimated considering that many island birds probably went extinct before they were documented (Steadman, 1995; Holdaway, Worthy, & Tennyson, 2001). Considering the vulnerability of island ecosystems to climate change and long-term disturbance, this high avian extinction risk on islands is likely to increase (Benning, LaPointe, Atkinson, & Vitousek, 2002; Gillespie, Claridge, & Roderick, 2008). Accordingly, for conservation purposes, restricted range species are frequently considered a high priority (Trevino et al., 2007).

Importance of Caribbean Species Conservation: The Caribbean region is well known for its high level of terrestrial biodiversity and, for some taxa, notably high levels of endemism in comparison to other parts of the world (Wunderle Jr, 2008). Moreover, the Caribbean is considered a global biodiversity hotspot and is ranked in the top six of the twenty-five identified global biodiversity hotspots (Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000; Wunderle Jr, 2008).

Like most developing regions around the world, the Caribbean has experienced high extinction rates (Wunderle Jr, 2008). Immediate conservation efforts are needed to mitigate species extinction in the Caribbean. Furthermore, targeting conservation efforts towards island avifauna species and their habitat can act as an ‘umbrella’ and help conserve other fauna species in the Caribbean (Hanser & Knick, 2011).

The importance of the conservation of Grenadian bird species: As Grenada is a small island located to the extreme south of the Lesser Antilles archipelago, threats towards the island’s resident terrestrial avifauna persistence may be amplified (Johnson & Stattersfield, 1990). Currently, Grenadian terrestrial avifauna faces some conservation threats including the introduction of invasive species such as the Indian mongoose (*Herpestes javanicus*) (Martin, 2007; Choudhary et al., 2013), habitat loss due to tourism and agriculture development (Lack and Lack, 1973; Rusk, 2009) and natural disasters (Koper and Grief, 2016).

The Indian mongoose was introduced to many Caribbean islands including Grenada during the 1870’s in an attempt to control snake and rat populations that inhabited sugar cane plantations (Choudhary et al., 2013). Although I could not find any study that looked at the effects of mongoose on Grenada’s fauna, research on other islands have shown that invasive populations

have negative effects on native fauna including birds, small mammals, invertebrates, and reptiles (Choudhary et al., 2013).

Since the colonization of Grenada by European settlers in the 1600's, the island has experienced extensive habitat conversion for agriculture (Ricklefs & Bermingham, 2008). In 2005, over 3/5 or 60% of the land use on the island of Grenada was dedicated to plantations, urban use or pasture (Henderson & Berg, 2006). Additionally, natural disasters such as Hurricane Ivan in 2004 and Hurricane Emily in 2005 have caused habitat alteration and destruction (Koper and Grief, 2016), demonstrating that both anthropogenic and natural disturbances may be influencing the conservation status of island's endemic and restricted-range avifauna species.

## **2.6 Natural History of Grenada's land bird Species:**

In the absence of natural-history and behavioral information, we cannot determine if detected differences among species have any bearing on individuals' choices of habitat (Martin, 1998; Jones 2001). As such, it is vitally important to understand the natural history of Grenada's terrestrial bird species in order to identify species' habitat choice and to pinpoint how human activities or the ambient environment may be influencing habitat choice.

Grenada has 35 recorded terrestrial avian species, and Table 1 below gives a general summary of these species (Lack & Lack, 1973). Left out of the list of species in Table 1 was the *Tyto alba* (Common Barn-owl), which is a nocturnal species, because avian surveys for this research were conducted during the day. I only discussed natural history of a selection of species listed in Table 1 (see subsections 2.6.1 to 2.6.4) as an example of the diverse natural histories of some of the land birds residing in the tri-island state of Grenada.

**Table 1. A summary of the resident terrestrial land bird species recorded in Grenada (Lack & Lack, 1973; IUCN, 2017; Campbell, 2019).**

Species common name	Scientific name	Order	Conservation status globally	Population trend globally	Conservation status in Grenada	Population trend in Grenada	Observed after the year 1972 (Lack et al., 1973)	Reference
Scaly-naped pigeon	<i>Patagioenas squamosa</i>	Columbiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Eared dove	<i>Zenaida auriculata</i>	Columbiformes	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Zenaida dove	<i>Zenaida aurita</i>	Columbiformes	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Common ground dove	<i>Columbina passerina</i>	Columbiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Grenada dove	<i>Leptotila welshi</i>	Columbiformes	Critically endangered	Decreasing	Critically endangered	Decreasing	√	IUCN, 2017
Ruddy quail-dove	<i>Geotrygon montana</i>	Columbiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Mangrove cuckoo	<i>Coccyzus minor</i>	Cuculiformes	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Smooth-billed ani	<i>Crotophaga ani</i>	Cuculiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Green-throated carib	<i>Eulampis holosericeus</i>	Apodiformes	Least Concern	Unknown	Unknown	Unknown	√	IUCN, 2017
Antillean crested hummingbird	<i>Orthorhynchus cristatus</i>	Apodiformes	Least Concern	Unknown	Unknown	Unknown	√	IUCN, 2017
Rufous-breasted hermit	<i>Glaucis hirsutus</i>	Apodiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Gray-rumped swift	<i>Chaetura cinereiventris</i>	Apodiformes	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Purple-throated carib	<i>Eulampis jugularis</i>	Apodiformes	Least Concern	Unknown	×	×	×	IUCN, 2017
House wren	<i>Troglodytes aedon</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Tropical mockingbird	<i>Mimus gilvus</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Cocoa thrush	<i>Turdus fumigatus</i>	Passerine	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Black-whiskered vireo	<i>Vireo altiloquus</i>	Passerine	Least Concern	Unknown	Unknown	Unknown	√	IUCN, 2017
Bananaquit (black and yellow morph)	<i>Coereba flaveola artermia</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Lesser Antillean tanager	<i>Tangara cucullata</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Shiny cowbird	<i>Molothrus bonariensis</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Carib grackle	<i>Quiscalus lugubris</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Blue-black grassquit	<i>Volatinia jacarina</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Yellow-bellied seedeater	<i>Sporophila nigricollis</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Lesser Antillean bullfinch	<i>Loxigilla noctis</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Black-faced grassquit	<i>Tiaris bicolor</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Spectacled thrush	<i>Turdus nudigenis</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Brown-crested flycatcher	<i>Myiarchus tyrannulus</i>	Passerine	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Caribbean elaenia	<i>Elaenia martinica</i>	Passerine	Least Concern	Unknown	Unknown	Unknown	√	IUCN, 2017
Yellow-bellied elaenia	<i>Elaenia flavogaster</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Gray Kingbird	<i>Tyrannus dominicensis</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Grenada flycatcher	<i>Myiarchus nugator</i>	Passerine	Least Concern	Decreasing	Unknown	Unknown	√	IUCN, 2017
Tropical Kingbird	<i>Tyrannus melancholicus</i>	Passerine	Least Concern	Increasing	×	×	×	IUCN, 2017
Euler's Flycatcher	<i>Lathrotriccus euleri</i>	Passerine	Least Concern	Stable	×	×	×	IUCN, 2017
Scaly-breasted Thrasher	<i>Allenia fusca</i>	Passerine	Least Concern	Unknown	×	×	×	IUCN, 2017
Blue-hooded Euphonia	<i>Euphonia elegantissima</i>	Passerine	Least Concern	Unknown	×	×	×	IUCN, 2017
Lesser Antillean Euphonia	<i>Euphonia flavifrons</i>	Passerine	Least Concern	Stable	Unknown	Unknown	√	IUCN, 2017
Broad-winged Hawk	<i>Buteo platypterus</i>	Accipitriformes	Least Concern	Increasing	Unknown	Unknown	√	IUCN, 2017
Grenada Hook-billed kite	<i>Chondrohierax uncinatus mirus</i>	Accipitriformes	Endangered	Decreasing	Endangered	Unknown	√	Campbell, 2019

### 2.6.1 Eared Dove (*Zenaida auriculata*):

Description: The Eared Dove, as the name implies, is a dove species that has a dark horizontal strip posterior to both eyes that resemble an ear on the species (Houvener, 2014). Eared doves are similar to the Mourning Dove (*Zenaida macroura*) in both pattern and colour; however, they have shorter tails, darker black bills, and plumage of bronze yellow metallic iridescence on the sides of neck and nape (Houvener, 2014). Eared Doves have brown and gray plumage (The Cornell Lab of Ornithology, 2010) with black primaries, black bars on the outer scapulars, black spots beneath the ear coverts, and a pink to vinaceous underbody and breast (Houvener, 2014).

Diet: Eared Doves primarily feed on seeds picked up off the ground, but they are known to exploit many available foods (Houvener, 2014). The eared dove's diet consists of small seeds collected from the ground (Houvener, 2014), insect pupae, caterpillars, snails, and aphids (Gibbs, Barnes, & Cox, 2001; Ranvaud et al., 2001; Houvener, 2014).

Geographic Range: Eared Doves have a geographic range that spans across the Caribbean and South America; they range from southern Argentina to Trinidad and other Caribbean islands including Grenada (Bucher, 1982; Gibbs et al., 2001; Houvener, 2014).

Habitat: Eared doves occupy a diverse range of habitat. They occur in semi-arid to arid scrublands that range up to 4,400 meters above sea level (Gibbs et al., 2001; Houvener, 2014). They typically inhabit open grassland or savanna with some woodland patches or trees and avoid tropical rainforests (Gibbs et al., 2001; Houvener, 2014). Eared Dove uses dense patches of vegetation for breeding, and nest under shrub and tree canopies and thorny bromeliads (Gibbs et al., 2001; Houvener, 2014). They also frequently occupy suburban and urban zones and agricultural areas (Gibbs et al., 2001; Houvener, 2014). Eared Doves' habitat region includes tropical, terrestrial, and temperate (Gibbs et al., 2001; Houvener, 2014).

Conservation Status: The Eared Doves are listed as Least Concern by the IUCN (2017); however, their population has not been quantified, and their population trend in Grenada is unknown.

### **2.6.2 Bananaquit (*Coereba flaveola arterrima*):**

Description: The Bananaquit (*Coereba flaveola*) is a polymorphic species, which consist of two distinct colour morphs, with yellow and black plumage variants (Theron et al., 2001). Unlike most of the islands and countries where Bananaquits reside, the island of Grenada host both morph variants of this species. The yellow morph found in Grenada, *C. f. arterrima*, resembles *C.*

*f. flaveola*, and has a black head, dark gray throat, white supercilium, and lemon-yellow breast that extends to the undertail (Koper and Grief, 2016). However, *C. f. arterrima* is different from *C. f. flaveola* by lacking a yellow rump, having a solid white spot on the outer wing, a white spot on the flip side of the tail, and a white undertail (Koper and Grief, 2016). The black morph that inhabits Grenada is predominantly black and has a slight greenish-yellow wash on the breast, uppertail-coverts, and lower underpart (Koper and Grief, 2016). In general, an adult Bananaquit has an average body length of ~ 11 cm (Hayden, 2002), and Bananaquits are known for their steep downward curving black beak and deep red to pale pink flanges (Koper and Grief, 2016).

Diet: Bananaquits principal food source includes nectar from flowers (Hayden, 2002). In addition to nectar, Bananaquits feeds on a variety of other food items including insects, other small arthropods, and fruits (Hayden, 2002; Douglas, Winkel, & Sherry, 2013).

Geographic Range: The geographic range of Bananaquits include South and Latin America (mainly from northern Argentina to Mexico), most of the Caribbean islands, and on rare cases in Florida (Merola-Zwartjes, 1998; Hayden, 2002).

Habitat: Bananaquits are typically found across a diverse habitat type throughout their range (Hayden, 2002), but they are predominantly found at low elevations and hardly in high altitudes (Hayden, 2002). Habitat types in which Bananaquits reside include agricultural fields, humid rain forest, dense forest, and some desert areas (Hayden, 2002). In Grenada, Bananaquits are found in most habitats including forest edge, a variety of dry to humid areas, distributed areas, shrubby habitat, gardens, and plantation (Koper and Grief, 2016). The yellow morph in Grenada (mainland) occupies the Southwestern (Point Saline peninsula) and the Northeastern (Levera-Bathway) part of the island while the black morph in Grenada can be found throughout the entire island (Koper and Grief, 2016).

Unique characteristics: Based on molecular phylogenetic studies, Bananaquits can be divided into three clades of subspecies including the *flaveola*, *bahamensis*, and *bartholemica* group (Koper and Grief, 2016). The *Coereba flaveola arerrima*, Bananaquit subspecies in Grenada and Grenadines, belongs to the *bartholemica* group (Koper and Grief, 2016). Bananaquits that live in Grenada are unique in comparison to their counterparts throughout their range, because the black morph variant is only found on few Caribbean islands including Grenada, St. Vincent and the Grenadines, and three islands off the coast of Venezuela (Wunderle, 1981, 1983; Theron et al., 2001).

Conservation Status: The conservation status of the *C. f. arerrima* is listed as least concern by the IUCN (2017); however, the population trend for Bananaquit in Grenada is unknown.

### **2.6.3 Grenada Flycatcher (*Myiarchus nugator*):**

Description: *Myiarchus nugator* has a long, black, triangular beak with fully-developed hook and rectal bristles (Koper and Grief, 2016). *M. nugator* has plumage that is brownish-gray on the dorsal part of the body, with a gray breast and throat and light-yellow under-tail coverts and abdomen (Koper and Grief, 2016). The outer web of the primaries has a cinnamon edging, and the outer web of the secondaries, tertials and median and greater coverts has white edging (Koper and Grief, 2016). *M. nugator* has dark legs and iris (Koper and Grief, 2016). The Grenada Flycatcher is bright orange inside of its mouth, which helps distinguish it from the Brown-crested Flycatcher (*Myiarchus tyrannulus*) (Koper and Grief, 2016).

Diet: *M. nugator* feeds predominantly on fruits, seeds, katydid, and insects including caterpillars and moths (Koper and Grief, 2016).

Geographic Range: The Grenada Flycatcher as the name implies is endemic to the island of Grenada and St. Vincent and the Grenadines, and therefore, *M. nugator* has a geographic range restricted to the Lesser Antilles (Koper and Grief, 2016).

Habitat: *M. nugator* occupy habitat in secondary forest, in open areas in proximity to human settlement, and lowland evergreen forest (Koper and Grief, 2016). The presence of Grenada Flycatchers has been recorded between elevations of 0 to 900 meters (Koper and Grief, 2016).

Unique characteristics: The Grenada Flycatcher was once considered to be a conspecific of *Myiarchus tyrannulus* (Brown-crested flycatcher); however, mitochondrial DNA analysis revealed that the Grenada Flycatcher is a distinct species (Koper and Grief, 2016).

Conservation Status: The Grenada Flycatcher is listed as Least Concern by the IUCN (2017); however, their population has not been quantified, and their population trend in Grenada is unknown.

#### **2.6.4 Gray Kingbird (*Tyrannus dominicensis vorax*):**

Description: In general, Kingbirds have a flat, broad-based beak and a large head (Koper and Grief, 2016). The Gray Kingbird has a semi-concealed red-to-yellow coronal patch and a dark gray head with eye masks that are darker (Koper and Grief, 2016). They have dark legs, iris, and beak (Koper and Grief, 2016). The feathers on their wings are dark brown to dusky black, and their wing remiges and coverts have white narrow margins and their primaries tips are slightly attenuated (Koper and Grief, 2016). Both the underparts and throat are with a yellow wash on the belly and grayish tinge across the breast (Koper and Grief, 2016). They have a notched dark brown to dark tail, and black upper-tail coverts with cinnamon edges (Koper and Grief, 2016).

Diet: The primary food of Grey Kingbirds is flying insects such as beetles, flies, and dragonflies. They also feed on fruits, arachnids, and small fish and lizards (Koper and Grief, 2016).

Geographic Range: The geographic range of the Gray Kingbird extends from the Bahamas to southeastern USA (Georgia, Mississippi, North Carolina, Florida), North Central Venezuela and the Greater Antilles, and other Caribbean islands where they are residents including Grenada (Haberman, Mackenzie, & Rising, 1991; Koper and Grief, 2016).

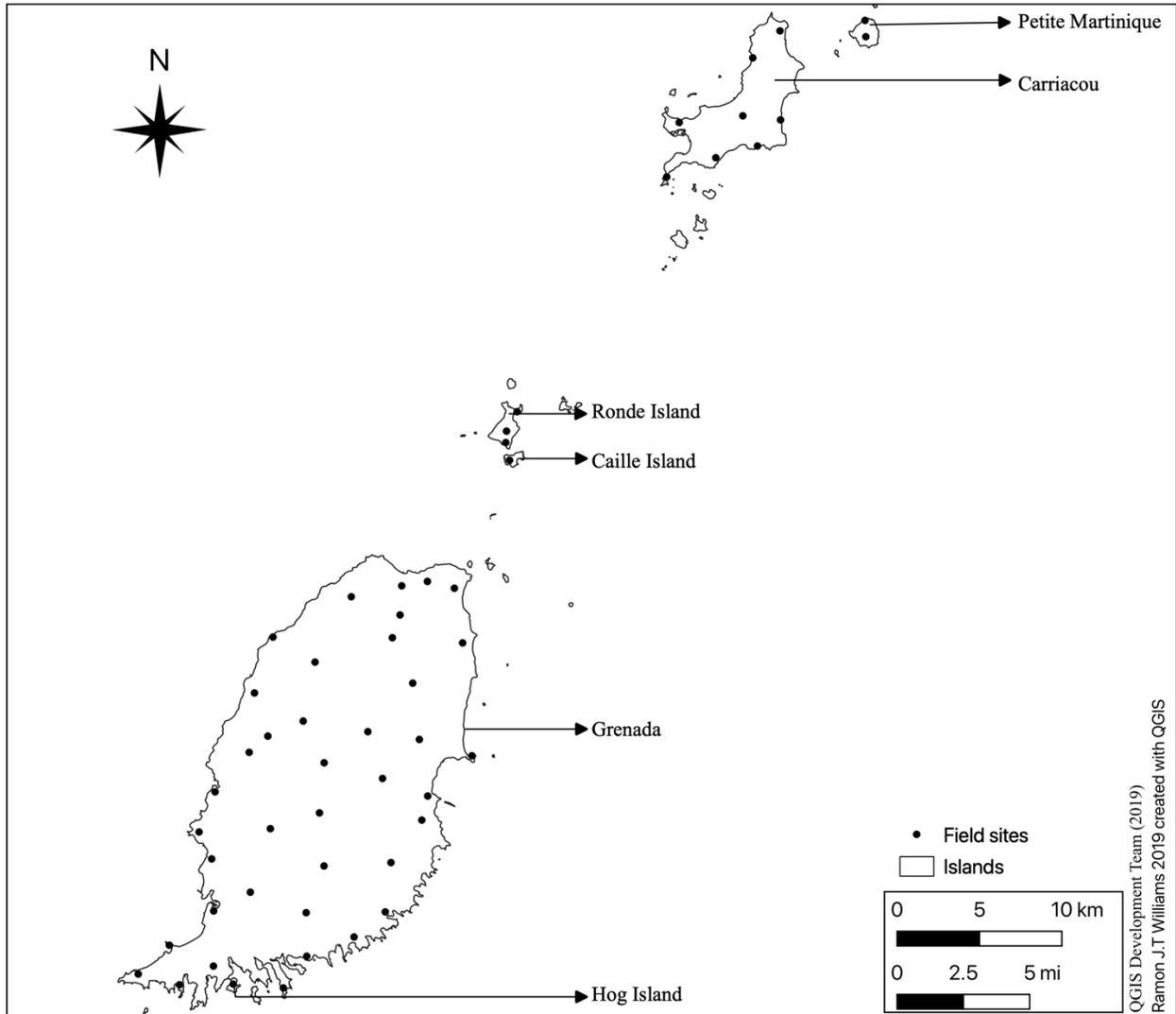
Habitat: Gray Kingbirds are found primarily adjacent to coastal areas near water; however, the Grenada's species, *T. d. vorax*, preferred habitat is open and dry areas (Koper and Grief, 2016).

Unique characteristics: There are two identified subspecies of *Tyrannus dominicensis*, which include *T. d. vorax* from the Lesser Antilles and *T. d. dominicensis* of northern South America, southeastern USA, and the Caribbean region apart from the Lesser Antilles (Koper and Grief, 2016). The Grey Kingbird on Grenada, *T. d. vorax*, was identified as the most closely related species of the *T. melancholicus* (tropical kingbird) through phylogenetic analysis (Koper and Grief, 2016).

Conservation Status: The Gray Kingbird is listed as Least Concern, and the global population throughout its geographic range is listed as stable by IUCN (2017); however, its population trend in Grenada have not been quantified.

## Chapter 3.0 STUDY AREA AND METHODS

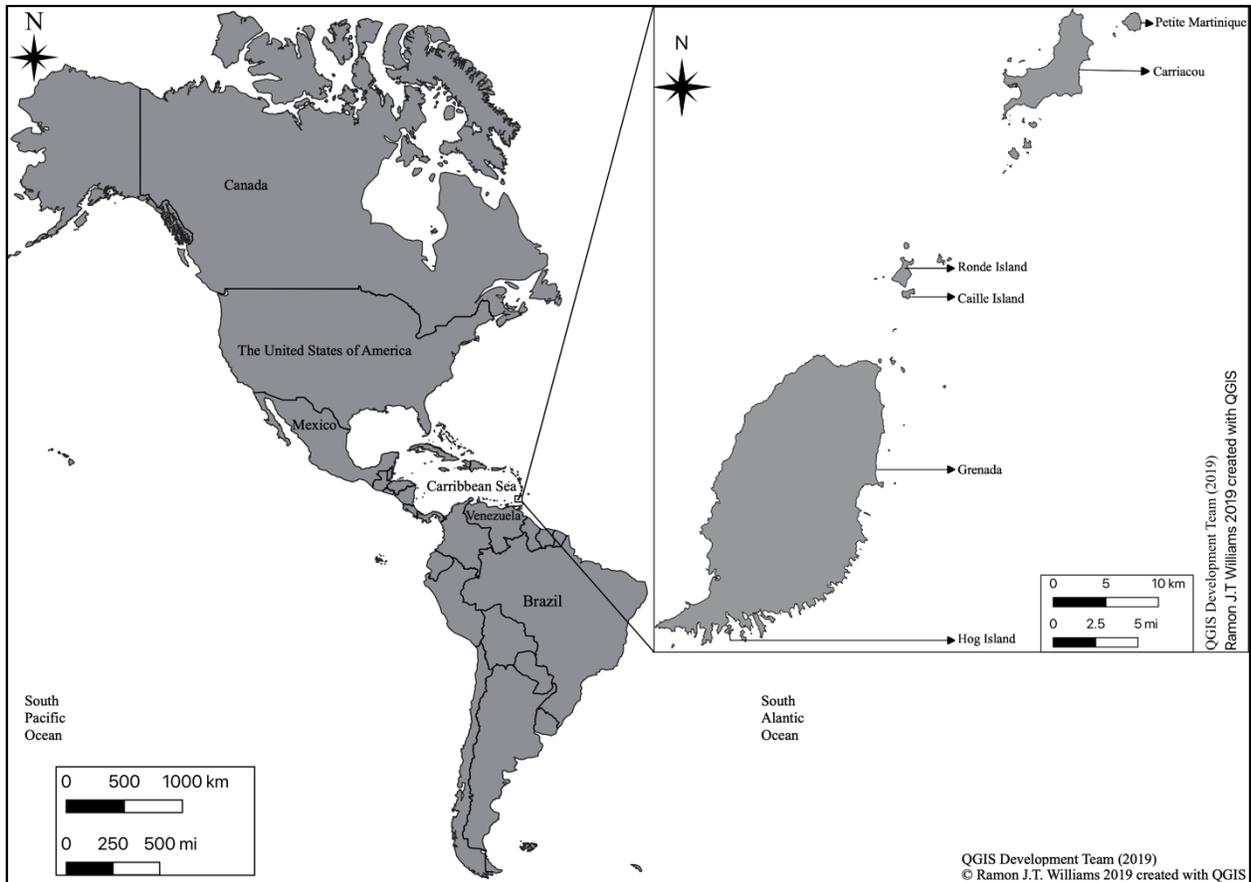
### 3.1 Study Area:



**Figure 1.** Map showing the location of my fifty-four (54) field sites across the six (6) islands surveyed in 2017.

This study was conducted throughout the country of Grenada and included all three permanently inhabited islands of the tri-island state: Grenada (12.133883°N, 61.669933°W), Carriacou (12.473567°N, 61.442567°W), and Petit Martinique (12.518300°N, 61.384333°W) along with some largely uninhabited offshore islands including Caille Island (Ile De Caille) (12.287350°N, 61.581300°W), Ronde Island (12.302433°N, 61.585167°W), and Hog Island (11.999483°N, 61.738300°W) (Figure 1). The tri-island state of Grenada is located in the southern-

most region of the Lesser Antilles archipelago in the Caribbean and is located north of Trinidad and Tobago.



**Figure 2. Map showing the geographic location of Grenada and the other islands surveyed in the Caribbean in 2017.**

Grenada is the largest oceanic island in the tri-island state. Carriacou is located 37 km north of Grenada, Petit Martinique is located 6 km east of Carriacou, and the offshore islands (except Hog Island) are located between Grenada and Carriacou (Rusk, 2009; Figure 1). Grenada has a total area of 311 km<sup>2</sup>, Carriacou has a total area of 32 km<sup>2</sup>, and Petit Martinique has a total area of 2.37 km<sup>2</sup> (Government of Grenada, 2013). The country of Grenada has a combined area of 348.5 km<sup>2</sup> (Department of Economic Affairs, 2001).

Grenada (the main island) is divided into six parishes of unequal sizes for administrative purposes (Rusk, 2009). The six parishes are St. Patrick, which is located to the north of the island,

St. Mark and St. John, which are located along the west coast, St. Andrew and St. David, which are located along the east coast, and St. George which is located to the south of the island. Across these parishes, Grenada is geographically characterized by mountainous terrain, which ascends steeply from the West Coast and gradually descends towards the East Coast (Department of Economic Affairs, 2001; Rusk, 2009). The island contains a diverse range of habitat types (Wunderle, 1985; Koper and Grieff, 2016). Forested habitats include montane forest, mature lowland forest, secondary forests of varying ages, cloud forest, and mangroves (Wunderle, 1985). Additional habitat types include secondary scrub, secondary grassland, and savanna (Wunderle, 1985; Koper and Grieff, 2016). Anthropogenic habitats include pastures, urban areas, and cultivated areas, including small row crop patches such as (okra, string bean, lettuce, corn, tomato, watermelon, sweet potato, cucumber, and bell pepper) and larger, diverse agroforest communities consisting of mixed species such as (pigeon pea, citrus, soursop, papaya, breadfruit, mango, banana, cocoa, and nutmeg) (Wunderle 1985; Koper and Grieff, 2016).

My study sights were stratified geographically to ensure I surveyed all the different habitat types of the tri-island state of Grenada and included the three Important Bird Areas (IBA) of Grand Etang, Mount Hartman and Perseverance dove sanctuary (which were identified as IBA based on seven key bird species that are all restricted to the Lesser Antilles) (Rusk, 2009). Study sites also included key habitats inland and along the coast (e.g. Woburn Bay Mangrove forests, Levera Wetlands, forests, and mixed secondary growth vegetation) as well as agricultural areas, urban sites, and other developed areas.

Carriacou and Petit Martinique are the second largest and smallest permanently inhabited islands of Grenada's tri-island state, respectively. Both Carriacou and Petit Martinique are dependencies of Grenada, and hence due to political affiliations, Grenada, Carriacou, and Petit

Martinique form the tri-island state of Grenada (Fitzpatrick et al., 2009). The rich fertile soil on Carriacou and Petit Martinique resulted in both islands experiencing extensive deforestation for agriculture and free-grazing livestock farming following European colonization (Peters, 2015). Although free grazing of livestock and agriculture continues in Carriacou, the island was estimated to be 65% forested consisting of forests and woodlands with only 135 hectares of forest designated as forest reserves, namely the High North Forest Reserve (Rusk, 2009; Turner, 2009). Forested areas on Carriacou include seasonal evergreen forest, deciduous forest, dry thorn scrub, and mangroves (Crask, 2012; Rusk, 2009).

### **3.2 Study Design:**

I used previous research on the detectability of Grenada's land birds to inform my study design (Bergen, 2020). Specifically, Bergen's (2020) results informed (1) the predicted detectability of species, (2) the appropriate time of day for surveys, (3) time of year to conduct surveys, and (4) the most efficient survey method (point counts).

#### **3.2.1 Field Sites:**

I surveyed 54 different sites from June to October during the wet season, which corresponds with the breeding season for most land birds and lasts from approximately June to December (World Bank Group, 2020). The 54 field sites were distributed among the different islands as follows: Grenada 39, Carriacou 8, Petit Martinique 2, Ronde Island 3, Caille Island (Ile De Caille) 1, and Hog Island 1.

Field sites were stratified to reflect all habitat types across the islands and to evenly cover all geographic locations within the islands. Field sites were separated by a minimum distance of at least 3 km in order to ensure that each site was independent. Within each site, I aimed to carry out 8 point-count plots which were separated by 100 meters in order to reduce the chances of double

counting individuals (Figure 3). I estimated and verified all single observer 25-m point count radius plots (see 3.3.2 below).

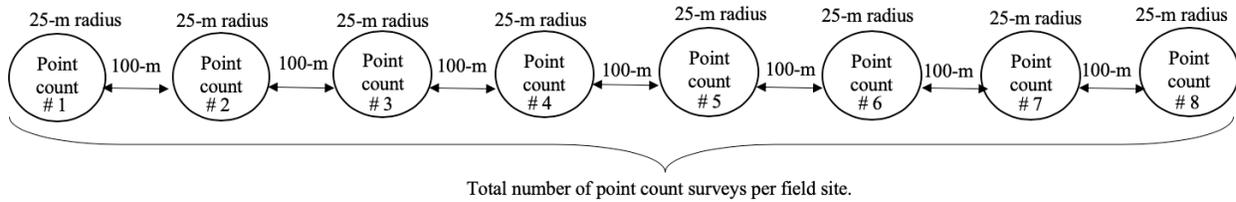


Figure 3. The arrangement and total number of point count at each field site.

### 3.3 Data Collection Method:

#### 3.3.1 Double Observer Method:

My field team and I conducted points counts by applying the dependent double-observer method as explained in Nichols et al. (2000) and recommended by Forcey et al. (2006). We employed the methods of Hutto, Pletschet, and Hendricks (1986) with slight modifications. The double-observer method means that two observers were present during all avian surveys when the double-observer survey method was conducted, and both observers collected data following Cook and Jacobson (1979) and modified by Nichols et al. (2000) for avian point count surveys, with small modifications. At each field site, one observer was appointed as the 'primary observer' and the other as the 'secondary observer.' The primary observer identified all land bird species heard and or seen and reported to the secondary observer (by hand gesture and speech) the species detected, the approximate distance of the detection from the point count, and the direction of flight or perch height of the species. Both primary and secondary observers verified the species identified. The secondary observer noted on a data sheet the species identified by the primary observer along with all other general measurements to identify the location of the species. The secondary observer also surveyed each field site for additional land bird species that the primary observer did not detect or may have missed. The secondary observer attempted to remain directly

behind the primary observer while conducting each point count survey, making visual cues less evident to the primary observer (as recommended by Nichols et al., 2000). Additional land bird species detected by the secondary observer were recorded under the secondary observer observation section on the data sheet. The number of species identified by the primary observer and by the secondary observer but missed by the primary observer were totaled at the end of each point count. Observers alternated roles of the primary and secondary observer among point counts. Alternating observer's roles allowed each observer to serve as a primary and a secondary observer for half of the surveys thus reducing observer bias (Nichols et al., 2000).

### ***3.3.2 Single Observer Method:***

The single observer method was employed (30%,  $n = 18$  out of 61 surveys) when the double-observer method was not possible, such as when field assistants were not able to attend field data collection sites (e.g. offshore islands).

### **3.4 Field Methods:**

Ambient environmental conditions, including temperature and wind speed, were measured using Kestrel (2000 Thermo Wind Meter) within each 25-m radius point count plot at the time of the survey. Two observers estimated and verified percentage cloud cover within each 25-m radius point count plot when the double observer method was conducted.

### ***3.4.1 Point Count Surveys:***

All bird species identified within and outside of a 25-meter radius of the observer(s) were recorded; however, only individuals within the 25-meter radius were used for data analyses. I assessed detectability within this 25-m radius using the computer programme DOBSERV (see section 5.1).

Point count surveys were only conducted on days with winds < 20 km per hour and without rain (Ralph et al., 1995). I aimed to conduct a total of 8 point counts at each field site (Figure 2); however, fewer than 8 point count surveys were conducted at some field sites ( $n = 6$  sites out of 54 field sites) due to wind or rain interruptions. Each point count survey was conducted for 5 minutes. Survey locations were recorded using a GPS unit (Garmin Etrex 20X Bundle). Observer(s) conducted point count surveys during two-time sampling periods, 1) from dawn to 10:00 (AM), and 2) from 16:30 until dusk (PM). One survey on Caille Island was allowed to continue until noon due to the inaccessibility of the island at other times. Surveying field sites at both dusk and dawn allowed for comparing the abundance and distribution of bird species at different times of the day. A total of 454 point counts were conducted during 61 surveys across 54 field sites.

#### ***3.4.1.1 Double Observer Point Counts:***

Before collecting double-observer research data, I trained two of my six field technicians to identify Grenadian land-bird species by both sight and sound by providing them with audiovisual examples and allocating two weeks (June 6 to June 19, 2017) for practice point counts. I then quizzed field technicians on identifying Grenadian birds to help me assess the quality of observers. I trained and examined my additional four field technicians at a later date. All my field technicians, except one, were students of St. George's University Marine, Wildlife, &

Conservation Biology program. My other technician was an alumnus of St. George's University Psychology program and had extensive experience identifying Grenadian land birds. All field technicians demonstrated an understanding of the dependent double-observer point count method and were experts in identifying Grenadian land birds given extensive ornithology training plus training specific to this study before collecting data.

From June 20 to September 15, 2017, both visual and acoustic means of identification were employed to conduct 44 dependent double-observer point counts across 42 field sites (Grenada  $n = 34$  sites, Carriacou  $n = 5$ , Petite Martinique  $n = 2$  sites, Hog Island  $n = 1$ ). Data were recorded for each 25-meter and unlimited radius point count. However, only data collected within 25-meter radius point count plots were used for data analysis.

### **3.4.2 *Habitat Structure:***

The land-use type at each field site was also recorded immediately after each point count. To classify the land-use, I made a land-use classification table and recorded the percentage of land-use type within the 25-meter radius of each point-count plot (Table 2). After each point count, percentage habitat type(s) were recorded within the 25-meter radius at each point count plot. At least two observers visually estimated percent cover of habitat type(s) and/or land use(s) within each 25-m radius point count plot. In order to aid in clarity, consistency, and to decrease observer error of habitat type classifications at each survey site, I provided the definition and a detailed example (e.g. dominant vegetation types and canopy heights) of all the different habitat types behind each datasheet. Each land use category was defined as follows: farmlands = land used for crops that have a short growing season (such as cash crops including (watermelon, corn, tomato, sweet potato, okra, string bean, lettuce, and cucumber), biannual, and annual crops) that are then clear-cut for crop rotations; Cocoa-dominated = a more permanent tree crop that has big leaves

and is maintained for decades without removing trees, and is often featuring small patches intercropped with other fruit trees such as mango, avocado, breadfruit, orange and other citrus species; Nutmeg-dominated = a more permanent tree crop that has small leaves and is maintained for decades without removing trees, and is often featuring small patches intercropped with other fruit trees such as mango, avocado, breadfruit, orange and other citrus species; Houses = a single house or group of houses on small plots of land that usually has a kitchen garden; Apartment(s) / Hotel(s) large complex(es) on much bigger plot(s) of land compared to a house; Roads = all paved and unpaved paths accessible by a motor vehicles; Airport = all airport facilities including fenced off areas that encompass the runway; Stadium = much larger complexes compared to parks or playing fields and used for more national than local events; Park = a much smaller, yet busier complex(es) compared to a stadium, and some are equipped with fluorescent night lights that are used for frequent local night football games that may affect land birds species. Businesses = small commercial buildings such as small shops with little or no noise pollution, and usually have little landscaping around them or located in the downstairs of a house; Factories = larger more industrial places such as the rum factory that have higher noise pollution and bigger ecological footprint.

**Table 2. Land use classification in Grenada. LU = Land use. All land use classifications were considered in my analysis (see results section).**

LU categories	Specific LU	LU measurement at each point count
Agriculture	Farmland	% farmland within 25-m radius
	Cocoa	% cocoa trees within 25-m radius
	Nutmeg	% nutmeg trees within 25-m radius
Residential	House(s)	% houses within 25-m radius
	Apartment(s) / Hotel(s)	% apartment complexes within 25-m radius
Transport	Road(s)	% roads within 25-m radius
	Airport	% airport within 25-m radius
Recreational	Stadium	% stadium within 25-m radius
	Park	% park within 25-m radius
Commercial / Industrial	Business(es)	% business place(s) within 25-m radius
	Factories	% factories within 25-m radius

### 3.5 Statistical Analysis Methods:

#### 3.5.1 Double Observer:

I used the program DOBSERV (Hines, 2000) to calculate observer perceptibility for each land bird species. In program DOBSERV (Hines 2000), I ran six models to test whether detection probability differed by observer, species, or group. “Group” within double-observer analyses referred to 2 or more species that were assumed to have equal detection probability, and as a result, they were analyzed together (Hines, 2000). Species are usually grouped to increase sample size so that the total number of individuals would be >10, which is the minimum number of species required for analysis in DOBSERV (Hines 2000). The six models that I compared were 1) detection probability = same for all observers, species, or groups: P(.,.); 2) detection probability = differs by observer, but same for all species or groups: P(.,I); 3) detection probability = differs by species, but same for all observers: P(S,.); 4) detection probability = differs by group, but same for all observers: P(G,.); 5) detection probability = differs between observers and by species: P(S,I); and 6) detection probability = differs between observers and by groups: P(G,I).

I used Akaike Information Criterion (AIC) values to select the model that best fit my data and ran the DOBSERV model “P(S,I)” to evaluate whether perceptibility varied by observer and species (see Table S1 in Appendix I). All analyzed perceptibility values were  $\geq 0.73$  (mean = 0.84; SD = 0.11; Standard Error = 0.02). I concluded that perceptibility was generally high and that I should not adjust my results for detectability, because adjusting for detectability may increase, rather than decrease, bias in results (Johnson, 2008). However, I recognize that my analyses thus underestimate density, as detectability is imperfect.

### ***3.5.2 Land Birds:***

Program R version 3.3.3 was used to conduct all other analyses. I used General Linear Models (GLM) for all my land bird analyses. In order to avoid model over-parametrization, where no individuals occurred within a treatment, I dropped that treatment for that species.

To determine which distribution to use for the response variable (land bird species density), I first evaluated whether a normal distribution fit the data by using both QQ plots and histograms. If a normal distribution did not fit the data, I then compared poisson and negative binomial distributions using the deviance / df ratio. If neither distribution fit the data, I concluded that I did not have sufficient data to model habitat selection of that species, and I did not model species for which I did not have enough data.

I first compared densities of birds among the five islands I surveyed. I then evaluated the relative effects of environmental variables (temperature, cloud cover, and wind speed) on avian species densities (see Table 3 below). I assessed habitat use by 21 avian species on the main island of Grenada, because I had more data for that island than the other islands. I also evaluated relative habitat use among habitat types (montane, mature lowland, secondary, cloud, and mangrove forests, secondary scrubs, secondary grasslands, savannas, pastures, and cultivated areas), and

compared use of a range of anthropogenic habitat types (farmlands, cocoa trees, nutmeg trees, houses, airport, stadium, businesses, and park) on the main island Grenada.

**Table 3. Structure of GLM models. Forested habitat = proportion of montane forest + proportion of mature lowland forest + proportion of secondary forest + proportion of cloud forest + proportion of mangrove forest. Low vegetated habitat = proportion of secondary scrub + proportion of secondary grassland + proportion of savanna. Agricultural habitat = proportion of pasture + proportion of cultivated. Agriculture within 25-m radius = percentage of farmland within each 25-m point count radius + percentage of cocoa plants within each 25-m point count radius + percentage of nutmeg plants within each 25-m point count radius. Residential buildings within 25-m radius = percentage of houses within each 25-m point count radius. Urban structures within 25-m radius = percentage of airport facilities within each 25-m point count radius + percentage of stadium facilities within each 25-m point count radius + percentage of business buildings within each 25-m point count radius. Date = time of the rainy season when surveys were conducted. Time of day = whether surveys were conducted in the morning and or evening.**

Response variable	Independent / explanatory variable
Species density	Island + Date + Time of day (AM & PM)
Species density	Temperature + Cloud cover + Wind speed
Species density	Forested habitat within 25-m + Low vegetated habitat within 25-m + Agricultural habitat within 25-m + Date + Time of day (AM & PM)
Species density	Proportion montane forest within 25-m + Proportion maturelowland forest within 25-m + Proportion secondary forest within 25-m + Proportion cloud forest within 25-m + Proportion mangrove forest within 25-m + Proportion secondary scrub within 25-m + Proportion secondary grassland within 25-m + Proportion savanna within 25-m + Proportion pasture within 25-m + Proportion cultivated area within 25-m + Date + Time of day (AM & PM)
Species density	Agriculture within 25-m radius + Residential buildings within 25-m radius + Urban structures within 25-m radius + Date + Time of day (AM & PM)
Species density	Proportion farmland within 25-m + Proportion cocoa trees within 25-m + Proportion nutmeg trees within 25-m + Proportion houses within 25-m + Proportion airport within 25-m + Proportion stadium within 25-m + Proportion businesses within 25-m + Proportion park within 25-m + date + Time of day (AM & PM)

### 3.5.3 Species Diversity Analysis:

I used the Shannon diversity index to evaluate avian species diversity across the different islands and between the natural and anthropogenic habitat types on Grenada. To ensure sufficient sample sizes for each habitat type, I grouped habitat types into three broad categories, namely forested, low-vegetated, and anthropogenic habitats.

## Chapter 4.0 RESULTS:

### *4.1 Detectability analysis:*

Double-observer analyses suggest that detectability of surveyed species was generally high and ranged from 57% to 100% with a mean detectability of 84% (SD = 0.10; Standard Error = 0.02; see Table S1 in Appendix 1). Thirty-two percent of species (10 out of 31 species) had a detectability > 0.91, 48% (15 out of 31 species) had detectability ranging between 0.81 to 0.86, 13% (4 out of 31 species) had detectability ranging between 0.73 to 0.76, and 7% (2 out of 31 species) had detectability < 0.59 (Common Ground Dove, detectability of 0.58, and Mangrove Cuckoo, detectability of 0.57). For the following analyses, we did not analyze species with < 10 observations (which included the Caribbean Elaenia, Blue-throated Macaw, Blue-black Grassquit, Fork-tailed flycatcher, Green-throated Carib, Grenada Dove, and Orange-winged Parrot) or species with detectability < 0.73 as > 0.70 is considered average correct perceptibility for most experienced observers (Bart, 1985). Because perceptibility was generally high, I chose not to adjust my results for detectability, as this can increase, rather than decrease, bias (Johnson, 2008). However, I recognize that my analyses thus underestimate density, as detectability is less than 1.0.

### *4.2 Abundance Relative to Environmental Variables:*

There were significant negative correlations between temperature and cloud cover, and cloud cover and windspeed, and a significant positive correlation between temperature and windspeed (Table 4). However, I retained all variables in the model because all rho values were < |0.45|.

The effects of temperature, cloud cover, and wind speed on land birds in Grenada varied among the different feeding guilds. Both nectarivores and insectivores were more likely to be detected when temperatures were lower while omnivores and frugivores were more likely to be

detected at higher temperatures (Table 4). Nectarivores were more likely to be detected when percentage cloud cover was higher while granivores, insectivores, and frugivores were more likely to be detected at lower percentage cloud cover. Both carnivores and nectarivores were more likely to be detected at lower wind speed. Other guilds showed variable relationships with temperature, cloud cover, and wind speed.

Restricted range and endemic species showed variable responses to environmental variables. Grenada Flycatchers were less likely to be detected at higher temperatures while Lesser Antillean Tanagers were more likely to be detected at higher percentage cloud cover. Only Lesser Antillean Bullfinches had no significant response to environmental variables.

**Table 4. Effects of weather variables (temperature, cloud cover, and wind speed) on land bird species density in Grenada in 2017. The response variable had a Poisson distribution. Increase = higher densities. Decrease = lower densities. All response variables were modeled using a Poisson distribution. For significant p-values see Table S4 in Appendix 1.**

Feeding Guild	Species	Temperature	Cloud Cover	Wind speed
Carnivore	Broad-winged Hawk			Decrease
Frugivore	Scaly-naped Pigeon	Increase	Decrease	Increase
	Zenaida Dove			
Granivore	Black-faced Grassquit	Decrease		
	Eared Dove		Decrease	
	Yellow-bellied Seedeater	Increase		
Insectivore	Cattle Egret		Decrease	Increase
	Gray-rumped Swift		Decrease	
	Grenada Flycatcher	Decrease		
	House Wren		Decrease	
Nectarivore	Antillean Crested Hummingbird	Decrease		Decrease
	Bananaquit			Decrease
	Rufous-breasted Hermit	Decrease	Increase	
Omnivore	Carib Grackle	Increase	Decrease	Increase
	Gray Kingbird			
	Lesser Antillean Bullfinch			Decrease
	Lesser Antillean Tanager		Increase	Increase
	Smooth-billed Ani		Decrease	
	Shiny Cowbird			
	Spectacled Thrush			
	Tropical Mockingbird	Increase	Decrease	

#### ***4.3 Density Variation Among Islands:***

Most species were more abundant on Grenada than on the smaller islands. Antillean Crested Hummingbirds were the only species found in significantly lower abundances on Grenada compared to all the other permanently inhabited (Carriacou and Petite Martinique) and largely uninhabited islands (Ronde Island and Caille Island). Bananaquits and Gray-rumped Swifts were the only other species found in significantly lower abundances on Grenada compared to the other largely uninhabited Caille Island and Ronde Island, respectively (Table 5). Species found in significantly lower abundances on Grenada compared to Carriacou were Bananaquits, Scaly-naped Pigeons, and Tropical Mockingbirds, and the only species found in significantly lower abundances on Grenada compared to Petite Martinique was Black-faced Grassquits. I detected higher densities of Shiny Cowbirds on Grenada compared to Carriacou.

Approximately 50% of species detections were independent of the date and time of day. Gray-rumped Swifts, Scaly-naped Pigeons, and Tropical Mockingbirds were more likely to be detected later in the season, and Gray-rumped Swifts and Tropical Mockingbirds were more likely to be detected in evenings while Black-faced Grassquits were more likely to be detected in mornings. Detections of Shiny Cowbirds were more likely to occur later in the season and during mornings. As date and time of day affected the detectability of some species, I kept those variables in all of my habitat selection and land use models. However, for conciseness, I discuss the effects of date and time of day only in this first analysis.

**Table 5. Statistical comparisons between Grenada and other islands, and the effects of date and time of day on land bird species density per 25-m radius plots in 2017. Date = number of days since the start of the survey during the rainy season. Time of day = whether surveys were conducted in the morning and or evening. ID = insufficient data. Increase = higher densities. Decrease = lower densities. All response variables were modeled using a Poisson distribution. For significant p-values see Table S2 in Appendix 1.**

Feeding Guild	Species	Carriacou	Petite Martinique	Ronde Island	Caille Island	Date	Time of day (AM & PM)
Carnivore	Broad-winged Hawk	ID	ID	ID	ID		Decrease
	Scaly-naped Pigeon	Increase	ID		Decrease	Increase	
Frugivore	Zenaida Dove			ID	ID	Increase	
	Black-faced Grassquit		Increase	ID	ID		Decrease
Granivore	Eared Dove			ID	ID	Increase	Decrease
	Yellow-bellied Seedeater	ID	ID	Decrease	ID		
	Cattle Egret	Decrease	ID	ID	ID		Decrease
Insectivore	Gray-rumped Swift		ID	Increase	ID	Increase	Increase
	Grenada Flycatcher		ID	ID	ID		
	House Wren	Decrease	ID	ID	ID	Increase	Decrease
Nectarivore	Antillean Crested Hummingbird	Increase	Increase	Increase	Increase		
	Bananaquit	Increase	Decrease		Increase		
	Rufous-breasted Hermit	ID	ID	ID	ID	Increase	Decrease
Omnivore	Carib Grackle						Increase
	Gray Kingbird				ID		Decrease
	Lesser Antillean Bullfinch	ID	ID	ID	ID	Decrease	Increase
	Lesser Antillean Tanager	ID	ID	ID	ID		
	Smooth-billed Ani	ID	ID		ID		
	Shiny Cowbird	Decrease		ID	ID	Increase	Decrease
	Spectacled Thrush	ID	ID	Decrease	ID		
	Tropical Mockingbird	Increase				Increase	Increase

#### ***4.4 Effects of Combined Habitat Types on Land Bird Species Density on Grenada:***

I first evaluated habitat selection across broad habitat categories (including forested habitat = montane + mature lowland + secondary + cloud + mangrove, low or short vegetated habitat = secondary scrub + secondary grassland + savanna, and agricultural habitat = pasture + cultivated), to maximize sample sizes and thus power within each category. To avoid overparameterization and consequent incorrect model conclusions, I dropped the habitat type(s) and land use variable(s) from my models where I had zero observation for each species.

Densities of land bird species and their respective feeding guild varied across the different combined habitat types. Several species (29%,  $n = 6$  out of 21 species) were found in significantly higher densities in sites with more agricultural habitat (Table 6). More than 50% ( $n = 11$  out of 21 species) of species had lower densities in sites containing higher proportion of combined forested habitats and 29% ( $n = 6$  out of 21 species) of species had lower densities in sites with low or short vegetated. I detected lower densities of Shiny Cowbirds in sites containing higher proportion of all combined habitats, and higher densities of hummingbirds in sites with higher extents of forested and agricultural habitats (Table 6). All nectarivores had higher densities in sites containing higher proportion of both combined forested and agricultural habitats. Other feeding guilds had variable densities in sites with more agricultural habitats.

Of the three restricted-range and endemic species analyzed, Grenada Flycatcher abundance was independent of habitat type. Both Lesser Antillean Bullfinches and Lesser Antillean Tanagers had lower densities in sites with higher extents of low or short vegetated, and Lesser Antillean Bullfinches had lower densities in sites containing higher proportion of forested and agricultural habitats.

**Table 6. Effects of combined habitat types on land bird species density on Grenada in 2017. Forested habitat = proportion of montane forest + proportion of mature lowland forest + proportion of secondary forest + proportion of cloud forest + proportion of mangrove forest. Low or short vegetated habitat = proportion of secondary scrub + proportion of secondary grassland + proportion of savanna. Agricultural habitat = proportion of pasture + proportion of cultivated. Date = number of days since the start of the survey during the rainy season. Time of day = whether surveys were conducted in the morning and or evening. ID = insufficient data. Increase = higher densities. Decrease = lower densities. All combined habitat types were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. For significant p-values see Table S5 in appendix 1.**

Feeding Guild	Species	Forested habitat	Short vegetated habitat	Agricultural habitat	Date	Time of day (AM & PM)
Carnivore	Broad-winged Hawk					
Frugivore	Scaly-naped Pigeon			Decrease	Increase	Decrease
	Zenaida Dove				Increase	ID
Granivore	Black-faced Grassquit	Decrease		Increase		Decrease
	Eared Dove	Decrease	Decrease	Decrease	Increase	Decrease
	Yellow-bellied Seedeater	Decrease	Decrease	Decrease		Decrease
Insectivore	Cattle Egret	Decrease		Decrease	Decrease	Decrease
	Gray-rumped Swift	Decrease		Increase	Increase	Decrease
	Grenada Flycatcher					
	House Wren	Decrease		Decrease	Increase	Decrease
Nectarivore	Antillean Crested Hummingbird	Increase		Increase		
	Bananaquit	Increase	Decrease	Increase	Increase	Increase
	Rufous-breasted Hermit	Increase		Increase	Increase	Decrease
	Carib Grackle	Decrease			Increase	Decrease
	Gray Kingbird	Decrease				
Omnivore	Lesser Antillean Bullfinch	Decrease	Decrease	Decrease	Decrease	Increase
	Lesser Antillean Tanager		Decrease			
	Smooth-billed Ani					
	Shiny Cowbird	Decrease	Decrease	Decrease		Decrease
	Spectacled Thrush			Increase		
	Tropical Mockingbird	Decrease		Decrease		

#### **4.4.1 Effects of Habitat Types on Land Bird Species Density on Grenada in 2017:**

I also evaluated habitat selection with fine-scaled habitat categories, to maximize precision in assessing habitat selection. The highest densities of focal species (33%,  $n = 7$  out of 21 species) were found in sites with higher extents of cultivated and secondary grassland habitats. In contrast,

several species avoided sites with higher extents of cloud and secondary forests (24%,  $n = 5$  out of 21 species). I detected higher densities of Shiny Cowbirds in sites with more secondary grasslands.

The effects of habitat types on species densities varied across the different feeding guilds. Granivores had lower densities in sites with more secondary and cloud forests, while nectarivores had higher densities in sites with those habitat types (Table 7). Frugivores, granivores, and insectivores had higher densities in sites containing higher extent of secondary grasslands while nectarivores had lower densities in sites with more secondary grasslands. Both nectarivores and granivores had higher densities in sites with higher extent of cultivated habitats, while use of sites with cultivated habitats varied among omnivores and insectivores. Omnivores, insectivores, and frugivores all had higher densities in sites with higher proportion of mangrove forests.

Both species of hummingbirds selected similar habitat types. Antillean Crested Hummingbirds and Rufous-breasted Hermits both had higher densities in sites with higher proportion of cloud forest, savanna, and cultivated habitat types. Only Rufous-breasted Hermits were found in higher densities in sites containing higher proportion of pastures and montane and secondary forests (Table 7).

Restricted range species selected various habitat types (Table 7). Grenada Flycatcher were found in higher densities in sites with more secondary scrubs, mangrove forests, and cultivated habitats (in order of highest to lowest densities (Table S6)), while Lesser Antillean Tanagers were found in higher densities in sites containing higher extents of cloud forests. Both Lesser Antillean Tanagers and Lesser Antillean Bullfinches were found in lower densities in sites with higher proportion of secondary scrubs. Lesser Antillean Bullfinches also had lower densities in sites containing higher extent of mature lowland and cloud forests, savannas, and cultivated habitats.

**Table 7. Effects of habitat types on land bird species density on Grenada in 2017. Date = number of days since the start of the survey during the rainy season. Time of day = whether surveys were conducted in the morning and or evening. ID = insufficient data. Increase = higher densities. Decrease = lower densities. All habitat types were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. For significant p-values see Table S6 in appendix 1.**

Feeding Guild	Species	Montane forest	Mature lowland forest	Secondary forest	Cloud forest	Mangrove forest	Secondary scrub	Secondary grassland	Savanna	Pasture	Cultivated	Date	Time of day (AM & PM)
Carnivore	Broad-winged Hawk	ID				ID		ID	ID				
Frugivore	Scaly-naped Pigeon	ID		Decrease	Decrease	Increase		Increase				Increase	Decrease
	Zenaida Dove	ID	ID		ID	ID		ID	ID	ID		Increase	ID
Granivore	Black-faced Grassquit			Decrease	Decrease	ID		Increase		Increase	Increase		Decrease
	Eared Dove			Decrease	ID	ID	Decrease			ID		Increase	Decrease
	Yellow-bellied Seedeater	ID			ID	ID			ID	ID			
Insectivore	Cattle Egret	ID	ID		ID		Increase	Increase		ID	Decrease	Decrease	Decrease
	Gray-rumped Swift	Increase		Decrease	ID			Increase		ID	Increase	Increase	Decrease
	Grenada Flycatcher					Increase	Increase		ID		Increase		
	House Wren	ID			ID							Increase	Decrease
Nectarivore	Antillean Crested Hummingbird				Increase				Increase		Increase		
	Bananaquit	Increase		Increase				Decrease	Decrease		Increase	Increase	Increase
	Rufous-breasted Hermit	Increase	ID	Increase	Increase	ID	ID	ID	Increase	Increase	Increase	Increase	Decrease
Omnivore	Carib Grackle	ID			ID		Increase	Increase				Increase	Decrease
	Gray Kingbird				Decrease		Decrease						
	Lesser Antillean Bullfinch		Decrease		Decrease		Decrease		Decrease	ID	Decrease	Decrease	Increase
	Lesser Antillean Tanager		ID		Increase	ID	Decrease						
	Smooth-billed Ani	ID	ID		ID	ID		Increase		ID			
	Shiny Cowbird	ID			ID			Increase				Increase	Decrease
	Spectacled Thrush	ID					Increase		Decrease		Increase		
	Tropical Mockingbird	ID	Decrease	Decrease	Decrease	Increase		Decrease			Decrease		

#### ***4.5 Combined Land-use Variables Effects on Focal Bird Densities:***

Species densities varied across the different combined land use categories. The highest densities of 33% ( $n = 7$  out of 21 species) of focal species were found in sites with more agricultural habitats (farmland + cocoa plants + nutmeg plants) and with more residential buildings. In contrast, only 5% ( $n = 1$  out of 21 species) of my focal species had higher densities in sites with higher extent of urban structures (Table 8). Fourteen percent ( $n = 3$  out of 21 species) of my focal species had lower densities in habitats containing higher proportion of agricultural and residential land uses, and 10% ( $n = 2$  out of 21 species) of my focal species had lower densities in habitats containing higher amounts of urban structures.

I detected higher densities of Shiny Cowbirds in residential sites. Both hummingbirds were found in higher densities in sites with more agricultural habitats and lower densities in sites with higher extent of urban or residential structures. Of my restricted-range species, Lesser Antillean Tanagers and Lesser Antillean Bullfinches were observed in higher densities in sites containing higher amounts of residential structures, while Grenada flycatchers used all habitat types. Bananaquits were found in lower densities in sites containing residential and urban structures. Only Gray-rumped swifts were found in higher densities in sites containing higher amounts of urban structures.

**Table 8. Effects of combined land-use variables on land bird species densities in Grenada in 2017. Agricultural land within 25-m radius = percentage of farmland within each 25-m point count radius + percentage of cocoa plants within each 25-m point count radius + percentage of nutmeg plants within each 25-m point count radius. Residential buildings within 25-m radius = percentage of houses within each 25-m point count radius. Urban structures within 25-m radius = percentage of airport facilities within each 25-m point count radius + percentage of stadium facilities within each 25-m point count radius + percentage of business buildings within each 25-m point count radius. Date = number of days since the start of the survey during the rainy season. Time of day = whether surveys were conducted in the morning and or evening. ID = insufficient data. Increase = higher densities. Decrease = lower densities. All combined land-use variables were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. For significant p-values see Table S7 in appendix 1.**

Feeding Guild	Species	Agricultural land within 25-m radius	Residential buildings within 25-m radius	Urban structures within 25-m radius	Date	Time of Day (AM & PM)
Carnivore	Broad-winged Hawk					
	Scaly-naped Pigeon	Decrease			Increase	Decrease
Frugivore	Zenaida Dove			ID	Increase	ID
	Black-faced Grassquit	Increase				Decrease
Granivore	Eared Dove	Increase	Increase		Increase	Decrease
	Yellow-bellied Seedeater				Increase	Decrease
	Cattle Egret	Decrease	Decrease		Decrease	
Insectivore	Gray-rumped Swift	Increase		Increase	Increase	Decrease
	Grenada Flycatcher					
	House Wren		Increase		Increase	Decrease
Nectarivore	Antillean Crested Hummingbird	Increase		Decrease		Decrease
	Bananaquit	Increase	Decrease	Decrease	Increase	Increase
	Rufous-breasted Hermit	Increase	Decrease		Increase	Decrease
Omnivore	Carib Grackle				Increase	Decrease
	Gray Kingbird					
	Lesser Antillean Bullfinch		Increase		Decrease	Increase
	Lesser Antillean Tanager		Increase			
	Smooth-billed Ani		Increase			
	Shiny Cowbird		Increase		Increase	Decrease
	Spectacled Thrush	Increase				
	Tropical Mockingbird	Decrease	Increase			

#### 4.5.1 Effects of Land-use Variables on Land Bird Species Density on Grenada in 2017:

Species densities varied across the different land use categories. Almost half (48%,  $n = 10$  out of 21 species) of all surveyed species had the highest densities on sites with more farmlands. Species also had higher densities on sites with higher amounts of houses (29%,  $n = 6$  out of 21 species) and cocoa trees (24%,  $n = 5$  out of 21 species). Few species had higher densities on sites

with more airport structures (14%,  $n = 3$  out of 21 species), nutmeg trees (10%,  $n = 2$  out of 21 species), businesses (5%,  $n = 1$  out of 21 of species), and parks (5%,  $n = 1$  out of 21 species).

Shiny Cowbirds were detected in higher densities in urban sites with higher amounts of houses and lower densities in agricultural sites with higher proportion of cocoa trees. Both species of hummingbirds were found in higher densities on sites more cultivated land, but Antillean Crested Hummingbirds were more abundant on cultivated sites with higher extents of farmlands and cocoa trees, while Rufous-breasted Hermits were more abundant on site with more nutmeg fields. Both restricted range Lesser Antillean Bullfinches and Lesser Antillean Tanagers were found in higher densities on sites with higher proportion of farmlands, while Lesser Antillean Bullfinches had lower abundances in sites with higher amounts of cocoa fields.

**Table 9. Effects of land-use variables on land bird species density on Grenada in 2017. Date = number of days since the start of the survey during the rainy season. Time of day = whether surveys were conducted in the morning and or evening. ID = insufficient data. Increase = higher densities. Decrease = lower densities. All land-use variables were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. For significant p-values see Table S8 in appendix 1.**

Feeding Guild	Species	Farmland	Cocoa	Nutmeg	Houses	Airport	Stadium	Business	Park	Date	Time of day (AM & PM)
Carnivore	Broad-winged Hawk					ID	ID		ID		
	Scaly-naped Pigeon	Decrease	Increase	Decrease		ID		Increase	ID	Increase	Decrease
Frugivore	Zenaida Dove	Increase					ID	ID	ID	Increase	ID
	Black-faced Grassquit	Increase	Increase		Decrease	Decrease				Increase	Increase
Granivore	Eared Dove	Increase	Decrease	Decrease	Increase		ID		ID	Increase	Decrease
	Yellow-bellied Seedeater	Increase			Increase		ID		ID		Decrease
	Cattle Egret	Decrease			Decrease	Increase	ID	ID	ID	Decrease	Decrease
Insectivore	Gray-rumped Swift	Increase	Decrease			Increase	ID		ID	Increase	Decrease
	Grenada Flycatcher					ID	ID		ID		
	House Wren				Increase	ID	ID			Increase	Decrease
Nectarivore	Antillean Crested Hummingbird	Increase	Increase			ID		Decrease			Decrease
	Bananaquit	Increase	Increase		Decrease	Decrease				Increase	Increase
	Rufous-breasted Hermit			Increase	Decrease	ID	ID		ID	Increase	Decrease
Omnivore	Carib Grackle						ID		ID	Increase	Decrease
	Gray Kingbird		Increase							Increase	
	Lesser Antillean Bullfinch	Increase	Decrease			ID			ID	Decrease	Increase
	Lesser Antillean Tanager	Increase			Increase	ID	ID		ID		
	Smooth-billed Ani	Increase			Increase	Increase	ID		ID		
	Shiny Cowbird		Decrease		Increase	ID			ID	Increase	Decrease
	Spectacled Thrush	Increase		Increase					ID		
	Tropical Mockingbird	Decrease	Decrease						ID		

#### ***4.6 Species Richness and Diversity:***

Species richness among the surveyed islands was proportional to island size (Table 10), except Hog island. The biggest surveyed island (Grenada) had the highest species richness, and bigger islands had higher species richness compared to smaller ones (Table 10). Every species observed on the smaller islands were also found on Grenada, aside from Blue-throated Macaws which were only observed on Carriacou.

Among the different islands, Grenada had the highest species diversity (Table 10). All other surveyed islands except Petite Martinique and Hog island had species diversity directly proportional to island size (Table 10) with the larger islands having higher species diversity.

**Table 10. Species richness and diversity of land birds observed on the different surveyed islands in 2017. ✓ = species observed on surveyed island.**

	Grenada (Size = 306 km <sup>2</sup> )	Carriacou (Size = 34 km <sup>2</sup> )	Ronde Island (Size = 2.70 km <sup>2</sup> )	Petite Martinique (Size = 2.37 km <sup>2</sup> )	Caille Island (Size = 0.7 km <sup>2</sup> )	Hog Island (Size = 0.35 km <sup>2</sup> )
Antillean crested Hummingbird	✓	✓	✓	✓	✓	✓
Bananaquit	✓	✓	✓	✓	✓	✓
Black-faced Grassquit	✓	✓		✓		✓
Broad-winged Hawk	✓					
Caribbean Elaenia	✓					
Cattle Egret	✓	✓				
Carib Grackle	✓	✓	✓	✓	✓	✓
Common Ground Dove	✓	✓	✓	✓	✓	
Eared Dove	✓	✓		✓		✓
Fork-tailed flycatcher	✓					
Green-throated Carib	✓					
Grenada Dove	✓					
Grenada Flycatcher	✓	✓				✓
Gray Kingbird	✓	✓	✓	✓		✓
Gray-rumped Swift	✓	✓	✓			
House Wren	✓	✓				✓
Lesser Antillean Bullfinch	✓					✓
Lesser Antillean Euphonia	✓					
Lesser Antillean Tanager	✓					
Macaw		✓				
Mangrove Cuckoo	✓	✓	✓	✓		✓
Orange-winged Parrot	✓					
Rufous-breasted Hermit	✓					
Smooth-billed Ani	✓		✓			
Shiny Cowbird	✓	✓				
Scaly-naped Pigeon	✓	✓	✓	✓		✓
Spectacled Thrush	✓		✓			✓
Tropical Mockingbird	✓	✓	✓	✓	✓	✓
Yellow-bellied Elaenia	✓					✓
Yellow-bellied Seedeater	✓		✓			
Zenaida Dove	✓	✓		✓		
Species Richness	30	17	12	11	5	14
Shannon Diversity Index	2.69	1.98	1.94	2.14	1.17	2.09
Distance From Grenada (km)		26.19	7.81	39.94	6.96	0.1227

#### **4.7 Species diversity between natural and anthropogenic habitats:**

Forested habitats had the lowest species diversity compared to low or less dense vegetation and anthropogenic habitats (Table 11).

**Table 11. Diversity of land bird species observed in the different habitat groups on Grenada in 2017. Forests = montane, mature lowland, secondary, cloud, and mangrove. Low-lying Vegetations = secondary scrub, secondary grassland, and savanna. Anthropogenic Habitats = pastures, urban areas, and cultivated areas.**

	Shannon Diversity Index
Forests	2.48
Low-lying Vegetations	2.69
Anthropogenic Habitat	2.67

## **Chapter 5.0 DISCUSSION:**

Anthropogenic landscapes both positively and negatively impacted avian species on Grenada. Most species selected specific anthropogenic (mainly cultivated habitats) and avoided urbanized and natural habitats. However, there were a few exceptions, including Shiny Cowbirds, which selected anthropogenic residential habitats, and the regional endemic Lesser Antillean Tanagers and near-endemic Grenada Flycatcher, which selected natural habitats. In an observational study like this, I cannot test the mechanisms; however, in the following discussion I suggests some mechanisms that may explain the observed patterns. Further research would be required to confirm exact mechanisms.

### ***5.1 Avian Species Abundance on Grenada Compared to Other Islands:***

Anthropogenic habitats in Grenada may provide essential habitats for exotic species such as Shiny Cowbirds to flourish at the expense of resident terrestrial species. Such disturbances and variations in specific land use across the different islands may influence prey abundances that in turn influence species densities across the islands.

#### ***5.1.1 Impacts of Disturbance on Species Abundance:***

Human disturbance is one of the most potent menaces to global avian biodiversity (Rapoport, 1993). Recent studies have shown that sites with less anthropogenic disturbance support greater avian abundance and richness (Okoth & Simon, 2016; Kang, Minor, Park, & Lee, 2015; Ntongani & Andrew, 2013; McKinney, Kick, & Fulkerson, 2010) and support more unique avian species (Fontu'rbel et al., 2015; Okoth & Simon, 2016). In disturbed landscapes, avian species abundance and richness often decline as land-use intensity increases (Elsen, Kalyanaraman, Ramesh, & Wilcove, 2017), and such disturbances often create fragmented

landscapes and more forest edges, which are ideal habitats for brood parasitic species such as shiny cowbirds (Robinson et al., 1993; Strausberger & Ashley, 1997).

My results are consistent with previous studies that have found generally negative impacts of urbanization (Elsen et al., 2017) on species abundances on Grenada. Antillean Crested Hummingbirds were found in significantly lower abundances on Grenada compared with all the other islands, perhaps as a result of anthropogenic disturbances on Grenada (Watanabe, 2013). My results indicated that Antillean Crested Hummingbirds utilized cloud forests, savannas, and cultivated habitats, and significantly avoided industrialized sites. My results also indicated that Bananaquits and Black-faced Grassquits were found in significantly lower abundances on Grenada compared to Carriacou and Caille Island and Petite Martinique, respectively, and both Bananaquits and Black-faced Grassquits also significantly avoided residential buildings and industrial sites on Grenada. Antillean Crested Hummingbirds, Black-faced Grassquits, and Bananaquits might thrive elsewhere as there are significantly fewer proportions of residential buildings and industrialized sites distributed across Carriacou and Petite Martinique compared to Grenada, and no industrialized sites on Ronde and Caille islands. Anthropogenic disturbances often indirectly decrease avian species abundances (Mammides et al., 2015). Some hummingbird species are known to positively respond to fragmented landscapes (Stouffer & Bierregaard, 1995) and urban structures (Escobar-Ibáñez & MacGregor-Fors, 2015). However, my results suggest that this is not always the case.

### ***5.1.2 Exotic Avian Species Among the Islands:***

Larger islands usually have higher carrying capacity with less competition for resources (for example more food and nesting sites), allowing individual species to reproduce successfully and persist in larger populations (MacArthur & Wilson, 1967). This may allow significant

opportunities for brood parasites such as Shiny Cowbirds to prey on nests. Shiny Cowbirds are well-known brood parasites that reduce the reproductive success of their host by killing their host's hatchling or destroying their host's eggs before laying their eggs in their host's nests (Wiley, 1985; Sackmann & Reboreda, 2003; Dominguez, Reboreda, & Mahler, 2015). The avian subspecies that have evolved in the Lesser Antilles were not exposed to cowbirds until the late 1800s (Cruz, Manolis, & Wiley, 1985; Post & Wiley, 1977). As such, Lesser Antillean species are highly unlikely to have anti-parasite strategies such as those of heterospecifics that co-evolved with cowbirds (Clark & Robertson, 1979; Robertson & Norman, 1976). The fact that Grenada (306 km<sup>2</sup>) is approximately nine times larger than Carriacou (34 km<sup>2</sup>) may shed light as to why I found significantly higher abundances of Shiny cowbirds on Grenada compared to Carriacou. My results were consistent with that of Connor, Courtney, and Yoder (2000) who investigated the relationship between animal population density and island area and found that birds population densities positively correlated with island area.

The creation of more edge habitat through higher intensities of industrialization on Grenada compared to Carriacou may also be facilitating the higher abundances of Shiny Cowbirds on Grenada. In 2004, approximately 809,371 m<sup>2</sup> of intact mangrove and secondary forests in Levera, St. Patrick were deforested to start a resort and golf course development project (Maison, King, Lloyd, & Eckert, 2010). Such developments create more suitable edge habitats on Grenada compared to other islands, and this may have helped Shiny Cowbird to persist (Robinson et al., 1993). In fact, I observed a Shiny Cowbird fledgling being fed by a Tropical Mockingbird at my Levera field site in August 2017, demonstrating that this species is successfully breeding on Grenada.

My results on habitat type and land-use on Grenada indicated that Shiny Cowbirds selected secondary grasslands and urban habitats containing houses. There are significantly higher proportions of houses on Grenada compared to Carriacou, and as such, houses (complemented with secondary grasslands) on Grenada may be providing suitable habitats for Shiny Cowbirds to flourish. My results are consistent with that of Phillips et al (2005) who found that cowbirds associated with anthropogenic dwellings and infrastructure had significantly higher rates of brood parasitism on host species. Such results make Shiny Cowbirds a conservation concern for other resident land birds in Grenada.

### ***5.1.3 Specific Land-use and Habitat Types on Species Abundance:***

The variations in specific habitat types across the different islands may be influencing the densities of avian species across the islands. We observed significantly higher abundances of Gray-rumped Swifts on Ronde Island and higher abundances of Bananaquits on Caille Island compared to Grenada, perhaps because of habitat differences among the islands. Although Ronde Island, unlike Grenada, is not a permanent human inhabited island, the fishermen that occasionally live on Ronde island cultivate high proportion of the land predominantly for watermelons. My results indicated that Gray-rumped Swifts selected cultivated habitats, farmlands, secondary grasslands, montane forests, and significantly avoided cocoa habitat and Bananaquits selected cultivated habitats, montane and secondary forests and significantly avoided industrial sites (Table 7 & 9). As there is no cocoa habitat on Ronde island and no industrial sites on Caille island compared to Grenada (where cocoa habitat and industrial sites are widely distributed across the entire island), perhaps variations in specific habitat types across the islands might explain why I found higher abundances of Gray-rumped Swifts on Ronde island and Bananaquits on Caille island compared

to Grenada. Specific habitat types are known to play a critical role in maintaining avian species population (Evans, Bradbury, & Wilson, 2003; Evans, Wilson, & Bradbury, 2007).

The habitat on Ronde island may also provide resources for swifts. Gray-rumped Swifts are well known aerial predators of arthropods (Collins, 2015). Aerial predators of arthropods are known to have higher abundances in farmlands (Evans et al., 2007), probably because higher abundances of aerial arthropods are often found in farmland (Hollander et al., 2015), so differences in specific land-use for different crops (watermelon on Ronde island and cocoa on Grenada) may have contributed to higher prey abundances on Ronde island compared to Grenada.

### ***5.2 Avian Species Abundance on Grenada:***

Of the 35 documented land bird species on Grenada, I analyzed 21 species and found uneven abundances across the eleven different natural and anthropogenic habitats (Table 12). The habitats selected by the most species included anthropogenic cultivated habitats and secondary grasslands, while habitats types avoided by the most species were cloud and secondary forests (Table 12). Agricultural habitats sometimes have relatively high conservation value for avian species (Petit & Petit, 2003). Nonetheless, even those natural cloud and secondary forests with relatively low species abundance were selected for by the regional endemic Lesser Antillean Tanagers, polymorphic Bananaquits, Antillean Crested Hummingbirds, and Rufous-breasted Hermits (Table 12). This emphasizes the importance of all habitat types within the anthropogenic mosaic of Grenada. These diverse habitats are also essential for other non-avian Grenadian species. For instance, cloud forests are also crucial for the conservation of amphibians, reptiles, plants, and mammals in Mexico (Almazán-Núñez et al., 2018), and secondary forests are essential for the conservation of frogs in Costa Rica (Hilje & Aide, 2012)

**Table 12. Densities of land bird species observed in different habitat types on Grenada in 2017.**

	Montane forest	Mature lowland forest	Secondary forest	Cloud forest	Mangrove forest	Secondary scrub	Secondary grassland	Savanna	Pasture	Cultivated
Birds that had high densities in this habitat type	Bananaquits, Gray-rumped Swifts, Rufous-breasted Hermits,		Bananaquits and Rufous-breasted Hermits	Antillean Crested Hummingbirds, Lesser Antillean Tanagers, and Rufous-breasted Hermits	Grenada Flycatchers, Scaly-naped Pigeons, and Tropical Mockingbirds	Cattle Egrets, Carib Grackles, Grenada Flycatchers, and Spectacled Thrushes	Black-faced Grassquits, Cattle Egrets, Gray-rumped Swifts, Smooth-billed Anis, Shiny Cowbirds, and Scaly-naped Pigeons	Antillean Crested Hummingbirds and Rufous-breasted Hermits	Black-faced Grassquits and Rufous-breasted Hermit	Antillean Crested Hummingbirds, Bananaquits, Black-faced Grassquits, Gray-rumped Swifts, Rufous-breasted Hermits, and Spectacled Thrush
Birds that did not have high or low densities in this habitat	Antillean Crested Hummingbirds, Black-faced Grassquits, Eared Doves, Grenada Flycatchers, Gray Kingbirds, Lesser Antillean Bullfinches, and Lesser Antillean Tanagers	Antillean Crested Hummingbirds, Bananaquits, Black-faced Grassquits, Broad-winged Hawks, Carib Kingbirds, Lesser Antillean Tanagers, House Wrens, Shiny Cowbirds, Scaly-naped Pigeons, Spectacled Thrushes, and Yellow-bellied Seedeaters	Antillean Crested Hummingbirds, Broad-winged Hawks, Cattle Egrets, Carib Grackles, Grenada Flycatchers, Gray Kingbirds, House Wrens, Lesser Antillean Bullfinches, Lesser Antillean Tanagers, Shiny Cowbirds, Scaly-naped Pigeons, Spectacled Thrushes, and Yellow-bellied Seedeaters, and Zenaida Doves	Bananaquits, Broad-winged Hawks, Grenada Flycatchers, and Spectacled Thrushes	Antillean Crested Hummingbirds, Bananaquits, Cattle Egrets, Carib Grackles, Gray Kingbirds, Gray-rumped Swifts, House Wrens, Lesser Antillean Bullfinches, Shiny Cowbirds, and Spectacled Thrushes	Antillean Crested Hummingbirds, Bananaquits, Black-faced Grassquits, Doves, Grenada Flycatchers, Gray Kingbirds, House Wrens, Lesser Antillean Bullfinches, Pigeons, Tropical Mockingbirds, Yellow-bellied Seedeaters, and Zenaida Doves	Antillean Crested Hummingbirds, Eared Doves, Grenada Flycatchers, Gray Kingbirds, House Wrens, Lesser Antillean Bullfinches, Lesser Antillean Tanagers, Spectacled Thrushes, and Yellow-bellied Seedeaters	Black-faced Grassquits, Cattle Egrets, Carib Grackles, Eared Doves, Gray Kingbirds, Gray-rumped Swifts, House Wrens, Lesser Antillean Tanagers, Smooth-billed Pigeons, and Tropical Mockingbirds	Antillean Crested Hummingbirds, Bananaquits, Broad-winged Hawks, Carib Grackles, Grenada Flycatchers, Gray Kingbirds, Kingbirds, House Wrens, Lesser Antillean Tanagers, Shiny Cowbirds, Scaly-naped Pigeons, Spectacled Thrushes, and Tropical Mockingbirds	Broad-winged Hawks, Carib Grackles, Eared Doves, Grenada Flycatchers, Gray Kingbirds, House Wrens, Lesser Antillean Tanagers, Shiny Cowbirds, Scaly-naped Pigeons, Spectacled Thrushes, and Zenaida Doves
Birds that had low densities in this habitat type		Lesser Antillean Bullfinches and Tropical Mockingbirds	Black-faced Grassquits, Eared Doves, Gray-rumped Swifts, and Tropical Mockingbirds	Black-faced Grassquits, Gray Kingbirds, Lesser Antillean Bullfinches, Scaly-naped Pigeons, and Tropical Mockingbirds		Eared Doves, Gray Kingbirds, Lesser Antillean Bullfinches, and Lesser Antillean Tanagers	Bananaquits and Tropical Mockingbird	Bananaquits and Spectacled Thrush		Cattle Egrets, Lesser Antillean Bullfinches, and Tropical Mockingbirds

### ***5.2.1 Importance of Food Resource in Habitat Selection:***

The uneven abundances of land birds across the different habitat types is likely due to variation in habitat requirements among species. One critically important factor in the habitat selection process is an abundance of food resources (Massé & Côté, 2012; Schlacher, Meager, & Nielsen, 2014; Wolfe, Johnson, & Ralph, 2014). On Grenada, very little work has been done to understand fine-scale resource use by avian communities, but hummingbirds and other nectarivores likely benefit from food resources in both gardens (van Heezik, Freeman, Porter, & Dickinson, 2013) and agroforestry systems (Schroth et al., 2013). All nectarivorous species (Antillean Crested Hummingbirds, Rufous-breasted Hermits, and Bananaquits), some insectivorous species (Grenada Flycatchers and Gray-rumped Swifts), and a frugivorous species (Scaly-naped Pigeons) that I studied selected agroforestry habitats (Table 7). However, all nectarivorous species avoided habitats with human settlement (Bananaquits and Rufous-breasted hermits), airport facilities (Bananaquits), or business places (Antillean Crested Hummingbirds). As gardens on Grenada are mostly close to houses (in both urban and rural areas) and some business places (example the botanical garden in St. George and on Carriacou), my results, therefore, suggest that nectarivorous species that I studied on Grenada are avoiding human disturbances despite the abundance of food resources available in gardens. Some birds are known to avoid adequate resources in the presence of human disturbances (Gill, 2007; Liley & Sutherland, 2007).

### ***5.3 Important Bird Habitat Types in Grenada:***

Mixed agroforestry habitats on Grenada can positively influence terrestrial avian biodiversity conservation. All combined habitat types except low lying vegetations were selected by at least some species (Table 6). The highest densities of species were found in agricultural

habitats while more than 50% ( $n = 11$  out of 21 species) of species had lower densities in forested habitats. However, both forested and agricultural habitats were particularly important for some species, including nectarivores. This, therefore, suggests that a mosaic of agriculture and forested landscapes on Grenada are critically essential for avian biodiversity. My results are consistent with past studies (Harvey & Villalobos, 2007; Jose, 2009; Schroth et al., 2013), that suggested that the use agroforestry systems played a vital role in biodiversity conservation. As such, a diverse mosaic of habitat types on Grenada is therefore important to conserve Grenada's avian community.

My results indicate the importance of conserving several specific natural habitats. Almost all individual habitat types were selected by at least some species (Table 7). Mangrove and cloud forests were particularly crucial for the near-endemic Grenada flycatcher and regional endemic Lesser Antillean Tanager respectively; thus, the conservation of Mangrove and Cloud forests are crucial for these species. Both secondary scrub and cultivated habitats were also critical habitat types for Grenada flycatchers and should also be conserved. As such, it is also essential to conserve specific natural habitats at the landscape scale for both endemic and forest-dependent or specialist species (Harvey et al., 2007). Past studies have found that both mangrove forests and cloud forests are known to support habitat specialist species (Nagelkerken et al., 2008; Habel, Hillen, Schmitt, & Fischer, 2016).

The use of anthropogenic habitats greatly varied among species. Habitats containing agricultural and residential land-uses had significantly higher densities of land birds compared to urban habitats (upland birds' densities were 33% or 7 of 21 species, 33% or 7 of 21 species, and 5% or 1 of 21 species, respectively). Our results were consistent with that of Blair (2004), who found that species densities peaked in moderately disturbed sites and was lower in urban habitats. On Grenada, several species including all nectarivores avoided urbanized areas, despite available

food resources from gardens (Brierley, 1985). Considering that the most extensive urbanized city in Grenada, the town of St. George's, is small (~4 km<sup>2</sup> in 2019), compared to other large metropolitan cities like New York (9511.03 km<sup>2</sup> in 2011) and Chicago (7008.38 km<sup>2</sup> in 2014) (Atlas of Urban Expansion, 2016a, 2016b), the effects of urbanization on avian densities on Grenada raised cause for conservation concerns and should be considered accordingly.

Some of our endemic species selected specific anthropogenic habitats. Farmlands had the highest densities of focal species and were suitable habitats for both regional endemic Lesser Antillean Tanagers and Lesser Antillean Bullfinches. In general, farmland ecosystems are known to have significant importance for bird's biodiversity conservation (Mulwa, Böhning-Gaese, & Schleuning, 2012; Gove et al., 2013). Anthropogenic habitats containing residential buildings were also particularly critical habitats for Lesser Antillean Tanagers, possibly because Tanagers were attracted to food resources in kitchen gardens near residential buildings (Brierley, 1985). Residential gardens are known to help conserve avian species (Chamberlain, Cannon, & Toms, 2004; Goddard, Ikin, & Lerman, 2017). As such, to adequately conserve Lesser Antillean Tanagers and Bullfinches and their habitats in Grenada's developing economy, both Lesser Antillean Tanagers' and Bullfinches' natural and anthropogenic habitats should be considered.

#### ***5.4 Avian species richness and diversity and the impacts of anthropogenic disturbance:***

##### ***5.4.1 The theory of island biogeography explained avian species richness across the islands:***

My results on the richness of avian species among the different islands are consistent with 'the theory of island biogeography.' All my surveyed islands, except Hog island, had species richness proportional to island size (Table 10), consistent with the prediction that larger islands have higher species richness compared to smaller islands (MacArthur & Wilson, 1967). On Hog island, however, I observed higher species richness compared to three bigger islands, namely

Ronde Island, Petite Martinique, and Caille Island. Although Hog Island is much smaller (0.35km<sup>2</sup>) than Ronde Island, Petite Martinique, and Caille Island (2.7km<sup>2</sup>, 2.37km<sup>2</sup>, and 0.7km<sup>2</sup>, respectively), it is only 0.123 km from Grenada. Islands closer to the mainland or source area are expected to have higher species richness compared to islands further away (MacArthur & Wilson, 1967). As such, new species migrating from Grenada would be more likely to encounter Hog Island than Caille Island (6.96 km from Grenada), Ronde Island (7.8 km from Grenada) or Petite Martinique (39.9 km from Grenada). My results, therefore, are consistent with the theory of island biogeography (MacArthur & Wilson, 1967).

#### ***5.4.1.1 Diversity of species on Grenada compared to other islands:***

The diversity of avian species on the different islands was rather surprising. Only 67% (4 out of 6) of the islands had species diversity proportional to island size. The exceptions were Petite Martinique and Hog Island (Table 10). Hog Island is exceptionally close to Grenada (0.1227 km apart) compared to the other surveyed islands, and as the theory of island biogeography implies, closer islands to the mainland are expected to have higher diversity than distant islands (MacArthur & Wilson, 1967). Petite Martinique, however, is the surveyed island farthest from Grenada, and as Petite Martinique (2.37 km<sup>2</sup>) is much smaller than Carriacou (34 km<sup>2</sup>), higher diversity on Petite Martinique was surprising (MacArthur & Wilson, 1967). Island area by itself is known to be a relatively weak predictor of avian species diversity (Power, 1972), especially in smaller islands, because of a phenomenon known as 'the small island effect' (Lomolino & Weiser, 2001). In essence, the small island effect implies that beyond some minimum island area, species richness may vary independently of island area, and beyond the range of the small island effect, species richness continuously increases with island size (Lomolino & Weiser, 2001). As such, due to Petite Martinique's small area, higher diversity on Petite Martinique is likely influenced by other factors

besides island area alone, such as habitat diversity and lower levels of both anthropogenic disturbance and habitat loss (Power, 1972; Burger, 1981). Avian species are known to benefit from less human disturbance (Burger, 1981) and anthropogenic habitat loss (Blake & Karr, 1984). Considering that three of my analyzed species (Antillean Crested Hummingbirds, Bananaquits, and Black-faced Grassquits) that were found with higher abundances on Petite Martinique avoided urban habitats, and as Petite Martinique is less urbanized and anthropogenically disturbed compared to Carriacou, I believe lower anthropogenic disturbance on Petite Martinique may be supporting higher species diversity compared to Carriacou.

#### ***5.4.2 The overall impact of human disturbance on birds in Grenada:***

Anthropogenically modified habitats can have positive (Lepczyk et al., 2008) or negative (Şekercioğlu et al., 2002) impacts on avian communities. Such impacts are well known for different groups of species or species' guilds (Lepczyk et al., 2008; Canaday, 1996). On Grenada, I found higher diversity of upland birds in anthropogenically modified habitats compared to forested habitats, and the highest diversity of species was in low-vegetated habitats (Table 11). Higher diversities of species in anthropogenically modified habitats may be the result of an abundance of food resources in farmlands and gardens that attract generalist species (Piha, Tiainen, Holopainen, & Vepsäläinen, 2007). For instance, most of the farming on Grenada is small-scale organic farming (Brierley, 1985; Graham, 2012), which may support higher abundances and diversity of weeds and invertebrate food (Piha et al., 2007) that attracts generalist species. High diversity of birds in anthropogenically modified habitats has been found elsewhere in the Caribbean, as Hernandez (2016) also found high diversities of birds in pasture-dominated habitats in Hispaniola and argued that alternative habitat types complemented with protected reserves are required to sustain biodiversity in tropical forested landscapes. According to Hernandez (2016)

protected reserves alone in tropical forested landscapes are not sufficient to sustain biodiversity as a 90% tropical forest loss can result in 50% biodiversity loss (Terborgh, 1992), and the effects of biodiversity loss from deforestation to accommodate human needs can persist for decades (Hansen et al., 2005). In other parts of the world, such as Europe and North America, organic farming is known to support higher abundances and richness of avian species when compared to inorganic farming (Christensen et al., 1996; Freemark & Kirk, 2001). My results again suggest the need for a mosaic of natural and anthropogenic habitat types in Grenada to sustain biodiversity.

### ***5.5 Importance of conservation in small islands:***

The conservation of islands is essential for sustaining biodiversity on Earth because islands have the highest global species endemism and species on islands are most vulnerable to extinction, especially smaller islands (Kier et al., 2009). When compared to their continental counterparts, islands support a factor of 9.5 and 8.1 more endemic species richness for plants and vertebrates, respectively (Kier et al., 2009). In fact, islands harbour such remarkable concentrations of unique biological assemblages and endemic species that they are regarded as biodiversity hotspots (Mittermeier et al., 2004; Whittaker & Fernández-Palacios, 2007). However, islands ecosystems, unlike their continental counterparts, are disproportionately threatened. Considering that islands make up only 5.3% of the landmass on earth, approximately 50% of the 724 documented animal extinction that occurred over the past 400 years were island species (CBD, 2010; Tershy et al., 2015). Such higher proportions of extinctions on islands relative to global landmass is not surprising because islands are fundamentally less resilient to biodiversity loss compared to continents (Frankham, 2005). Islands generally have a higher risk of natural disasters (e.g. volcanic eruptions, hurricanes, and storms) and anthropogenic threats (e.g. habitat destruction and

introduced species) may be more concentrated on islands (Riera et al., 2014). As such, it is vitally important to focus conservation efforts on islands to sustain global biodiversity conservation.

### **Chapter 6.0 CONCLUSION AND RECOMMENDATIONS:**

Anthropogenic disturbances, specific land use, and urbanization impacted the abundances, distribution, and diversity of avian species across the surveyed islands. On Grenada, most species selected anthropogenic cultivated habitats and avoided cloud and secondary forests and secondary scrubs. However, several species including the regional endemic Lesser Antillean Tanagers, near-endemic Grenada Flycatcher and most nectarivores selected those natural cloud and secondary forests and secondary scrub with relatively low species abundance. Some species also avoided urban habitats, suggesting that urbanization may be negatively affecting the diversity of species. My results, therefore, suggest that a mosaic of habitats is needed to properly conserve biodiversity on Grenada and that further urbanization should be limited to maintain species diversity.

Conservation statuses of most terrestrial species on Grenada are unknown, there are no known legal regulations (to my knowledge) that protect Grenada's land birds from anthropogenic habitat disturbance, except for the globally critically endangered Grenada Doves. My results indicated that some of Grenada's near-endemic and restricted-ranged species (Lesser Antillean Tanagers and Grenada Flycatcher) also require specific habitats. My results also indicated that urbanization and anthropogenic habitat disturbance are cause for land bird conservation concern in Grenada. As rapid developmental changes are occurring on Grenada, I strongly implore the Grenadian government to consider implementing legal protection for other avian species and their habitats so that national development and wildlife conservation can strive together and benefit all stakeholders along with Grenada's wildlife.

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## APPENDIX 1

**Table S1. Double observer compared to Ramon’s detectability of focal species on Grenada in 2017.**

	Ramon Williams Detectability With in 25-m Radius				Double Observer Detectability With in 25-m Radius			
	Detectability	Standard Error	95% Confidence Interval		Detectability	Standard Error	95% Confidence Interval	
			Lower	Upper			Lower	Upper
Antillean crested Hummingbird	0.75	0.045	0.66	0.84	0.91	0.025	0.87	0.96
Bananaquit	0.81	0.021	0.77	0.85	0.94	0.010	0.92	0.96
Black-faced Grassquit	0.91	0.028	0.86	0.97	0.98	0.010	0.96	0.99
Blue-black Grassquit	0.83	0.108	0.62	1.04	1.00	0.067	0.87	1.13
Broad-winged Hawk	0.92	0.063	0.71	0.96	1.00	0.041	0.92	1.08
Carib Grackle	0.93	0.036	0.89	1.03	0.99	0.013	0.96	1.01
Caribbean Elaenia	1.00	<0.0001	1.00	1.00	1.00	0.333	0.35	1.65
Cattle Egret	0.96	0.036	0.89	1.03	0.99	0.013	0.96	1.01
Common Ground-dove	0.58	0.136	0.31	0.85	0.77	0.120	0.54	1.01
Eared Dove	0.95	0.031	0.89	1.01	0.99	0.009	0.97	1.00
Green-throated Carib	0.83	0.108	0.62	1.04	1.00	0.067	0.87	1.13
Fork-tailed flycatcher	0.83	0.108	0.62	1.04	1.00	0.067	0.87	1.13
Gray Kingbird	0.84	0.037	0.76	0.91	0.97	0.013	0.94	0.99
Gray-rumped Swift	0.84	0.063	0.71	0.96	0.98	0.013	0.96	1.01
Grenada Dove	0.83	0.108	0.62	1.04	1.00	0.067	0.87	1.13
Grenada Flycatcher	0.86	0.098	0.66	1.05	0.97	0.032	0.91	1.03
House Wren	0.97	0.031	0.91	1.03	1.00	0.005	0.99	1.01
Lesser Antillean Bullfinch	0.85	0.051	0.75	0.94	0.94	0.025	0.90	0.99
Lesser Antillean Tanager	0.97	0.027	0.92	1.03	1.00	0.005	0.99	1.00
Macaws	0.83	0.108	0.62	1.04	1.00	0.067	0.87	1.13
Mangrove Cuckoo	0.57	0.258	0.07	1.08	0.73	0.248	0.24	1.21
Orange-winged Parrot	1.00	<0.0001	1.00	1.00	1.00	0.000	1.00	1.00
Rufous-breasted Hermit	0.81	0.083	0.64	0.97	0.95	0.035	0.88	1.02
Scaly-naped Pigeon	0.73	0.037	0.65	0.80	0.93	0.017	0.90	0.97
Shiny Cowbird	0.83	0.072	0.69	0.97	0.96	0.027	0.91	1.02
Smooth-billed Ani	0.84	0.153	0.54	1.14	0.96	0.055	0.85	1.07
Spectacled Thrush	0.75	0.061	0.64	0.87	0.90	0.039	0.82	0.97
Tropical Mockingbird	0.84	0.024	0.80	0.89	0.98	0.007	0.96	0.99
Yellow-bellied Elaenia	0.93	0.067	0.80	1.06	0.98	0.021	0.94	1.02
Yellow-bellied Seedeater	0.81	0.077	0.66	0.96	0.99	0.012	0.96	1.01
Zenaida Dove	0.76	0.158	0.45	1.07	0.95	0.068	0.82	1.08
Mean	0.84				0.96			
Standard deviation	0.10				0.06			
Standard error	0.02				0.01			

**Table S2. Species density comparisons between Grenada and other islands, and the effects of date and time of day on land bird species density per 25-m radius plots in 2017. Date = number of days since the start of the survey during the rainy season (a significant negative beta value means that detections decreased later in the rainy season). Time of day = whether surveys were conducted in the morning and or evening (a significant negative beta value means that either the mornings or evenings had fewer detections, as determined by examining the mean density of each species identified in AM compared to the PM). ID = insufficient data. All response variables were modeled using a Poisson distribution. Significant p-values ( $p < 0.05$ ) are in bold.**

		Carriacou	Petite Martinique	Ronde Island	Caille Island	Date	Time of day (AM & PM)
Antillean Crested Hummingbird	Beta	0.437	0.668	0.559	0.718	-0.004	-0.154
	Standard Error	0.189	0.253	0.258	0.342	0.003	0.092
	p-value	<b>0.021</b>	<b>0.008</b>	<b>0.030</b>	<b>0.036</b>	0.116	0.092
Bananaquit	Beta	0.187	-0.624	-0.095	0.419	-0.0005	0.087
	Standard Error	0.093	0.187	0.142	0.175	0.001	0.048
	p-value	<b>0.043</b>	<b>0.001</b>	0.501	<b>0.017</b>	0.729	0.067
Black-faced Grassquit	Beta	0.159	0.771	ID	ID	-0.001	-0.599
	Standard Error	0.220	0.271	ID	ID	0.003	0.120
	p-value	0.469	<b>0.004</b>	ID	ID	0.869	<b>&lt;0.0001</b>
Broad-winged Hawk	Beta	ID	ID	ID	ID	-0.016	-1.091
	Standard Error	ID	ID	ID	ID	0.013	0.602
	p-value	ID	ID	ID	ID	0.239	<b>0.070</b>
Cattle Egret	Beta	-2.160	ID	ID	ID	0.005	-0.735
	Standard Error	0.787	ID	ID	ID	0.007	0.313
	p-value	<b>0.006</b>	ID	ID	ID	0.456	<b>0.019</b>
Carib Grackle	Beta	0.135	-0.660	-0.301	-0.772	0.029	-0.282
	Standard Error	0.272	0.574	0.435	0.414	0.005	0.178
	p-value	0.619	0.250	0.489	0.063	<b>&lt;0.0001</b>	0.113
Eared Dove	Beta	-0.389	-0.613	ID	ID	0.019	-0.308
	Standard Error	0.230	0.390	ID	ID	0.004	0.152
	p-value	0.091	0.116	ID	ID	<b>&lt;0.0001</b>	<b>0.043</b>
Grenada Flycatcher	Beta	-1.071	ID	ID	ID	0.004	0.104
	Standard Error	0.553	ID	ID	ID	0.007	0.273
	p-value	0.053	ID	ID	ID	0.526	0.703
Gray Kingbird	Beta	-0.260	0.050	-0.851	ID	-0.009	-0.007
	Standard Error	0.252	0.375	0.475	ID	0.003	0.112
	p-value	0.302	0.894	0.073	ID	<b>0.007</b>	0.950
Gray-rumped Swift	Beta	-0.480	ID	1.541	ID	0.012	1.024
	Standard Error	0.261	ID	0.288	ID	0.004	0.148
	p-value	0.0662	ID	<b>&lt;0.0001</b>	ID	<b>0.001</b>	<b>&lt;0.0001</b>
House Wren	Beta	-4.243	ID	ID	ID	0.018	-0.547
	Standard Error	1.006	ID	ID	ID	0.004	0.211
	p-value	<b>&lt;0.0001</b>	ID	ID	ID	<b>&lt;0.0001</b>	<b>0.010</b>
Lesser Antillean Bullfinch	Beta	ID	ID	ID	ID	-0.015	0.565
	Standard Error	ID	ID	ID	ID	0.004	0.128
	p-value	ID	ID	ID	ID	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Lesser Antillean Tanager	Beta	ID	ID	ID	ID	-0.006	-0.317
	Standard Error	ID	ID	ID	ID	0.006	0.231
	p-value	ID	ID	ID	ID	0.253	0.170
Rufous-breasted Hermit	Beta	ID	ID	ID	ID	0.013	-1.241
	Standard Error	ID	ID	ID	ID	0.005	0.299
	p-value	ID	ID	ID	ID	<b>0.010</b>	<b>&lt;0.0001</b>
Smooth-billed Ani	Beta	ID	ID	0.958	ID	0.005	-0.329
	Standard Error	ID	ID	0.777	ID	0.010	0.412
	p-value	ID	ID	0.217	ID	0.619	0.425
Shiny Cowbird	Beta	-2.176	-1.178	ID	ID	0.020	-2.666
	Standard Error	0.554	0.714	ID	ID	0.006	0.544
	p-value	<b>&lt;0.0001</b>	0.099	ID	ID	<b>0.001</b>	<b>&lt;0.0001</b>
Scaly-naped Pigeon	Beta	0.857	ID	0.006	-2.293	0.011	-0.004
	Standard Error	0.130	ID	0.211	0.411	0.002	0.071
	p-value	<b>&lt;0.0001</b>	ID	0.977	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	0.953
Spectacled Thrush	Beta	ID	ID	-2.505	ID	-0.005	-0.030
	Standard Error	ID	ID	0.902	ID	0.003	0.129
	p-value	ID	ID	<b>0.006</b>	ID	0.109	0.814
Tropical Mockingbird	Beta	0.930	-0.095	0.135	-0.131	0.008	0.403
	Standard Error	0.137	0.237	0.212	0.320	0.002	0.072
	p-value	<b>&lt;0.0001</b>	0.687	0.523	0.683	<b>0.0003</b>	<b>&lt;0.0001</b>
Yellow-bellied Seed-eater	Beta	ID	ID	-2.145	ID	0.006	-0.418
	Standard Error	ID	ID	0.987	ID	0.006	0.261
	p-value	ID	ID	<b>0.030</b>	ID	0.270	0.110
Zenaida Dove	Beta	0.721	-0.415	ID	ID	0.030	-0.385
	Standard Error	0.590	1.025	ID	ID	0.012	0.355
	p-value	0.222	0.685	ID	ID	<b>0.011</b>	0.279

**Table S3. Density of land birds across all surveyed islands (Grenada, Carriacou, Petite Martinique, Caille Island, Ronde Island) in 2017. Mean = average density of species across all survey islands. AM = density of species surveyed in the morning (dawn until noon). PM = density of species surveyed in the evening (4:00 pm until dusk). ID = insufficient data.**

		Grenada	Carriacou	Petite Martinique	Caille Island	Ronde Island	Mean	AM	PM
Antillean crested Hummingbird	Density	1.104	1.314	1.662	1.662	1.472	1.194	1.264	1.080
	Standard deviation	1.404	1.634	2.088	1.178	1.748	1.496	1.509	1.473
Bananaquit	Density	4.074	4.850	2.154	5.999	3.516	4.150	3.989	4.412
	Standard deviation	3.127	4.196	1.933	4.530	2.500	3.346	3.098	3.708
Black-faced Grassquit	Density	0.807	0.849	1.571	ID	ID	0.844	1.021	0.576
	Standard deviation	1.329	1.512	1.783	ID	ID	1.389	1.474	1.205
Broad-winged Hawk	Density	0.067	ID	ID	ID	ID	0.067	0.090	0.028
	Standard deviation	0.336	ID	ID	ID	ID	0.336	0.399	0.172
Cattle Egret	Density	0.179	0.024	ID	ID	ID	0.147	0.187	0.084
	Standard deviation	1.405	0.225	ID	ID	ID	1.256	1.580	0.401
Carib Grackle	Density	0.172	0.747	0.471	0.538	0.500	0.314	0.320	0.306
	Standard deviation	0.597	1.438	0.876	0.813	0.948	0.876	0.830	0.948
Eared Dove	Density	0.400	0.672	0.529	ID	ID	0.459	0.485	0.419
	Standard deviation	1.484	1.511	0.772	ID	ID	1.471	1.679	1.083
Grenada Flycatcher	Density	0.158	0.069	ID	ID	ID	0.140	0.136	0.145
	Standard deviation	0.566	0.417	ID	ID	ID	0.539	0.522	0.566
Gray Kingbird	Density	0.920	0.436	0.598	ID	0.214	0.775	0.792	0.747
	Standard deviation	1.397	0.822	0.977	ID	0.732	1.281	1.272	1.298
Gray-rumped Swift	Density	0.320	0.422	ID	ID	2.522	0.481	0.351	0.696
	Standard deviation	1.401	2.750	ID	ID	5.921	2.315	1.520	3.222
House Wren	Density	0.359	0.012	ID	ID	ID	0.287	0.340	0.205
	Standard deviation	0.799	0.112	ID	ID	ID	0.726	0.801	0.587
Lesser Antillean Bullfinch	Density	0.764	ID	ID	ID	ID	0.764	0.623	1.012
	Standard deviation	1.547	ID	ID	ID	ID	1.547	1.147	2.053
Lesser Antillean Tanager	Density	0.288	ID	ID	ID	ID	0.288	0.323	0.226
	Standard deviation	0.707	ID	ID	ID	ID	0.707	0.732	0.660
Rufous-breasted Hermit	Density	0.271	ID	ID	ID	ID	0.271	0.359	0.116
	Standard deviation	0.814	ID	ID	ID	ID	0.814	0.957	0.429
Smooth-billed Ani	Density	0.077	ID	ID	ID	0.298	0.095	0.108	0.068
	Standard deviation	0.427	ID	ID	ID	1.576	0.602	0.699	0.353
Shiny Cowbird	Density	0.211	0.056	0.150	ID	ID	0.178	0.280	0.021
	Standard deviation	0.769	0.521	0.410	ID	ID	0.717	0.894	0.206
Scaly-naped Pigeon	Density	1.160	4.871	2.063	ID	0.245654	1.830	1.645	2.131
	Standard deviation	2.986	5.862	2.131	ID	0.654259	3.891	3.766	4.080
Spectacled Thrush	Density	0.827	ID	ID	ID	0.047	0.766	0.763	0.771
	Standard deviation	1.317	ID	ID	ID	0.250	1.283	1.279	1.295
Tropical Mockingbird	Density	1.056	4.359	1.554	1.628	1.903	1.742	1.354	2.374
	Standard deviation	1.613	7.572	1.201	1.542	2.544	3.786	1.825	5.629
Yellow-bellied Seedeater	Density	0.227	ID	ID	ID	0.044	0.213	0.234	0.172
	Standard deviation	0.720	ID	ID	ID	0.233	0.696	0.742	0.599
Zenaida Dove	Density	0.032	0.263	0.082	ID	ID	0.080	0.082	0.078
	Standard deviation	0.251	0.636	0.329	ID	ID	0.374	0.377	0.372

**Table S4. Weather variables (temperature, cloud cover, and wind speed) effects on land bird species density in Grenada in 2017. All response variables were modeled using a Poisson distribution. Significant p-values ( $p < 0.05$ ) are bolded.**

		Temperature	Cloud Cover	Wind Speed
Antillean Crested Hummingbird	Beta	-0.126	-0.001	-0.041
	Standard Error	0.034	0.001	0.016
	p-value	<b>0.0002</b>	0.497	<b>0.010</b>
Bananaquit	Beta	0.017	-0.0004	-0.062
	Standard Error	0.018	0.001	0.009
	p-value	0.333	0.564	<b>&lt;0.0001</b>
Black-faced Grassquit	Beta	-0.101	-0.0005	-0.015
	Standard Error	0.040	0.002	0.018
	p-value	<b>0.012</b>	0.745	0.407
Broad-winged Hawk	Beta	0.081	-0.0023	-0.284
	Standard Error	0.178	0.006	0.117
	p-value	0.650	0.718	<b>0.015</b>
Cattle Egret	Beta	-0.065	-0.022	0.088
	Standard Error	0.096	0.005	0.030
	p-value	0.501	<b>&lt;0.0001</b>	<b>0.004</b>
Carib Grackle	Beta	0.225	-0.007	0.048
	Standard Error	0.064	0.003	0.024
	p-value	<b>0.0005</b>	<b>0.016</b>	<b>0.043</b>
Eared Dove	Beta	-0.036	-0.008	-0.024
	Standard Error	0.054	0.002	0.024
	p-value	0.507	<b>0.001</b>	0.321
Grenada Flycatcher	Beta	-0.214	-0.006	-0.073
	Standard Error	0.108	0.004	0.053
	p-value	<b>0.047</b>	0.144	0.171
Gray Kingbird	Beta	-0.078	0.002	-0.034
	Standard Error	0.041	0.002	0.019
	p-value	0.059	0.160	0.070
Gray-rumped Swift	Beta	0.019	-0.005	-0.030
	Standard Error	0.055	0.002	0.025
	p-value	0.732	<b>0.024</b>	0.226
House Wren	Beta	-0.136	-0.008	0.021
	Standard Error	0.070	0.003	0.027
	p-value	0.053	<b>0.0048</b>	0.442
Lesser Antillean Bullfinch	Beta	0.005	-0.004	-0.065
	Standard Error	0.054	0.002	0.024
	p-value	0.9287	0.071	<b>0.006</b>
Lesser Antillean Tanager	Beta	-0.039	0.016	0.068
	Standard Error	0.081	0.004	0.027
	p-value	0.628	<b>&lt;0.0001</b>	<b>0.013</b>
Rufous-breasted Hermit	Beta	-0.185	0.026	-0.044
	Standard Error	0.085	0.005	0.043
	p-value	<b>0.029</b>	<b>&lt;0.0001</b>	0.311
Smooth-billed Ani	Beta	0.205	-0.018	-0.044
	Standard Error	0.161	0.006	0.058
	p-value	0.203	<b>0.004</b>	0.442
Shiny Cowbird	Beta	-0.131	-0.004	0.056
	Standard Error	0.087	0.004	0.031
	p-value	0.133	0.279	0.067
Scaly-naped Pigeon	Beta	0.213	-0.008	0.052
	Standard Error	0.026	0.001	0.009
	p-value	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Spectacled Thrush	Beta	-0.089	0.002	-0.009
	Standard Error	0.052	0.002	0.021
	p-value	0.087	0.240	0.675
Tropical Mockingbird	Beta	0.132	-0.011	0.016
	Standard Error	0.027	0.001	0.011
	p-value	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	0.148
Yellow-bellied Seedeater	Beta	0.262	-0.0004	-0.030
	Standard Error	0.100	0.004	0.038
	p-value	<b>0.009</b>	0.906	0.427
Zenaida Dove	Beta	0.193	0.004	0.011
	Standard Error	0.133	0.006	0.054
	p-value	0.147	0.490	0.846

**Table S5. Combined habitat types effects on land bird species density on Grenada in 2017. Forested habitat = proportion of montane forest + proportion of mature lowland forest + proportion of secondary forest + proportion of cloud forest + proportion of mangrove forest. Low or short vegetated habitat = proportion of secondary scrub + proportion of secondary grassland + proportion of savanna. Agricultural habitat = proportion of pasture + proportion of cultivated. Date = number of days since the start of the survey during the rainy season (A significant negative beta value means that detections decreased later in the rainy season). Time of day = whether surveys were conducted in the morning and or evening (a significant negative beta value means that either the mornings or evenings had fewer detections, as determined by examining the mean density of each species identified in the AM compared to the PM). ID = insufficient data. All combined habitat types were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. Significant p-values (p<0.05) are in bold.**

		Forested habitat	Low vegetated habitat	Agricultural habitat	Date	Time of day (AM & PM)
Antillean Crested Hummingbird	Beta	0.007	-0.001	0.013	0.004	-0.180
	Standard Error	0.002	0.003	0.002	0.003	0.120
	p-value	<b>0.006</b>	0.860	<b>&lt;0.0001</b>	0.205	0.133
Bananaquit	Beta	0.004	-0.004	0.007	0.005	0.140
	Standard Error	0.001	0.002	0.001	0.001	0.059
	p-value	<b>0.002</b>	<b>0.004</b>	<b>&lt;0.0001</b>	<b>0.001</b>	<b>0.017</b>
Black-faced Grassquit	Beta	-0.014	0.003	0.008	0.007	-0.619
	Standard Error	0.004	0.003	0.003	0.004	0.149
	p-value	<b>&lt;0.0001</b>	0.252	<b>0.002</b>	0.059	<b>&lt;0.0001</b>
Broad-winged Hawk	Beta	0.006	-0.025	0.008	-0.006	-0.917
	Standard Error	0.010	0.022	0.010	0.015	0.615
	p-value	0.563	0.257	0.438	0.684	0.136
Cattle Egret	Beta	-0.018	0.008	-0.033	-0.019	-1.134
	Standard Error	0.007	0.005	0.008	0.008	0.333
	p-value	<b>0.007</b>	0.084	<b>&lt;0.0001</b>	<b>0.017</b>	<b>0.001</b>
Carib Grackle	Beta	-0.026	0.006	-0.002	0.029	-0.900
	Standard Error	0.009	0.005	0.006	0.007	0.326
	p-value	<b>0.003</b>	0.273	0.721	<b>&lt;0.0001</b>	<b>0.006</b>
Eared Dove	Beta	-0.039	-0.018	-0.010	0.023	-0.852
	Standard Error	0.006	0.004	0.004	0.004	0.206
	p-value	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.009</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Grenada Flycatcher	Beta	0.002	0.010	0.010	0.007	-0.032
	Standard Error	0.007	0.007	0.007	0.007	0.300
	p-value	0.730	0.121	0.122	0.306	0.915
Gray Kingbird	Beta	-0.006	-0.004	-0.0003	-0.006	-0.023
	Standard Error	0.003	0.003	0.002	0.003	0.125
	p-value	<b>0.019</b>	0.175	0.893	0.091	0.852
Gray-rumped Swift	Beta	-0.015	0.005	0.026	0.040	-0.848
	Standard Error	0.006	0.005	0.004	0.005	0.251
	p-value	<b>0.014</b>	0.353	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.001</b>
House Wren	Beta	-0.013	-0.007	-0.014	0.013	-0.618
	Standard Error	0.004	0.004	0.004	0.005	0.211
	p-value	<b>0.001</b>	0.052	<b>0.001</b>	<b>0.004</b>	<b>0.003</b>
Lesser Antillean Bullfinch	Beta	-0.008	-0.015	-0.007	-0.013	0.528
	Standard Error	0.003	0.003	0.003	0.004	0.132
	p-value	<b>0.002</b>	<b>&lt;0.0001</b>	<b>0.012</b>	<b>0.001</b>	<b>&lt;0.0001</b>
Lesser Antillean Tanager	Beta	0.001	-0.029	-0.002	-0.001	-0.215
	Standard Error	0.004	0.009	0.004	0.006	0.237
	p-value	0.891	<b>0.001</b>	0.684	0.821	0.363
Rufous-breasted Hermit	Beta	0.029	-0.009	0.032	0.020	-0.880
	Standard Error	0.007	0.014	0.007	0.006	0.309
	p-value	<b>&lt;0.0001</b>	0.523	<b>&lt;0.0001</b>	<b>0.001</b>	<b>0.004</b>
Smooth-billed Ani	Beta	-0.003	-0.0004	0.003	0.007	-0.182
	Standard Error	0.009	0.009	0.009	0.011	0.438
	p-value	0.703	0.966	0.752	0.507	0.678
Shiny Cowbird	Beta	-0.021	-0.013	-0.020	0.012	-2.631
	Standard Error	0.005	0.005	0.006	0.007	0.545
	p-value	<b>&lt;0.0001</b>	<b>0.008</b>	<b>0.001</b>	0.072	<b>&lt;0.0001</b>
Scaly-naped Pigeon	Beta	-0.003	0.004	-0.007	0.007	-0.484
	Standard Error	0.002	0.002	0.002	0.003	0.116
	p-value	0.139	0.066	<b>0.005</b>	<b>0.012</b>	<b>&lt;0.0001</b>
Spectacled Thrush	Beta	-0.005	0.001	0.009	0.002	-0.043
	Standard Error	0.003	0.003	0.003	0.004	0.133
	p-value	0.079	0.825	<b>0.001</b>	0.479	0.748
Tropical Mockingbird	Beta	-0.021	-0.002	-0.019	-0.002	-0.018
	Standard Error	0.003	0.002	0.003	0.003	0.111
	p-value	<b>&lt;0.0001</b>	0.399	<b>&lt;0.0001</b>	0.442	0.874
Yellow-bellied Seedeater	Beta	-0.021	-0.018	-0.011	0.008	-0.553
	Standard Error	0.005	0.006	0.005	0.006	0.264
	p-value	<b>&lt;0.0001</b>	<b>0.002</b>	<b>0.023</b>	0.195	<b>0.036</b>
Zenaida Dove	Beta	-0.018	-0.039	-0.001	0.033	ID
	Standard Error	0.013	0.023	0.011	0.013	ID
	p-value	0.156	0.097	0.905	<b>0.014</b>	ID

**Table S6. Habitat types effects on land bird species density on Grenada in 2017. Date = number of days since the start of the survey during the rainy season (A significant negative beta value means that detections decreased later in the rainy season). Time of day = whether surveys were conducted in the morning and or evening (a significant negative beta value means that either the mornings or evenings had fewer detections, as determined by examining the mean density of each species identified in the AM compared to the PM). ID = insufficient data. All habitat types were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. Significant p-values (p<0.05) are in bold.**

		Montane forest	Mature lowland forest	Secondary forest	Cloud forest	Mangrove forest	Secondary scrub	Secondary grassland	Savanna	Pasture	Cultivated	Date	Time of day (AM & PM)
Antillean Crested Hummingbird	Beta	0.003	0.005	0.006	0.008	0.003	-0.005	-0.002	0.011	0.010	0.013	0.005	-0.227
	Standard Error	0.007	0.005	0.003	0.003	0.007	0.004	0.007	0.005	0.007	0.002	0.003	0.126
	p-value	0.623	0.385	0.052	<b>0.015</b>	0.638	0.198	0.805	<b>0.020</b>	0.1506	<b>&lt;0.0001</b>	0.166	0.071
Bananaquit	Beta	0.007	0.002	0.006	0.0006	0.006	0.001	-0.032	-0.009	-0.006	0.008	0.005	0.224
	Standard Error	0.003	0.003	0.001	0.002	0.003	0.002	0.006	0.004	0.005	0.001	0.002	0.061
	p-value	<b>0.024</b>	0.393	<b>&lt;0.0001</b>	0.756	0.057	0.553	<b>&lt;0.0001</b>	<b>0.009</b>	0.238	<b>&lt;0.0001</b>	<b>0.001</b>	<b>0.0003</b>
Black-faced Grassquit	Beta	-0.013	-0.005	-0.011	-0.022	ID	0.005	0.013	-0.018	0.017	0.009	0.007	-0.638
	Standard Error	0.012	0.007	0.004	0.008	ID	0.003	0.005	0.011	0.007	0.003	0.004	0.154
	p-value	0.267	0.511	<b>0.013</b>	<b>0.008</b>	ID	0.121	<b>0.016</b>	0.101	<b>0.014</b>	<b>0.001</b>	0.078	<b>&lt;0.0001</b>
Broad-winged Hawk	Beta	ID	0.018	0.014	0.014	ID	-0.009	ID	ID	0.0408	0.013	-0.013	-0.999
	Standard Error	ID	0.014	0.011	0.013	ID	0.020	ID	ID	0.021	0.010	0.017	0.645
	p-value	ID	0.203	0.194	0.261	ID	0.668	ID	ID	0.054	0.189	0.4286	0.121
Cattle Egret	Beta	ID	ID	0.0001	ID	0.006	0.012	0.037	0.007	ID	-0.020	-0.016	-1.404
	Standard Error	ID	ID	0.007	ID	0.015	0.005	0.006	0.010	ID	0.007	0.009	0.364
	p-value	ID	ID	0.985	ID	0.683	<b>0.013</b>	<b>&lt;0.0001</b>	0.524	ID	<b>0.0066</b>	<b>0.063</b>	<b>0.0001</b>
Carib Grackle	Beta	ID	-0.009	-0.026	ID	0.012	0.012	0.027	-0.031	-0.015	0.007	0.033	-0.993
	Standard Error	ID	0.020	0.014	ID	0.013	0.005	0.009	0.027	0.032	0.006	0.008	0.357
	p-value	ID	0.647	0.061	ID	0.385	<b>0.020</b>	<b>0.003</b>	0.236	0.640	0.287	<b>&lt;0.0001</b>	<b>0.005</b>
Eared Dove	Beta	-0.032	-0.006	-0.032	ID	ID	-0.008	0.007	-0.031	ID	0.002	0.026	-0.836
	Standard Error	0.028	0.009	0.009	ID	ID	0.004	0.008	0.017	ID	0.004	0.005	0.216
	p-value	0.258	0.495	<b>0.0002</b>	ID	ID	<b>0.050</b>	0.367	0.072	ID	0.6008	<b>&lt;0.0001</b>	<b>0.0001</b>
Grenada Flycatcher	Beta	-0.023	0.010	-0.0004	-0.001	0.026	0.021	-0.049	ID	-0.001	0.015	0.006	0.125
	Standard Error	0.048	0.011	0.010	0.012	0.012	0.007	0.039	ID	0.029	0.007	0.008	0.321
	p-value	0.634	0.362	0.968	0.906	<b>0.024</b>	<b>0.0020</b>	0.214	ID	0.968	<b>0.027</b>	0.432	0.696
Gray Kingbird	Beta	-0.010	-0.008	-0.006	-0.014	0.005	-0.008	-0.002	0.003	0.006	-0.005	-0.004	-0.120
	Standard Error	0.009	0.006	0.003	0.005	0.006	0.004	0.006	0.005	0.008	0.003	0.004	0.130
	p-value	0.257	0.161	0.067	<b>0.010</b>	0.423	<b>0.037</b>	0.700	0.506	0.437	0.855	0.286	0.354
Gray-rumped Swift	Beta	0.035	0.012	-0.031	ID	0.021	0.006	0.036	-0.005	ID	0.037	0.053	-1.043
	Standard Error	0.010	0.014	0.013	ID	0.011	0.006	0.008	0.016	ID	0.004	0.006	0.267
	p-value	<b>0.0004</b>	0.369	<b>0.012</b>	ID	0.069	0.331	<b>&lt;0.0001</b>	0.732	ID	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
House Wren	Beta	ID	-0.0042	-0.002	ID	0.012	0.0038	-0.006	-0.029	-0.019	-0.007	0.012	-0.430
	Standard Error	ID	0.008	0.004	ID	0.007	0.004	0.010	0.018	0.023	0.004	0.005	0.219
	p-value	ID	0.606	0.588	ID	0.101	0.311	0.515	0.102	0.390	0.107	<b>0.011</b>	<b>0.049</b>
Lesser Antillean Bullfinch	Beta	-0.029	-0.018	-0.001	-0.020	-0.008	-0.019	-0.006	-0.012	ID	-0.005	-0.011	0.495
	Standard Error	0.016	0.008	0.003	0.008	0.009	0.005	0.006	0.006	ID	0.003	0.004	0.135
	p-value	0.080	<b>0.025</b>	0.639	<b>0.0084</b>	0.380	<b>0.0002</b>	0.306	<b>0.049</b>	ID	<b>0.041</b>	<b>0.012</b>	<b>0.0002</b>
Lesser Antillean Tanager	Beta	0.007	ID	-0.005	0.019	ID	-0.032	-0.011	-0.014	0.0043	0.002	-0.013	-0.022
	Standard Error	0.010	ID	0.006	0.005	ID	0.014	0.016	0.015	0.016	0.004	0.009	0.255
	p-value	0.457	ID	0.439	<b>&lt;0.0001</b>	ID	<b>0.025</b>	0.504	0.333	0.795	0.700	0.146	0.931
Rufous-breasted Hermit	Beta	0.060	ID	0.025	0.048	ID	ID	ID	0.042	0.041	0.045	0.024	-0.969
	Standard Error	0.009	ID	0.008	0.007	ID	ID	ID	0.013	0.013	0.007	0.008	0.362
	p-value	<b>&lt;0.0001</b>	ID	<b>0.001</b>	<b>&lt;0.0001</b>	ID	ID	ID	<b>0.001</b>	<b>0.001</b>	<b>&lt;0.0001</b>	<b>0.0026</b>	<b>0.007</b>
Smooth-billed Ani	Beta	ID	ID	0.014	ID	ID	-0.006	0.032	-0.004	ID	0.0108	0.011	-0.161
	Standard Error	ID	ID	0.008	ID	ID	0.014	0.012	0.023	ID	0.008	0.011	0.452
	p-value	ID	ID	0.094	ID	ID	0.643	<b>0.006</b>	0.862	ID	0.184	0.325	0.722
Shiny Cowbird	Beta	ID	-0.0038	-0.007	ID	-0.003	-0.011	0.024	-0.014	0.015	-0.009	0.016	-2.729
	Standard Error	ID	0.012	0.005	ID	0.014	0.006	0.009	0.016	0.018	0.005	0.008	0.570
	p-value	ID	0.749	0.181	ID	0.812	0.0701	<b>0.006</b>	0.375	0.395	0.0941	<b>0.0408</b>	<b>&lt;0.0001</b>
Scaly-naped Pigeon	Beta	ID	0.004	-0.0001	-0.038	0.015	0.004	0.011	0.003	-0.017	-0.004	0.011	-0.572
	Standard Error	ID	0.004	0.002	0.011	0.004	0.002	0.004	0.005	0.016	0.002	0.003	0.120
	p-value	ID	0.288	<b>0.002</b>	<b>0.001</b>	<b>0.0001</b>	0.079	<b>0.006</b>	0.535	0.273	0.096	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Spectacled Thrush	Beta	ID	0.0009	-0.002	-0.010	0.005	0.007	-0.004	-0.029	0.006	0.011	0.002	0.044
	Standard Error	ID	0.006	0.004	0.006	0.008	0.003	0.007	0.014	0.009	0.003	0.004	0.138
	p-value	ID	0.881	0.683	0.102	0.508	<b>0.048</b>	0.617	<b>0.041</b>	0.491	<b>&lt;0.0001</b>	0.520	0.750
Tropical Mockingbird	Beta	ID	-0.065	-0.017	-0.050	0.009	0.002	-0.0095	0.0003	-0.025	-0.017	-0.0002	0.064
	Standard Error	ID	0.018	0.004	0.016	0.004	0.002	0.005	0.004	0.017	0.003	0.003	0.117
	p-value	ID	<b>0.0004</b>	<b>&lt;0.0001</b>	<b>0.0020</b>	<b>0.031</b>	0.331	<b>0.036</b>	0.927	0.143	<b>&lt;0.0001</b>	0.933	0.585
Yellow-bellied Seedeater	Beta	ID	-0.006	-0.003	ID	ID	-0.007	0.008	ID	ID	0.001	0.009	-0.457
	Standard Error	ID	0.012	0.006	ID	ID	0.006	0.009	ID	ID	0.004	0.007	0.267
	p-value	ID	0.607	0.538	ID	ID	0.246	0.406	ID	ID	0.859	0.172	0.087
Zenaida Dove	Beta	ID	ID	0.004	ID	ID	-0.015	ID	ID	ID	0.013	0.035	ID
	Standard Error	ID	ID	0.012	ID	ID	0.021	ID	ID	ID	0.011	0.014	ID
	p-value	ID	ID	0.763	ID	ID	0.477	ID	ID	ID	0.219	<b>0.016</b>	ID

**Table S7. Combined land use variables effects on land bird species densities in Grenada in 2017. Agriculture within 25-m radius = percentage of farmland within each 25-m point count radius + percentage of cocoa plants within each 25-m point count radius + percentage of nutmeg plants within each 25-m point count radius. Residential buildings within 25-m radius = percentage of houses within each 25-m point count radius. Urban structures within 25-m radius = percentage of airport facilities within each 25-m point count radius + percentage of stadium facilities within each 25-m point count radius + percentage of business buildings within each 25-m point count radius. Date = number of days since the start of the survey during the rainy season (A significant negative beta value means that detections decreased later in the rainy season). Time of day = whether surveys were conducted in the morning and or evening (a significant negative beta value means that either the mornings or evenings had fewer detections, as determined by examining the mean density of each species identified in the AM compared to the PM). ID = insufficient data. All combined land-use variables were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. Significant p-values (p<0.05) are in bold.**

		Agriculture within 25-m	Residential buildings within 25-	Urban structures within 25-m	Date	Time of day (AM & PM)
Antillean Crested Hummingbird	Beta	0.009	-0.001	-0.040	0.005	-0.236
	Standard Error	0.002	0.004	0.014	0.003	0.121
	p-value	<b>&lt;0.0001</b>	0.722	<b>0.004</b>	0.115	<b>0.052</b>
Bananaquit	Beta	0.007	-0.004	-0.011	0.005	0.129
	Standard Error	0.001	0.002	0.004	0.002	0.059
	p-value	<b>&lt;0.0001</b>	<b>0.017</b>	<b>0.002</b>	<b>0.0015</b>	<b>0.029</b>
Black-faced Grassquit	Beta	0.011	0.002	0.010	0.008	-0.537
	Standard Error	0.002	0.004	0.005	0.004	0.149
	p-value	<b>&lt;0.0001</b>	0.616	0.064	<b>0.039</b>	<b>0.0003</b>
Broad-winged Hawk	Beta	0.007	0.005	-0.079	-0.007	-1.093
	Standard Error	0.007	0.014	0.108	0.015	0.617
	p-value	0.374	0.727	0.4639	0.651	0.077
Cattle Egret	Beta	-0.029	-0.064	-0.003	-0.014	-0.779
	Standard Error	0.006	0.020	0.010	0.007	0.333
	p-value	<b>&lt;0.0001</b>	<b>0.001</b>	0.758	<b>0.048</b>	0.019
Carib Grackle	Beta	0.0003	0.010	-0.001	0.032	-0.754
	Standard Error	0.005	0.008	0.012	0.007	0.315
	p-value	0.960	0.188	0.920	<b>&lt;0.0001</b>	<b>0.017</b>
Eared Dove	Beta	0.011	0.025	0.012	0.032	-0.831
	Standard Error	0.003	0.005	0.007	0.005	0.206
	p-value	<b>0.002</b>	<b>&lt;0.0001</b>	0.066	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Grenada Flycatcher	Beta	0.004	-0.0001	-0.070	0.009	-0.026
	Standard Error	0.005	0.009	0.056	0.007	0.305
	p-value	0.351	0.996	0.206	0.194	0.931
Gray Kingbird	Beta	0.004	0.005	0.005	-0.006	-0.014
	Standard Error	0.002	0.003	0.005	0.004	0.126
	p-value	0.057	0.175	0.309	0.106	0.913
Gray-rumped Swift	Beta	0.034	0.011	0.027	0.046	-0.732
	Standard Error	0.004	0.007	0.007	0.005	0.238
	p-value	<b>&lt;0.0001</b>	0.138	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.002</b>
House Wren	Beta	-0.005	0.023	-0.020	0.019	-0.702
	Standard Error	0.004	0.004	0.013	0.005	0.211
	p-value	0.205	<b>&lt;0.0001</b>	0.130	<b>&lt;0.0001</b>	<b>0.001</b>
Lesser Antillean Bullfinch	Beta	0.002	0.007	-0.003	-0.013	0.524
	Standard Error	0.002	0.003	0.008	0.004	0.133
	p-value	0.252	<b>0.047</b>	0.659	<b>0.002</b>	<b>&lt;0.0001</b>
Lesser Antillean Tanager	Beta	0.004	0.015	-0.136	<0.0001	-0.437
	Standard Error	0.004	0.006	0.083	0.006	0.239
	p-value	0.2606	<b>0.008</b>	0.102	0.992	0.067
Rufous-breasted Hermit	Beta	0.011	-0.077	-0.069	0.022	-1.099
	Standard Error	0.004	0.019	0.043	0.006	0.314
	p-value	<b>0.0024</b>	<b>&lt;0.0001</b>	0.111	<b>0.0003</b>	<b>0.0005</b>
Smooth-billed Ani	Beta	0.010	0.024	0.023	0.012	-0.333
	Standard Error	0.008	0.010	0.013	0.012	0.439
	p-value	0.187	<b>0.022</b>	0.080	0.320	0.449
Shiny Cowbird	Beta	-0.005	0.023	0.004	0.017	-2.640
	Standard Error	0.005	0.006	0.011	0.007	0.544
	p-value	0.309	<b>&lt;0.0001</b>	0.716	<b>0.018</b>	<b>&lt;0.0001</b>
Scaly-naped Pigeon	Beta	-0.008	-0.001	-0.004	0.007	-0.441
	Standard Error	0.002	0.003	0.005	0.003	0.117
	p-value	<b>&lt;0.0001</b>	0.791	0.451	<b>0.010</b>	<b>0.0002</b>
Spectacled Thrush	Beta	0.012	0.006	-0.001	0.004	-0.041
	Standard Error	0.002	0.004	0.007	0.004	0.135
	p-value	<b>&lt;0.0001</b>	0.118	0.844	0.229	0.759
Tropical Mockingbird	Beta	-0.012	0.003	<0.0001	0.001	0.094
	Standard Error	0.002	0.003	0.005	0.003	0.113
	p-value	<b>&lt;0.0001</b>	0.252	0.996	0.734	0.404
Yellow-bellied Seed eater	Beta	0.008	0.029	0.012	0.014	-0.631
	Standard Error	0.004	0.006	0.010	0.007	0.265
	p-value	0.076	<b>&lt;0.0001</b>	0.215	<b>0.0366</b>	<b>0.017</b>
Zenaida Dove	Beta	0.020	0.030	ID	0.038	ID
	Standard Error	0.011	0.017	ID	0.015	ID
	p-value	0.072	0.085	ID	<b>0.010</b>	ID

**Table S8. Land-use variables effects on land bird species density on Grenada in 2017. Date = number of days since the start of the survey during the rainy season (A significant negative beta value means that detections decreased later in the rainy season). Time of day = whether surveys were conducted in the morning and or evening (a significant negative beta value means that either the mornings or evenings had fewer detections, as determined by examining the mean density of each species identified in the AM compared to the PM). ID = insufficient data. All land-use variables were measured as the percentage present within a 25-m radius. All response variables were modeled using a Poisson distribution. Significant p-values (p<0.05) are in bold.**

		Farmland	Cocoa	Nutmeg	Houses	Airport	Stadium	Business	Park	Date	Time of day (AM & PM)
Antillean Crested Hummingbird	Beta	0.009	0.012	0.011	-0.0005	ID	-0.015	-0.037	0.215	0.005	-0.243
	Standard Error	0.009	0.005	0.006	0.004	ID	0.022	0.017	0.124	0.003	0.124
	p-value	<b>&lt;0.0001</b>	<b>0.012</b>	0.080	0.901	ID	0.483	<b>0.027</b>	0.084	0.131	<b>0.050</b>
Bananaquit	Beta	0.008	0.007	0.001	-0.005	-0.046	0.006	-0.0074	0.0703	0.005	0.123
	Standard Error	0.001	0.003	0.004	0.002	0.014	0.005	0.005	0.081	0.002	0.060
	p-value	<b>&lt;0.0001</b>	<b>0.008</b>	0.715	<b>0.009</b>	<b>0.0007</b>	0.272	0.138	0.386	<b>0.001</b>	<b>0.041</b>
Black-faced Grassquit	Beta	0.008	0.007	0.001	-0.005	-0.046	0.006	-0.007	0.070	0.005	0.123
	Standard Error	0.001	0.003	0.004	0.002	0.014	0.005	0.005	0.081	0.002	0.060
	p-value	<b>&lt;0.0001</b>	<b>0.008</b>	0.715	<b>0.009</b>	<b>0.0007</b>	0.272	0.138	0.386	<b>0.001</b>	<b>0.041</b>
Broad-winged Hawk	Beta	0.007	0.022	-0.047	0.006	ID	ID	-0.064	ID	-0.006	-1.129
	Standard Error	0.009	0.015	0.048	0.014	ID	ID	0.108	ID	0.015	0.621
	p-value	0.393	0.142	0.321	0.667	ID	ID	0.552	ID	0.662	0.069
Cattle Egret	Beta	-0.023	-0.027	-0.089	-0.063	0.025	ID	ID	ID	-0.016	-0.791
	Standard Error	0.008	0.022	0.062	0.020	0.011	ID	ID	ID	0.007	0.333
	p-value	<b>0.005</b>	0.216	0.148	<b>0.0017</b>	<b>0.022</b>	ID	ID	ID	<b>0.028</b>	<b>0.017</b>
Carib Grackle	Beta	0.010	-0.043	-0.100	0.009	0.013	ID	-0.010	ID	0.032	-0.851
	Standard Error	0.006	0.030	0.071	0.008	0.017	ID	0.019	ID	0.007	0.318
	p-value	0.077	0.158	0.160	0.263	0.466	ID	0.589	ID	<b>&lt;0.0001</b>	<b>0.007</b>
Eared Dove	Beta	0.024	-0.125	-0.086	0.022	0.016	ID	0.015	ID	0.030	-0.964
	Standard Error	0.003	0.035	0.039	0.005	0.013	ID	0.009	ID	0.005	0.208
	p-value	<b>&lt;0.0001</b>	<b>0.0004</b>	<b>0.028</b>	<b>&lt;0.0001</b>	0.227	ID	0.100	ID	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
Grenada Flycatcher	Beta	0.005	0.006	0.005	0.0009	ID	ID	-0.056	ID	0.009	-0.021
	Standard Error	0.006	0.014	0.020	0.009	ID	ID	0.054	ID	0.007	0.309
	p-value	0.399	0.677	0.786	0.923	ID	ID	0.300	ID	0.201	0.945
Gray Kingbird	Beta	0.0016	0.019	-0.014	0.005	0.0015	-0.007	0.012	0.298	-0.006	-0.045
	Standard Error	0.002	0.005	0.010	0.003	0.011	0.017	0.007	0.108	0.004	0.129
	p-value	0.498	<b>&lt;0.0001</b>	0.171	0.131	0.894	0.685	0.106	<b>0.006</b>	0.097	0.728
Gray-rumped Swift	Beta	0.045	-0.041	-0.002	0.013	0.058	ID	-0.004	ID	0.045	-0.963
	Standard Error	0.004	0.018	0.019	0.008	0.010	ID	0.015	ID	0.006	0.243
	p-value	<b>&lt;0.0001</b>	<b>0.025</b>	0.896	0.089	<b>&lt;0.0001</b>	ID	0.807	ID	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
House Wren	Beta	-0.0003	-0.027	-0.010	0.023	ID	ID	-0.010	0.263	0.020	-0.751
	Standard Error	0.004	0.017	0.019	0.005	ID	ID	0.013	0.200	0.005	0.215
	p-value	0.949	0.119	0.584	<b>&lt;0.0001</b>	ID	ID	0.468	0.189	<b>&lt;0.0001</b>	<b>0.0005</b>
Lesser Antillean Bullfinch	Beta	0.007	-0.022	<b>&lt;0.0001</b>	0.006	ID	-0.002	0.005	ID	-0.014	0.487
	Standard Error	0.002	0.009	0.010	0.004	ID	0.016	0.009	ID	0.004	0.134
	p-value	<b>0.0064</b>	<b>0.016</b>	0.998	0.113	ID	0.914	0.553	ID	<b>0.001</b>	<b>0.0003</b>
Lesser Antillean Tanager	Beta	0.007	0.0008	-0.013	0.015	ID	ID	-0.126	ID	-0.0002	-0.469
	Standard Error	0.004	0.011	0.018	0.006	ID	ID	0.085	ID	0.006	0.241
	p-value	<b>0.004</b>	0.943	0.449	<b>0.008</b>	ID	ID	0.138	ID	0.974	0.051
Rufous-breasted Hermit	Beta	0.002	0.009	0.054	-0.073	ID	ID	-0.042	ID	0.023	-0.932
	Standard Error	0.005	0.009	0.008	0.019	ID	ID	0.038	ID	0.006	0.324
	p-value	0.624	0.290	<b>&lt;0.0001</b>	<b>0.0001</b>	ID	ID	0.276	ID	<b>0.0003</b>	<b>0.004</b>
Smooth-billed Ani	Beta	0.022	-0.043	-0.139	0.022	0.043	ID	0.016	ID	0.007	-0.548
	Standard Error	0.008	0.039	0.106	0.011	0.021	ID	0.021	ID	0.013	0.445
	p-value	<b>0.006</b>	0.270	0.189	<b>0.046</b>	<b>0.036</b>	ID	0.452	ID	0.565	0.218
Shiny Cowbird	Beta	0.006	-0.126	-0.015	0.023	ID	0.020	0.004	ID	0.018	-2.690
	Standard Error	0.006	0.051	0.024	0.006	ID	0.013	0.014	ID	0.007	0.546
	p-value	0.248	<b>0.014</b>	0.534	<b>0.0001</b>	ID	0.140	0.792	ID	<b>0.018</b>	<b>&lt;0.0001</b>
Scaly-naped Pigeon	Beta	-0.009	0.019	-0.113	-0.0004	ID	-0.041	0.011	ID	0.005	-0.470
	Standard Error	0.003	0.004	0.026	0.003	ID	0.047	0.005	ID	0.003	0.117
	p-value	<b>0.0002</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	0.897	ID	0.378	<b>0.033</b>	ID	<b>0.044</b>	<b>&lt;0.0001</b>
Spectacled Thrush	Beta	0.013	-0.012	0.028	0.005	-0.030	0.013	-0.0002	ID	0.004	-0.011
	Standard Error	0.002	0.008	0.006	0.004	0.025	0.010	0.011	ID	0.004	0.137
	p-value	<b>&lt;0.0001</b>	0.109	<b>&lt;0.0001</b>	0.2190	0.230	0.204	0.987	ID	0.234	0.938
Tropical Mockingbird	Beta	-0.008	-0.043	-0.013	0.002	-0.009	-0.022	0.007	ID	0.001	0.081
	Standard Error	0.003	0.012	0.011	0.003	0.010	0.024	0.006	ID	0.003	0.113
	p-value	<b>0.004</b>	<b>0.0002</b>	0.257	0.575	0.365	0.373	0.212	ID	0.778	0.477
Yellow-bellied Seed eater	Beta	0.010	0.002	-0.010	0.027	0.005	ID	0.020	ID	0.013	-0.659
	Standard Error	0.005	0.014	0.022	0.006	0.023	ID	0.012	ID	0.007	0.268
	p-value	<b>0.040</b>	0.863	0.636	<b>&lt;0.0001</b>	0.838	ID	0.110	ID	0.053	<b>0.014</b>
Zenaida Dove	Beta	0.028	-0.080	0.030	0.027	ID	ID	ID	ID	0.038	ID
	Standard Error	0.012	0.085	0.043	0.018	ID	ID	ID	ID	0.015	ID
	p-value	<b>0.020</b>	0.350	0.481	0.135	ID	ID	ID	ID	<b>0.012</b>	ID