Status and Distribution of Two Diurnal Raptors on the Island of Grenada: Grenada Hook-Billed Kite (*Chondrohierax uncinatus mirus*) and Antillean Broad-Winged Hawk (*Buteo platypterus antillarum*)

by

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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

Department of Natural Resources Institute

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One of my favourite photos of a juvenile Grenada Hook-billed Kite, taken in 2012 by a most admirable person and one of the main reasons for me studying this species in Grenada, Dr. Andrea Easter-Pilcher

Thank you for your positive attitude and for never giving up on me and all of your Grenadian/Caribbean students!

SUMMARY

Habitat loss and fragmentation have had significant negative impacts on overall biodiversity and have led to a massive decline in the populations of numerous species around the world. Because raptors usually occur at low density and occupy large territories, they are sensitive to habitat degradation and loss. On the island of Grenada, located in the southern Caribbean Sea, two of the resident subspecies of inland diurnal raptors on the island include the Grenada Hook-billed Kite (*Chondrohierax uncinatus mirus*) and the Antillean Broad-winged Hawk *(Buteo platypterus antillarum)*. Both species have been understudied in terms of their distribution on the island. In this thesis I assessed the key factors that affect habitat use of these two resident diurnal raptors in Grenada. Using a double observer approach, I surveyed these raptors using point counts and road transects in both the wet season (June-November 2016) and dry season (January-April 2017). I modeled detectability of Broad-winged Hawks using *N*-Mixture modelling, and I determined whether time of day, day of year, land cover and elevation significantly influenced detectability, abundance and availability using the point count data. I compared the fit of species distribution models (SDM) using Maximum Entropy (MaxEnt) and generalized linear models (GLM) based on elevation and land cover from the road transects data. Although I detected no kites on these surveys, there were seven incidental sightings of kites by community members in the same general area where my surveys were conducted. For Broad-winged Hawks detections, 70% (*n*=182) were observed in the wet season and 30% (*n*=80) occurred in the dry season. The results of the *N*-mixture models suggest that these hawks are easier to detect earlier in the year, later in the day and in human-modified land cover classes. Based on the SDM, the probability of occurrence of Broad-winged Hawks was best explained by elevation and land cover and not by season, and this result was consistent with both methods; however, the GLM-based method performed better than the MaxEnt approach. Based on both SDM methods, land cover had a larger influence on Antillean Broad-winged Hawk occurrence. Both the GLM-based and MaxEnt-based species distribution models suggest that the probability of occurrence for Broad-winged Hawks was highest in low elevation areas. Regardless of season, Broad-Winged Hawks were associated with both built-up areas and nutmeg and mixed-wood agriculture. My findings suggest that Broad-winged Hawks are widely distributed on Grenada, contrary to the elusive Kite. While the restricted range of the Kite may be explained by limited availability of food (i.e. arboreal snails), the food resources of the generalist Broad-winged Hawk are known to occur in both natural landscapes and human-dominated landscapes. Thus, while fragmentation and degradation of forests may not as negatively impact Broad-winged Hawks, the habitat of the Grenada Hook-billed Kite will likely be further restricted in its range with this increasing deforestation and development.

ACKNOWLEDGEMENTS

I would like to start by expressing my deepest appreciation to my supervisor, Dr. Nicola Koper and my committee members, Dr. Andrea Easter-Pilcher and Dr. Jack Kirkley for their support and guidance throughout this study. Dr. Nicola Koper offered me the opportunity to do this Masters and as my core supervisor, she was exceptional, understanding and helpful.

I owe an enormous debt of gratitude to my dearest friend Jody N. Daniel-Simon for her unequivocal support and encouragement throughout this process, particularly, with the statistical analyses. Thank you for keeping me on track and pushing me to complete this thesis.

Data collection would not have been possible without the help and support of my field assistant, Shanell Cyrus. I am grateful for your time and all the hard work we put into this field study together.

I am thankful for the support from a number of friends and colleagues including, Roxanne Graham, Olando Harvey, Andre Joseph-Witzig, Christabelle Andrews, Krisma Moore, Shoulan Carter, Carleen Batson, Amrita Mahabir, Tawfiq Hasan, Tosan Okorosobo and everyone in Koper's lab.

To my Winnipeg family, Durdana Islam, Shamailah Islam and Shamel Islam, you truly made me feel like home everyday when I was in Winnipeg. To Shamailah, every kind word, note, cup of tea or meal you made me when you sense something was frustrating me or just because, was really appreciated, and I am grateful for your kind and sweet ways.

I thankful to my mom Sandra Kennedy for her support and encouragement. To my dad, Christopher Campbell thank you for your continuous support and for being my driver at times during my surveys. Finally, I am most grateful to my husband Sean Lucas, you are my rock and my everything, thank you for always believing in me.

Funding for my research was provided by Natural Sciences and Engineering Research Council of Canada, and the University of Manitoba.

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Figure 7A: Plot of the probability of detection for Broad-winged Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of occurrence. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Ribbons on the plot show 95 % confidence intervals. This model shows no abundance or availability covariates. This is the least complex model/best fit model among the following 5 top models (7A-E) produced from the N-mixture models analysis using the point count data.

Figure 7B: Plot of the probability of detection for Broad-winged Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted availability based on land cover class. Ribbons on the plot show 95 % confidence intervals. This model shows no abundance covariates.

Figure 7C: Plot of the probability of detection for Broad-wing Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted availability based on elevation. Ribbons on the plot show 95 % confidence intervals. This model shows no abundance covariates.

Figure 7D: Plot of the probability of detection for Broad-wing Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted abundance with land cover class. Ribbons on the plot show 95 % confidence intervals. This model shows no availability covariates.

Figure 7E: Plot of the probability of detection for Broad-wing Hawks against time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted availability based on elevation, and model (E) shows that predicted abundance based on abundance. Ribbons on the plot show 95 % confidence intervals.

LIST OF ACRONYMS

AIC	Akaike information criterion
AUC	Area Under the Curve
DEM	Digital Elevation Model
ENM	Ecological Niche Model
GLM	Generalized Linear Model
IUCN	International Union for Conservation of Nature
MaxEnt	Maximum Entropy
SDM	Species Distribution Model

1. CHAPTER 1: INTRODUCTION

1.1. Background

Globally, the continued loss of habitat from natural and anthropogenic disturbances is a major threat to raptor (birds of prey) populations and other avian populations (Bildstein, Schelsky, Zalles, & Ellis, 1998; Carrete, Tella, Blanco, & Bertellotti, 2009a; Ferrer-Sánchez & Rodríguez-Estrella, 2015; Thiollay, 1989). This is especially true for many island species because the size of an island's bird population is limited by the size of the island, as well as by the availability of suitable habitat remaining on that island (Ferrer-Sánchez & Rodríguez-Estrella, 2016). In tropical areas, both continental and insular, the extensive loss of forest habitat has led to declines in raptors and other avian species (Bildstein et al., 1998). Although some studies have shown that various species of raptors, particularly in continental ecosystems, can adapt to anthropogenic habitat changes (Ferrer-Sánchez & Rodríguez-Estrella, 2015; Thiollay, 1989), habitat fragmentation is known to have more significant negative effects on raptors that are dependent on specialized dietary niches and diets (e.g. Snail Kite *(Rostrhamus sociabilis),* Hook-billed Kite *(Chondrohierax uncinatus)*)) (Navarro-López & Fargallo, 2015).

On the island of Grenada, located in the southern Caribbean Sea, two of the resident subspecies of inland diurnal raptors include the Grenada Hook-billed Kite *(Chondrohierax uncinatus mirus)* (Blockstein, 1991; Bond, 1961; Friedmann, 1934; Smith & Temple, 1982) and the Antillean Broad-winged Hawk *(Buteo platypterus antillarum)* (Clark, 1905). As top predators, these raptors can act as important indicators species that mirror the overall biodiversity and ecosystem health of the environments they inhabit (e.g., Carrete et al., 2009; Rodriguez-Estrella et al., 1998). However, the current conservation status and distribution of these two Grenada raptors are unknown and there is very little information available on their population sizes, geographic distribution, productivity and seasonal habitat requirements.

The Grenada Hook-billed Kite *(Chondrohierax uncinatus mirus)* is generally recognized as an endemic subspecies of the Hook-billed Kite *(Chondrohierax uncinatus)* (Friedmann, 1934; Johnson, Thorstrom, & Mindell, 2007). Prior to Hurricane Janet in 1955, the Grenada Hook-billed Kite was considered to be extinct on the island (Groome, 1970; King, 1978), but a number of subsequent reports and sightings of the kite disproved those earlier speculations asserting its extinction (Smith & Temple, 1982). This elusive kite subspecies is considered to be an endangered subspecies (Smith & Temple, 1982) due to its low abundance (Blockstein, 1988; Bond, 1961; Johnson et al., 2007; Smith & Temple, 1982). The most recent population estimates of this kite, indicates that possibly only 50 – 75 individuals may currently exist on the island (Thorstrom & Mcqueen, 2008).

The Antillean Broad-winged Hawk *(Buteo platypterus antillarum),* which is easily mistaken for the kite and vice versa in Grenada, is considered to be a distinct subspecies of the Broad-winged Hawk *(Buteo platypterus)* (Clark, 1905). This subspecies is found only on the lesser Antillean islands of Grenada, St. Vincent and possibly Tobago. The current status of the widespread parent species *B. platypterus* as shown on IUCN Redlist of Threatened Species has a status of "Least Concern" throughout its range (BirdLife International, 2016). Like the kite, little is known about the status, geographic range, seasonal distribution and habitat preferences of this hawk in Grenada. Apart from Clark (1905), there has been no known research focused on the this Antillean sub-species of the Broad-winged Hawk. Although these two diurnal raptors *(C. u. mirus and B. p. antillarum)* have been observed nesting in close proximity to one another, hawks are sighted more frequently than the kites *(Pers. comm. Jeremiah 2015).* Moreover, in 2012, hawks were found to be nesting in trees that were previously documented as kite nesting trees *(Pers. obs*.) In some instances, hawks have been observed displaying aggressive behavior towards kites *(pers. comm. Easter-Pilcher 2016).* This agonistic behavior between the two raptors may also be a contributing factor in the historically sparse population of kites, as well as playing a role n the more recently suspected decline in the kite population. However, more intensive monitoring of the interactions between these two species is needed to provide more insight into the possible influence that they may be having on one another.

1.2. Objectives

The objectives of this research were to assess the key factors that affect habitat use of the two resident diurnal raptors (Grenada Hook-billed Kite and the Antillean Broad-winged Hawk) in Grenada:

1. To undertake surveys of the two focal species of raptors in Grenada, using reproducible survey techniques, to provide updated information on their status and distribution.
2. To determine the impacts of habitat loss from rural development on habitat suitability and habitat availability for the two focal species of raptors.
3. To determine the effects of the alternating wet and dry seasons on landscape-scale habitat selection for the two focal species of raptors.

1.3. Hypotheses

One of the most variable factors that can impact a population of raptors is human disturbances (Thiollay, 1989). Habitat loss resulting from unsustainable rural development can often have a negative impact on breeding success of certain raptor species due to loss of suitable nesting sites, as well as reduction in the density and availability of prey (Kirk & Hyslop, 1998). Additionally, the timing of the disturbances in relation to a raptor's breeding status, can be crucial, because sensitivity to human disturbance tends to be greatest during nesting and especially during incubation period (Kirk & Hyslop, 1998). Therefore, increased human disturbance from development, particularly in vegetative alterations in xeric habitat, such as on the southern lowlands of Grenada, may be expected to result in a greater probability of declines in the kite population.

On the other hand, some raptor species display much more tolerance to human-modified landscapes (Anderson, 2001; Panasci & Whitacre, 2006). Because raptors can be expected to select habitats with adequate prey availability, a raptor species with a specialized diet would be expected to be more vulnerable to human disturbances than would a species with a more generalist diet (Navarro-López & Fargallo, 2015). Thus, habitat alterations may be expected to have a greater negative influence on the Grenada Hook-billed Kite population because these raptors predominantly feed on specific kinds of tree snail that require certain types of forest habitat (Thorstrom, Massiah, & Hall, 2001). In contrast, the Broad-winged Hawk, which utilizes a much greater diversity of prey should be expected to be less negatively affected by human alterations of Grenada's native habitats.

Rainfall regimes in Grenada are characterized by a dry season (January to May) and a wet season (June to December). Since raptor abundance is generally influenced by the availability of prey (Kirk & Hyslop, 1998), (in this case tree snails for kites) and assuming that water availability affects the abundance of these tree snails, there should be a higher abundance of kites in the low lying areas of Grenada during the wet season as compared to the dry season. Furthermore, recently and possibly as a result of climate change, the islands in the Caribbean have been experiencing highly unpredictable weather patterns (i.e. longer periods of the dry season as well as an increased incidence of intense hurricanes (Biasutti et al 2012). Therefore, a shift in raptor distribution and abundance may be expected, such as seasonal shifts from xeric woodlands to deciduous montane forest, especially during the dry season.

1.4. Organization of the Thesis

This thesis has been organized into four chapters this being the first Chapter which provides an introduction of the thesis topic and includes the general objectives and the hypotheses of the study. Chapter Two presents the literature review which comprise of background information on raptors, habitat loss and fragmentation and statistical techniques used to model the species distribution. I also presented information on the life history and status of the two focal species. Chapter Three is the main research paper which contains the introduction, methods, results and a general discussion of the overall findings, and my conclusions about this research. The final Chapter explores the management implications and recommendations for the conservation of the two focal species.

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2. CHAPTER 2: LITERATURE REVIEW

2.1. Habitat Loss and Habitat Fragmentation

Habitat loss and fragmentation have led to a massive declines in the populations of numerous species, which has negatively affected biodiversity overall (Fahrig, 2007; Laurance, 2010). Habitat loss refers to the reduction in the amount of a species' habitat within a defined area (Koper, Walker, & Champagne, 2009), whereas habitat fragmentation involves the subdivision of a larger expanse of habitat into smaller patches, which typically occurs because of local habitat destruction and various degrees of habitat alteration (Fahrig, 2003). The effects of habitat loss and fragmentation are often correlated (Fahrig, 2003), but they can have diverse negative effects on species richness and population abundance in different regions (Laurance, 2010). For example, in tropical island ecosystems, species are believed to be more frequently exposed to intense environmental pressures from habitat loss and fragmentation than is true for most continental species (Ferrer-Sánchez & Rodríguez-Estrella, 2015). This is due to the limited land space available on these islands and consequently the limited availability of suitable habitat for access to food resources, and breeding and nesting habitats (Ferrer-Sánchez & Rodríguez-Estrella, 2016), which largely determine the size of home range of these wildlife species (Powell & Mitchell, 2012). Several studies have shown that some of the key causes of habitat loss and fragmentation in island ecosystems include clearing of forests for agriculture, urban development, catastrophic natural disasters and climate change related events (UNEP, 2007).

2.2. Anthropogenic Impacts on Island Habitat

There has been a growing concern about the effects of anthropogenic habitat loss due to deforestation and human development including roads (Carrete, Tella, Blanco, & Bertellotti, 2011). Anthropogenic activities have intensified fragmentation in insular ecosystems, which reduces the quality and quantity of core habitat and exposes forest edges to external influences (Thiollay, 1985, 1989). This may affect habitat suitability and prey availability for specialist species like the Grenada Hook-billed Kite (*Chondrohierax uncinatus mirus*) and the Cuban Kite (*Chondrohierax wilsonii*) (Ferrer-Sánchez & Rodríguez-Estrella, 2015; Thorstrom & Mcqueen, 2008). The impact of anthropogenic disturbances on raptors inhabiting small islands have resulted in the reduction in nesting success (Wiley, 1985), changes in distribution, behavioral pattern. Consequently, human disturbances have led to decline in some raptor populations (Stalmaster & Newman, 2007). However, some studies reported that various raptors species, particularly generalist species like the Antillean Broad-winged Hawk, can tolerate and behaviorally adapt to habitat changes (Ferrer-Sánchez & Rodríguez-Estrella, 2015; J.-M. Thiollay, 1985). In contrast, specialist raptor species tend to be more sensitive to disturbance and therefore are more prone to population declines as a result of disruptions (Ferrer-Sánchez & Rodríguez-Estrella, 2015; J.-M. Thiollay, 1985).

2.3. Tropical Climate and Seasonal Changes

In addition, habitat destruction from climate change (i.e. which may affect seasonal weather changes) is considered to be one of the growing threats to biodiversity in many regions of the world including the tropics (Şekercioĝlu, Primack, & Wormworth, 2012). The unpredictable changes in timing and the intensity of precipitation events during both wet and dry seasons along with the increased duration of dry spells could intensify the habitat impact and vulnerability of certain species in tropical ecosystems (Pal, Anderson, Salvucci, & Gianotti, 2013). These changes in seasonal weather patterns are probable causes of avian species declines in tropical islands since many components across the entire ecosystem are affected. Many studies have focused on the effect of seasonal variation on the habitat selection of birds in temperate regions; however, there are few studies of the effects of seasonal changes on the avian communities in tropical regions (Harris et al., 2011). Some studies show that the rising temperatures experienced on islands due to climate events, can impact specialist species by forcing them to shift to higher elevations (Şekercioĝlu et al., 2012). This may be related to a lower relative prey availability thus raising concerns particularly for the distribution of endemic species (Ferrer-Sánchez & Rodríguez-Estrella, 2015). Species with access to intact habitats with a wide range spanning a higher elevation are expected to be less affected by seasonal changes (e.g. Clark et al., 1999; Ray et al., 2005). Some species may be especially susceptible to increased rainfall, seasonality and to extreme weather events, such as heat waves, cold spells, and tropical cyclones (Şekercioĝlu et al., 2012).

2.4. Survey Design and Detectability in Diurnal Raptors

Understanding the differences in detectability before the implementation of a selected survey design is important in designing surveys (Meyer et al., 2011). This is particularly true when detecting breeding and non-breeding raptors (Fuller & Mosher, 1987) such as the Hook-billed Kite and Broad-winged Hawk because their low densities and cryptic nature make them difficult to survey in tropical forest habitat (Whitacre, 2012). There are many factors that can affect the detectability of raptors in raptor field surveys, including vegetation cover, terrain and weather conditions. as well as the different sizes and behavioral habitat of each species of raptor, making some species easier to observe than others. Some literature on survey techniques highlights the fact that different survey methods have different advantages and disadvantages. For example, point count surveys are useful at small spatial scales and are useful in providing for present/absence data, while also improving repeatability, due to the use of established sampling sites. On the other hand, broad scale roadside surveys for raptors are useful for sampling larger expanses of a study area when it is important to locate the breeding areas and to study habitat use patterns (Bildstein & Bird, 2007). Despite the limitations associated with road surveys this method remains one of the most practical methods available for rapidly assessing raptor distribution (Gregory, Gibbons, & Donald, 2004; Lewis, Fuller, & Titus, 2004). Roadside surveys have been used to estimate relative abundance of diurnal raptor species as well as to determine the status and distribution of raptors in various habitats (Wiley, 1985). However, roadside counts are not necessarily reliable indicators of short-term changes in the population size and reproductive success of avian nesting populations at local scales (Baskett, 1994). Combining the roadside count and the point count survey methods can increase one's chances of detecting of raptors in different habitat. For example, "combined fixed- and unfixed-radius" point counts along primary and secondary roads of Puerto Rico and Vieques island were used in surveys of Scaly-naped Pigeon *(Patagioenas squamosa)* and this method was effective for assessing the distribution and habitat preferences of that species (Rivera-Milan, 1995).

2.5. Species Distribution Models (SDM)

Historically, the impacts of anthropogenic development and exploitation of natural resources have led to the uneven distribution of many species within various ecosystems (Elith & Leathwick, 2009). Species distribution models (SDM), also referred to as Ecological Niche Models (ENM), are used to understand how species are distributed across the landscape (Hijmans & Elith, 2013) by combining observations of species occurrence or abundance with environmental assessments of habitat components and seasonal changes (Elith & Leathwick, 2009; Hijmans & Elith, 2013). This type of model uses various parameters to predict the probability of occurrences and distributions of species across landscapes by noting the presence and abundance of a focal species. Modelling species distributions commonly makes use of logistic regression methods (e.g. Generalized Linear Model (GLM) (Guisan & Zimmermann, 2000) to model relative habitat use. Further, models such as MaxEnt have been developed to execute presence-only SDMs and have been widely adopted and applied (Elith et al., 2011). Given the design of the SDMs it would appear to make this an appropriate model to investigate habitat selection by these two raptor species in Grenada.

2.6. Life History of Diurnal Raptors found in Grenada

2.6.1. Grenada Hook-Billed Kite (Chondrohierax uncinatus mirus)

The Grenada Hook-billed Kited is a small (43-51 cm in length) elusive raptor found only on the island of Grenada in the Lesser Antilles, West Indies. The kite is considered to be an endemic subspecies of the South American Hook-billed Kite *(Chondrohierax uncinatus)* (Friedmann, 1934; Johnson et al., 2007). As is typical of raptors, female kites are slightly larger than males and are typically brown above with a bright rufous barring on the light belly. Males are gray on the back with a lightly barred belly. In both sexes, individuals show varying numbers of tail bands (Ferguson-Lees & Christie, 2001). Juveniles are dark brown above and creamy-white on the underparts (Ferguson-Lees & Christie, 2001). Females and juvenile Hook-billed Kites are often confused with Broad-wing Hawks; however, the kite has a larger bill, a light nuchal collar and its wingtips are more rounded (Whitacre, 2012). Kites have been observed in both xeric and mesic habitat and are believed to have been isolated on Grenada for the last 20,000-120,000 years (Smith & Temple, 1982). Hook-billed Kites are usually found alone or in small groups of 2-3 individuals. However, several kites may gather at abundant food sources, in areas where arboreal snails are concentrated (Lewis et al., 2004).

This kite species is noteworthy because it has a specialized diet consisting mainly arboreal snails, including, two endemic species *Bulimulus wiebesi* and *Endolichotus grenadensis* (Smith & Temple 1982), and other arboreal snails including *Orthalicus undatus, Pleurodonte perplexa,* and possibly juvenile *Megalobulimus oblongus* (Daniel & Dyerson, 2013). Kites forage by searching for snails on the limbs in the lower canopy of the dense understory. They have been observed hopping from branch to branch, sometimes even hanging upside-down from a branch to snatch the snails from its underside (Kricher, 1997). During the nesting period (May to November), parental kites will hunt throughout the day to feed their chicks.

The Grenada Hook-billed Kite is vulnerable and declining. The most recent studies estimated a 35% population decline from before the two hurricanes in 2004 and 2005 and after, which has been attributed to widespread habitat destruction brought on by the these hurricanes (Thorstrom & Mcqueen, 2008). Although the forest has since regenerated and returned to relatively favourable nesting conditions for kites, ongoing habitat alterations due to expansion in agriculture, tourism and residential development may further reduce the range and habitat available for these kites (Campbell et al., 2013).

2.6.2. *Antillean Broad-winged Hawk (Buteo platypterus antillarum)*

The Broad-winged Hawk is a small (34–44 cm in length), stocky raptor. On the island of Grenada and St. Vincent the resident species are sometimes considered a subspecies – Antillean Broad-winged Hawk *(Buteo platypterus antillarum)* because of its small size and slightly varying coloration (Clark, 1905). Female hawks tend to be slightly larger than males. Both male and female adults have a brown back and an underside that has rust-coloured barring. The tail is broad with black-and-white bands. Juveniles differ slightly in colouration – they have a blotched underside and have less distinct tail bands. Hawks are typically found in deciduous forest or mixed coniferous-deciduous forest near water sources and forest edges. Little is known about breeding status of Antillean Broad-winged Hawk on Grenada and St. Vincent; however, other subspecies such as the Puerto Rican Broad-winged Hawk *(Buteo platypterus brunnesce)* have been observed breeding between January to March (Vilella & Hengstenberg, 2006).

Broad-winged Hawks have a much more generalized diet than Grenada Hook-billed Kites. Hawks. They tend to feed on small mammals and amphibians but are also known to feed on small reptiles, birds, and various invertebrates. During nesting female hawks stay on or near their nest with their young while males hunt and bring food back to the nest (Fitch, 1974; Vilella & Hengstenberg, 2006).

The current status of the widely distributed parent species *(B. platypterus)* on the IUCN Redlist of Threatened Species is designated as "Least Concern" throughout its range (BirdLife International, 2016). However, little is known about the status, range, distribution and habitat preference of the Antillean Broad-winged Hawk in Grenada. Additional information is required on the Antillean Broad-winged Hawk's distribution and nesting ecology to help provide recommendations for future research on habitat conservation for this raptor in Grenada.

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3. CHAPTER 3: STATUS AND DISTRIBUTION OF TWO DIURNAL RAPTORS ON THE ISLAND OF GRENADA: GRENADA HOOK-BILLED KITE (*CHONDROHIERAX UNCINATUS MIRUS)* AND ANTILLEAN BROAD-WINGED HAWK (*BUTEO PLATYPTERUS ANTILLARUM*)

ABSTRACT

Habitat loss and fragmentation have had significant negative impacts on overall biodiversity, and led to a massive decline in the populations of numerous species around the world. Because raptors usually occur at low density and occupy large territories, they are sensitive to habitat degradation and loss. On the island of Grenada, located in the southern Caribbean Sea, two of the resident subspecies of inland diurnal raptors on the island include the Grenada Hook-billed Kite (*Chondrohierax uncinatus mirus*) and the Antillean Broad-winged Hawk *(Buteo platypterus antillarum)*. Using a double observer approach, I surveyed these raptors using point counts and road transects surveys in both the wet season (June-November 2016) and dry season (January-April 2017). A total of 262 hawks were detected during the surveys, 70% (*n*=182) in the wet season and 30% (*n*=80) in the dry season; however, no kites were detected. I compared the fit of species distribution models using Maximum Entropy (MaxEnt) and generalized linear models (GLM) based on elevation and land cover using the road transects data. I modeled detectability of Broad-winged Hawks using N-Mixture modelling, and I determined whether time of day, day of year, land cover and elevation influenced detectability, abundance and availability using the point count data. My findings suggest that hawks are widely distributed on Grenada, contrary to the elusive kite. The probability of occurrence of hawks was best explained by elevation and land cover and not by season, and was highest in low elevation areas. Finally, the *N*-mixture models suggest that hawks are easier to detect earlier in the year, later in the day and in human-modified land cover classes.

3.1. Introduction

Habitat loss and fragmentation have had significant negative impacts on overall biodiversity and led to a massive decline in the populations of numerous species around the world (Brooks et al., 2006; Fahrig, 2003; Haddad et al., 2015; Laurance, 2010). Extensive research has established that the loss and/or changes to species' habitats directly affects species' distribution, richness and abundance (Andrén, 1994; Ferrer-Sánchez & Rodríguez-Estrella, 2016; Laurance, 2010). This is particularly detrimental to threatened and endangered species (Smith & Temple, 1982), which are already experiencing declining numbers and severe anthropogenic threats. As such, understanding habitat requirements and the specific factors that influence a species' habitat are crucial in protection and conservation efforts (Austin, 2002). Further, for many island species, their populations are limited by the size of the island they inhabit and the availability of suitable habitats within those islands (Ferrer-Sánchez & Rodríguez-Estrella, 2016). In tropical areas such as the Caribbean, raptors and other avian communities are particularly vulnerable due to the extensive loss of forest habitat. This may explain why raptor populations have significantly declined in the Caribbean over the past decade (Bildstein et al., 1998).

Raptors usually occur at low densities and occupy large territories. As such, they are particularly sensitive to habitat degradation (Thiollay, 1989). Further, raptors are considered top predators in many ecosystems and food webs, and thus they can serve as indicators of biodiversity and environmental health (Donázar et al., 2016). Although some studies have shown that various species of raptors, particularly in continental ecosystems, can adapt to anthropogenic habitat changes (Ferrer-Sánchez & Rodríguez-Estrella, 2016; J.-M. Thiollay, 1985, 1989), the literature conclusively indicates that loss of habitats and changes in land use can have adverse effects on many species of raptors, particularly those dependent on specialized niches and diets, such as the

Snail Kite and Grenada Hook-billed Kite (Ferrer-Sánchez & Rodríguez-Estrella, 2015; Navarro-López & Fargallo, 2015).

On the island of Grenada, located in the southern Caribbean Sea, two of the resident subspecies of inland diurnal raptors on the island include the Grenada Hook-billed Kite (*Chondrohierax uncinatus mirus*) and the Antillean Broad-winged Hawk *(Buteo platypterus antillarum)*. Both species have been understudied in terms of their distribution on the island.. As top predators, these raptors can act as important indicators species of the overall biodiversity and ecosystem health of the island (Carrete, Tella, Blanco, & Bertellotti, 2009b; Rodriguez-Estrella et al., 1998). Their current conservation status and distribution, however, are poorly known, and there is very little information available on their population dynamics, range, productivity and seasonal habitat requirements.

The Grenada Hook-billed Kite *(Chondrohierax uncinatus mirus)* is considered to be an endemic subspecies of the more widely distributed Hook-billed Kite *(Chondrohierax uncinatus)* (Friedmann, 1934; Johnson et al., 2007). Prior to Hurricane Janet in 1955, the Grenada Hook-billed Kite was thought to be extinct on the island (Groome, 1970; King, 1978), but numerous reports and sightings debunked this claim (Smith & Temple, 1982). This small, elusive kite is also considered an endangered sub-species (Smith & Temple, 1982) due to its low abundance (Blockstein, 1988; Bond, 1961; Johnson et al., 2007). The most recent population estimates place the total population of kites to be in the range of of 50-75 individuals remaining on the island (Thorstrom & Mcqueen, 2008).

The Antillean Broad-winged Hawk *(Buteo platypterus antillarum)*, which is often mistaken for the kite, is generally recognized as a subspecies to the widely distributed Broad-winged Hawk *(Buteo platypterus)* (Clark, 1905). The range of this subspecies comprises the lesser

Antillean islands of Grenada and St. Vincent to Tobago. The current status of the widely distributed species of Broad-winged Hawk on IUCN Redlist of Threatened Species is “Least Concern” throughout its extensive range (BirdLife International, 2016). Like the kite, little is known about the status, range, distribution and habitat preference of this hawk species in Grenada. There are no known research focused on the study and monitoring of the Antillean Broad-winged hawk in the Lesser Antilles.

Both the Grenada Hook-billed Kite and the Antillean Broad-winged Hawk have been observed nesting in close proximity to one another in Grenada, with the hawks occurring in much higher abundances than the kites. Moreover, in 2012, hawks were found to be using previously documented kite nesting trees, and in some instances, hawks were observed displaying aggressive behavior towards kites *(Pers Comm. Easter-Pilcher 2016).* These observations suggest a competitive interaction between the two raptors that could be a contributing factor in the population decline of kites. However, this negative interspecific relationship is highly speculative and further research is required to confirm this interaction.

The detection of highly mobile species such as raptors can be difficult (Coxen, Frey, Carleton, & Collins, 2017). Satellite and radio tracking studies are often used to determine and model species habitat use of over large areas (Hays, Åkesson, Godley, Luschi, & Santidrian, 2001). However, these methods are costly, time consuming (Bridge et al., 2011), and can be difficult to implement with elusive species, and there is concern of harm to the captured individuals, particularly those that may be at risk (Calvo & Furness, 1992). Alternatively, species distribution models (SDM) are commonly used to predict the distribution of a species and provide important baseline data on key habitat variables, which are instrumental to the conservation and management of species (Hijmans & Elith, 2011). Further, many species distribution modelling applications can link presence-only data from field observations to a set of environmental covariates to predict a species' distribution (Hijmans & Elith, 2011). Since there is no known information on home range and movement patterns, habitat use, and juvenile dispersal for either of this study's focal species, I used two approaches for Species Distribution Modelling: (i) Generalized Linear Model (GLM); and (ii) Maximum Entropy Model (MaxEnt).

The overarching aim of this research project was to assess the key factors affecting habitat suitability of the two (2) resident diurnal raptors in Grenada (Grenada Hook-billed Kite and the Antillean Broad-winged Hawk), using systematic, reproducible survey techniques. However, the limited observations of the Grenada Hook-billed Kite made it impossible to quantify its status and distribution. Nevertheless, I described the small sample number of kite of observations qualitatively. Further, I looked at the detectability of Broad-wing Hawks during point counts using *N*-Mixture models to determine how the observer, time- of- day, day- of- year, land cover and elevation, influenced detection probabilities and abundances of the hawks. An understanding of these relationships is imperative for future monitoring of this species and management of important ecosystems.

I predicted that: (i) the high amount of rural development in the xeric habitat, particularly in the low elevation areas of Grenada, combined with the effects of climate change, may have resulted in further declines in Grenada Hook-billed Kite populations since prior surveys; and (ii) since raptors often select habitats based on prey availability, species that have specialized diet such as the kite are expected to be more vulnerable to human disturbances than species with a more general diet such as the Antillean Broad-winged Hawks. Therefore, the hawks are expected to be more widely distributed than the kites on the island of Grenada.

3.2. Methods

3.2.1. Study Area

The study was conducted on the main island of Grenada (Latitude: 12°03′N; Longitude: 61°45′W), which is in the southern end of the Eastern Caribbean (Figure 1). The island has an area of approximately 34,400 ha and is characterized by a tropical climate with a dry season (January to May) and a wet season (June to December). Precipitation in Grenada ranges between 990-1500 mm in the coastal areas, and between 3750-5000 mm in the high montane areas. The mean daily temperature is 27°C throughout the year and can drop to about 19–24°C in the higher montane areas. Vegetation varies from xeric woodland forest along the low elevation and coastal areas, to mixed deciduous and dense montane forest towards the higher elevation interior of the island (Appendix 1). The highest point above sea level is 840 m, at the peak of Mt. St. Catherine (Grenada NBSAP 2014). Large old growth trees suitable for raptors nesting occur in both the xeric and mesic habitats; however, recent anthropogenic development (particularly in the xeric coastal areas) and impacts from natural disasters, i.e. storms and hurricanes, have reduced the amount of natural habitat and mature trees available for these two diurnal raptor species (Thorstrom and McQueen, 2008).

3.2.2. Data Collection

3.2.2.1. Survey Design

Raptor surveys were conducted from July 2016 to May 2017, to sample both the wet season (June to December) and the dry season (January to May). Each survey replicate was conducted 4 times during the wet season and 4 times during the dry season. The two raptor species included in the survey are the only year-around resident diurnal raptors on the island, with the exception of the Ospreys *(Pandion haliaetus)*. Seven transect routes were surveyed using two common survey methods: roadside transects counts and point counts (Andersen 2007). These survey methods were selected because they are best suited for covering large areas at a relatively low cost, but they still allow for quantitative comparison between seasons and among habitat types. Each route was surveyed every 4-5 weeks by two observers (including the principal investigator). Surveys started 3 hours after local sunrise (sunrise is approximately 6:30 AM) or sometimes later when adverse early morning weather conditions reduced raptor activity. Each survey route was completed in 2-3 hours. All diurnal raptors along each transect were recorded, noting whether, upon detection, the individuals were flying or perched and seen or only heard. The horizontal distance to each hawk encountered was recorded using a range finder, when possible, or visually estimated. For raptors that were soaring in the sky above, we estimated the centre of it's circling flight during displays or soaring flights and then measured the distance from this point to the transect, usually with a range finder. I avoided double counting of individuals by selecting survey transects routes that were well-spaced. Point counts were located within 500 m of a road survey route and spaced at least 1.6 km (1 mile) apart. Only one survey route transect was surveyed on a given day and transects were separated more than 1km from each other, also minimizing the chances of counting the same bird in two different transects (Buckland et al., 2001; Rosenstock, Anderson, Giesen, Leukering, & Carter, 2002). No surveys were conducted during adverse weather conditions such as heavy rain and strong wind. The time of surveys and distance travelled was also recorded to permit standardization of encounter data.

3.2.2.2. Roadside Surveys

The island was divided into eight quadrats in which one start point was randomly selected along primary roads. The road survey routes were preselected using google maps and included both primary and secondary roads. A preliminary survey was conducted in June 2016 to ground-truth the roadside survey route and to ensure that the preselected point count sites provided appropriate vantage points and were accessible. Each survey transect was 25-26 km in length in order to survey as wide an area of the island as possible. Two observers, the principal investigator/driver plus one other observer in the front seat of the car, collaboratively conducted surveys along each transect. The vehicle was driven at a speed of 20-40 km/hr while the observers scanned the area for perched and soaring raptors (Steenhof & Kochert, 1982). Every time a raptor was seen or heard within a 500-m buffer on either side of the road the car was stopped, and the observer(s) recorded the species, distance, direction and time of observation and the individual's behavior (i.e, perched, flying, etc.). Raptors more than 500 m away were recorded as incidentals. Where possible, raptors that could not be identified, due to distance, were observed for as long as possible and sometimes followed until their identification could be attempted at a closer distance. When possible, behaviour or other features such as feather wear / absence of feathers were noted to help us prevent double counting.

3.2.2.3. Point Counts

Point counts were selected along the road transect routes. Each road transects included 6 point-count plots, which were selected using the following criteria: (1) plots were located within 500 m of a road and at least 1.6 km (1 mile) from the nearest count point, and (2) plots included areas with an unobstructed view of at least 90 degrees within a 500 m radius. To allow us to calculate detectability, we conducted independent double observer sampling where two observers did surveys for 6 minutes at each point count location. Each survey included a 1-minute scan with bare eyes then 2 minutes' scan with binoculars, and then was repeated. At the end of each point count the two observers compared their results. All raptors seen or heard within the 500 m radius were recorded, along with the distance and direction of the raptor from the observer. Incidental raptors observed outside 500 m were also recorded to minimize double counting. The time was recorded at the start of each point count location.

3.2.2.4. Spatial Data

Land use, land cover and elevation data were obtained from the Caribbean Risk Information Program and specific predictor variables (land use, land cover and elevation) that might have effects on habitat selection by diurnal raptors were extracted. The land use data were produced by the British Geological Survey (BGS) with a 2-m resolution. The BGS used a combination of Earth Observation satellite data for 2014, existing data and ground-truthing exercises to create the land use raster file (CHARIM, 2016b). The elevation data were derived from LiDAR by the International Institute for Geo-Information Science and Earth Observation. The resolution of the elevation data was 5-m, and the sinks in the digital elevation model were filled using data from the NASA Shuttle Radar Topography Mission (CHARIM, 2016a).

3.2.3. *Data Analysis*

3.2.3.1. Species Distribution Model

Models of the distribution of Antillean Broad-winged Hawks were created using the road transect data. Two modeling approaches (i) generalized linear model (GLM) and (2) Maximum Entropy (MaxEnt) were used to see whether the results were robust and to determine which was the better method for the dataset. Furthermore, both methods are recommended for developing

SDMs, though MaxEnt is more commonly used when predicting habitat suitability and species distributions especially from presence-only data (Rivera & Lopez-Quilez, 2017). Before implementing the species distribution models, all urban land covers were reclassified to a single variable named "built-up" (i.e., buildings, roads and other built-up surfaces, golf course and quarry). All models were implemented in R (R Core Team, 2017).

3.2.3.1.1. Generalized Linear Model

The road transect data was analyzed using the GLM with a presence-available model, because I only had presence data. To assess habitat selection, pseudo-absence locations were randomly selected (Elith et al., 2011). These pseudo-absence locations are often described as background points, which characterize the landscape in which the species were detected (Elith et al., 2011). To ensure that the equivalent number of absence to presence locations were available, I selected 19 random points per land cover class for the observations in the wet season (n = 290) and 10 for the observations in the dry season (n = 180). I used the Stratified function in the dismo package (Hijmans, Phillips, Leathwick, & Elith, 2017) to locate these pseudo-absence locations. Then, I extracted the land cover class and elevation for each observation and pseudo-absence, which were later used in the GLM, using the extract function in the dismo package (Hijmans et al., 2017).

To evaluate the relationship between season, land cover class and elevation on the probability of occurrence of Broad-Winged Hawks I ran 16 GLMs using the glm function in the stats package (R Core Team, 2017). First, I ran six models on all the data. The first model assumed that probability of occurrence was random (null model). Then, I evaluated whether there was a difference in occurrence between seasons (wet and dry). Following, I evaluated which model would best explain how elevation and land cover class affected occurrence:

1. Elevation × Land Cover + Elevation + Land Cover
2. Elevation × Land Cover + Elevation
3. Elevation × Land Cover + Land Cover
4. Elevation + Land Cover

Finally, using the above four models and a null model, for observations in the dry season and wet season, I evaluate whether occurrence was similarly influenced by land cover and elevation. I used the model with the highest Akaike Information Criterion (AIC) weight (or lowest AIC value) to model Broad-winged Hawk distributions. Further, by using the evaluate function in the dismo package (Hijmans et al., 2017), I cross-validated the best GLMs (one each for both seasons, dry season and wet season) using the full set of pseudo-absences and observations.

A *k*-fold cross validation was then used to validate the model. Because cross validations results may be unstable with small sample sizes, I repeated the validation three times, using area under the curve (AUC) to determine model fit. A 3-fold validation was used because I found that at this number, I was most likely to capture all land cover classes in the training set. Therefore, after I separated the data into three equally-sized groups, I used two groups to train the model and one group to test the model. I repeated this twice, and for each iteration, I selected a different group to test the model and the remaining groups to train the model. The mean AUC value was used to determine the performance of models.

3.2.3.1.2. Maximum Entropy

Maximum Entropy (MaxEnt) was also used to model species distributions using the road transect data. MaxEnt models species distributions using both presence data and background points. MaxEnt identifies which environmental conditions the species are found in and contrasts these conditions with background points (Elith et al., 2011). While MaxEnt is one of the better and more widely used approaches to predict species distribution with presence only data, there are some constraints, and caution should be taken when interpreting the results. Typically, MaxEnt uses a cross-validation bootstrapping approach with replacement. This means that the function selects a portion of the data to build the model and the rest to test the model; this is repeated using the entire dataset with replacement, so the same data used in the first iteration may be used in the subsequent ones. Because MaxEnt models assume that species are sampled randomly, and also that there is no bias in sampling (Merow, Smith, & Silander, 2013), it can produce unreliable estimates of occurrences when sites are revisited (as in my case), which must be considered during interpretation of the results. Regardless, I used the dismo package to implement MaxEnt (Hijmans et al., 2017). Using land cover (i.e., Nutmeg & Mixed Wood Agriculture, Pastures & Cultivated Land, Drought Deciduous Open Woodland, Deciduous, Coastal Evergreen, Mixed Forest or Shrubland, Semi-deciduous Forest, Evergreen & Seasonal Evergreen Forest, Elfiin & Sierra Palm Cloud Forest, Built-Up Surfaces, Water, Wetland) and elevation as predictors, I implemented the MaxEnt function, specifying the number of background points as 10,000.

I also used a *k*-fold cross validation to validate the model. A 10-fold cross validation was used as opposed to 3-fold as with the GLM because the inclusion of background points in MaxEnt meant that all land cover classes were captured in the training set. After running the validation ten times, I used the mean AUC value to determine the performance of models.

3.2.3.2. Detectability

The point count data was analyzed using *N*-mixture model. This model was used to determine how time of day, day of year, land use/cover and elevation influenced detection probabilities and abundances. I treated each point-count plot as independent. For modelling detection probabilities, the same date and time were assigned to both observations for each visit. I also extracted the elevation and land cover type at each point count location. I used the gcount function in the unmarked package (Fiske & Chandler, 2011) to model detection probabilities, and I allowed the function to set *K*, the upper index of integration for *N*-mixture, at the maximum number of birds detected (5) + 100. In *N*-mixture modeling, we can specify which covariates are likely to influence detection (those that influence the probability of seeing a bird) versus those that would influence availability (those that influence whether a bird can use an area) and abundance (those that affect the number of birds that can use an area). Thus, I assumed the time of day and Julian date influenced detection probability, while land cover and elevation might influence abundance. I used AIC to rank the fit among these models:

1. Abundance (Null); Availability (Null); Detection (Null)
2. Abundance (Null); Availability (Null); Detection (Time + Julian)
3. Abundance (Null); Availability (Null); Detection (Time + Julian + Land Cover)
4. Abundance (Null); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)
5. Abundance (Null); Availability (Land Cover); Detection (Time + Julian + Land Cover) *
6. Abundance (Null); Availability (Elevation); Detection (Time + Julian + Land Cover)
7. Abundance (Null); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)
8. Abundance (Elevation); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)
9. Abundance (Elevation + Land Cover); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)
10. Abundance (Land Cover); Availability (Null); Detection (Time + Julian + Land Cover)
11. Abundance (Elevation + Land Cover); Availability (Null); Detection (Time + Julian + Land Cover)
12. Abundance (Elevation + Land Cover); Availability (Null); Detection (Time + Julian + Land Cover)
13. Abundance (Land Cover); Availability (Land Cover); Detection (Time + Julian + Land Cover)

14. Abundance (Land Cover); Availability (Elevation); Detection (Time + Julian + Land Cover)

3.3. Results

3.3.1. Diurnal Raptor Observations

A total of fifty-six (56) roadside surveys were conducted along seven road transects in the wet season of 2016 (July to December) and dry season of 2017 (January to May). Forty-two (42) repeated point count surveys were conducted using the independent double observer sampling method at 6 points along each transect during the same period. Of the two (2) focal species (Grenada Hook-Billed Kite and the Antillean Broad-winged Hawk) only one species – the Antillean Broad-winged Hawk was sighted during the surveys.

3.3.1.1 Antillean Broad-winged Hawk Observations

A total of 262 sightings of the Antillean Broad-winged Hawk were recorded along the road transect surveys during the study. 70% (*n*=182) were observed in the wet season and 30% (*n*=80) in the dry season (Figure 2). We noted a higher incidence of hawk observations in areas near human settlement than elsewhere (Figure 2).

Antillean Broad-winged Hawks were observed feeding on a variety of food types during the study. We observed hawks eating mostly reptiles such as the tree lizard and the ground lizard and occasionally small rodents and birds. We often saw smaller birds such as the grey kingbird *(Tyrannus dominicensis)* attacking the hawks, perhaps because hawks pose threats to nests of kingbirds as well as other birds. Evidence of breeding (i.e. courtship display and copulation) of the hawk was observed during the dry season between January and March.

3.3.1.2 Grenada Hook-Billed Kite Observations (outside of the survey transects completed)

During the survey period, no Grenada Hook-Billed Kites were observed along the transects. This suggests that the density of kites is extremely low. However, we followed up on observations made by locals/citizens and other researchers where kites were found elsewhere. We found seven (7) areas where Grenada Hook-billed Kite were sighted this way. We visited the sites to confirm the identification of the species and recorded the GPS locations of these local observations to create a map (Figure 3). Evidence of breeding of the Grenada Hook-Billed Kite was observed at two sites: Morne Delice and Mount Hartman (in Figure 3). At each site there was at least one breeding pair. Based on the local knowledge gathered, the Grenada Hook-Billed Kite was observed using the same nest site at these two locations during consecutive years, from 2014 - 2016. In 2017, we revisited the Morne Delice site twice and did not record any observations of kites.

3.3.2 Species Distribution Models

The probability of occurrence of Antillean Broad-winged Hawks was best explained by elevation and land cover and not by season (Table 1). However, in the interest of completeness, I created models of the probability of occurrence across both seasons, in the dry season and in the wet season for both species distributions models. For both the GLM and MaxEnt outputs, land cover had a larger influence on the probability of occurrence than did elevation. For the GLM, I assumed that predictors that had confidence intervals that did not overlap with zero had an influence on the probability of occurrence. Further, all land cover types (e.g., Deciduous, Coastal Evergreen, Mixed Forest or Shrubland, Semi-deciduous Forest, Evergreen & Seasonal Evergreen

Forest, Elfin & Sierra Palm Cloud Forest, Built-Up Surfaces) had an effect on the probability of occurrence (Table 2).

Similarly, based on the permutation of importance, which is an estimate of how influential an environmental variable is on the probability of occurrence based on permutations of the data in MaxEnt, land cover had the largest influence on hawk occurrence (both seasons: land cover – 61.5 %, elevation – 38.5 %; wet season: land cover –78.6 %, elevation –21.4 %; dry season: land cover –70.6 %, elevation –29.4 %).

3.3.2.1 Model Performance

The GLM-based species distribution models performed better than those created using MaxEnt. Based on the AUC results, all GLM-based species distribution models were rated as fair to good (both seasons: 81.1 %; dry season: 81.0 %; wet season: 79.6 %). However, MaxEnt-based species distribution models models ranged from poor to fair (both seasons: 71.7 %; dry season: 69.5 %; wet season: 75.2 %).

3.3.2.2 Elevation

Both the GLM-based and MaxEnt-based species distribution models suggest that the probability of occurrence for Broad-winged Hawks was highest in coastal areas (Figure 4). Regardless of season, hawk occurrences were highest at mid-to low elevation areas. The MaxEnt output suggests that occurrences were highest between 8-280 m above sea level, peaking at 50m (Figure 4B). In the wet season, based on the MaxEnt output, Broad-winged Hawks were most commonly seen between 8-300 m above sea level, peaking at 80 m (Figure 4D). Also based on the MaxEnt output, in the dry season, Broad-winged Hawks were associated with elevations between 8-258 m, peaking at 41 m (Figure 4F).

3.3.2.3 Land Cover

The relationship between the probability of occurrence of Broad-winged Hawks and land cover differed slightly between seasons for the MaxEnt-based species distribution model. Regardless of season, Broad-Winged Hawks were associated with both built up areas and nutmeg and mixed-wood agriculture (Figure 5 A, C, F). However, for the MaxEnt-based species distribution models across both seasons, hawk occurrences were highest in built-up areas, and were less likely to be seen in semi-deciduous, evergreen and seasonal, or elfin and sierra palm forests (Figure 5B). Further, in the dry season, hawk occurrences were highest in both built-up areas and cloud forest, and they avoided deciduous and semi-deciduous forests (Figure 5D). In the wet season, hawks were also most commonly observed in built-up areas, but were also associated with nutmeg and mixed-wood agriculture and pastures and cultivated fields (Figure 5F).

3.3.2.4 Habitat Suitability

Both the GLM-based and Maxent-based species distribution models suggest that Hawks are widely distributed across the island (Figure 6). Both models also suggest that Hawks are more widely distributed in the wet season (Figure 6C & 6F) than the dry season (Figure 6B & 6D) and that distribution in the wet season is similar to when we look at all observation throughout the survey period. However, hawks are most commonly found in the north east and south west of the island and are less likely to be found in the island's interior (Figure 6).

3.3.3 Detection Probabilities

There were five competitive models (delta AIC within 2 AIC units of the best model), and they each suggest that detectability is influenced by land cover, time of day and day of year (Table 3; Figure 7A-7E). However, the models differed in whether the site covariates influence abundance and availability. Because AIC selects overly complex models (Arnold 2010, Mundry 2011), I chose the least complex model among the 5 models as the best model (Figure 7A), and this model has no abundance or availability covariates. Detection probabilities were higher earlier in the day and earlier in the year (Figure 7A); also, detection probabilities were generally high in all land cover classes apart from evergreen forests. Importantly, these relationships were the same across all top-ranking models (Figure 7A-7E).

3.4 Discussion

Understanding the distributions of diurnal raptors in Grenada is essential for their effective management and conservation. This is particularly important because of the limited range and habitat available for raptors on Grenada, which are are further reduced by the ongoing anthropogenic threats and habitat alterations resulting from activities such as the expansion of the agricultural sector, uncontrolled tourism development and urbanization. In the case of the Antillean Broad-wing Hawks, the study confirmed that they are widely distributed across the island of Grenada. This was supported by the results of both Generalized Linear Models (GLM) and Maximum Entropy (MaxEnt) – two common approaches used when predicting habitat suitability and distributions of species (Rivera & López-Quílez, 2017). The comparison of the predictive efficiency of the two models were necessary in modelling the distribution of the Antillean Broad-wing Hawks using on the road transect data because both models vary in, (i) the type of input data (i.e. presence and absence data or presence data only) and, (ii) the modelling procedures. With these procedures to model species distributions, the model predictions represent the probable distribution of species rather than their real distribution. As such, the probability of occurrence predicted by the two models also likely reflects the habitat suitability for that specific species (Angelieri, Adams-Hosking, Ferraz, de Souza, & McAlpine, 2016).

Further, based on the SDM, the probability of occurrence of Antillean Broad-winged Hawks was best explained by elevation and land cover, and not by season. This was consistent with both modeling approaches; however, the results suggest that the GLM-based approach performed better than the MaxEnt approach. Also, both models had similar results with respect to the land cover, suggesting that land cover exhibited a larger influence on the probability of occurrence of the Antillean Broad-winged Hawk than elevation. However, based on a comparison of the AUC for both methods, the GLM approach for species distribution models performed better than the MaxEnt approach. It is worth noting, however, that the habitat selection by the Antillean Broad-winged Hawks could have also been influenced by the absence of several biological variables such as conspecific attraction, availability of prey, and avoidance of features like roads, that were not taken into account in the model.

Nevertheless, based on the two predictive variables considered in this study, land cover was found to be the more important element influencing the presence of the Antillean Broad-winged Hawks in Grenada. Land cover is known to have an impact on the distribution of numerous species, since it largely determines the availability of suitable areas where individuals may establish home ranges with ample food resources, which in turn have a direct impact on the population size, reproductive success, and survival of most wildlife species (LeBrun, Thogmartin, Thompson, Dijak, & Millspaugh, 2016; Ngai et al., 2008). Furthermore, the results of the GLM-based models also indicated that there was a greater correlation between hawks and the two land cover types (i.e. built-up areas and nutmeg and mixed-wood agriculture areas), even higher than anticipated based on information in the literature review. Therefore, if the Broad-winged Hawks on Grenada are indeed non-migratory as the literature suggests, then their greater densities in built-up areas and nutmeg and mixed-wood agriculture areas may, in part, be explained by the much smaller amount of habitat available to these hawks. Additionally, it is also reasonably plausible that the high density of these hawks may be related to the adaptability of this species to human-developed areas (Pérez-García, Sebastián-González, Alexander, Sánchez-Zapata, & Botella, 2014; Thiollay, 1985). Perhaps this phenomenon can be explained by the possibility that these human-developed areas promote a higher abundance of small rodents and reptiles, hence, providing a more accessible food source for hawks.

Conversely, some studies have suggested that in other parts of their range, because Broad-winged Hawks are perch hunters (Fitch, 1974), built-up areas can have a negative impact on their habitat selection (Bloom, McCrary, & Gibson, 1993). In the case of the Broad-winged Hawk (*Buteo platypterus brunnescens*) in Puerto Rico, the literature suggests that their range is limited to the old age and mature mountain forest (Wiley, 1985; Vilella & Hengstenberg, 2006). This Broad-winged Hawk sub-species is endemic to the island of Puerto Rico (Goodrich, Crocoll & Senner, 1996; Vilella & Hengstenberg, 2006) but unlike the Lesser Antillean subspecies it is considered endangered due to its declining populations as a result of the destruction of large areas of virgin forests in Puerto Rico (Wiley, 1985). Additionally, the more limited habitat preference of the Broad-winged Hawk in Puerto Rico may be a function of its specific adaptation to these more limited environments (Vilella & Hengstenberg, 2006). One possible explanation for the difference in habitat selection/preference between the two subspecies can be simply attributed to the limited space and habitat available to these species. For instance, the island of Puerto Rico (~13,791 km^2), is almost 40 times larger than the island of Grenada (~344 km^2); therefore, the Puerto Rico subspecies would have a larger area of mature forest habitat, possibly with a the higher prey density in that forest habitat than is the case of the Antillean subspecies in Grenada. Hence, the Puerto Rican subspecies may not have been as pressured to adapt to human development. Studies on Broad-winged Hawks in Puerto Rico reported that this sub-species is primarily found in deciduous or mixed forest habitats, and is rarely found in built-up, human-developed landscapes (Stouffer, 2011).

With respect to the the results of my study regarding distribution of Antillean Broad-winged Hawks across the wet and dry season, the results of the road transect indicated that more hawks, 70% (n=182) were observed in the wet season, than in the dry 30% (n=80). While there were some differences detected in the specific habitat used during the two seasons, it was not significant and may be inferred that habitat use is similar between seasons. Interestingly, however, it does appear that the Antillean Broad-wing Hawks are moving into the slightly more mesic habitat in the dry season, perhaps because of the seasonal availability of prey (Jedlicka, Greenberg, Perfecto, Philpott, & Dietsch, 2006).

The results of the *N*-mixture models (based on the point count data) suggested that detectability of Antillean Broad-winged Hawks was affected by land cover, time of day and day of year. However, the models also showed that the effects of time of day on detectability of the Antillean Broad-winged Hawks varied slightly over the two seasons. In fact, surveys in the later in the day reported the highest number hawks as compared to the early morning. Also, more raptors were detected in earlier in the year i.e. the dry season than the wet season. Since the Antillean Broad-winged Hawks are generalist species and mainly hunt small rodents and reptiles (e.g. lizards) and tend to have a delayed activity period (Ellis et al. 2007) i.e. mid-morning to afternoon, variations in the peak hunting period may have affected the number of detectable birds during the surveys. Another explanation could be based on the poor visibility due to denser canopy cover in the wet season as compared to the dry season.

In the case of the Grenada Hook-billed Kite, due to the absence of observational data, it was not possible to evaluate their status and distribution. The limited number of reported sightings suggests that the density of Grenada Hook-billed Kites on the island is extremely low. This low density maybe be as a result of the highly specialized diet of the Grenada Hook-billed Kites, consisting mainly of arboreal snails *(i.e. Endolichotus grenadensis, Bulimulus wiebesi, Orthalicus undatus, Pleurodonte perplexa,* and possibly juvenile *Megalobulimus oblongus)* (Daniel & Dyerson, 2013; Thorstrom et al., 2001). Due to factors such as extensive human development and the impacts of climate change, such as longer periods of droughts and increased risk of intense hurricanes (Biasutti, Sobel, Camargo, & Creyts, 2012), it is possible that the abundance of arboreal snails has declined precipitously over time, or has shifted from xeric woodlands areas along the coast to the interior deciduous montane forest. However, there are very few studies that have been published on habitat preference and distribution of arboreal snails in island ecosystems to support this hypothesis. The lack of detection of the kites during the surveys also suggests that the population remains small, vulnerable and possibly declining. In 2004 and 2005, following the widespread habitat destruction after two hurricanes, Thorstrom & Mcqueen, (2008) reported a 35% population decline in Grenada Hook-billed Kite. However, our lack of kite observations may suggest further decline, since the previous population estimates of kites reported 40 individuals or more on the island (Whitacre, 2012).

Stephens & Anderson (2003) attributes declines in Broad-winged Hawks in North America to the loss of old-growth, native forests. Forest habitat destruction can pose a serious threat to diurnal raptors and this may be particularly true for the Grenada Hook-billed kite as well. In this regards, I recommend that this research be complemented by an intensive survey method to target this specialist raptor species and to identify whether the areas presumed to be suitable for the Grenada Hook-billed Kite are indeed suitable.

In conclusion, I found that Broad-winged Hawks are widely distributed on Grenada, contrary to the elusive Grenada Hook-billed Kite. Regardless of the survey methods used (i.e., related point counts or road transects), I detected no Grenada Hook-billed Kites, and this is unsurprising because as a specialist species, the restricted range of their food resources prohibit them from occupying human-related land cover classes. The generalist Broad-winged Hawk, however, was associated with land cover classes with high levels of human disturbance. This may be because some of their food sources (i.e., reptiles and rodents) are also associated with human-developed land covers in island ecosystems. Thus, while fragmentation and degradation of forests may not have had major negative impact on the Antillean Broad-winged Hawks, the Grenada Hook-billed Kite will likely be further restricted in its range with this increasing deforestation and development.

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Table 1: AIC, delta AIC and AIC weight for the generalized linear models predicting the probability of occurrence based on season, elevation and land cover. The best model is the one with the highest AIC weight and lowest delta AIC value, and this model is represented by "*".

Data	Model	AIC	Delta AIC	AIC Weight
Both Seasons	Null	765.80	212.200	0.000
	Season	766.80	213.200	0.000
	Elevation × Land Cover + Elevation + Land Cover	559.60	6.000	0.045
	Elevation × Land Cover + Elevation	627.46	73.861	0.000
	Elevation × Land Cover + Land Cover	559.60	6.000	0.045
	Elevation + Land Cover	553.60	0.000	0.909*
Dry Season	Null	249.30	59.100	0.000
	Elevation × Land Cover + Elevation + Land Cover	196.60	6.400	0.038
	Elevation × Land Cover + Elevation	221.33	31.126	0.000
	Elevation × Land Cover + Land Cover	196.60	6.400	0.038
	Elevation + Land Cover	190.20	0.000	0.925*
Wet Season	Null	517.50	140.200	0.000
	Elevation × Land Cover + Elevation + Land Cover	387.00	9.700	0.082
	Elevation × Land Cover + Elevation	421.40	44.103	0.000
	Elevation × Land Cover + Land Cover	387.00	9.700	0.082
	Elevation + Land Cover	377.30	0.000	0.836*

Table 2: Coefficients from best generalized linear model predicting the occurrence of Broad-winged Hawks in both seasons, in dry season and in the wet season. All values are in comparison with abundance in Nutmeg & Mixed Wood Agriculture, which was the reference land cover type. Confidence intervals are 95 %. *(All habitat types (Drought deciduous Open Woodland, Water and Wetland where the hawks were not observed were removed from the GLM)*

Model Parameter	Both Seasons			Dry Season			Wet Season		
	Estimate	Upper CI	Lower CI	Estimate	Upper CI	Lower CI	Estimate	Upper CI	Lower CI
Intercept	2.024	2.597	1.451	2.277	3.325	1.229	1.982	2.690	1.274
Elevation (β)	-0.003*	-0.001	-0.006	-0.006*	-0.001	-0.010	-0.003	0.000	-0.005
Pastures & Cultivated Land (β)	-2.345*	-1.574	-3.116	-2.642*	-1.235	-4.049	-2.276*	-1.346	-3.206
Deciduous, Coastal Evergreen, Mixed Forest or Shrubland (β)	-1.887*	-1.177	-2.597	-1.869*	-0.635	-3.103	-1.953*	-1.072	-2.834
Semi-deciduous Forest (β)	-1.955*	-1.244	-2.666	-2.390*	-1.038	-3.742	-1.816*	-0.965	-2.667
Evergreen & Seasonal Evergreen Forest (β)	-1.844*	-1.051	-2.637	-2.441*	-0.702	-4.181	-1.705*	-0.778	-2.632
Elfiin & Sierra Palm Cloud Forest (β)	-2.533*	-1.275	-3.791	-0.731	1.241	-2.702	-3.802*	-1.636	-5.968
Built-Up Surfaces ((β)	-1.133*	-0.487	-1.779	-1.287*	-0.140	-2.434	-1.099*	-0.307	-1.891

Table 3: AIC, delta AIC and AIC weight for the six models predicting detection probabilities and abundance. Models with "*" were equivalent because they were with 2 delta AIC units of each other. As such, these models were equivalent to the best model.

Model	AIC	Delta AIC	AIC Weight
Abundance (Null); Availability (Null); Detection (Null)	838.33	9.635	0.002
Abundance (Null); Availability (Null); Detection (Time + Julian)	836.42	7.721	0.005
Abundance (Null); Availability (Null); Detection (Time + Julian + Land Cover) *	829.99	1.296	0.119
Abundance (Null); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)	830.92	2.222	0.075
Abundance (Null); Availability (Land Cover); Detection (Time + Julian + Land Cover) *	828.94	0.241	0.202
Abundance (Null); Availability (Elevation); Detection (Time + Julian + Land Cover) *	830.67	1.976	0.085
Abundance (Null); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)	837.45	8.756	0.003
Abundance (Elevation); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)	832.82	4.121	0.029
Abundance (Elevation + Land Cover); Availability (Elevation + Land Cover); Detection (Time + Julian + Land Cover)	839.62	10.923	0.001
Abundance (Land Cover); Availability (Null); Detection (Time + Julian + Land Cover) *	828.70	0.000	0.228*
Abundance (Elevation + Land Cover); Availability (Null); Detection (Time + Julian + Land Cover)	830.92	2.222	0.075
Abundance (Elevation + Land Cover); Availability (Null); Detection (Time + Julian + Land Cover)	830.70	2.003	0.084
Abundance (Land Cover); Availability (Land Cover); Detection (Time + Julian + Land Cover)	835.46	6.759	0.008
Abundance (Land Cover); Availability (Elevation); Detection (Time + Julian + Land Cover) *	830.68	1.984	0.085

Figure 1: Map showing the location of seven (7) road transects and forty-two (42) point counts area surveyed for diurnal raptors on the island of Grenada. Grenada is shown in the smaller box and the larger box shows the Caribbean Region where Grenada is located.

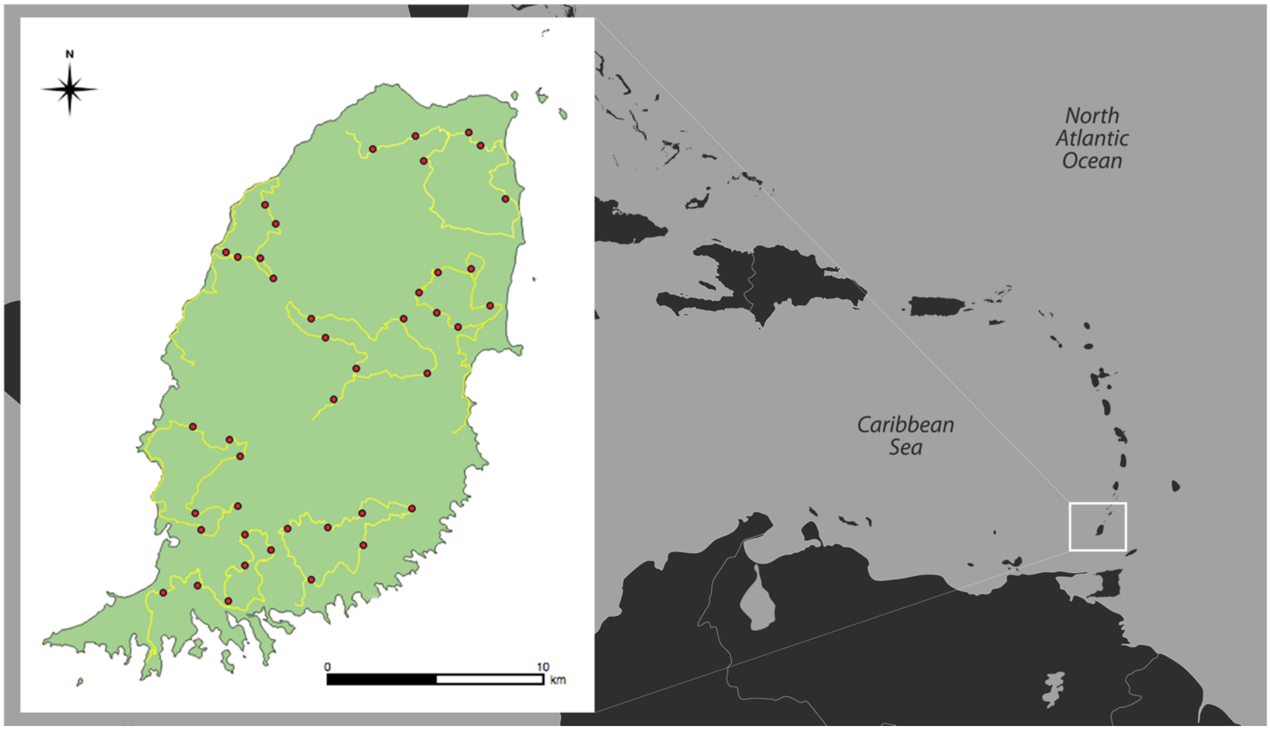


Figure 2: Map of the sites where Antillean Broad-Winged Hawk observations were made during road transect surveys conducted in 2016 & 2017. Triangles (△) show where Antillean Broad-Winged Hawks were seen in the dry season (survey period), and circles (○) are where they were seen in the wet season survey period (survey period).

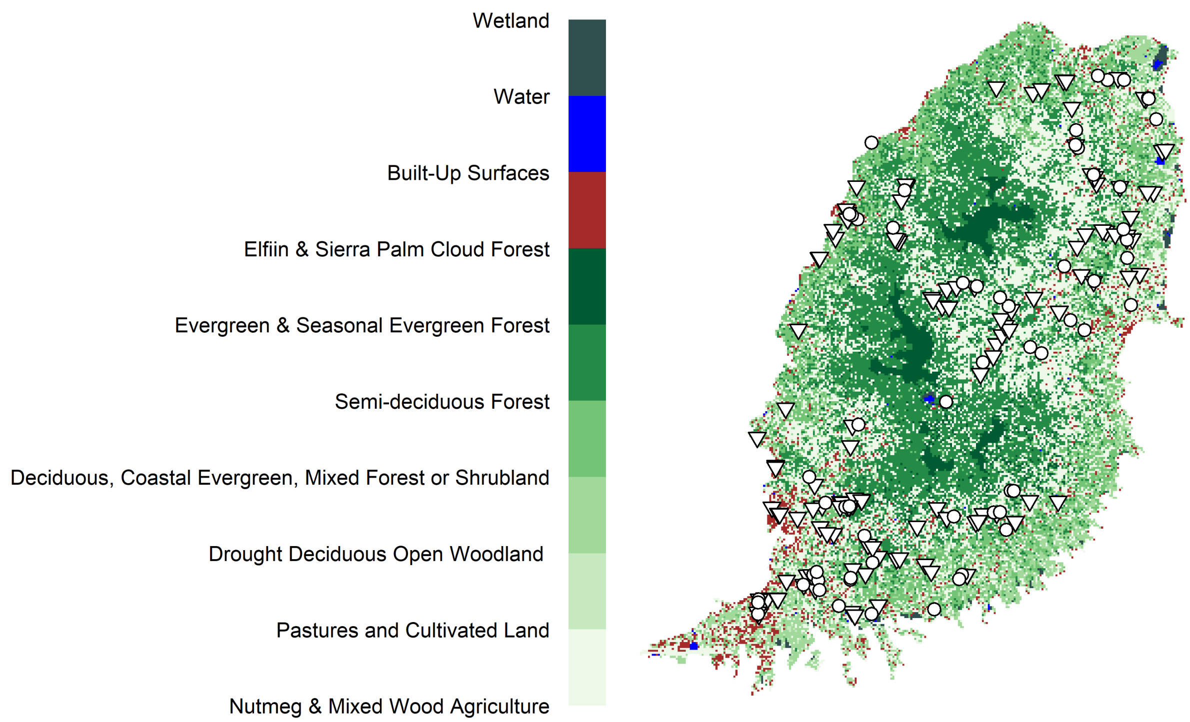


Figure 3: Map of the sites where Grenada Hook-Billed Kite observations were made by locals/citizens during the study period. Diamond (◇) are the locations of the point count locations where Grenada Hook-Billed Kites were not observed (survey period). Squares (■) show where they were seen by locals/citizens and other researchers between 2015 & 2017). Sites labelled Mt. Hartman & Morne Delice are sites where evidence of breeding of the Grenada Hook-Billed Kite was observed during consecutive years, from 2014 – 2016.

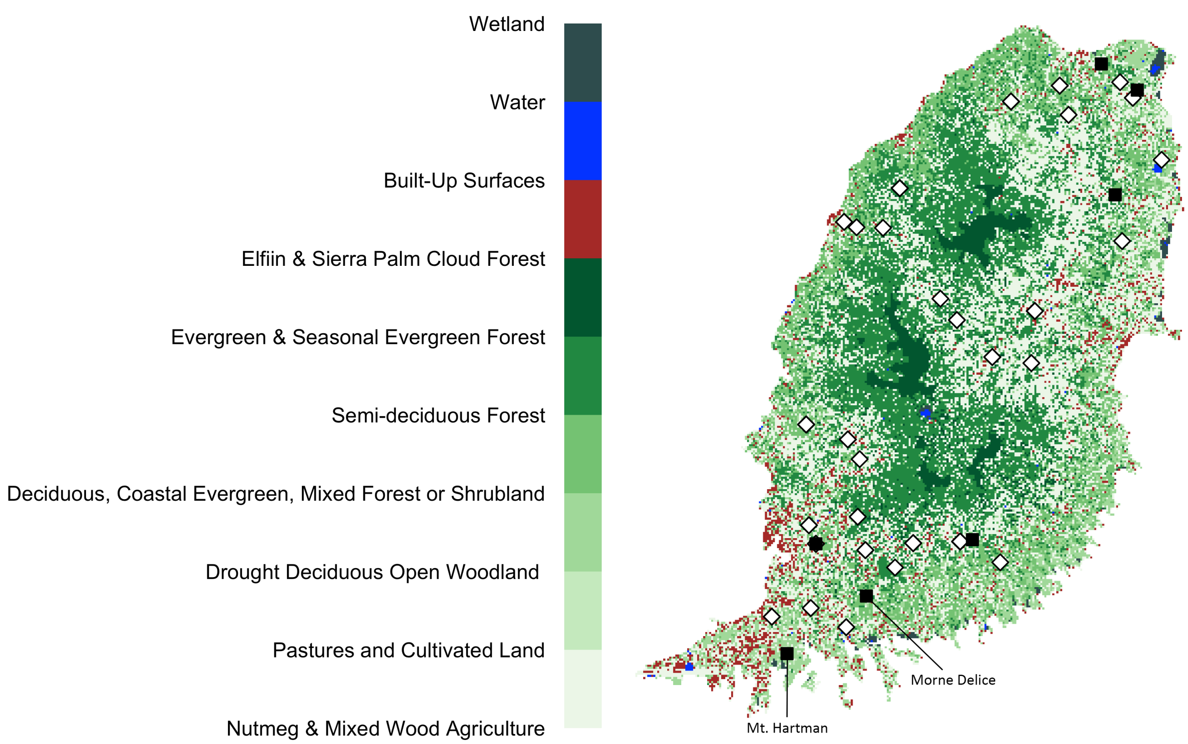


Figure 4: Plots of the probability of occurrence of Antillean Broad-winged Hawks varying with elevation and land cover type across both seasons (A-B), in the dry season (C-D) and the wet season (E-F). For the elevation plots, I used the most commonly observed land cover type (Nutmeg & Mixed Wood Agriculture) when predicting the probability of occurrence. Because it is not possible to estimate error for MaxEnt outputs for response curves, only the generalized linear model plots show the 95 % confidence intervals.

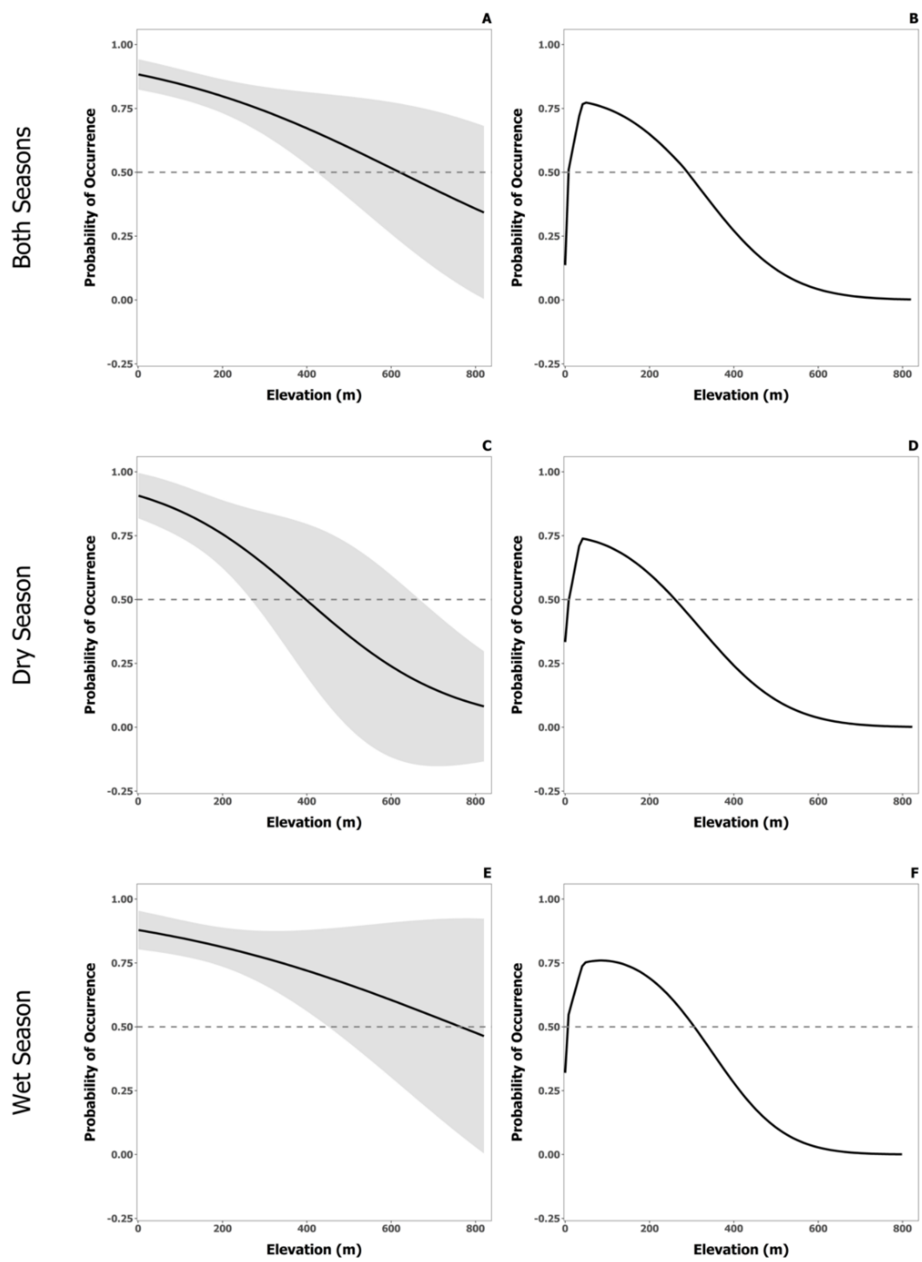


Figure 5: Plots of the probability of occurrence of Antillean Broad-winged Hawks varying with land cover type across both seasons (A-B), in the dry season (C-D) and the wet season (E-F) from the generalized linear model (A, C and F) and MaxEnt (B, D and F). For the land cover plots, I used the mean elevation across the background points (198.55 m) when predicting the probability of occurrence. Because it is not possible to estimate error for MaxEnt output for response curves, only the generalized linear model plots show the 95 % confidence intervals.

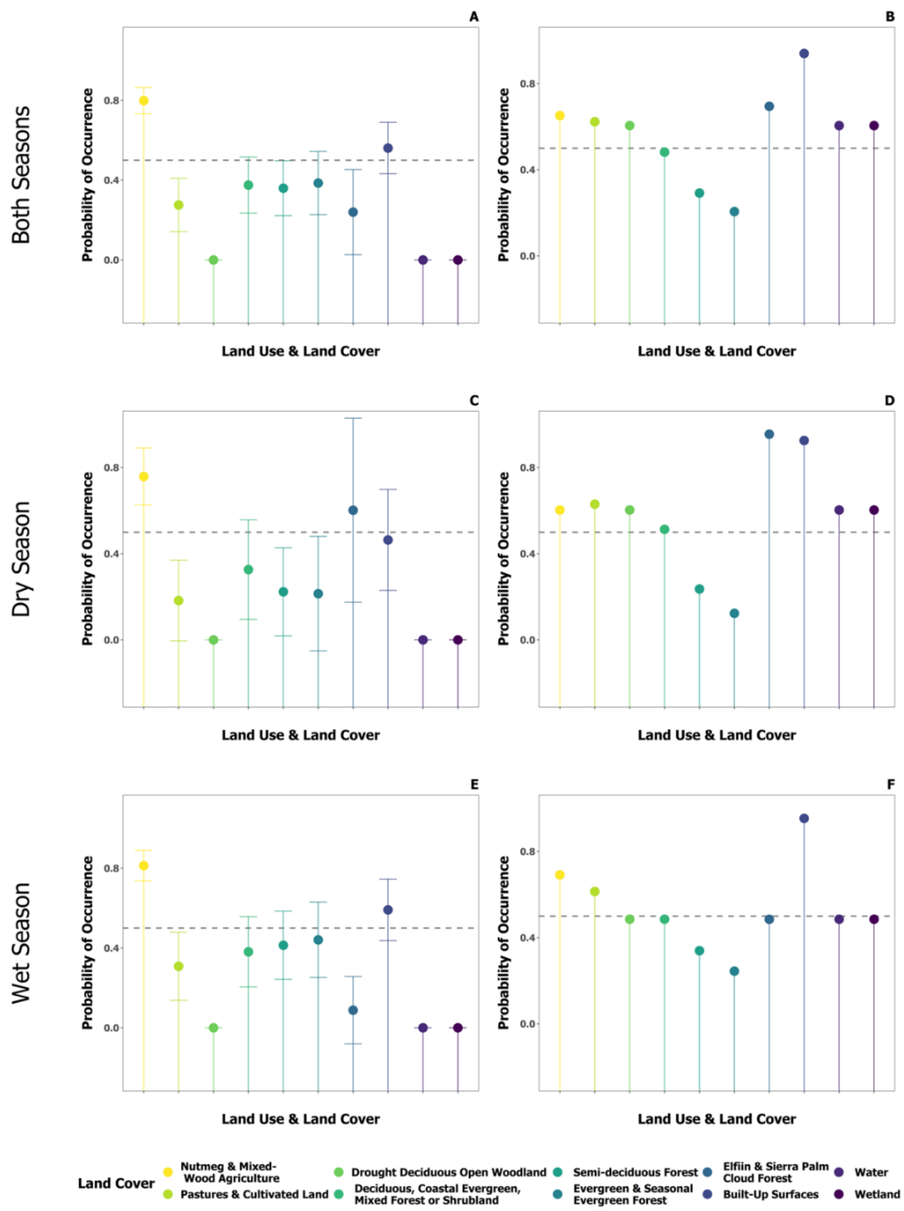


Figure 6: Probability of occurrence maps produced by a generalized linear model and MaxEnt for Broad-wing Hawks observed across all road transect surveys (A & D), in the wet season and (B & E) in the dry season (C & F). A probability of one indicates a high likelihood of finding the species within the raster square, and zero indicates that it is unlikely that the species will be found there.

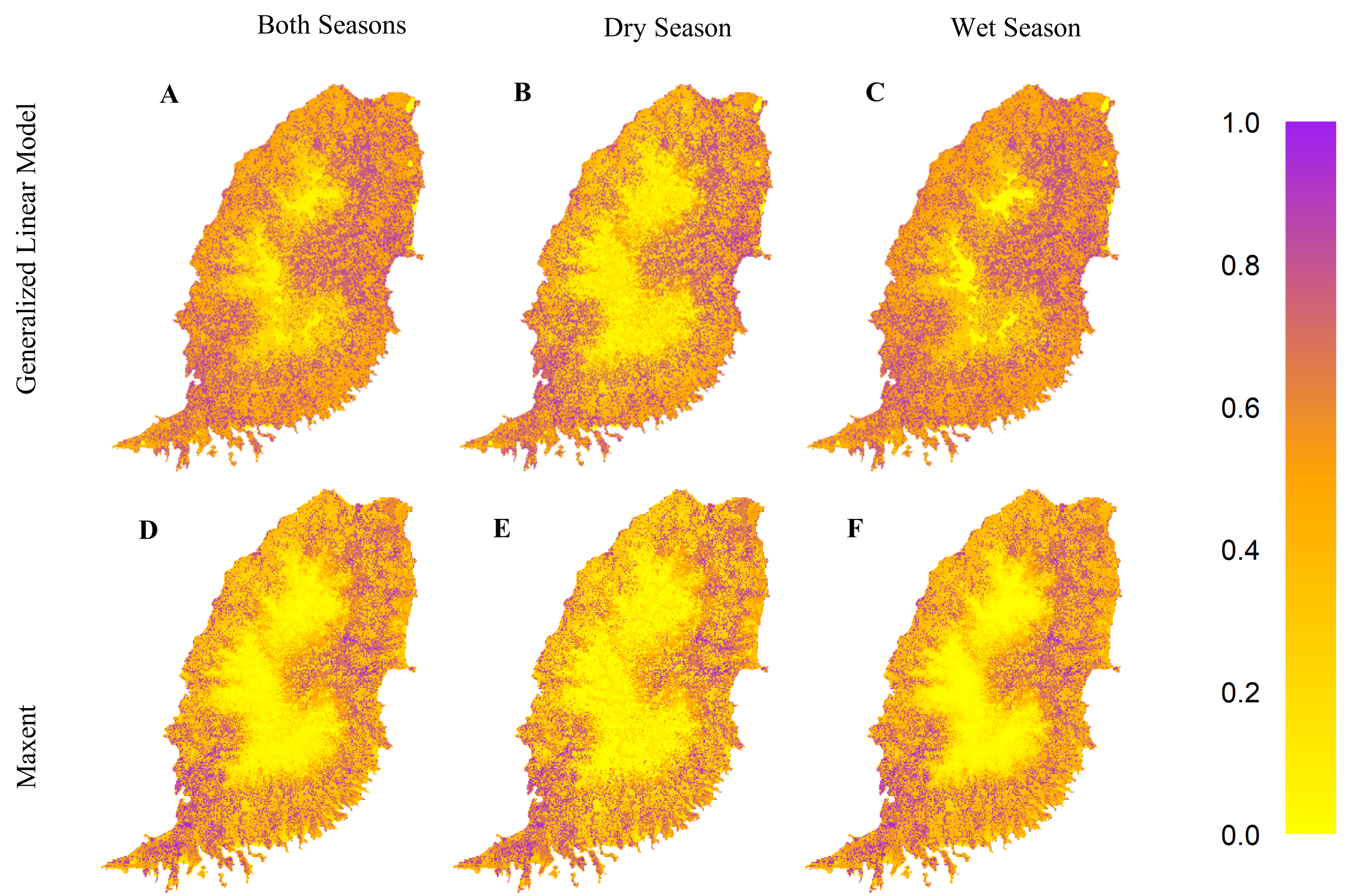


Figure 7A: Plot of the probability of detection for Broad-winged Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of occurrence. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Ribbons on the plot show 95 % confidence intervals. This model shows no abundance or availability covariates. <u>This is the least complex model/best fit model among the following 5 top models (7A-E) produced from the N-mixture models analysis using the point count data.</u>

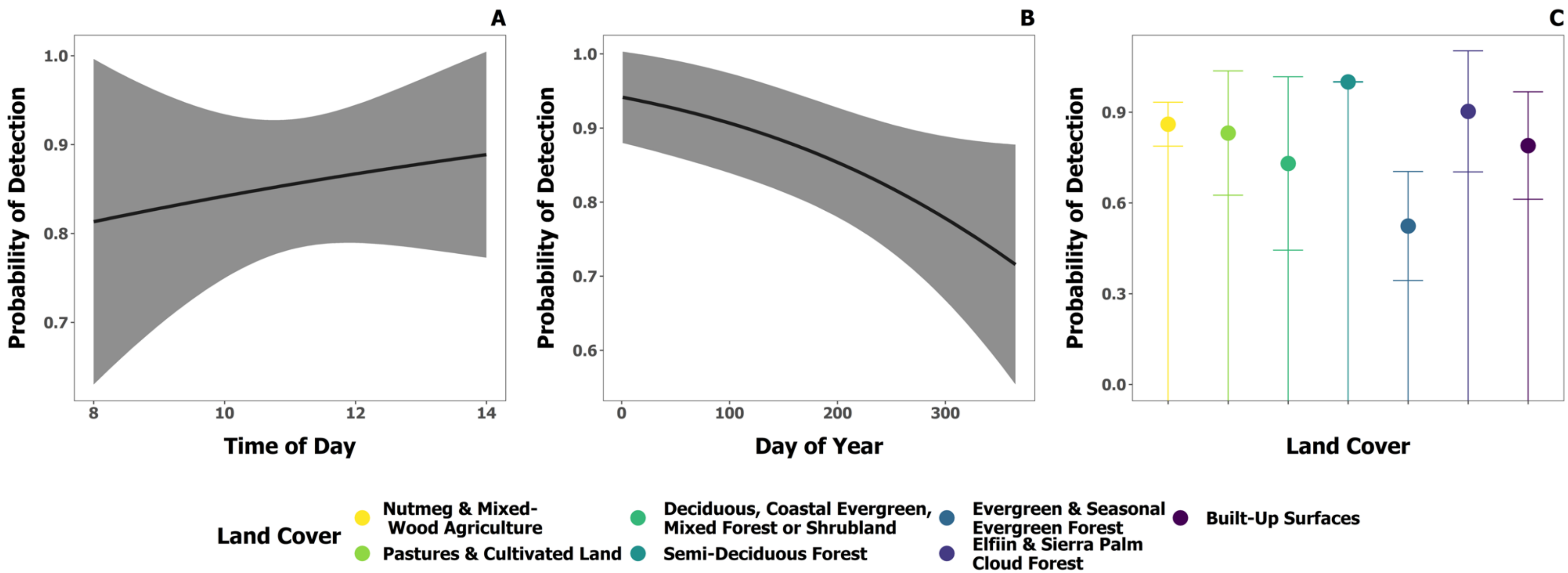


Figure 7B: Plot of the probability of detection for Broad-winged Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted availability based on land cover class. Ribbons on the plot show 95 % confidence intervals. This model shows no abundance covariates.

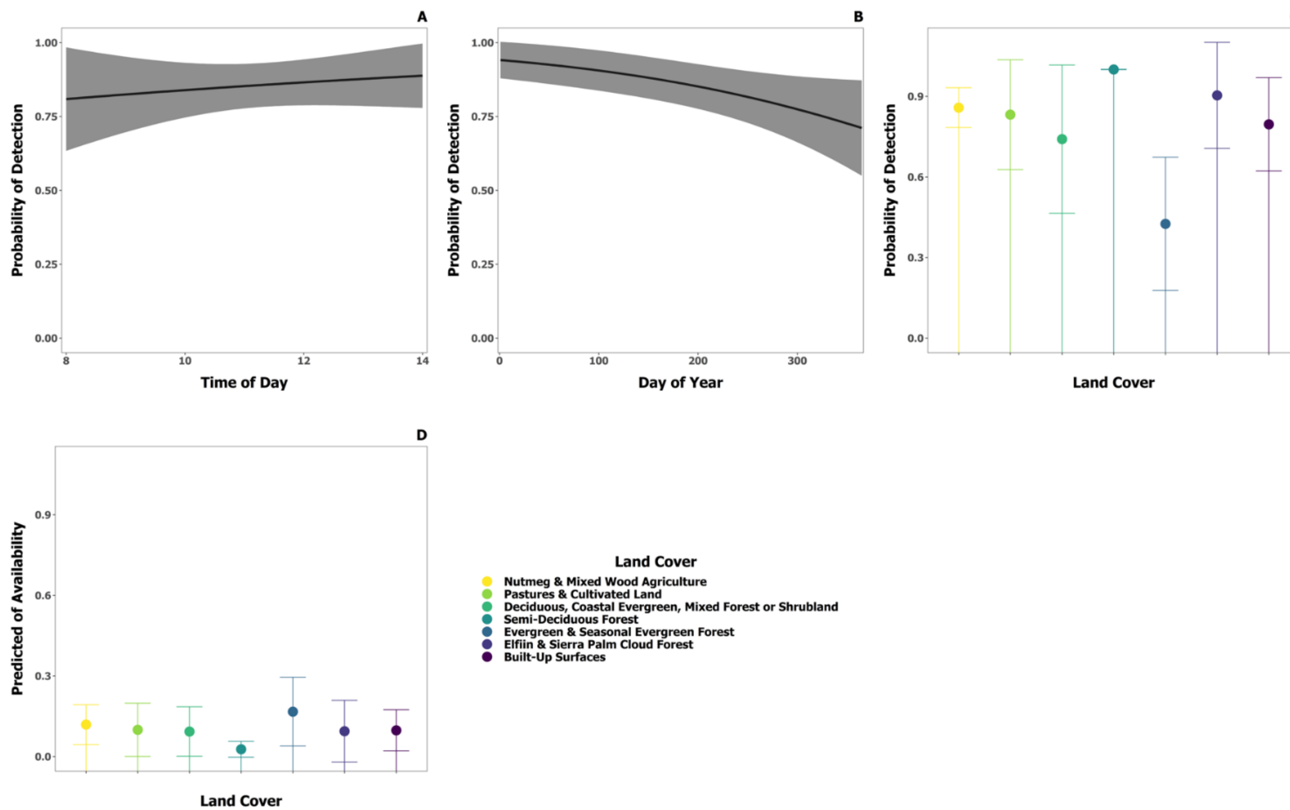


Figure 7C: Plot of the probability of detection for Broad-wing Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. <u>Model (D) shows the predicted availability based on elevation.</u> Ribbons on the plot show 95 % confidence intervals. This model shows no abundance covariates.

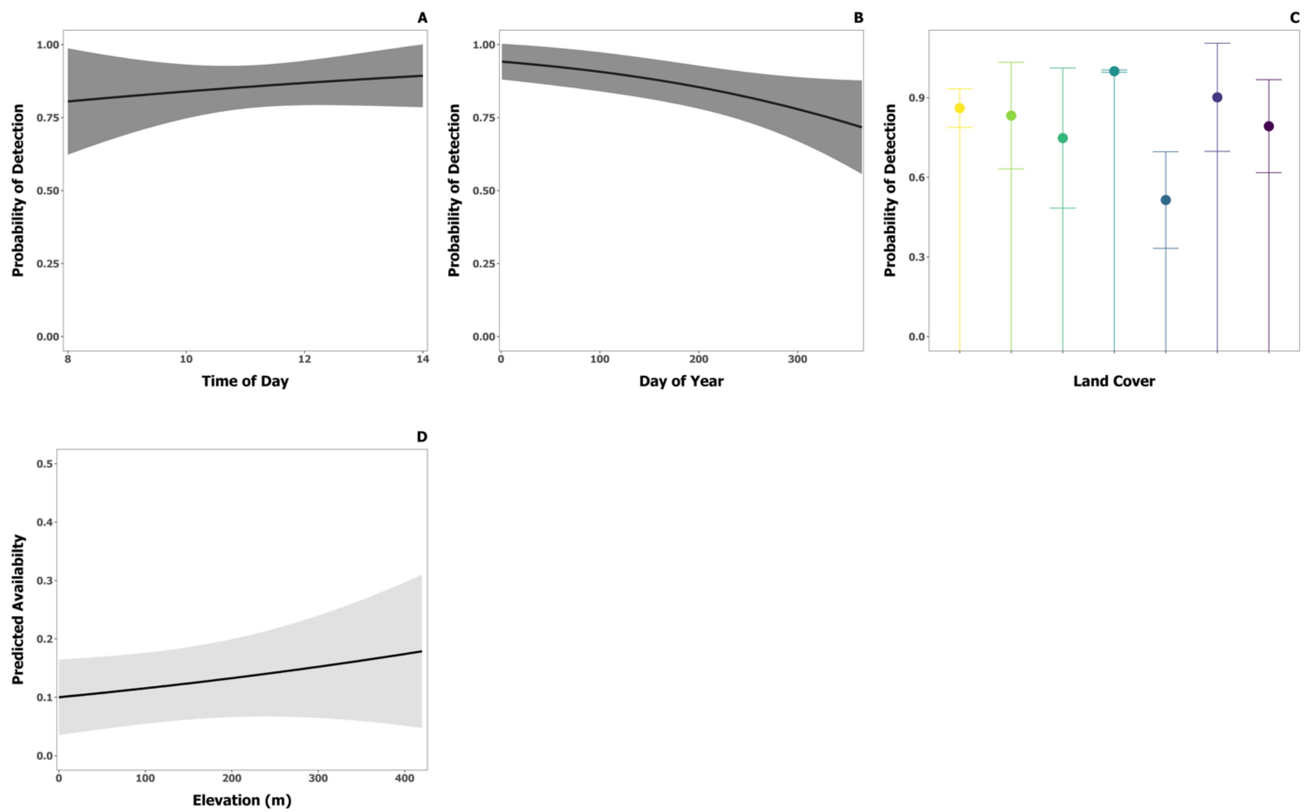


Figure 7D: Plot of the probability of detection for Broad-wing Hawks with time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted abundance with land cover class. Ribbons on the plot show 95 % confidence intervals. This model shows no availability covariates.

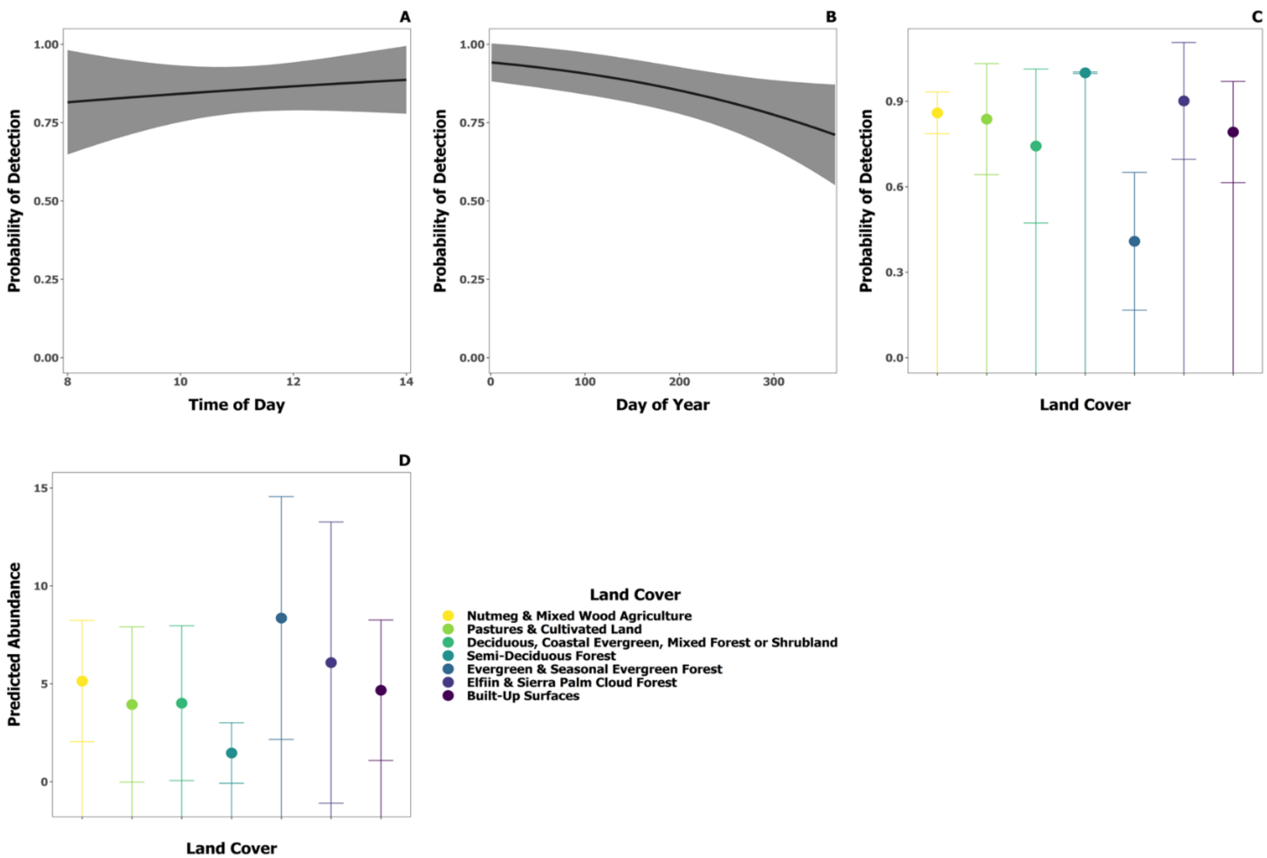
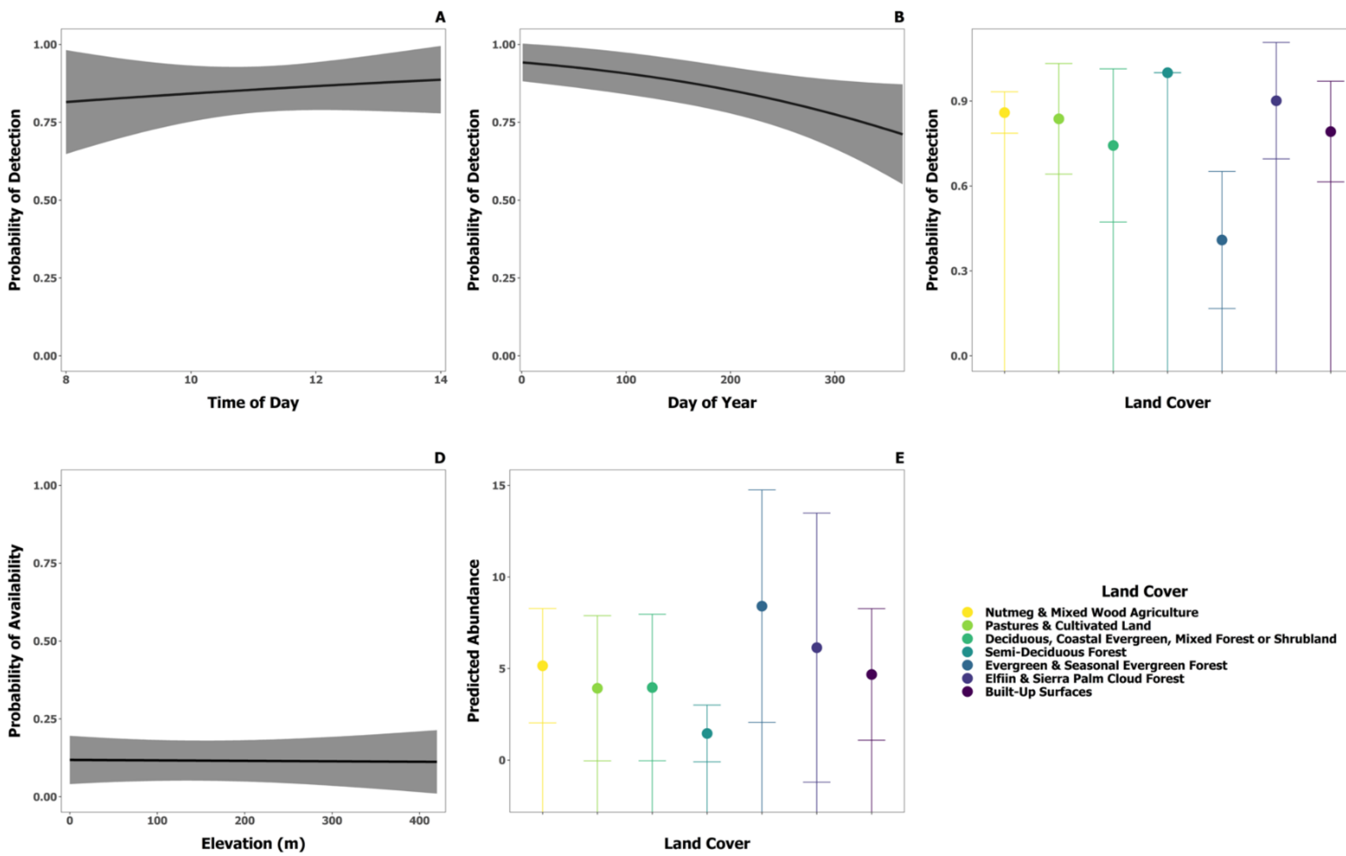


Figure 7E: Plot of the probability of detection for Broad-wing Hawks against time of day and day of year the survey was conducted. For the time of day model (A), I used the mean number of days across surveys (290) to predict the probability of detection. For the day of year model (B), I used the average start time of the surveys (11.40) to predict the probability of detection. Model (D) shows the predicted availability based on elevation, and model (E) shows that predicted abundance based on abundance. Ribbons on the plot show 95 % confidence intervals.



4. CHAPTER 4: SUMMARY AND MANAGEMENT IMPLICATIONS

4.1. Implications

Raptors have endured a long history of persecution owing to negative interactions with anthropic interests, and in more recent times, some populations of raptors have suffered population declines due to environmental contaminants, such as DDT and mercury. However, the most common challenge to raptor populations today is habitat loss, a problem that is particularly true for the Grenada Hook-billed Kite. Despite this alarming reality, there have been no specific conservation efforts aimed at the protection or management of this raptor species in Grenada. However, given the ecological and taxonomic uniqueness of the Antillean Broad-winged Hawk and Grenada Hook-billed Kite; as well as their function as key indicators of biodiversity and environmental health in to Grenadian's ecosystems, a strong case can be made for urgent conservation initiatives. In general, raptors are significantly sensitive to environmental changes and their ecological requirements largely depend on the health of their habitat. As such, their habitats must be preserved as a matter of urgency, to ensure these birds continue to play their integral role in Grenada's ecosystems. Although some strides are being made regarding research and environmental awareness among Grenada's citizenry, and some protective efforts have been gaining momentum, information and data on these species are still largely limited and the overall conservation status of these two raptor species remain unfavorable.

In general, the management of birds require clear definition and guidance, and should in some cases involve a collaborative and inclusive process involving neighboring countries. For the Antillean Broad-winged Hawk this collaboration should include the islands of St. Vincent and Grenada and possibly Tobago. Further, resource managers have generally found that the most effective plans associated with raptor management utilize strategic management frameworks, which offer specific guidance and assessment tools to ensure countries are addressing key aspects of management in a coherent and effective manner (Humphreys, Wernham, Crick, & Scotland, 2007; Kovács & Williams, 2007; Romin & Muck, 2002).

The common management priorities generally include habitat protection and public education and research. However, given that habitat destruction/degradation are the most immediate threats to these raptors, especially to the Grenada Hook-billed Kite, habitat protection and restoration ought to be considered a top priority and will be required for long-term kite conservation. Protected areas, for example, can be an effective means of raptor conservation (Thiollay, 2006), and the identification and safeguarding of important breeding sites, such as the northeastern and southwestern sectors of the island, should be a priority for preserving kite habitat. In addition, since kites and hawks are known to build nest in large old growth and mature growth trees such as Silk Cotton trees *(Ceiba pentandra)* and Naked Indian tree *(Bursera simaruba)* within various habitats types on in Grenada (Campbell et el. 2013) immediate conservation action should be directed towards protecting these primary nesting trees/forest throughout the island. Further, various studies on the parent species of the Hook-billed Kites and Broad-winged Hawks in the Neotropics also suggest that they nest predominantly in mature or well-developed vegetated habitats that support patches of thorn-scrub forest (Whitacre, 2012; Hengstenberg and Vilella, 2004). Hence, mature forests should be protected to serve as both foraging and nesting habitat.

It is important to bear in mind that protected areas alone are unlikely to be sufficient to conserve a species. According to McClure et al., (2018), identification and designation of protected areas will only conserve raptor populations if accompanied by appropriate monitoring, management, and protective enforcement actions. Further, for best results, the key players should be involved and consulted in the development of conservation and management plans. For example, if developers and agriculturalist are causing habitat loss and fragmentation, then these developers, farmers, ornithologists, and local private or public land managers should be involved when recommendations for the minimization of habitat degradation are being determined.

Moreover, education and awareness of raptors is a particularly relevant area for emphasis in Grenada. Only if raptors are understood and valued will the public accept the need for, and the cost of, their conservation. Actions can include public education, field research and community-based initiatives. Aggressive education campaigns could be initiated by working with teachers and schools throughout Grenada and, in the case of the Broad-winged Hawk, St. Vincent and the Grenadines. Many studies have revealed that the educational system enables wildlife conservationists to reach large numbers of people, while using limited resources. An interesting element is the use of injured raptors that are unable to be rehabilitated to the wild, to support education talks such as presentations to school and other groups. It is also essential to work actively with print and broadcast media to promote conservation to the general public and the private sector.

This education and outreach should extend to the government as well. Local government and conservation agencies should be informed of the location of raptor 'hot spots', such as active raptor nests, and be aware of the potential for raptor conservation problems. If authorities are unaware of the location or importance of such nesting and foraging sites, and often it may be too late to protect these areas once development commences. Additionally, advocacy and conservation actions are credible and effective if they are well grounded in sound scientific research and evidence. Thus, the development and dissemination of accurate information about raptors is critical to conservation and management efforts.

Regarding research for both the Grenada Hook-billed Kite and the Antillean Broad-winged Hawk, examining current and past population trends is ranked as the most common research priorities for raptors within Red List assessments (McClure et al 2018). In this regard, the geographic sites that are important for raptor conservation should be identified by researchers along with the refinement of methods to estimate their population sizes, distribution and trends. According to (De Grammont & Cuarón, 2006), the IUCN Red List methodology is considered the 'gold standard'. But Red List assessments are only as good as the knowledge informing them. As such, further research and resources need to be dedicated to raptors in Grenada, as initial steps in conserving and protecting these critical species.

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