AN ABSTRACT OF THE DISSERTATION OF

Carlos A. Bianchi for the degree of Doctor of Philosophy in Wildlife Science presented on March 2, 2010.

Title: Rapid Endangered Species Assessment: a Novel Approach to Improve Extinction Risk Assessments in Poorly Known Species.

Abstract approved:

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Susan M. Haig

The number of endangered species is rapidly increasing while paucity of adequate information and resources delays establishment of conservation actions. The IUCN's listing system is insufficient to determine conservation priorities and many species lack information even to be evaluated (i.e., "data deficient"). Here I proposed and tested the Rapid Endangered Species Assessment approach, combining methods including distribution modeling, landscape/habitat availability analysis and an evaluation of population spatial structure to improve information about species of concern and make future extinction risk assessments more attainable. I used the Pfrimer's Parakeet (*Pyrrhura pfrimeri*) an endemic Brazilian species, as a case study.

I modeled and validated the potential distribution of the species, known to occur in association with the tropical dry forests in central Brazil, using the Maxent method. The model predicted potential occurrence in three regions in central Brazil. Field surveys used to validate model found the species at 17 sites, all located in the dry forests of the Paranã River Basin. Modeling results set boundaries for the analysis of loss and fragmentation of the species' habitat. Satellite imagery and remote sensing techniques were used to estimate deforestation trends over a large spatiotemporal scale (31 years). Results indicated a 66.3% decrease in forest extent, average annual deforestation rate of 2.1% and significant increase in fragmentation, suggesting that these forests may disappear in less than 20 years if current deforestation rates persist. The habitat availability analysis set boundaries for the investigation of spatial arrangement of local populations of Pfrimer's Parakeets, which was carried out by collecting information on abundance, densities estimates, species home range, and habitat use. Twenty individuals were monitored with radio transmitters and home range estimates averaged between 195.7 ha (fixed kernel) and 261.8 ha (minimum convex polygons). Habitat use was estimated with behavioral observations of birds flying through a mosaic of forests and pastures. I found no evidence that the species used open areas farther than 300m from the forest edge. Systematic line transects and observations of parakeets per time effort produced estimates of population densities at 11.7 individuals/km^2; indicating strong variation in abundance indices among areas, suggesting a population decline. The Rapid Endangered Species Assessment represents a broad and integrative approach carried out over a short term and was successfully used to produce relevant data about a poorly known species. Thus, I propose the use of this approach as a minimally ideal yet scientifically viable method to generate information for extinction risk assessment of species.

RAPID ENDANGERED SPECIES ASSESSMENT: A NOVEL APPROACH TO IMPROVE EXTINCTION RISK ASSESSMENTS IN POORLY KNOWN SPECIES

by
Carlos A. Bianchi

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented March 2, 2010
Commencement June 2010

Doctor of Philosophy dissertation of Carlos A. Bianchi
presented on March 2, 2010.

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Carlos A. Bianchi, Author

ACKNOWLEDGEMENTS

A number of individuals and organizations have contributed to the completion of my degree at Oregon State University. I am very grateful to my major professor, Dr. Susan M. Haig, for her advice, support, encouragement and enthusiasm during the execution of this work and to my education. I am also indebted to all members of my graduate committee, Dr. Jonathan Ballou, Dr. Selina Heppell, Dr. Robert Mason, Dr. Christian Torgersen and Dr. J. Antonio Torres for enlightening contributions and discussions about this project. P. Haggerty and G. Lienkaemper from the USGS have made my way through the GIS world much easier with their valuable guidance and patience. I thank D. Pflugmacher and S. Brant for help and critical discussions about remote sensing analysis. A. Portella and F. Bianchi provided outstanding assistance during most of my fieldwork in Brazil. M. Bizerril, R. Cardoso, F. Ervilha, I. Faria, M. Reis also helped with radiotelemetry and trapping. I also thank the landowners C. Koch, S. Aldir, D. Marcelina, Z. Guilherme for granting permission to work on their properties as well as R. Schultz and A. Denito for support in Terra Ronca State Park.

The USGS Forest and Rangeland Ecosystem Science Center, Fundação O Boticário de Proteção à Natureza, Cleveland Metroparks Zoo (Scott Neotropical Fund), Parrots International, Canadian Parrot Symposium, Department of Fisheries and Wildlife (OSU) and Pacific Islands Conservation Research Association have provided financial support for this study. The Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) and the Centro Nacional de Pesquisa para Conservação das Aves Silvestres (CEMAVE) granted permits (16808-1; 3041/1) for the fieldwork in Brazil. I thank CAPES and the Fulbright Program for a doctoral scholarship (Grant #201604-4/15053166). I am also grateful to S. Santos and F. Veppo (CAPES), T.

Koerber and A. Ben-Hamallah (Institute of International Education) and M. Trevino (Oregon State University) for their administrative assistance with my scholarship.

B. Cline, J. D’Elia, H. Draheim, E. Elliot-Smith, C. Funk, B. Johnson, M. Johnson, N. Johnson, D. Kesler, J. Matthews, D. Mercer, M. Miller, T. Mullins, C. Spiegel, and O. Taft are current and past members of the Haig Lab that have contributed in many ways to my experience in the graduate school. I am thankful to faculty members of the Fisheries and Wildlife Department, in particular to N. Allen, K. Dugger, D. Edge, and D. Roby. Various people at the USGS Forest and Rangeland Ecosystem Science Center helped in a number of ways: D. Bateman, J. Dunham, S. Dunham, C. Ferland, E. Forsman, D. Hockman-Wert, J. Hagar, R. Hoffman, P. Loschl, C. Mcnamee, L. Nielsen, S. Price, C. Scarbrough, T. Snetsinger, L. Veitch, D. Wiens, and T. Young. Many friends and colleagues in Brazil have also helped in this project: Y. Barros, S. Brant, R. Macedo, R. Machado, O. Marini-Filho, A. Sampaio, A. Sevilha, and B. Walter. Furthermore, G. Luedemann, M. Ferreira, I. Figueiredo, P. Valdujo from the Pesquisa e Conservação do Cerrado helped as well.

Finally, I thank my family in Brazil for their belief in me and constant support. Above all, I thank my wife Cintya and my children Gustavo and Larissa for their love, support and patience during the hard times I had to be away from home, either in the field or hiding in my office.

CONTRIBUTION OF AUTHORS

This study was performed in the laboratory of Dr. Susan M. Haig, who provided financial support, advice, assistance in manuscript organization and development, field equipment and office space throughout the research.

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DEDICATION

I dedicate this work to my wife Cintya, my son Gustavo and my daughter Larissa, for being eager to join me on this journey and for always supporting me with their immense and unconditional love.

RAPID ENDANGERED SPECIES ASSESSMENT: A NOVEL APPROACH TO IMPROVE EXTINCTION RISK ASSESSMENTS IN POORLY KNOWN SPECIES

CHAPTER 1

INTRODUCTION

1.1 Extinction Risk Assessment

Current rates of species extinctions and threatened status worldwide are at an unparalleled high (IUCN 2010). The number of endangered species is growing much faster than conservation efforts for two major reasons: (1) intense human expansion leading to exploitation of natural resources and (2) lack of time and resources needed to collect adequate information in order to establish reasonable conservation measures. Although the increase in listed species (e.g., IUCN Red List, Brazilian National Red List) following defined criteria is a step forward in acknowledging their current situation, the threats designated as causes of their decline are usually broadly defined (e.g., habitat loss and fragmentation, illegal trade and/or overexploitation) postponing more direct actions for species protection.

The World Conservation Union's listing system (i.e., IUCN Red List) has been widely used throughout the world because of its broad application (Burgman et al. 1999, Akçakaya et al. 2000, Hoffmann et al. 2008) and the possibility to evaluate a species using quantitative criteria (Mace and Lande 1991). The categories of threat provide a general assessment of extinction risk under current circumstances but are insufficient to determine priorities for conservation action (IUCN 2010). Thus, if a candidate species is considered to have "adequate data", it is evaluated through a number of criteria that consider population size, geographic range, and area of occupancy to define a probability of extinction and, consequently, a classification risk category (IUCN 2010 – see categories and criteria). Otherwise, the species is considered as *data deficient* and no conservation action is taken. Because "adequate data" is not clearly defined, IUCN assessment method deals with inference and projection of scenarios based on extrapolation of current and potential threats that can be reasonably supported, as the data used to evaluate taxa against the criteria are often estimated with considerable uncertainty (Mrosovsky and Godfrey 2008, IUCN 2010). Also, the way in which uncertainty is handled for risk assessment might considerably change the resulting classification of threat (Burgman et al. 1999, Akçakaya et al. 2000).

Few species of concern have enough information available for proper assessment of extinction risk and, consequently, for the establishment of effective conservation strategies. For example, only 41% (470/1148) of the U.S. Endangered Species Act listed animal species have recovery plans (United State Fish and Wildlife Service, USFWS 2010). Similarly, in Brazil, there is significant lack of information for the majority of the 160 Red-listed birds (Machado et al. 2008). Worldwide, the worst scenario is represented by species that do not have enough information even to be evaluated and are classified as *data deficient*. In the IUCN Red Data List, 16.4% of 35,508 animals listed are classified under this category, thus precise classification and consequently recovery activities are curtailed until further information has been gathered (IUCN 2010).

Clearly, there are monumental financial, political, and societal obstacles to gathering the appropriate data needed for all these species. In some cases, scientists have tried to address these issues via modeling tools (e.g., population viability models); however, these analyses require years of detailed abundance or demographic data and will only be possible for a small proportion of species worldwide (see Beissinger et al. 2006). Ecologists facing similar problems identifying threats to unique ecosystems have developed the “Rapid Ecological Assessment” (REA), which consists in a method to set rapid assessment techniques that generate useful information for conservation planning at multiple scales (Sayre et al. 2000). REAs are usually carried out in a remote area and for a relatively short period of time, where scientists collect a suite of data that will give them a better basis for considering future conservation options. It is time for endangered species biologists to consider a similar approach so that appropriate data can be obtained for more species over a shorter period of time.

Based on the same principles as in the Rapid Ecological Assessments, in this dissertation I propose and evaluate the **Rapid Endangered Species Assessment – RESA**, a novel approach to improve the means by which we gather information about species of concern. This approach represents a combination of several methods of study used in ecology that will allow biologists to collect data about particular species over a short period of time (one year), to produce useful information for extinction risk assessment, and to guide the establishment of conservation actions. My goal is to make future extinction risk assessments more attainable for more species, particularly in species for which we know very little. Commonly, there are three fundamental questions to be answered when dealing with potentially threatened species: (1) what is the species' distribution?; (2) what is the extent of the species' habitat in time and space?; and (3) how does the species use its habitat and how are populations distributed and arranged? This information is even more crucial for species considered as poorly known or "data deficient", as they lack basic reference data from which assessments of extinction risk can be inferred. Therefore, the Rapid Endangered Species Assessment aims to provide a baseline addressing ways to answer these questions by taking the following approaches summarized below.

1.2 SPECIES DISTRIBUTION MODELS

The geographical occurrence of a species is the primary information needed for assessment of conservation status. Species distributions models (SDM) are increasingly being applied as inferential procedures that provide robust and reliable answers crucial to biodiversity analysis and conservation planning (Scott et al. 2003, Jepsen et al. 2005, Muñoz et al. 2005, Peterson 2005, Lawler et al. 2006, Frey 2006, Rhodes et al. 2006, Peterson 2001, Peterson and Kluza 2003, Elith et al. 2006, Elith and Graham 2009). The core of predictive geographical modeling is based on the species-environment relationship and consequently how environmental factors control distribution of species and communities (Guisan and Zimmermann 2000). Thus, distribution models are powerful tools that convert point-locality records into hypothetical distributional range for a species (Pearson 2007). The basic idea is to contrast geographic locations of the dataset with environmental information such as elevation, soil, vegetation, climate and others, producing a potential distribution range for the species (Stockwell and Peters 1999, Anderson et al. 2003, Philips et al. 2006). Predictive distribution models use various approaches such as multivariate analysis, environmental envelopes and artificial-intelligence based algorithms (Nix 1986, Stockwell and Noble 1992, Carpenter et al. 1993, Godown and Peterson 2000, Guisan et al. 2002, Phillips et al. 2006). Although some caution must be used on how results are interpreted (Loiselle et al. 2003, Beissinger et al. 2006, Lawler et al. 2006), species' distribution models may represent a useful approach to evaluate conservation issues (Elith et al. 2006, Rhodes et al. 2006, Elith and Grahan 2009).

In Chapter 2, I used the maximum entropy method (MAXENT, Phillips et al. 2006) for modeling the potential distribution of Pfrimer's Parakeet (*Pyrrhura pfrimeri*), a threatened and endemic species occurring in the dry forests of central Brazil's Cerrado region (see section 1.5 for more information about the species). The results of the potential distribution modeling provided a starting point to set the boundaries for field investigations and the analysis of habitat availability on multiple spatial and temporal scales.

1.3 Habitat Loss and Fragmentation in Spatiotemporal Scale

Habitat loss and fragmentation have long been recognized as the greatest threats to biodiversity worldwide (Huxell and Hastings 1999, Wilson 2002, Groom and Vynne 2006, Schipper et al. 2008). Although their definitions can be confusing (Franklin et al. 2002, Villard 2002, Fahrig 2003), they represent important ecological processes that have severe consequences on ecosystems and populations (Robinson et al. 1992, Chapin et al. 2000, Van Den Busche et al. 2003, Kerr and Deguise 2004, Ritchie et al. 2009). Effects of these processes depend on the organism, scale, habitat type, landscape, geographic regions and species range (Kouki et al. 2001, Haila 2002, Schmiegelow and Mönkkönen 2002, Fahrig 2003). Usually, they cause reduction in habitat availability (Fahrig 2001, Franklin et al. 2002) through modification of landscape patterns such as heterogeneity, configuration, and connectivity (Groom and Vynne 2006, Noss et al. 2006). With fewer habitats available, individual dispersal and population persistence are affected, resulting in reduction of distribution, demographic rates and genetic variability (Young and Clark 2000). Rare species or species of restricted range or habitat type are more vulnerable to the effects of habitat loss and fragmentation (Carlson 2000, Simberloff 2000, Goodsell and Connell 2002, Manu et al. 2005). Moreover, as both processes occur at different scales, the history of fragmentation influences the species' occurrence (Gu et al. 2002). Understanding the consequences of spatiotemporal changes of landscape structure in population dynamics is crucial because the amount of remaining habitat and its configuration over time influence population persistence (Fahrig 1992, 1997, Goodsell and Connell 2002, Gu et al. 2002, Kerr and Deguise 2004, Alderman et al. 2005).

Understanding patterns and processes of habitat loss and fragmentation and the resulting effects is crucial for developing conservation strategies (Fahrig and Merriam 1994, Fahrig 1997, 2003, Villard 2002). Thus, in Chapter 3, I evaluated trends of both processes on the tropical dry forest landscape used by Pfrimer's Parakeet through a spatiotemporal scale, using satellite images and remote sensing analysis.

1.4 POPULATION SPATIAL STRUCTURE

Population structure is a broad term that may refer to many aspects of population ecology revealing the arrangement of individuals of a particular species in relation to their distribution in the habitat, social organization, distribution of genes, age, etc. (Begon et al. 2006, Rockwood 2006). An increasingly popular approach to population studies in conservation biology includes several ways to evaluate or to model populations and then to predict future scenarios (Beissinger et al. 2006). Models can include population dynamics, spatial distribution, and genetic variability. Some examples are deterministic single-population models that work on predictions of population size between time intervals, based on survival, growth and reproduction of individuals (Caswell 2001, Meretsky et al. 2000, Kauffmann et al. 2003, Peery et al. 2006). Stochastic population viability models include annual variation in vital rates to make long-term population projections that are central to population viability analysis (Beissinger and McCullough 2002, Oro et al. 2004, Sæther et al. 2005). Metapopulation models incorporate landscape structure into population dynamics to predict species persistence considering dispersal ability (Hanski 1998, 1999; Grimm et al. 2004; Thomas and Hanski 2004; With 2004). Spatially explicit population models are more complex because they incorporate exact spatio-temporal locations and can be built for single populations or an entire metapopulation (Akçakaya 2000, Cooper et al. 2002, Walters et al. 2002, Beissinger et al. 2006). Genetic models deal mainly with genetic variability and inbreeding depression, focusing in ways to improve the effective population size (N_e) and are directly related to molecular techniques (Haig 1988, DeYoung et al. 2005), population viability (Avise and Hamrick 1996), and pedigree analysis (Haig and Ballou 2002). One major concern about the use of population models is that data volume and quality necessary to produce reliable results, despite critically needed, are extremely time consuming to obtain and usually available for very few species (Beissinger et al. 2006). Poorly known species potentially facing imminent threats may have their protection hindered until enough data is collected to support conservation actions, thus a short term approach to obtain relevant information is urgently needed. Therefore, my goal in chapter four was to provide a starting point to understanding how temporal changes in habitat configuration might have affected the current population densities and spatial structure of the Pfrimer's Parakeet. Data collected in this study will form a baseline addressing investigation priorities on the species' population structure to be used for future its population modeling and conservation.

1.5 The Tropical Dry Forests of Central Brazil and the Pfrimer's Parakeet

Tropical dry forests are broadly defined as a vegetation type typically dominated by deciduous trees and frequently connected to savannahs, with mean annual precipitation range from 250 to 2,000 mm and temperatures above 21°C (Sánchez-Azofeifa et al. 2005a). Tropical dry forests have long been considered the most endangered tropical forest ecosystem (Janzen 1988, Sánchez-Azofeifa et al. 2005b, Miles et al. 2006) as land conversion to pastures and agriculture represent major threats and reflect a long-history of human occupation (Maass 1995, Fajardo et al. 2005, Sánchez-Azofeifa et al. 2005a, Miles et al. 2006). These forests are widely distributed in the world (Murphy and Lugo 1986), including areas in the Brazilian Cerrado (Scariot and Sevilha 2005).

The Cerrado biome is one of the Earth's biodiversity hotspots (Myers et al. 2000, Brandon et al. 2005), considered the richest savanna in the world and is the second most threatened biome in Brazil with deforestation rates higher than the Amazon rainforest (Klink and Machado 2005). Estimates show that 55% of the Cerrado has already been cleared or transformed for human uses (Machado et al. 2004) while only 2.2% of its extension is legally protected (Cavalcanti and Joly 2002). The most heterogeneous biome in Brazil, with five landscapes and fifteen ecological units identified (Silva et al. 2006), the Cerrado has savannas as the dominant vegetation, covering almost 72% of the region. Patches of dry forests and savannas (forming savanna-forest transitions) comprise 24% of the land-cover with the remaining 4% being dry forest (Silva and Bates 2002).

The forests of the Paranã River Basin are one of the most significant formations of tropical dry forest in Brazil (Scariot and Sevilha 2005). Located in the central part of the Cerrado, they comprise areas of extremely high biological importance (Ministério do Meio Ambiente 2002) and one of the most extensive cave systems in Brazil (Auler 2002). Deforestation for pasture and agriculture currently represent the main threats to the forest in the region (Scariot and Sevilha 2005). Consequently, species associated with this habitat, including the endemic forest bird Pfrimer's Parakeet have been potentially experiencing decline over the past few years.

Pfrimer's Parakeet is believed to occur in less than 15,000km^2 associated with the dry and gallery (riparian) forests along rivers of the Paranã River Basin (Olmos et al. 1997, Bianchi 2008). It has been observed feeding on a few forests species or rice plantations but general aspects of feeding and breeding habitats remain unknown. There are few protected areas within the species range and these areas are unlikely to maintain viable populations (Bianchi 2008). At this point, there has been no formal natural history study on the species although its conservation status has been evaluated and the species is currently classified as Endangered (Birdlife International 2008) on the IUCN Red List. The Pfrimer's Parakeet was chosen as the target species to test the suite of methods I proposed for the *rapid endangered species assessment*, considering the lack of information about its ecology.

1.6 OBJECTIVES

The major goal of this dissertation was to establish a suite of methods for a “Rapid Endangered Species Assessment” that can be used to improve information about species of concern worldwide. As a case study, I evaluated the consequences of anthropogenic pressures over ecological processes on the endemic Pfrimer’s Parakeet, a species with a restricted range in South America by taking a broad, integrative, short-term, but quantitatively intense approach ranging from distribution modeling, landscape and habitat availability analysis to population spatial structure. This approach will be used to benefit future extinction risk assessments and support sound conservation strategies.

In the second chapter, I identified and evaluated the potential distribution of the species using data from fieldwork and distribution modeling tools such as MAXENT. Identification of the species potential and known distribution provided an understanding of its habitat preferences and also may indicate areas of “equivalent value” for future conservation projects (i.e., for translocation or reintroduction). Additionally, the potential distribution was used to set the geographical boundaries for the evaluation of habitat loss and fragmentation.

The third chapter is focused on the assessment of habitat availability on a multi-temporal and spatial scale through the analysis of dry forest loss and fragmentation. I used GIS and remote sensing tools in the analysis of satellite imagery in three time intervals ranging from 1977 to 2008. This chapter has produced unique results that will also benefit other species with close association with the dry forests in the central Cerrado.

In the fourth chapter I report on an investigation of how Pfrimer's Parakeet populations are spatially arranged in the region of occurrence. Using radio telemetry techniques, systematic surveys, and behavioral observations of the species in its habitat, I was able to depict important information regarding home range sizes, population relative abundances, areas of occurrence and habitat use.

Taken together, the chapters in this dissertation comprise a comprehensive approach for rapid assessment of a species of concern when little is known about it. Results will be useful for designing conservation measures for the Pfrimer's Parakeet as well as serve as a model approach for rapidly filling the gap in the information needed to determine the conservation status of other "data deficient" species around the world.

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CHAPTER 2

PREDICTION AND VALIDATION OF THE DISTRIBUTION OF THE ENDEMIC THREATENED PFRIMER'S PARAKEET (*PYRRHURA PFRIMERI*) IN BRAZIL

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To be submitted:

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2.1 Abstract

We modeled and evaluated the distribution of the threatened Pfrimer's Parakeet (*Pyrrhura pfrimeri*), one of two endemic parrot species of the Cerrado biome in Brazil. The species is known to occur in close association with the tropical dry forests in central Brazil but the extent of its distribution and the existence of populations outside of this range were unknown. We used the maximum entropy method (Maxent) to model its potential distribution by combining 13 unique occurrence points with seven environmental variables. The model predicted potential occurrence in three large regions in central Brazil. The most conservative threshold suggested a total distribution area of at least 40,290 km^2. We tested the model carrying out extensive field surveys in each predicted area and found the species in 17 out of 75 visited sites, all located in the dry forests of the Paranã River Basin. Finally, a refined distribution was modeled after incorporating 10 new occurrence points into our original dataset. The resulting map matched closely the original prediction, with emphasis in the region comprising the bulk of tropical dry forests. Our study shows that the use of distribution modeling tools combined with field verification resulted in a robust approach to define with reasonable accuracy the current distribution poorly known species like the Pfrimer's Parakeet.

2.2 INTRODUCTION

Species distribution models are now widely used in ecology, biogeography and conservation. Their basic operational principle is to predict species distributions by combining known occurrence records with a set of environmental variables (Guisan and Zimmermann 2000, Peterson 2006, Pearson 2007). However, while an increasing number of methods and modeling tools have been tested under different scenarios (Elith et al. 2006, Tsoar et al. 2007, Wisz et al. 2008), it remains crucial to understand the concepts and applications of distribution models to ensure the appropriate interpretation of their predictions (Guisan and Zimmermann 2000, Austin 2002, Guisan and Thuiller 2005, Soberón and Peterson 2005, Araújo and Guisan 2006, Kearney 2006, Soberón 2007, Jiménez-Valeverde et al. 2008, Elith and Grahan 2009).

Distribution modeling tools play a special role in conservation. For example, they were used in the discovery of new species by modeling the distribution range of closely related taxa (Raxworthy et al. 2003) and to assess the level of protection provided by reserve networks (Marini et al. 2009 but see Loiselle et al. 2003). One important application of species distribution models refers to their ability to predict the potential areas of occurrence for rare or threatened species when robust predictions for such species are difficult to achieve as they are known from a limited number of localities (Pearson et al. 2007, McPherson and Jetz 2007, Franklin et al. 2009, Kumar and Stohlgren 2009, Thorn et al. 2009).

Maxent is considered one of the best modeling tools available (Elith et al. 2006, Wisz et al. 2008) and has proven to produce reliable predictions even when only small sample sizes of occurrence records are available (Hernandez et al. 2006, Papes and Gaubert 2007, Pearson et al. 2007, Kumar and Stohlgren 2009, Thorn et al. 2009). Maxent produces probability estimates for species distributions, requires only presence data, and allows continuous and categorical variables as predictors (Phillips et al. 2006). More specifically, it uses functions called "features," derived from environmental variables, to constrain the probability distribution drawn from occurrence data (Phillips and Dudík 2008). Output from Maxent includes the regularized training gain to indicate how close the model is concentrated around "presence" samples, the area under the curve (AUC) of the receiver operating characteristic, a threshold independent statistic to evaluate model fit, and maps with representation of the probabilities of occurrence (Phillips 2005, Phillips et al. 2006, Phillips and Dudík 2008).

In this study, we used the maximum entropy method (Maxent, version 3.3.0) to model the potential distribution of the endemic, threatened, and little known Pfrimer's Parakeet (*Pyrrhura pfrimeri*) from the Cerrado region of central Brazil. Throughout the study we test the association of Pfrimer's Parakeets with the tropical dry forests of the Cerrado biome.

2.3 METHODS

A three-step approach was used to assess the current distribution of Pfrimer's Parakeet. First, we modeled the species' potential distribution, creating a map with the predicted area of occurrence, hereby named "original model". Later, we tested the model using the original map to guide our field investigation and collect new occurrence points to be incorporated into a second model, hereby named "refined model". Last, we described the actual distribution of the species making inferences based on comparisons of field observations and the maps of predicted areas.

2.3.1 Study area and species

The Cerrado biome is a global biodiversity hotspot and is considered the richest savannah in the world (Myers et al. 2000). Its original area is estimated to be approximately two million km^2 (Klink and Machado 2005) but nearly 50% of this area has been modified for human activities (Machado et al. 2004). There are two predominant climates in the Cerrado, dry and rainy seasons, and the original landscape is remarkably heterogeneous, ranging from open grasslands and woodlands to riparian and deciduous dry forests (Ribeiro et al. 1998). One of the most significant formations of dry forests in the Cerrado is located in the Paranã River Basin in the states of Tocantins and Goiás (Scariot and Sevilha 2005; Figure 2.1). The core of this area extends from the north in Dianópolis (Tocantins) south into

Goiás state where it separates into two branches: one eastward towards the municipalities of Mambaí and Sítio D'Abadia and the other westward towards Iaciara and Nova Roma. Dry forests are the most threatened tropical forest formation in the world (Janzen 1988, Sanchéz-Azofeifa 2005) and populations of many species associated with this ecosystem are potentially in decline.

The Pfrimer's Parakeet is one of two endemic parrot species of the Cerrado biome. It was described by Miranda-Ribeiro (1920) and later considered a subspecies of the White-eared Conure *Pyrrhura leucotis* (Berla 1946). Only after Joseph (2000) was it granted full species status. Further clarification on its relationships within the *Pyrrhura* complex can be found in Ribas et al. (2006). The species is listed as Endangered at the global level (Birdlife International 2008) and Vulnerable at the national level (Ministério do Meio Ambiente 2003). Habitat loss is considered the main cause of potential population declines, which is aggravated by its limited distribution in tropical dry forests (Olmos et al. 1997, Bianchi 2008, Birdlife International 2008). Recent estimates indicate an abrupt decline in dry forest extent in the region with high levels of fragmentation (Bianchi and Haig *in review*).

There are three protected areas within the species range, the Terra Ronca State Park, the Mata Grande National Forest and the São Domingos Area of Environmental Protection, but these areas are unlikely to maintain viable populations in the long term (Bianchi 2008). Currently, there is no official captive conservation initiative (Birdlife International 2008) although there are a few captive birds in private collections. Little is known about its ecology, other than it has been historically reported to occur in the Paranã River Basin in association with tropical dry forests. More specifically, there are occurrence records in Taguatinga (formerly Santa Maria do Tocantins; Miranda-Ribeiro 1920), Iaciara (Silva 1989), Nova Roma and surroundings of Terra Ronca State Park (Olmos et al. 1997), Aurora do Tocantins and the valley of the Palmeira River (Pacheco and Olmos 2006). In 2000-2001, CAB carried out a pilot project on the species' ecology and recorded its occurrence at several additional sites. However, current distribution limits remain unknown and there is no information about other populations outside of this range.

2.3.2 Occurrence records and environmental data

To build the original model, we compiled occurrence records from unpublished data collected by CAB and from other known localities documented in Miranda-Ribeiro (1920), Silva (1989), Olmos et al. (1997), and Pacheco and Olmos (2006). Some points were clustered near Terra Ronca State Park (13°31'S 46°23'W) so we applied a five kilometer buffer to each record after a spatial autocorrelation analysis using Moran's I tool available in ESRI ArcMap (ESRI Inc., USA), and then selected 13 unique (non-overlapping) points. Given the species dependence on dry forest habitat, we prioritized site selection based on the existence of dry forests to investigate the species' occurrence during the 2007-2008 field surveys. We visited all selected sites either by car or walking and used binoculars and playbacks to search and record the species. We then tested our original model using field data as test sample. Furthermore, we included new records selected after spatial autocorrelation analysis (using the 5 km buffer) into the original dataset of 13 points to build the refined distribution map. Lastly, we evaluated the actual distribution of *P. pfrimeri* by comparing information on occurrence points, predicted areas of our models, and current status of habitat availability in the region.

The initial dataset of environmental layers included 24 predictors. We selected nineteen bioclimatic variables derived from monthly temperature and precipitation data available for download from the Worldclim database (Hijmans et al. 2005). In addition, we used four topographical variables including altitude, slope and two linear predictors named "northness" and "eastness", derived from topographic aspect using ESRI ArcGis® 9.3 (see Pearson et al. 2007 for details). Finally, we included a categorical predictor representing a vegetation map of the Cerrado biome (EMBRAPA-CPAC and Conservation International, unpublished). All environmental layers were projected into the geographical coordinate system WGS 1984 with grid cell resolution of 1km and extent set as the boundary of the Cerrado biome using the map available from the Brazilian Ministry of Environment database (http://mapas.mma.gov.br/i3geo/ datadownload.htm).

2.3.3 Environmental variables selection

Careful examination of the predictor variables should be considered in species distribution modeling as issues such covariance strongly influences model outputs (Guisan and Zimmermann 2000, Araújo and Guisan 2006, Heikkinen et al. 2006). In addition, reduction in the number of predictors may simplify interpretation of the species' distribution by using the best subset of variables available (Buermann et al. 2008, Yost et al. 2008, Kumar and Stohlgren 2009). We applied two selection methods to reduce the number of environmental variables during the construction of the original and the refined models. First, a multi-colinearity analysis was performed by drawing a correlation matrix (Pearson's *r*) using values from the 13 point dataset and a 500 point dataset randomly selected within the Cerrado boundaries. We grouped variables with correlation order $r \geq 0.8$ and selected one variable from each group based on its relevance regarding the Cerrado's climatic seasonality. Therefore, eleven variables were selected: isothermality (Bio3), temperature seasonality (Bio4), maximum temperature of warmest month (Bio5), temperature annual range (Bio7), precipitation seasonality (Bio15), precipitation of driest quarter (Bio17), precipitation of warmest quarter (Bio18), precipitation of coldest quarter (Bio19), altitude, slope, and "eastness". In the subsequent step, we used the jackknife test of variable importance available in Maxent to reduce the number of variables as described in Yost et al. (2008). The jackknife test evaluates the importance of each model variable whether it is used alone or omitted from the modeling process (Phillips 2005) and produces three specific outputs (i.e., training gain, test gain and AUC). Gain is a measure closely related to the deviance in goodness of fit tests used in generalized additive and linear models. During a model run, the tool generates a probability distribution over the pixels in the grid, beginning with a uniform distribution and repeatedly improving the fit to the data (Philips 2005). Gain is defined as the average log probability of the presence samples minus a constant that maintains the uniform distribution with zero gain. At the end of a run, gain indicates how closely the model is concentrated around the presence points (Phillips 2005). Regularized training gain and test gain refers to training and test samples in the model, respectively.

Given our small sample size and lack of test data, we selected training gain to assess variable importance on each model. According to Yost et al*.* (2008), training gain seems to be the most sensitive parameter affected by variable removal during the modeling process. Hence, we built a full model including the eleven bioclimatic variables previously selected and the vegetation map, ranked the drop in training gain caused by omission of each variable independently (from the full model output) and gradually removed each ranked variable to create subsequent reduced models. A one-tailed Wilcoxon Rank Test was used to evaluate differences on average training gain between the full and each reduced model, after partitioning occurrence data into thirteen subsets of twelve points. The best model had the lowest number of predictor variables with average training gain not significantly different from the full model. This model selection process indicated the same seven environmental variables to be used in generating the species' potential distribution in the original and refined model: maximum temperature of warmest month (Bio5), temperature annual range (Bio7), precipitation of warmest quarter (Bio18), precipitation of coldest quarter (Bio19), slope, "eastness", and vegetation.

2.3.4 Threshold selection and model parameters

Selection of a threshold is important for model interpretation, validation and to distinguish adequate and inadequate areas (Manel et al. 2001, Pearson et al*.* 2004, Wilson et al. 2005). Several approaches have been tested regarding the appropriate choice of a threshold even though most methods are suitable only to presence-absence data (Liu et al*.* 2005). We selected two thresholds following Pearson et al. (2007): the minimum training presence threshold (hereafter MTP) and the fixed cumulative threshold of 10 (hereafter FC10), given our small sample size and the need to test model predictions (see below). Briefly, MTP threshold represents the set of pixels predicting species' presence that is as suitable as those pixels where the species has been recorded (occurrence points), assuring zero omission in the training dataset. The FC10 threshold gives a larger area of predicted presence as it discards the lowest 10% of possible predicted values. Pearson et al. (2007) suggest the application of the second if the goal is to guide field investigation of unknown distributional areas as in the case of our study. We used the default settings of Maxent with number of iterations set to 1,000 and selected the “auto features” box to create different feature types, conditioned to the number of occurrence points in each model (Phillips and Dudík 2008).

2.3.5 Model performance

Model performance was assessed using two independent-threshold statistics produced by Maxent, the AUC score and the regularized training gain for all models. In addition, we used the jackknife method described in Pearson et al. (2007) to evaluate the predictive performance of the original model before carrying out fieldwork. The technique was implemented for small sample sizes and consisted of removing each occurrence point from the training dataset to be set aside as a test locality, building a model with the remaining records and evaluating each model performance according to capacity of correctly predicting the excluded point. Results are presented as the percentage of successful predictions followed by a *p*-value (see Pearson *et. al* 2007 for computation program). Finally, we used all new observations collected in the field as an independent test sample to evaluate the original model using the binomial test from the Maxent output.

2.4 RESULTS

2.4.1 Original model

The original model predicted three main regions of parrot occurrence within the Cerrado biome (Figure 2.1), with total area extent ranging from 40,290 km^2 (minimum training presence) to 74,450 km^2 (fixed cumulative threshold of 10). One region is located in the central-northwest axis of Goiás state, the second is located over the borders of Goiás-Tocantins-Bahia states including the Serra Geral massif, and the third is located further north in the states of Piauí and Maranhão.

The regularized training gain in the original model was 3.539, indicating that the model was very capable of differentiating environmental conditions among the occurrence points from those available in the background area. The average likelihood of points predicted present is 34.4 times higher than that of a random background point (exponential of 3.539; see Phillips 2005). The AUC score was also very high (0.996) indicating non-random prediction (>0.5). Maxent used linear and quadratic features, based on a sample size of 13 occurrence points. Furthermore, the predictive performance of the original model based on the jackknife test was very high, with 92% of successful predictions, and statistically significant ($p<0.0001$) for both thresholds (MPT and FC10).

2.4.2 Field investigation

We applied the FC10 threshold to define the area surveyed during fieldwork and focused our search mostly on the dry forests of the Paranã River Basin. In addition, two localities not predicted in the original model but known to have dry forest habitat were included in our sampling scheme, one located near the municipality of Natividade (11°42'S 47°43'W, in Tocantins) and the other adjacent to the city of São Desidério (12°22'S 44°58'W, in Bahia). Furthermore, we used ancillary data from 18 localities recently visited by CAB to assess the species presence in central Goiás and in southern Piauí and Maranhão.

We analyzed a total of 75 sites and found the species in 17 localities (Figure 2.1). All predicted areas visited outside the Paranã River Basin lacked similar dry forest habitat therefore, we failed to find the species in central Goiás and in the region of Piauí and Maranhão.

2.4.3 Refined model

Before building the refined model, we tested the predictive power of the original model using all new observations as an independent test sample. Test gain (4.08) and AUC score (0.992, SD = 0.003) for the test data were very high and results from the binomial test were highly significant for all thresholds (all p-values < 0.0001), indicating that the original prediction was quite reliable.

The refined model had an AUC score of 0.997 and regularized training gain equal to 3.953 after the addition of 10 occurrence points into the original dataset as suggested by the spatial autocorrelation analysis. The calculated average likelihood of the presence samples was 52.1, which represents more than a 65% increase over that predicted in the original model. Linear, quadratic and hinge features were used as sample size increased to 23 points. As a result, the refined model predicted the same three regions of occurrence for the parakeets as the original model. However, the area had a significant reduction in extent, ranging from 33,812 km^2 (MTP threshold) to 50,864 km^2 (FC10 threshold), supporting the prediction of Pfrimer's distribution within the Paranã River Basin (Figure 2.1).

2.4.4 Variable importance

The analysis of variable importance based on the jackknife test in Maxent for both models indicated that three bioclimatic variables were significant in determining the Pfrimer's distribution area (Figure 2.2), with combined percent of contribution higher than 84%. In the original model, precipitation of the warmest quarter (Bio18) was the most important variable when used alone, followed by precipitation of the coldest quarter (Bio19) and temperature annual range (Bio7), meaning that these variables have the most useful information by themselves in predicting the distribution. Similarly, precipitation of the coldest quarter (Bio19) was the variable that caused the largest decrease in training gain when omitted from the model, followed by temperature annual range (Bio7) and precipitation of the warmest quarter (Bio18), indicating that these three variables also have information that is not present in any other. We found a similar pattern in the refined model as Bio18 remained the most important variable when used alone, followed respectively by Bio7 and Bio19. Also, Bio7 was the most important variable when omitted from the model, followed by Bio19 and Bio18. Surprisingly, the only categorical predictor (CPAC-CI vegetation map) was not considered important (≤ 1.8%) in any predictions, when it was omitted or used alone in either model (Figure 2.2).

2.5 Discussion

The geographical occurrence of a species is the primary information needed for assessment of conservation status and the use of species distribution models have contributed significantly in this field. There are a vast number of threatened species for which this type of information is still lacking, hindering the implementation of conservation strategies. Few studies using species distribution models have taken a similar approach as we have shown here: from modeling the potential distribution of a species, evaluating the predicted range using independent field dataset and later improving the original prediction (Raxworthy et al. 2003, Guisan et al. 2006, Tsoar et al. 2007, Ortiz-Martínez 2008). The informative results in this study regarding the distribution of the Pfrimer's Parakeet supports the use of species' distribution models as an important tool in conservation to improve current knowledge of little known species.

The concepts and theory behind the interpretations of our modeling method follow the discussions of Guisan and Thuiller (2005), Kearney (2006) and Jiménez-Valverde et al. (2008). The approach of modeling the species distribution and validating the results with field investigation resulted in an efficient way to define the current distribution of Pfrimers' Parakeet with reasonable accuracy. It also highlights the importance of carrying out model validation with independent data (Guisan and Zimmermann 2000, Pearson 2007).

2.5.1 Model performance

Distribution modeling tools usually produce better predictions for species with a restricted range than for those that are widely distributed (Berg et al. 2004, Brotons et al. 2004, Segurado and Araújo 2004, Hernandez et al. 2006, McPherson and Jetz 2007, Tsoar et al. 2007, Wisz et al. 2008). Our evaluation of model outputs and visual inspection of predicted areas in the original and the refined maps are concordant with this. The Pfrimer's Parakeet is known to be a habitat-restricted endemic parrot from central Brazil. However, the largest predicted area in our models has 74,450 km^2 (FC10 threshold from the original model), which corresponds to approximately 3.7 % of the two million km^2 corresponding to the extent of the Cerrado.

We evaluated model performance in Maxent by employing (a) the jackknife test for small sample sizes (Pearson et al. 2007); (b) independent test data collected from the field and, (c) AUC score and (d) regularized training gain. The first two are threshold-dependent methods and had significant results, indicating the original and refined models were quite robust. The jackknife test (Pearson et. al 2007) is a special case of validation using test data given that one record is left out for testing during model simulations. In our original model, the rate of successful predictions using this test was 92% (P>0.0001) for the MTP and FC10 thresholds. Validation using independent test data, like we carried out here, is the best alternative for testing model predictions (Guisan and Zimmermann 2000, Araújo et al. 2005, Araújo and Guisan 2006, Heikkinen et al. 2006, Pearson 2007), although this is not always feasible (Pearson et al. 2007).

The AUC is widely used as the threshold-independent statistic to evaluate the accuracy of species distribution models (Fielding and Bell 1997, Manel et al. 2001, McPherson et al. 2004). In addition, the AUC scores tend to be high for species with narrow distribution (Phillips 2005, Tsoar et al. 2007). Indeed, we obtained high AUC scores in our models (0.996 and 0.997) suggesting strong indicators of good quality predictions. However, Lobo et al. (2008) made several criticisms about the use of

AUC as a measure to evaluate model performance stating, among other reasons, that the score is heavily influenced by the relative occurrence area, which is the ratio between the extent of occurrence and the whole extent of the study area. Smaller relative occurrence areas would produce higher AUC values as the number of background points used as absence increases during the modeling process (Jiménez-Valverde et al. 2008). As an exercise (results not shown here), we modeled the distribution of the species using the same set of occurrence points and environmental layers but setting the study area size as all of Brazil (four-fold the size of Cerrado) and obtained even higher AUC scores. According to Lobo et al. (2008), the only useful application of AUC in assessing model performance is to provide information about the restricted or widespread distribution of the target species.

Interestingly, we noticed a similar trend in the model results with the regularized training gain, another metric produced in Maxent. The large values of regularized training gain obtained in our models indicate that the algorithm was able to efficiently differentiate environmental conditions present in occurrence data from background points. One possible reason for large values of regularized training gain is that species with restricted distributions tend to have clustered occurrence records and therefore, the range of values for each environmental predictor should not be expected to vary as much as they would for widely distributed species. Consequently, because the spectrum of environmental possibilities is limited by the set of occurrence points, the predicted distribution will necessarily be more accurate. However, the ability of Maxent to make this difference more or less evident depends directly on the extent of the region of occurrence in a similar way as it does for the AUC score. The increase in training gain was also observed in our simulation using the entire extent of Brazil as the study area. Therefore, we see AUC and training gain as valuable ways to evaluate model results in Maxent, but recommend caution on their use given that both are subject to different degrees of variation. This variation depends on some parameters in the model, such as the relative occurrence area and the number and relevance of environmental layers being used. Furthermore, the use of other methods to test the performance of presence-only models, such as the null models developed by Raes and Steege (2007), might be recommended as an alternative path.

2.5.2 Environmental predictors

The association between Pfrimer's Parakeet and dry forest habitats has previously been described as noteworthy (Olmos et al. 1997, Silva 1997, Bianchi 2008). Therefore, the predictor variable representing the vegetation types was expected to have great influence on determining its distribution in our models; however its contribution was insignificant (≤ 1.8%). Alternatively, the species distribution was strongly shaped by the exceptional input of the bioclimatic variables Bio7 (temperature annual range), Bio18 (precipitation of warmest quarter), and Bio 19 (precipitation of coldest quarter). Altogether, they accounted for a minimum of 84.9% of relative contribution in both models. Although Phillips (2005) recommends caution on interpreting percentages of variable contribution because of multi-colinearity issues, we consider these results fairly solid particularly after correlated variables had been removed from the dataset.

The climatic variation across the Cerrado biome is quite remarkable, with average annual temperatures ranging from 18° to 28°C and average annual precipitation ranging from 800 to 2,000 mm (Oliveira-Filho and Ratter 2002). It is interesting to note that regions with deciduous forests in the biome have the highest rates of precipitation (Scariot and Sevilha 2005). Other studies have shown that the strong seasonality of rainfall is the most important factor in determining the distribution of dry forests in central and South America (Murphy and Lugo 1995, Sampaio 1995). Thus, we find it reasonable to assume that the potential distribution predicted in our models endorse the association between the species and dry forests, even though the vegetation map had no significant impact on our predictions. Bioclimatic variables (precipitation in particular) may have acted as surrogates for vegetation given that the distribution of dry forests is strongly associated with rainfall seasonality. Additional reasons for why the vegetation map failed to help our predictions are unknown but warrant further investigation, particularly with regard to scale and accuracy. Furthermore, other aspects related to ecophysiological and biophysical processes (Austin 2007) are certainly influential on determining the species' distribution but these are beyond the scope of our study.

2.5.3 Potential distribution

Our models predicted the potential occurrence of the Pfrimer's Parakeet in three distinct regions (Figure 2.1). The area located in the central-northwest axis of Goiás has been heavily converted for agriculture and pastures; however, it was once the transition between open cerrados to semi-deciduous and deciduous forests in the northern limit of a region known as "Mato Grosso de Goiás" (Faissol 1952). The second region comprises formerly open cerrado flat lands in the east of the Serra Geral massif, and dry forests over calcareous soils in the Paranã River Basin to the west. These dry forests are the only place where Pfrimer's Parakeets have been recorded. Finally, the regions located further north in the states of Piauí and Maranhão have also a predominance of open cerrados and areas of transition to the xeric Caatinga biome, which is also considered a different type of dry forest under a broader definition (Sampaio 1995). In a coarse geographical scale, this entire predicted range was once part of a much larger ecosystem formed by dry forests that have connected the Caatinga biome in northeastern Brazil to the semi-deciduous forests in southeastern Brazil, southern Paraguay and central-northern Argentina

(Prado and Gibbs 1993, Oliveira-Filho and Ratter 2002, Scariot and Sevilha 2005). Hence, under the same scale, the prediction of this "corridor" should not be completely unexpected from a bioclimatic perspective, especially considering the set of environmental variables that most influenced our model outputs. However, recording the species only in the deciduous forests of the Paranã River Basin (Figure 2.1), based on the results of our surveys and historical data, suggests that other important factors influencing its distribution were not captured in our models.

Biogeographical analyses of the Cerrado avifauna suggest that the Pfrimer's Parakeet originated in this region during the Pleistocene, after the isolation of an ancestor of humid forests (Silva 1997). In fact, among the three former subspecies of *Pyrrhura leucotis* restricted to Brazil, Pfrimer's Parakeet is the only taxa occurring outside the Atlantic forest range (humid) in very different (dry) habitat (Olmos et al. 2005). Some studies consider the calcareous forest throughout the Cerrado as a particular form of deciduous dry forests (Prado and Gibbs 1993, Oliveira-Filho and Ratter 2002). Moreover, according to Silva (1997) the forests of the Paranã River Basin have a distinct structure and floristic composition from other deciduous forests in central Brazil. Surveys carried out in dry forests elsewhere in the Cerrado biome never reported the occurrence of Pfrimer's Parakeet (Olmos et al. 1997, Olmos 2008). Therefore, the most direct explanation for their absence in the two other regions is the lack of appropriate habitat. We found the arguments above and our results to be complementary and support the association between the species and the dry forests of the Paranã River Basin.

Pfrimer's Parakeet was found in 17 sites visited during our surveys and some records represent new localities. Unfortunately, dry forests are no longer the predominant landscape in the region and new observations along the Paranã River Basin were usually recorded in locations with markedly disjunct habitat patches. Although the species was always observed near forest habitats, the degree of fragmentation within the predicted range is overwhelming and much of the original forest has been left to remnants growing close to limestone outcrops (Bianchi and Haig *in review*). This process may be affecting the persistence of local populations as we failed to find the species in some fragments with apparently suitable habitat. Moreover, the species was not observed by us nor reported by local people in a number of sites where occurrence was known less than a decade ago (CAB, personal observation).

Deforestation is a widespread phenomenon in the Paranã River Basin since the intense occupation of settlers in the 1970's (Scariot and Sevilha 2005). In our surveys, forest patches were the least common landscape in many areas. The regions of Natividade and São Desidério are the farthest and most isolated forest formations outside the core area of dry forests in the Paranã River Basin. The first one is located 126 km west of the closest presence point at Fazenda Tarumã (11°55'S 46°36'W, Pacheco and Olmos 2006) and has approximately 2,300 ha of fragmented dry forest mostly over limestone outcrops surrounded by cattle ranches. The second region, separated from the core area of distribution by the Serra Geral massif is approximately 65 km east of the closest occurrence point at Fazenda Poções (12°39'S 46°28'W, Aurora do Tocantins). The area is formed by highly disturbed forest fragments that add up to less than 1,000 ha. Although our efforts to find the species were unsuccessful in both regions, it seems reasonable to assume that it has been present there in the past, given the existence of the same habitat and the history of forest expansions and contractions in central Brazil (Prado and Gibbs 1993, Oliveira-Filho and Ratter 2002). It is possible that reduced fragment size associated with distance from the source area had driven the species to local extinction in these areas.

Based on our findings in this study and on the historical records, we conclude that the actual distribution of Pfrimer's Parakeet remains restricted to the dry forest fragments of the Paranã River Basin. It is limited in the north in the municipalities of Ponte Alta do Bom Jesus and Novo Jardim (Tocantins) extending to the west across the Paranã River near Nova Roma (Goiás) to the south, in flat remnants of Iaciara and finally to the east along the forests and limestone outcrops parallel to the Serra Geral massif. Mapping of forest fragments using satellite imagery and remote sensing tools could significantly improve the accuracy of the actual distribution. Moreover, further investigation of forest fragments regarding the species presence/absence could elucidate population spatial structure and indicate potential unoccupied areas for future reintroduction if this becomes a necessary conservation measure.

ACKNOWLEDGEMENTS

We thank J. D'Elia and A. Yost for valuable discussions during data analysis. R. Pearson provided advice on using the Jackknife test. P. Haggerty helped with GIS issues related to preparation of the environmental predictors. M. Huso provided advice on statistical analysis. A. Portella and F. Bianchi provided help during fieldwork. The USGS Forest and Rangeland Ecosystem Science Center, Fundação O Boticário de Proteção à Natureza, Cleveland Metroparks Zoo (Scott Neotropical Fund), Parrots International, Canadian Parrot Symposium, Pesquisa e Conservação do Cerrado (PEQUI), Pacific Islands Conservation Research Association have provided financial support for this study. The Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) and the Centro Nacional de Pesquisa para Conservação das Aves Silvestres (CEMAVE) granted permits (16808-1; 3041/1) for the fieldwork in Brazil. CAB was supported by a CAPES/Fulbright doctoral scholarship (15053166/201604-4).

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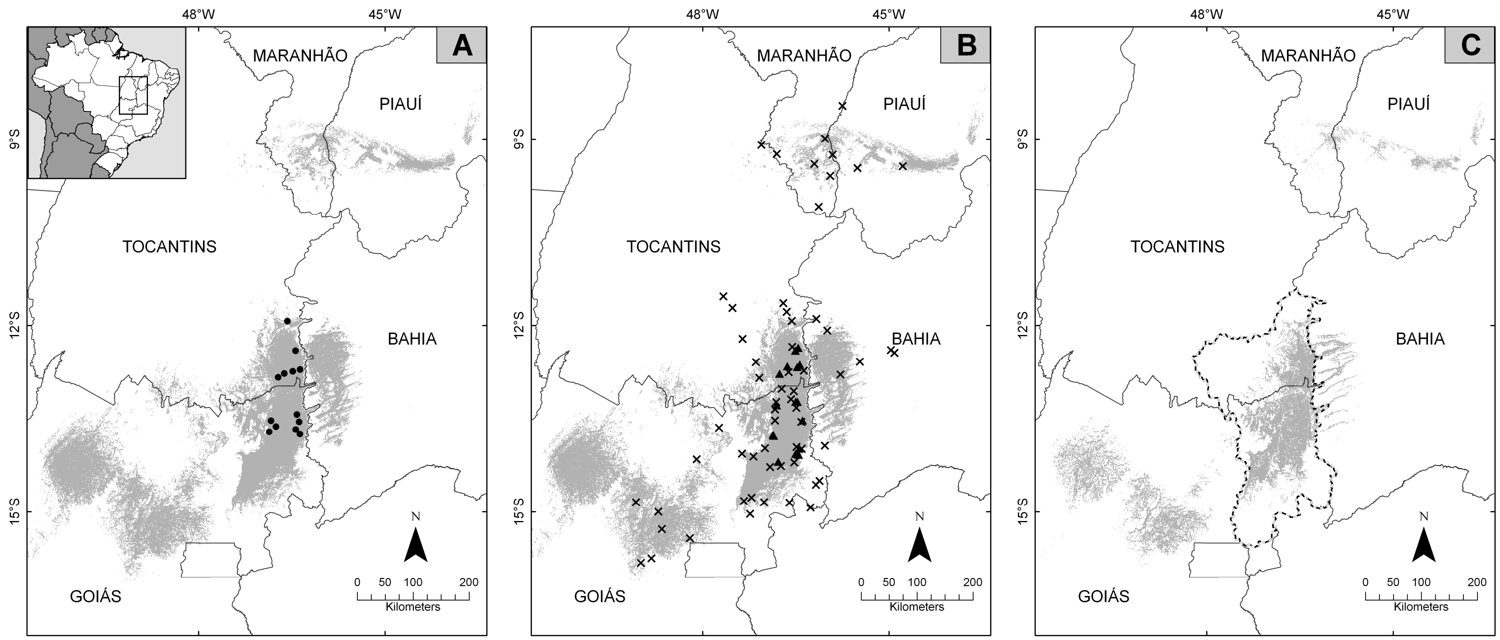
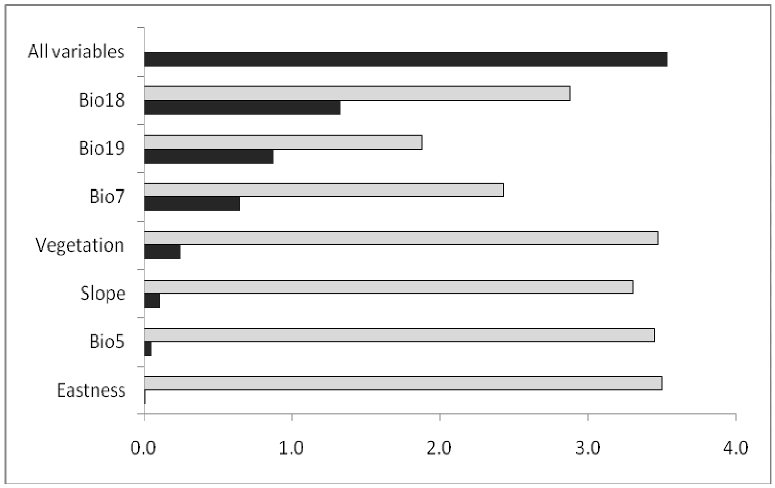


Figure 2.1. Potential distribution of Pfrimer’s Parakeet in the Cerrado biome of Brazil. (A) Occurrence points (dots) used to model the distribution range (grey) in the original model using Maxent with threshold of fixed cumulative 10 (FC10). (B) Sites visited during field investigation (X) and localities with new observations (black triangles). (C) Distribution range (grey) after model refinement using threshold of minimum training presence (MTP); dashed line represents the Paranã River Basin.

A



B

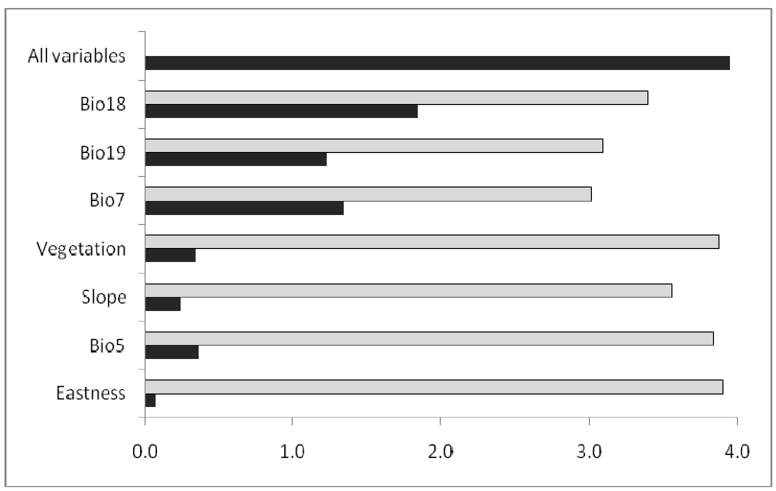


Figure 2.2. Regularized training gain (RTG) for predictor variables in the original model (A), and the refined model (B), for modeling the potential distribution of Pfrimer's Parakeet in central Brazil. Grey bars represent RTG without the variable and black bars represent RTG with the variable used alone. Coded bioclimatic variables: Bio5 (maximum temperature of warmest month); Bio7 (temperature annual range); Bio18 (precipitation of the warmest quarter; and Bio19 (precipitation of coldest quarter).

CHAPTER 3

DEFORESTATION TRENDS IN TROPICAL DRY FORESTS OF THE PARANÃ RIVER BASIN, CENTRAL BRAZIL

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To be submitted:

Forest Ecology and Management

Elsevier Publishing

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3.1 ABSTRACT

Tropical dry forests are the most threatened forest type in the world yet a paucity of research about them stymies development of appropriate conservation actions. The Paranã River Basin has one of the most significant dry forest formations in central Brazil and is threatened by intense land conversion to pastures and agriculture. We used Landsat imagery to estimate deforestation rates and fragmentation in the basin, covering three time intervals over 31 years. Our results indicate a 66.3% decrease in forest extent between 1977 and 2008, with an average annual deforestation rate of 2.1%. Landscape metrics further indicate severe forest loss and fragmentation, resulting in an increase in the number of fragments and reduction in patch sizes. Forest fragments in flatlands have virtually disappeared and the only significant remnants are mostly found over limestone outcrops in the eastern part of the basin. If current patterns persist, we project that these forests will disappear within 16 to 20 years. Thus, creation of protected areas and involvement of local people to preserve small fragments that can be managed for restoration is needed.

3.2 INTRODUCTION

Tropical dry forests are broadly defined as a vegetation type dominated by deciduous trees with markedly seasonality in precipitation (Holdridge 1967, Murphy and Lugo 1986, Sánchez-Azofeifa et al. 2005a; Scariot and Sevilha 2005, Miles et al. 2006).

Although they are distributed worldwide and frequently associated with savannas (Furley et al. 1992), their original extent remains unknown (Murphy and Lugo 1986). Current estimates indicate that over a million square kilometers still exist, with notable areas in Indochina, Central and South America (Miles et al. 2006). During the last glacial period, tropical dry forests covered a large corridor known as “dry diagonal” across South America, linking the biomes of Caatinga, Cerrado and Chaco (Prado and Gibbs 1993). In Brazil, significant enclaves of dry forests are found in disjunct distributions amid the savannas of Cerrado and Caatinga, in regions with marked precipitation seasonality ranging from 650 to 3000 mm, altitudes between 200 and 1800m and temperature between 16-27°C (Scariot and Sevilha 2005). A particular form of dry forest, known as calcareous forest, is found on karst soils throughout the Cerrado biome (Oliveira-Filho and Ratter 2002).

Tropical dry forests have long been known as the most threatened and overlooked forest formation in the world (Janzen 1988, Hoekstra et al. 2005, Sanchez-Azofeifa et al. 2005a, Miles et al. 2006). Land conversion to pastures and agriculture is the major threat to this ecosystem, reflecting a long-history of human occupation attracted by fertile soils, flat landscapes, climatic seasonality for development of short cycle crops and lower structural complexity (Maass 1995; Scariot and Sevilha 2005; Fajardo et al. 2005; Sánchez-Azofeifa et al. 2005a, 2005b; Miles et al. 2006). Recent efforts have called attention to the urgent need for multidisciplinary studies about tropical dry forests around the world (Sanchez-Azofeifa et al. 2005a, 2005b). Priorities include research on ecological aspects such as distribution, community structure, species composition, phenology and forest regeneration; the use of remote sensing techniques to estimate forest extent, changes in land cover, degree of fragmentation and spectral diversity; and socioeconomic research to identify historic occupation, ethnobotanical elements, and existence of traditional populations. Because of the strong association between humans and dry forests, only a comprehensive understanding of how the ecosystem has been changed over many decades will provide enough understanding for establishment of sound conservation strategies for these forests (Sanchez-Azofeifa et al. 2005b, Espírito-Santo et al. 2006). There has been a recent increase in research focusing on tropical dry forests (Stoner and Sanchez-Azofeifa 2009), but many critical regions still lack basic information.

Similar to other tropical dry forests in the world, Brazil's dry forests are seriously threatened because of extensive land conversion to agriculture (Scariot and Sevilha 2005). Moreover, only 3.9% of the tropical dry forest's 273,678 km^2 range in Brazil is protected (Espírito-Santo et al. 2008). This study is part of a broad approach (Bianchi and Haig *in review a,b*) to investigate the consequences of anthropogenic pressures over ecological processes on the endemic Pfrimer's Parakeet (*Pyrrhura pfrimeri*) a species with a restricted range in the dry forests of the Paranã River Basin.

Given the strong association between the species and its habitat, we wanted to evaluate deforestation trends over large spatial and temporal scales of the tropical dry forests of the Paranã River Basin in central Brazil. Our goal is to provide perspective regarding the current status of the dry forests in the region and projections for its future.

3.3 METHODS

3.3.1 Study area and fieldwork

The Paranã River Basin (Figure 3.1) is a large depression (59,403 km^2) located between two plateaus in the central Brazilian states of Goiás and Tocantins (Scariot and Sevilha 2005, Carvalho Jr. et al. 2006). As part of the Tocantins River Basin, which is a major tributary of the Amazon River, the region represents a transition between the Amazon tropical humid forests and the savannas of the Cerrado and Caatinga biomes. The climate is typical of a tropical savanna (Köppen Aw) characterized by well marked dry (April-September) and rainy (October-March) seasons, with average precipitation of 1200-1300 mm and average annual temperatures ranging from 16 to 21°C (BRASIL 1982, Scariot and Sevilha 2005). A vast patch of fertile karst soils derived from the Bambuí geological group, supports one of the most significant formations of tropical dry forests in Brazil. The region was recently deemed to be of "extremely high" biological importance, given the singular habitat and occurrence of several endemic species of fauna and flora (Ministério do Meio Ambiente 2002). This area includes the flat areas in the west to the limestone outcrops in the east, where it forms one of the largest cave systems in South America (Auler and Farrant 1996, Auler 2002). However, government incentives to develop the region in the 1970s triggered a rapid increase in human occupation, establishing an economic cycle of timber exploitation followed by land conversion into pastures (Espírito-Santo et al. 2009). Current additional threats include charcoal production and limestone mining, as the region is still considered the last development frontier in the state of Goiás. This is particularly true in central-south depression known as the Paranã Valley (Scariot and Sevilha 2005).

During our investigations about the occurrence of the Pfrimer's Parakeet in the region (Bianchi and Haig *in review a*), we carried out an extensive search for dry forest fragments and recorded information about land cover type (dry forest, riparian forest, savanna, pasture, and agriculture) in 269 sites in the region in 2008. Sites were visited by car or walking depending on access and exact locations of points in the field were recorded using a GPS (GPSMAP 76S, Garmin Intl. Inc., USA).

3.3.2 Processing and classification of satellite imagery

To estimate deforestation trends in the Paranã River Basin, we used satellite imagery from the sensors Landsat 3 MSS and Landsat 5 TM, available from the Brazilian National Institute for Space Research – INPE (http://www.dgi.inpe.br/CDSR/). We selected images acquired near the end of the rainy season (February-April), when deciduous forests still have full dense canopy but cloud cover is significantly reduced. We used fifteen scenes spanning 31 years and divided them into three intervals for the years 1977, 1993/1994 and 2008 (Table 3.1). A composite of scenes from two different years (1993 and 1994) was necessary for the analysis of the second interval, given that cloud-free images covering our study region were unavailable. All imagery was pre-processed in ERDAS IMAGINE 8.7 (Leica Geosystems GIS and Mapping, LLC, USA), following methods described in Kennedy et al. (2007), including a geometric correction with cubic convolution to output cell size of 25 meters in the polynomial model and projection to datum WGS 84. Next, we performed unsupervised classification of each image using 30 classes, 40 iterations and a convergence threshold of 0.99. This was followed by analysis and visual interpretation between each original and corresponding classified image to a post-classification scheme, producing binary maps with the categories “forest” and “non-forest”. Overall classification accuracy and Kappa statistics were estimated only for 2008, given the possibility to obtain updated information on ground control points for accuracy assessment. We used a binomial distribution sampling scheme to collect ground control points, aiming for a minimum overall accuracy of 85% (Foody 2002) with a 95% confidence level (Congalton and Green 1999, Czaplewski 2003). We used 211 field points at least 1 km apart selected from a dataset of 269 points collected during our fieldwork in 2008.

3.3.3 Geographic boundaries and deforestation analysis

We built one map in Arc GIS (ESRI Inc., USA) for each time interval by combining the corresponding five classified images and aggregating pixels to the size of one hectare using the boundaries of the basin to set the extent. Additionally, we created a mask polygon corresponding to the distribution limits of the dry forests within the basin to be used as the boundary for the deforestation analysis. This polygon was delimited by hand after visual interpretation of the original imagery and closely matches the limits of the dry forest in the region defined in Carvalho Jr. et al. (2006) using precipitation parameters and NDVI (normalized difference vegetation index) derived from the MODIS sensor. We also wanted to estimate deforestation rates within the Paranã Valley, considering the economic importance of this zone and the governmental incentives directed to its development.

Landscape pattern indices were calculated using Fragstats 3.3 (McGarigal et al. 2002) on the patch and class levels and by applying the neighborhood rule of eight cells. The selection of metrics to compute spatiotemporal changes in forest followed recommendations of Neel et al. (2004) and Gergel (2007). The selected variables are among those most commonly used in the literature (Griffith et al. 2000, Fassnacht et al. 2006, Cushman et al. 2008, Nagendra et al. 2008, Gasparri and Grau 2009, Songer et al. 2009): (1) total area, (2) proportion of landscape (3) number of patches, (4) patch area (mean and SD), (5) largest patch index, and (6) clumpiness index. Detailed information about these indexes and formulas are found in McGarigal et al. (2002) but briefly, total area and proportion of landscape are simple metrics directly related to the extent of the target class; number of patches, patch area and largest patch index are related to extent but also can indicate levels of fragmentation. The clumpiness index is a measure of class aggregation that ranges from -1 when the target class is maximally disaggregated to +1 otherwise, and usually is a robust metric used to evaluate fragmentation, given its particular independence to variations in class area (Neel et al. 2004, Gergel 2007). Finally, we calculated estimates of annual forest cover change (FCC) using the adapted formula of Puyravaud (2003) presented in Boletta et al. (2006).

3.4 RESULTS

3.4.1 Assessment of classification accuracy and Kappa statistic

Overall accuracy of the 2008 image classification was estimated at 89.6% with 189 points correctly classified and Kappa statistics of 0.78 (Table 3.2). Although we have not assessed accuracy for time intervals 1 (year 1977) and 2 (years 1993/94) given the absence of corresponding ground control points, we found it reasonable to assume that these intervals would have similar accuracy to the 2008 image, based on the quality of the images and use of the same criteria for image classification.

3.4.2 Forest loss and fragmentation

Over 31 years, there was a 66.3% reduction in forest cover within the polygon of dry forests in the Paranã River Basin (Figure 3.2 a-c). Reduction in forest cover was estimated at 35.7% between 1977-1993/94 and at 47.6% between 1993/94-2008. The estimated annual forest cover change for the same intervals was -2.6% and -4.6%, respectively. Results further suggested an asymmetrical trend in deforestation, showing more aggregations of forest remnants towards the eastern limits of the basin over the years (Figure 3.2 a-c). In the Paranã Valley, deforestation rates were slightly higher than in the dry forest polygon, with reduction of 38.3% for the first interval and 54.4% for the second interval. Overall loss in forest cover was estimated at 71.9% and forest cover change estimates were -2.8% and -5.6%, respectively.

Forest loss and fragmentation were also evident based on all landscape metrics in the dry forest polygon (Table 3.3). While the number of patches increased 51% overall, the mean patch size decreased from 2.72 to 0.44 km^2 (84%) between the first and last interval. Likewise, the largest patch index suffered a sharp reduction of more than 96% and the clumpiness index decreased 4.1%. The distribution of fragments per size and correspondent forest area (Table 3.4) showed that small fragments (≤ 2.5 km^2) have increased in number over the years and were dominant in the landscape in all three intervals, comprising more than 97% of the total number of patches. In 1977 they represented only 3.9% of the forest extent but had increased to 38.4% in 2008 (Figure 3.3). In contrast, even though the number of fragments in the largest category (>10 km^2) had also increased in 31 years (Table 3.4), they suffered a drastic reduction in the percentage of forest extent, dropping from 94.4% in 1977 to 51% in 2008 (Figure 3.3).

3.5 Discussion

This study is the first attempt to quantify the process of forest loss and fragmentation across large temporal (31 years) and spatial (59, 403 km^2) scales for the Paranã River Basin. It represents a unique perspective about the deforestation trends in one of the most significant formations of tropical dry forests in South America. Even though the remote sensing analysis was carried out on a coarse scale (and not on a pixel-to-pixel basis), our results will serve as a baseline for monitoring of future trends, benefit upcoming research and help on establishing conservation planning for a region that has been classified as of high biological importance (Ministério do Meio Ambiente 2002).

3.5.1 Accuracy assessment and sources of error

In general, the accuracy of our classification was very satisfactory as the estimates were above the minimum acceptable levels at 85% for overall accuracy and no less than 70% for individual classes (Foody 2002). However, prior to further interpretation of our results, it is important to underline potential sources of error and limitations that are likely incorporated in the analysis during different processing stages (Johnson 1990, Fassnacht et al. 2006, Langford et al. 2006).

First, use of a binary categorization system of “forest” and “non-forest” represents a simplification of the actual landscape, which makes inferences about particular vegetation types almost impossible. However, it was appropriate in our study because forests were the category of interest and could be easily identified in a vegetation mosaic with savannas. Moreover, two category classifications have been largely used with success in many similar studies (Grau et al. 2005, Nagendra et al.

2008, Gasparri and Grau 2009, Songer et al. 2009, Whitehurst et al. 2009). One particular reason for using only a binary system is the difficulty to differentiate some typical Cerrado physiognomies found in transition zones (such as “Cerradão”) from dry forests using remote sensing techniques. In fact, distinction between these vegetation types can be quite complex to achieve even for observations *in situ*, and is frequently only possible based on analysis of species composition or soil types (Ratter 1992; A. Sampaio, Brazilian Institute of Environment – IBAMA, pers. comm.). Thus, techniques to discriminate these physiognomies using a remote sensing approach warrant further investigation. Another potential source of error in our analysis is the combination of different scenes from subsequent years (1993 and 1994, see Table 3.1) in the map composition for the second interval. However, considering the annual rate of deforestation found in this study (2.1%) and the correspondent spatial coverage of those scenes in relation to the basin’s total extent, we believe this error is negligible when accounting for the overall results of 31 years.

3.5.2 Deforestation analysis

Our rates of deforestation compared similarly to estimated rates reported from other dry forests. Andahur (2001) carried out a similar investigation focusing on a sample of 180,877 hectares located near the center of the basin and found an overall decrease of 65.8% in forest cover between 1990 and 1999. The annual deforestation rate was estimated in this study at 2.1% and is similar to those reported for other tropical dry forests in the world, such as 1.1 to 2.6% in Venezuela (Fajardo et al. 2005), 2.1% in Costa Rica (Steininger et al. 2001), 0.83% (Gasparri and Grau 2009) to 5% (Boletta et al. 2006) in Argentina; and 1.8% in Myanmar (Songer et al. 2009). Furthermore, based on estimates of all landscape metrics, our results confirmed that forest loss and fragmentation have considerably impacted forests in the region. All area related metrics – total area, percentage of landscape, mean patch area and largest patch index – have shown significant decrease over the years. Following a similar trend, the increase in the absolute number of patches and the reduction in the clumpiness index were reliable indicators of fragmentation (Table 3.3).

It is difficult to determine estimates of the extent of tropical dry forests in the Paranã River Basin before the escalation of human activities in the 1970s. Two early governmental initiatives, carried out in central Brazil to survey natural resources, provided partial estimates about the extent of dry forest in the region. The RADAMBRASIL project mapped 50,137 km^2 of forests and ecotones between parallels 12° and 16°S and meridians 42° and 48°W (BRASIL 1982). However, only about 10 to 15% (5,000-7,600 km^2) of this extent can be inferred as forest occurring within the boundaries of the Paranã River Basin. The second study mapped 13,861.8 km^2 of forests and transition zones in the northeast of Góias state, which also partially overlaps the basin (Instituto Brasileiro de Geografia e Estatística, IBGE 1995). Both studies used a classification system based primarily on phytophysiognomies that includes areas of savannas, forests (semi-deciduous and deciduous) and ecotones with forest enclaves, without further details about forest type within these transition zones. Moreover, these studies have different geographic limits than our study area and just partially overlapped the basin's boundaries. Therefore, extrapolations concerning original forest extent within the basin remain limited.

Based on the overall rate of deforestation in 31 years (66.3%) and the remaining extent of forest (4,352 km^2) estimated in this study, we predict that, without significant and immediate intervention, tropical dry forests in the Paranã River Basin may no longer exist within 16-20 years. Understanding current practices and conservation efforts may help focus future needs. As a general rule, deforestation practices in the basin tend to replace all forest cover with large pastures for livestock, which is typically evident along the western segment, particularly within the Paranã Valley. The topography in the valley is marked by extensive flat lands that have likely favored the use of heavy machinery for land conversion during the establishment of early settlers. Furthermore, early governmental policies stipulated more than 90% of this area to be used for development of croplands and pastures (Andahur and Chaves 2003). As a consequence, the region was heavily modified and currently encompasses large cattle ranches (>500 hectares; Scariot and Sevilha 2005, Espírito-Santo et al. 2009).

The Paranã Valley is a good example of how the decrease in forest cover is inversely proportional to the increase in cattle population, as the region has been ranked first in the state of Goiás in livestock growth rate over the last few years (Superintendência de Pesquisa e Informação do Governo de Goiás, SEPIN 2009). While the annual deforestation rate in the area between 2002 and 2007 was estimated at 2.3%, the cattle population has grown 7.4% per year in the same period, twenty times higher than the average growth rate for the entire state (SEPIN 2009). Furthermore, governmental regulations that prohibit deforestation of sensitive areas (e.g., vegetation of riparian zones and steep areas) or require that 20% of the extent in each property must be preserved (known as the "legal reserve" law for the Cerrado biome) have not been followed by many landowners (Sampaio 2006). Within this scenario, forest remnants of significant size are already scarce in this portion of the basin and likely fated to completely disappear in few years.

Land conversion in the region seems to be limited only by the topographical barrier represented by the limestone outcrops (Figure 3.4). During our fieldwork we noticed that most well preserved forest fragments were found over or surrounding these large blocks of exposed rock, forming islands or linear habitats. This rugged landscape gradually increases its occurrence towards the eastern limits of the basin, forming a north-south array where a massive cave system is found. This topographic pattern in the occurrence of outcrops likely explains the eastward aggregation of forest fragments observed in our analyses (Figure 3.2 a-c). In contrast to the western region, this portion contains a high number of small farms (up to 100 hectares each), usually characterized by a mosaic of pastures amid outcrops and ravines with forest, where the main economic activities are related to subsistence agriculture and cattle (Scariot and Sevilha 2005, Espírito-Santo et al. 2009). Although forest fragments associated with outcrops are usually less disturbed and might represent potential areas for conservation, some studies have shown that these forests have different floristic and physiognomic characteristics (Pedralli 1997) with reduced number of species when compared to those found in flat areas (Scariot and Sevilha 2005, Silva and Scariot 2003).

A recent study by the Brazilian government classified 83% of the Paranã River Basin as high priority area for biodiversity conservation (Ministério do Meio Ambiente 2007), although such designation does not imply immediate legal protection. Thus, it is still unclear how these recommendations will tackle early development policies such as the agro-ecological zoning in northeastern Goiás (IBGE 1995), which suggested land conversions into economic activities like ranching and agriculture (Andahur and Chaves 2003). In the short term, creation and effective implementation of protected areas such as national or state parks or biological reserves is the best chance for persistence of this ecosystem. Nevertheless, creation of conservation units is usually seen as a barrier for economic growth and is heavily dependent on political interests and opportunities. Espírito-Santo et al. (2009) have shown that less than 4,300 km^2 (7.2%) of forests in the basin are currently protected. However, the largest and only reserve of restrictive use (Terra Ronca State Park) has half of its 570 km^2 represented by dry forests occurring mostly over limestone outcrops and, although created in 1989, is yet to be fully implemented. All other protected areas in the region are unlikely to effectively conserve tropical dry forests, as they belong to less restrictive reserve categories that allow the use of natural resources and human occupation to some extent (Espírito-Santo et al. 2009). Other proposals being considered include creation of two state parks to protect a mosaic of savannas and forests in the southeastern Tocantins state, which will include about 180 km^2 of tropical dry forests (Olmos 2008). Our results and field inspections suggest that further investigations for the establishment of reserves should be carried out in the municipalities of Aurora, Novo Alegre and Combinado in Tocantins state and in Divinópolis and São Domingos in Goiás, where mosaics of forests fragments with reasonable size (> 10 km^2) still exist.

Another possible alternative to recover the last remnants of tropical dry forests occurring in the flatlands of the Paranã Valley is to promote establishment of private reserves within rural properties, known in Brazil as the Private Natural Heritage Reserves (IBAMA 2009). Such protected areas are recognized under the national system of conservation units and has many attractive fiscal benefits to complying landowners. It has been shown that tropical dry forests have good potential for recovery when appropriate management techniques are applied (Sampaio et al. 2007, Vieira and Scariot 2006, Powers et al. 2009, Quesada et al. 2009). Therefore this might be an excellent opportunity to work on the restoration of those isolated fragments to establish ecological corridors as a strategy for the perpetuation of dry forests in the western portion of the basin.

A recurrent legal problem is the lack of specific environmental policies to protect tropical dry forests within the Cerrado biome. For example, in 1965 the Brazilian Forestry Code (Federal Decree 4771/65) stipulated the “legal reserve” which mandated protection of 20% of the area of rural properties in the Cerrado biome. However, the law does not discriminate or recommend protection to any particular vegetation type. While improvement of some legal aspects remains necessary, technical support from law enforcement agencies towards the establishment of ecosystem-oriented legal reserves might also be a beneficial step with low implementation cost. Several other measures regarding modifications in land use policies have been discussed (Espírito-Santo et al. 2009) but these actions might not have a fast enough impact on recovery of the dry forests of the Paranã River Basin. Nevertheless, we emphasize other authors concerns in that future efforts to preserve tropical dry forests should be based on reliable information collected through multidisciplinary approaches integrating ecological, social and economic dimensions (Sanchez-Azofeifa et al. 2005a, Espírito-Santo et al. 2006, Quesada et al. 2009).

3.6 CONCLUSIONS

Our analyses of the tropical dry forests of the Paranã River Basin demonstrate severe deforestation over the last three decades as a result of intense human occupation. Patterns in deforestation have shown an eastward displacement of forest remnants, indicating that forest habitat in flat areas suffered higher levels of loss and fragmentation than in regions where limestone outcrops are found. Deforestation rates estimated in this study suggest that the forest could disappear in less than 20 years unless urgent measures for its protection are implemented. Information presented here will help to set priorities for further investigations for the conservation of the tropical dry forests in central Brazil.

ACKNOWLEDGMENTS

We thank C. Torgensen and D. Pflugmacher for their assistance with methods, data analysis and valuable discussions during project development. P. Haggerty provided help with GIS issues. A. Portella and F. Bianchi helped in fieldwork. The USGS Forest and Rangeland Ecosystem Science Center, Fundação O Boticário de Proteção à Natureza, Cleveland Metroparks Zoo (Scott Neotropical Fund), Parrots International, Canadian Parrot Symposium, Pesquisa e Conservação do Cerrado (PEQUI), Pacific Islands Conservation Research Association have provided financial support for this study. The Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) and the Centro Nacional de Pesquisa para Conservação das Aves Silvestres (CEMAVE) granted permits (16808-1; 3041/1) for the fieldwork in Brazil. CAB was supported by a CAPES/Fulbright doctoral scholarship (15053166/201604-4).

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Table 3.1. Landsat images including path/row numbers and acquisition date obtained from the National Institute for Space Research database in Brazil and used for the analysis of deforestation in the Paranã River Basin.

Satellite	Path/Row	Date	Time interval
MSS	236/69	07 February 1977	1
MSS	236/70	15 March 1977	1
MSS	237/68	16 March 1977	1
MSS	237/69	16 March 1977	1
MSS	237/70	16 March 1977	1
TM	220/69	10 April 1993	2
TM	220/70	10 April 1993	2
TM	221/68	20 April 1994	2

- Continued -

Table 3.1. (*Continued*). Landsat images including path/row numbers and acquisition date obtained from the National Institute for Space Research database in Brazil and used for the analysis of deforestation in the Paranã River Basin.

Satellite	Path/Row	Date	Time interval
TM	221/69	20 April 1994	2
TM	221/70	20 April 1994	2
TM	220/69	18 March 2008	3
TM	220/70	18 March 2008	3
TM	221/68	10 April 2008	3
TM	221/69	10 April 2008	3
TM	221/70	10 April 2008	3

Table 3.2. Accuracy assessment of the binary classification scheme for the Landsat images of 2008 for the analysis of deforestation in the Paranã River Basin, Brazil.

	Forest	Non-forest	Total	Producer's Accuracy (%)
Forest	71	10	81	87.7
Non-forest	12	118	130	90.8
Total	83	128	*N*=211	
User's Accuracy (%)	85.6	92.2		

Overall Accuracy (%) = 89.6; Kappa = 0.78

Table 3.3. Landscape metrics for the deforestation analysis of the dry forest polygon in the Paranã River Basin, central Brazil.

Year	Total Area (km^2)	% Landscape[a]	N patches	Patch Area (mean)	Patch Area (SD)	Largest Patch Index	Clumpiness
1977	12,919.7	21.7	4746	2.72	172.10	59.0	0.8072
1993/94	8,311.0	14	8074	1.03	45.62	20.1	0.7897
2008	4,352.0	7.3	9691	0.44	4.99	1.7	0.7738

[a] Relative to the Paranã River Basin (area = 59,344 km^2)

Table 3.4. Number of fragments per category of size and respective mean patch size (MPS) in three intervals over 31 years in the dry-forest polygon in the Paranã River Basin, Brazil.

	1977		1993/94		2008	
Size Class (km^2)	N Fragments	Patch size (mean + SD) in km^2	N Fragments	Patch size (mean + SD) in km^2	N Fragments	Patch size (mean + SD) in km^2
≤ 2.5	4,686	0.10 (0.24)	7,914	0.14 (0.30)	9,474	0.14 (0.29)
2.5-5.0	27	3.52 (0.67)	81	3.57 (0.73)	98	3.52 (0.64)
5.0-7.5	9	6.14 (0.74)	19	6.16 (0.76)	41	6.05 (0.70)
7.5-10	8	8.51 (0.81)	11	9.04 (0.82)	21	8.57 (0.59)
10 <	16	762.49(2,959)	49	136.10 (575.61)	57	38.96 (52.05)
Total	4,746		8,074		9,691	

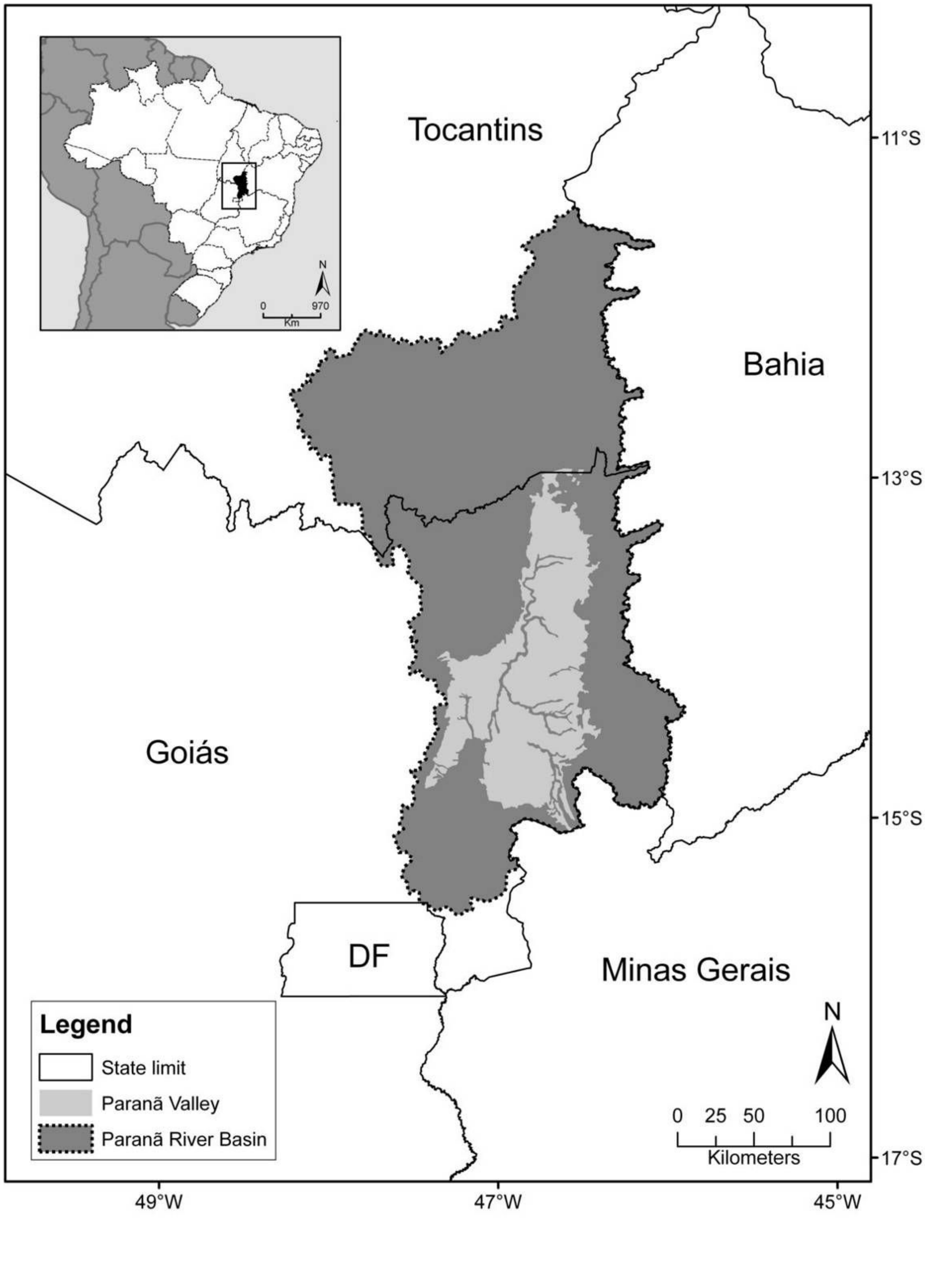

Figure 3.1. Location of the Paranã River Basin and the Paranã Valley in central Brazil.

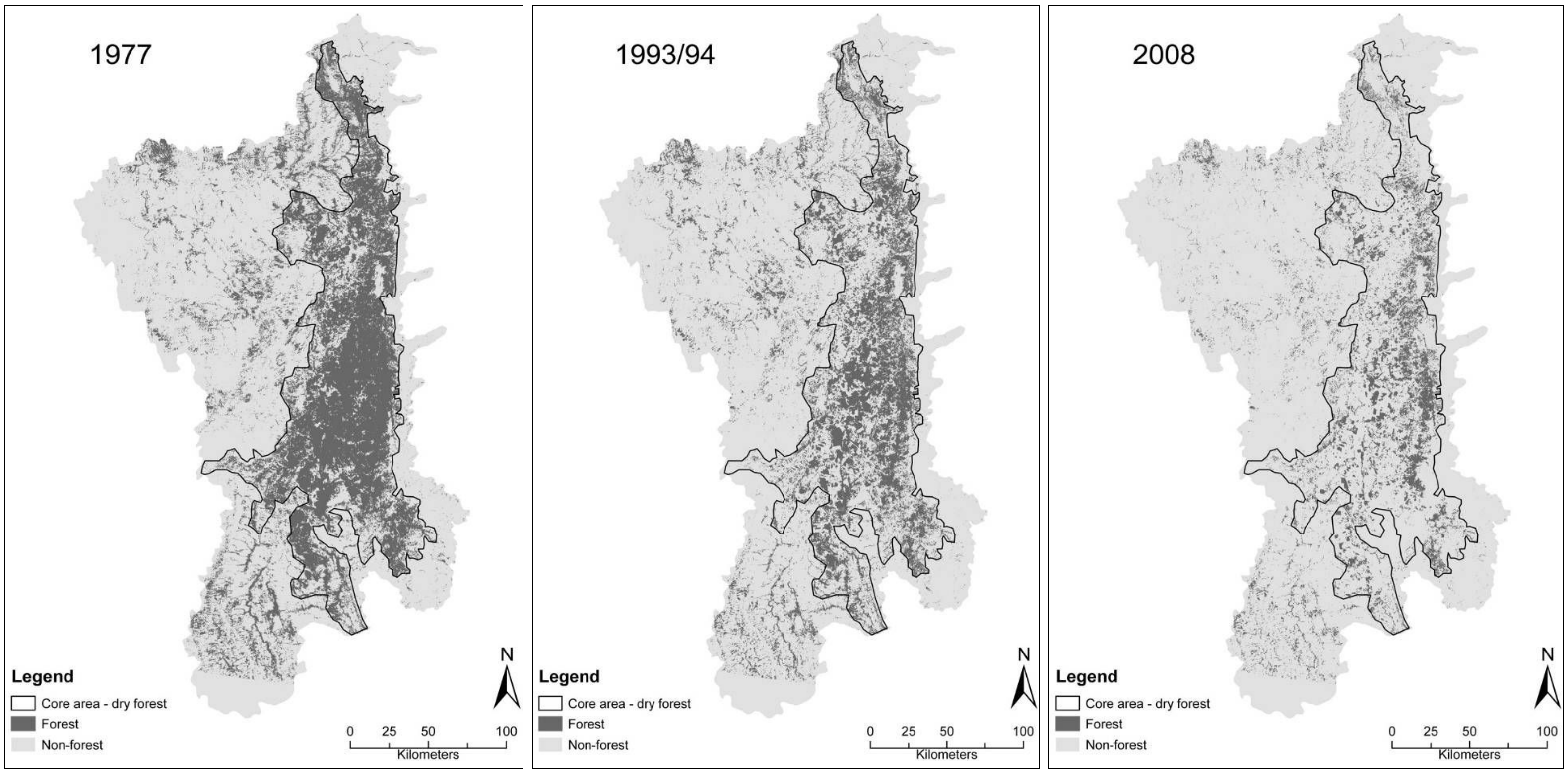

Figure 3.2. Forest extent using a binary classification (forest; non-forest) in the Paranã River Basin, Brazil in three intervals over 31 years.

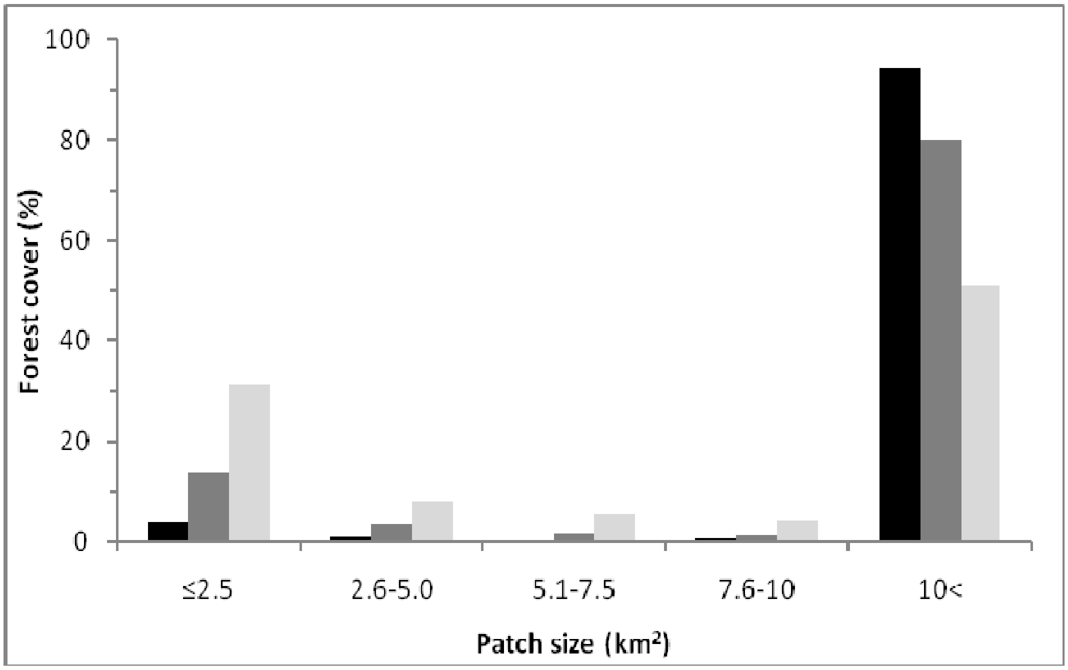

Figure 3.3. Distribution of fragments per size in the dry forest polygon of the Paranã River Basin, Brazil in three intervals (black=1977; dark gray=1993/94; light grey=2008).

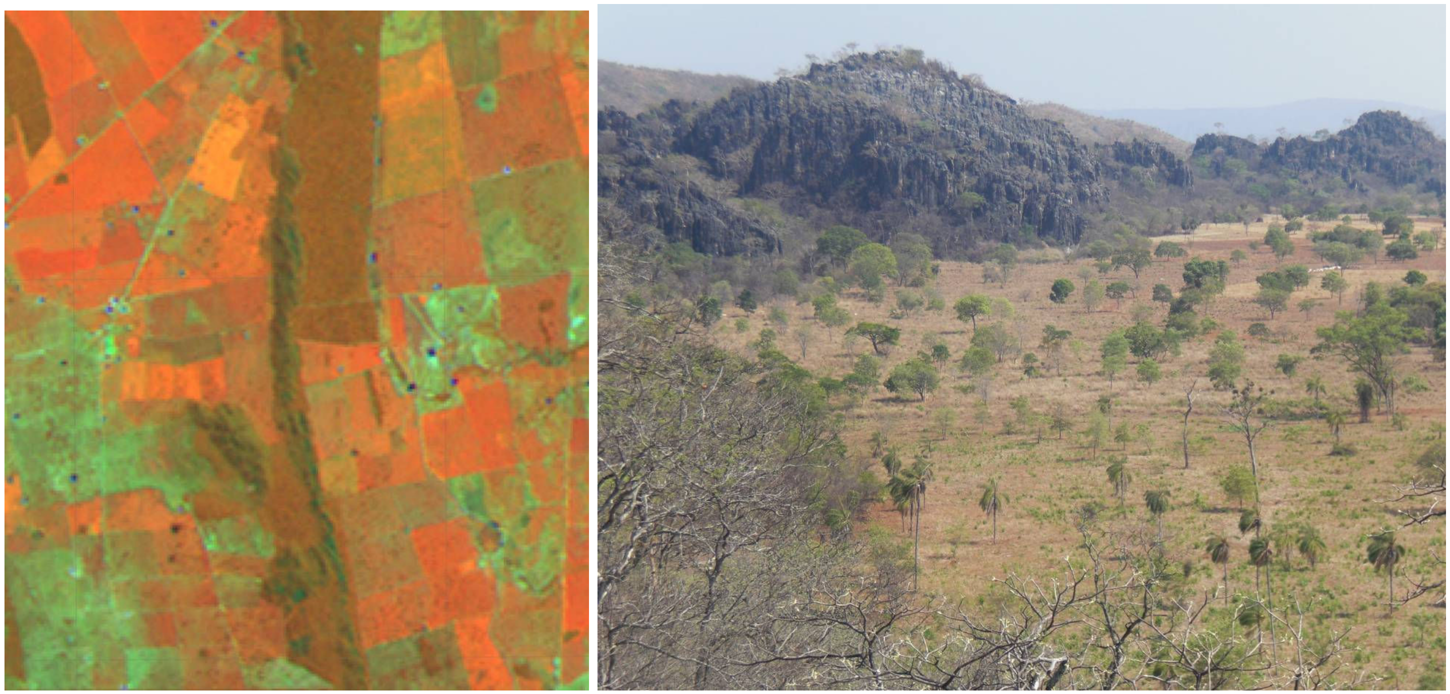

Figure 3.4. Pattern of deforestation showing pastures and croplands limited by the presence of limestone outcrops. On the left, a limestone outcrop in the center of a Landsat image from the municipality of Iaciara, Goiás (2008). On the right, outcrops with forest surrounded by pastures.

CHAPTER 4

HOME RANGE, HABITAT USE AND POPULATION DENSITY ESTIMATES FOR PFRIMER'S PARAKEET IN CENTRAL BRAZIL

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4.1 Abstract

The Pfrimer's Parakeet (*Pyrrhura pfrimeri*) is a poorly known endemic and threatened parrot of the Cerrado biome in Brazil. The species is strongly associated with the declining and heavily fragmented dry forests of the Paranã River Basin. Having almost no prior research carried out on them, their precarious status required an efficient and strategic research approach that would provide the most basic of population assessments as quickly as possible. Thus, we took a broad approach to investigate the species home range, habitat use and population estimates. Twenty individuals were monitored with radio transmitters in two areas during four months. Estimates of home ranges using fixed kernel and minimum convex polygons averaged 195.7 and 261.8 ha, respectively. Use of habitat was estimated through behavioral observations of birds flying in a mosaic of forests and pastures. We found no evidence that the species occurred in disturbed areas further than 300m from the forest edge. Moreover, the average amount of forest habitat within home ranges was less than 50% of the total home range area, but over 90% when a 300m buffer zone was added to the forest as a functional habitat. Systematic line transects and random observations of parakeets per time effort were used to estimate relative abundance. Population densities ranged between 11.2 and 14.7 individuals/km^2 and observations of birds in different areas indicate that relative abundance varies strongly among areas, suggesting the decline of populations currently found in peripheral dry-forest

fragments. Our strategic approach to learning about a little known, yet declining, species serves as a method that can be replicated for better understanding of the many species of concern for which we do not have enough information to correctly assess their status.

4.2 INTRODUCTION

Habitat loss and fragmentation have long been the greatest causes of biodiversity loss worldwide (Huxell and Hastings 1999, Wilson 2002, Schipper et al. 2008). Habitat loss usually triggers habitat fragmentation and although both processes have confounding effects, the consequences of the first on biodiversity are said to outweigh the latter (Andrén 1994, Fahrig 1997, Goodsell and Connell 2002, but see Simberloff 2000a). However, there is increasing evidence that the effects of both processes have different intensities depending on landscape type, ecological scales, geographic regions and species ranges (Haila 2002, Fahrig 2003, Wiegand et al. 2005). Therefore, habitat loss and fragmentation have an effect on landscape structure (Kouki et al. 2001, Plieninger 2006), animal populations (Bender et al 1998, Carlson 2000, Wiegand et al. 2005, Pichancourt et al. 2006), reproduction and survival of organisms (Fahrig 1998, Stephens et al. 2004), foraging (Stoner et al. 2002), and population genetic structure (Gibbs 2001; Bates 2002; Yamamoto et al. 2004).

Two components of the landscape are significantly affected by habitat loss and fragmentation: landscape composition, which refers to the amount and type of landscape elements, and spatial configuration (Turner 1989, Fahrig 1997, Wiegand et al. 2005, Ritchie et al. 2009). Responses to changes in these components vary among species, with some being more sensitive to alterations in landscape composition (Fahrig 2003), while others seem to be more affected by changes in configuration (Villard et al. 1999, Betts et al. 2006). Understanding the consequences of changes in landscape composition and configuration is crucial because both components influence the persistence of animal populations over time (Fahrig 1992, 1997; Gu et al. 2002, Kerr and Deguise 2004, Alderman et al. 2005). This becomes particularly important when dealing with rare species or species of restricted range, as they are intrinsically more vulnerable to habitat loss and fragmentation (Simberloff 2000b, Goodsell and Connell 2002, Flather and Sieg 2007) and are more prone to become threatened.

Habitat loss and fragmentation have impacted natural populations in the vast majority of species on the IUCN Red List (IUCN 2010). While these species classifications into categories of extinction risk are useful to define conservation priorities, they often do not provide further information on how to deal with the causes of population decline. Therefore, mitigation of the consequences of habitat loss and fragmentation require understanding of their effects at the species level, given the specificity of the scale of occurrence (Haila 2002, Fahrig 2003, Wiegand et al. 2005). Although the effects of these processes are known to affect several biological aspects of natural populations (Fahrig 1998, Bates 2002, Stoner et al. 2002, Stephens et al. 2004), a large number of threatened species still lacks this basic information.

4.2.1 Pfrimer's Parakeet

The Pfrimer's Parakeet (*Pyrrhura pfrimeri*) is an endemic threatened parrot of the Cerrado biome in central Brazil. The species was described by Miranda-Ribeiro (1920), later designated as a subspecies of the White-eared Conure (*Pyrrhura leucotis*) by Berla (1946), but most recently the taxonomy of the group was reviewed by Joseph (2000) and Ribas et al. (2006). They concluded Pfrimer's Parakeet should be granted full species status together with others in the White-eared Conure group. This decision is currently accepted by the Brazilian Ornithological Records Committee (CBRO 2006, resolution 111) and South American Classification Committee (Remsen et al. 2006). The species has a restrict range and little is known about its ecology and behavior other than it is strongly dependent on the highly fragmented and reduced dry forests of the Paranã River Basin (Silva 1997, Olmos et al. 1997, Bianchi 2008). Recent efforts to model its potential distribution (Bianchi and Haig *in review a*) suggested that the Pfrimer's Parakeet could occur in a much larger area (between

40,000-75,000 km^2), comprising three disjunct areas within the Brazilian Cerrado. However, field investigation failed to find the species in regions other than the dry forests of the Paranã River Basin.

The species is listed as Endangered at global level (Birdlife International 2008) and Vulnerable at national level (Ministério do Meio Ambiente 2003). Habitat loss is considered the main cause of the population decline, which is aggravated by its limited distribution (Olmos et al. 1997, Bianchi 2008, Birdlife International 2008). Recent estimates have shown an abrupt decline in forest extent in the region with high levels of fragmentation (Bianchi and Haig *in review b*). There are three protected areas within the species range, the Terra Ronca State Park, the Mata Grande National Forest and the São Domingos Area of Environmental Protection, but these areas are unlikely to maintain viable populations in the long term (Bianchi 2008). Information on poaching is unknown, yet the species is listed under CITES Appendix II (UNEP – World Conservation Monitoring Centre 2010). Captive populations are likely very small and primarily managed for commercial purposes by a few private aviculturists. Currently, there is no official captive conservation initiative. In 2000, the Brasilia Zoological Garden started a captive breeding program with ten individuals but none survived after six years (Birdlife International 2008).

In this study, we investigated Pfrimer's Parakeet use of a mosaic of forest and open areas across its range through the use of radiotelemetry and direct observations. Additionally, we describe current distribution and abundance of populations over the fragmented landscape in the Paranã River Basin. Finally, we provide an overall estimate of population densities to be used as a baseline for future monitoring and management.

4.3 METHODS

Given the potentially precarious status of Pfrimer's Parakeet and limited resources that can be directed toward their recovery, our approach to this study was to design a methodology that would yield critical population parameters in the most efficient way possible in the short term so conservation efforts could be established quickly.

4.3.1 Study area

Our study was carried out in the tropical dry forests of the Paranã River Basin, located in the Cerrado biome of central Brazil (Figure 4.1). These forests are associated with fertile karst-derived soils (BRASIL 1982), forming an eastward gradient ranging from flat areas to numerous limestone outcrops, and including one of the largest cave systems in South America (Auler and Farrant 1996, Auler 2002). The climate is typical of a tropical savanna (Köppen Aw) and is marked by a dry (April-September) and a rainy season (October-March). The annual precipitation varies between 750-2000 mm and average annual temperature ranges from 16 to 21°C

(Scariot and Sevilha 2005). The contrast between dry forests and the surrounding *cerrado* (savanna-like vegetation) is remarkable. Forest canopy is usually 20-25 m high with a fairly dense foliage structure in the rainy season that changes completely during the drought period (April-September), when approximately 90% of the trees shed their leaves (Scariot and Sevilha 2005). This xeric landscape closely resembles the *caatinga* vegetation found in the northeast of Brazil and is considered a relic of the “dry diagonal”, a large stretch of deciduous forests that connected the Caatinga and Chaco biomes in South America during the last glacial period (Prado and Gibbs 1993, Oliveira-Filho and Ratter 2002).

The dry forests in the region have extreme biological importance because they are a distinctive habitat and contain of a number of rare and/or endemic species (Ministério do Meio Ambiente, 2002). However, similar to many other tropical dry forests in the world (Janzen 1988, Sanchez-Azofeifa et al. 2005), it is threatened by rapid land conversion for human use (Scariot and Sevilha 2005) as a consequence of early government incentives and lack of adequate protection (Espírito-Santo et al. 2009). The current landscape is a mosaic of pastures, agriculture and sparse forest fragments. We estimated a 66% decrease in forest extent within the Paranã River Basin over the last 30 years (Bianchi and Haig *in review b*). Moreover, forest remnants of significant size are mostly found in association with limestone outcrops, as much of the forest on flat lands has become increasingly scarce.

Fieldwork was carried out at several sites from September to December of 2007 and 2008, which represents the period of transition between dry and rainy seasons (Figure 4.1). However, the drought period in 2007 was longer than usual, with the first rains starting in December. The cumulative precipitation during the 4-month study period ranged between 250-500 mm (Centro de Previsão de Tempo e Estudos Climáticos, CPTEC-INPE 2010). In contrast, 2008 was marked by intense rains starting in October resulting in a cumulative precipitation between 600 and 900 mm from September to December (CPTEC-INPE 2010).

4.3.2 Radiotelemetry

The radiotelemetry study was carried out in two mosaics of forest fragments, one in Aurora and one in Monte Alegre (respectively, areas 1 and 3 in Figure 4.1). These fragments are approximately 68 km apart and were selected based on the local abundance of parakeets, their geographic location in relation to the forest remnants identified by Bianchi and Haig (*in review b*), and area accessibility granted by landowners. Parakeets were captured using fixed mist-nets (2.6 x 6-9 m; 60 mm mesh) placed near foraging points. Each captured individual was measured, weighed and had blood samples collected for sex determination and genetic analysis prior to banding and radio deployment. Sex identification was obtained through molecular analysis of blood samples using polymerase chain reaction methods (PCR; Zoogen, Inc; USA). Birds were marked with stainless-steel bands provided by CEMAVE/ICMBio (Registry 281786; permit 3041/1), and fitted with a 2.1 g (4% of body weight) radio-collar transmitter package (model BD-2C, Holohil Systems Ltd., Canada). The radio ground-range was about 2-3 km and estimated lifespan was 10-12 weeks. Immediately after radio deployment, birds were kept about 20-30 minutes in a portable cage for observation and then released at the capture site. Usually individuals climbed up on trees or took short flights toward dense vegetation where they could be located for up to 60 minutes. We were able to see collared birds flying without any problem and did not observe any negative effects caused by the transmitters on the parakeets.

We used 3-element hand-held Yagi antennas, model R2000 receivers (Advanced Telemetry Systems Inc, USA), compasses and GPS (GPSMAP 76S, Garmin Intl. Inc., USA) during each telemetry session to record two simultaneous bearings per bird. Field trials were performed with test transmitters placed in known locations to determine accuracy of estimated locations and detection range (White and Garrott 1990), particularly to address concerns over potential signal bouncing in areas with limestone outcrops. Parrots were located up to six times a day in intervals of 1-15 days. Daily sampling effort was divided and balanced in 2-hour time blocks over a 12-hour daylight period (06:00-18:00), with occasional bearings taken before and after this interval to assess nocturnal movement.

Home range estimates can be calculated with a variety of methods and considerations regarding advantages and drawbacks (Powell 2000, Kenward 2001, Kernohan et al. 2001, Laver and Kelly 2008). Two methods are commonly used, one based on probabilistic densities of locations (e.g., fixed or adaptive kernels), which provides information about the internal structure (i.e., utilization distribution) of an animal's home range. Another assumes uniform use of the area encompassed by animal's movements, which links all distances between locations (e.g., minimum convex polygons; Kenward 2001, Kernohan et al. 2001). In this study, we used fixed kernel estimates with 95% and 50 % contours as the primary home range estimator given our interested in quantify home range internal structure (utilization distribution). Minimum convex polygons were used to obtain an estimate of total area used by the parakeets.

Bearings were recorded in universal transverse mercator (UTM) and entered in program LOAS (Location of a Signal, Ecological Software Solutions, USA) to estimate parrot locations. We used maximum likelihood estimators combined with best biangulation as a fallback for error estimates, bearing adjustments (Standard Deviation; $SD = 2$) and 60 iterations. Error polygons were the only associated error estimates given that just biangulations (two bearings) were used. We removed all bearing pairs that either failed to identify a location ($n = 10$) or generated error polygons larger than 10% of the (individual) home ranges calculated with the remaining locations using 95% fixed kernel estimates.

Assessment of location data prior to analysis is recommended to address a number of factors that influence the sensitivity of home ranges and movement data (White and Garrott 1990, Kernohan et al 2001, Laver and Kelly 2008). Of particular concern are issues associated with minimum sample size (Seaman et al. 1999, Girard et al. 2006, Wauters et al. 2007), autocorrelation (Schoener 1981, Swihart and Slade 1985, 1997, Solla et al. 1999, Börger et al. 2006, Hodder et al. 2007), site fidelity (Spencer et al. 1990, Kernohan et al. 2001), and bandwidth selection (Gitzen et al. 2006, Horne and Garton 2006, Fieberg 2007). Sensitivity to sample size was assessed using the asymptote analysis available in the ABODE extension (Laver 2005) for ArcMap (ESRI Inc., USA). We created area-observation plots using kernel density estimators for each individual to obtain an average of 20.3 (*SD* = 7.7, range 9-37) location points necessary to reach 90% of the home range. Serial autocorrelation of bearing groups was assessed for each bird using the Schoener's index (Schoener 1981) calculated with the Home Range Tools extension (HRT; Rodgers et al. 2007) for Arc Map. Schoener's index averaged 1.8 (*SD* = 0.4; values <1.6 or >2.4 indicate significant autocorrelation) and two individuals were excluded of subsequent analysis (values <1.6).

Home ranges were calculated using the HRT extension to estimate bivariate normal fixed kernel estimators with contours of 95% and 50% (core area), using least-squares cross-validation (LSCV) as bandwidth selection and grid resolution of 25 cells. Additionally, we calculated 100% minimum convex polygons (MCP, fixed mean) to estimate the total area encompassed by movements of individual parrots. All estimates (kernel 50%, 95% and MCP) are reported in hectares with mean and standard deviations (±*SD*). We used Kolmogorov-Smirnov goodness-of-fit test (KS-GOF) to test deviation from normality of home ranges. We assessed the influence of three explanatory variables on determining home range size: study areas, which had different extents; precipitation, which is the crucial component determining the transition between the two seasons in the region, and sex. Two-way ANOVA (Ramsey and Schafer 2002; S-PLUS v. 8.0, Insightful Corp. 2007) with statistical significance considered at $\alpha \leq 0.05$ was used to evaluate the effects of site, cumulative precipitation (September-December), sex and the interaction term including all variables (Site x Precipitation x Sex).

4.3.3 Habitat use

We recorded observations of parakeets during visits to mosaics of “forest” and “non-forest” habitats to evaluate how far they flew from the forest edge into the open landscape. At all visited sites, forest fragments were arranged in a variety of shapes, sizes and positions, with distances ranging from several meters to more than 1-2 km. For all detections, we recorded time of the day, number of birds and distance from the edge of the closest forest fragment. We considered distance as zero when birds were observed flying within or over the forest canopy. Observations were separated by at least 30 minutes to ensure independence and were carried out during a 12-hour daylight period (06:00-18:00) divided in four 3-hour time blocks to balance number of samples. Birds were detected with binoculars and recorded either as a single individual or cluster size. Distances were estimated in meters using a laser rangefinder (Yardage Pro 500, Bushnell Corp, USA). Habitat use (forest versus non-forest areas) was estimated using relative frequencies of observations per categories of distances.

A posterior analysis using telemetry data was used to infer habitat utilization by the parakeets. We used a binary (forest versus non-forest) land cover map adapted from Bianchi and Haig (*in review b*) to estimate the percentage of each habitat type found within individual home ranges. In addition, we created a map with a buffer zone around the fragments, based on the maximum distance birds were observed from the forest edge, and considered this zone as additional habitat for the species. Then, we overlaid each map with all three home range estimates obtained for each bird to quantify the percentage of "forest", "forest + buffer" and "non-forest" habitats within individual home ranges. Results are presented as the mean percentage of habitat types for each home range estimate (kernel 50%, 95% and MCP).

4.3.4 Population density estimates

Systematic surveys using line transects with a single observer (Buckland et al 2001) were carried out to estimate population densities in three areas: Aurora, Monte Alegre and the north portion of the Terra Ronca State Park located in the municipality of São Domingos (Figure 4.1). We established ten permanent transect lines either along the edge or within forest fragments, covering 40 km (mean line length = 4.0 km; *SD* = 1.8). Surveys were carried out by walking along transects between 07:00-10:00 and 15:30-18:00, using binoculars, GPS (GPSMAP 76S, Garmin Intl. Inc., USA), laser rangefinder (Yardage Pro 500, Bushnell Corp., USA) and angle ruler. For each visually detected group of parakeets, we recorded cluster size, time, distance of animals to the observer and respective angle to the line transect. Distances and angles were measured to the center of clusters. Each line was surveyed on average 6.1 times during the study period (*SD* = 3.7, range 3-12), tallying 226 km of sampling effort. Data analyses were carried out in program Distance (Thomas et al. 2006). Prior to parameter estimation, we assessed data to verify the potential presence of evasive movement, heaping and rounding, following recommendation for exploratory analysis (Buckland et al. 2001). Temporal replicates of each transect were pooled and treated as a single sample within sites because of the small number of survey lines. Additionally, it is recommended to restricted inferences only to density estimates by assuming a Poisson distribution of the variance estimate with the overdispersion factor set to zero (Buckland et al. 2001, Thomas et al. 2006). Thus, population densities were calculated for each study site separately and then grouped to estimate values for the entire region. Visual inspection of model fit and the Akaike's Information Criterion (AIC) provided by program Distance were used to select the best model for each particular dataset. Results are presented as number of encounters, density estimates per square kilometer with 95% confidence interval, coefficients of variation and probabilities of detection.

In addition to systematic surveys, we recorded the number of parrots observed during searches for the species at 15 sites selected based on Bianchi and Haig (*in review b*) and the existence of forest fragments with apparent good habitat for the species. These observations were converted into an index to estimate the relative abundance per site (number of individuals/100 hrs; Willis 1979; Willis and Oniki 1981) and are presented by municipality for geographical reference. We used a simple linear regression model (Ramsey and Schafer 2002; S-PLUS v. 8.0, Insightful Corp. 2007) to test the association between sampling effort and indices of temporal relative abundance.

4.4 RESULTS

4.4.1 Home range estimates

We captured and marked 30 adult parakeets (15M:15F). Four birds disappeared during the study and transmitters were never found and three were depredated, as we found transmitters with body parts (1) or feathers (2) no more than 10 (2) and 42 days (1) after radio deployment. Therefore, we were able to track 23 individuals: 12 (5M:7F) in Aurora and 11 (5M:6F) in Monte Alegre. A total of 923 successful detections were obtained, with an average of 40.1 (*SD* = 5.7; range 31-55) locations per bird. Telemetry data were collected from September to December of 2007 and 2008, with duration of monitoring ranging from 27 to 62 days (*mean* = 45.8; *SD* = 13.2) per individual. The average number of days with successful locations per bird was 13.5 (*SD* = 3.4, range 8-20), the interval between detection days ranged from 1 to 15 days (*mean* = 3.7; *SD* = 4.3). On average, 2.9 (*SD* = 1.5; range 1-6) daily locations were recorded for each bird, with an average interval between locations of 154.8 minutes (*SD* = 88.5, range 40-662). Mean error between actual and estimated locations was 57.8 m (*SD* = 16.1; n = 3) and mean azimuth error of 5.9° (*SD*= 1.3°; n=3).

We were able to estimate home ranges of Pfrimer's Parakeets based on data from 20 individuals, with a mean number of 38.7 locations (*SD* = 5.9, range 30-53) and 0.7 ha as the overall mean error polygon. Fixed kernel estimates calculated at different contours (95% and 50% - core area) were normally distributed (95% fixed kernel; *KS-GOF*= 0.233; $P = 0.192$; and 50% fixed kernel; *KS-GOF*= 0.244; $P = 0.154$). The mean size of 95% fixed kernel was 195.7 ha ($SD = 168.7$), ranging from 13.4 to 535.9 ha (Table 4.1). Significant differences were found between sites (ANOVA; $F_{1,12}$= 20.310; $P = 0$), cumulative precipitation ($F_{1,12}$= 5.697; $P = 0.034$) but not between sex ($F_{1,12}$= 1.962; $P = 0.186$) nor the interaction including all three variables ($F_{1,12}$= 0.561; $P = 0.468$). The interaction term between sites and precipitation also had significant effects on the 95% kernel estimate ($F_{1,12}$= 6.368; $P = 0.026$). The 50% fixed kernel (core area) indicated a mean home range size of 42.6 ha ($SD = 36.3$; range 2.5-109 ha; Table 4.1). No differences were found between sex (ANOVA; $F_{1,12}$= 0.947; $P = 0.349$) or the interaction among sites, precipitation and sex ($F_{1,12}$= 0.303; $P = 0.591$). However, we found differences between sites ($F_{1,12}$= 17.677; $P = 0.001$) and suggestive but inconclusive evidence of difference in precipitation ($F_{1,12}$= 3.440; $P = 0.088$) and in the interaction between sites and precipitation ($F_{1,12}$= 4.593; $P = 0.053$). Finally, minimum convex polygons were normally distributed (*KS-GOF* = 0.226; $P = 0.225$) and had an average size of 261.8 ha ($SD = 224.2$; range 20.9-626 ha; Table 4.1). We found significant differences in MCP between sites (ANOVA; $F_{1,12}$ = 24.466; $P = 0$), precipitation ($F_{1,12}$ = 12.681; $P = 0.003$) and the interaction of sites and precipitation ($F_{1,12}$= 11.001; $P = 0.006$); but not between sex ($F_{1,12}$ = 2.304; $P = 0.154$) or the interaction including all three variables ($F_{1,12}$= 0.008; P = 0.928). Home range sizes per site and year are presented in Figure 4.2, and suggested that home ranges at the Aurora site in 2007 were larger than in 2008 for that site and also larger than in Monte Alegre in both years.

4.4.2 Habitat use

Habitat use was recorded at 15 sites (n = 283 obs.), with an average of 70.8 (*SD* = 19.9) observations per time block. Parakeets were found flying less than 100 m away from the forest edge in 80.9% (*n* = 229) of the observations. Over half (52.6%, *n* = 149) of the observations were recorded within or over the forest canopy (distance = 0 m; Figure 4.3). The average distance of individuals or groups from the edge (excluding distances equal to zero) was 89.6 m (*SD* = 58.4; *n* = 134), with no record beyond 300 m (range 8-281). Although the typical behavior of a bird was to fly near or within forest patches, they were also seen crossing open areas (e.g., pastures). They tended to follow the forest edge and then use the shortest path connecting two fragments when moving between fragments. Often, they would make quick stops (2-3 min) in trees in the open areas. On other occasions, birds flew to isolated trees where they spent time foraging or resting before returning to the forest. Based on the maximum observed distance estimate (280 m) and behavioral observations, we considered a maximum distance of 300 m from the forest edge to be set as the buffer representing the “functional boundary” of the species’ habitat in the subsequent analysis using home range estimates.

The mean percentage of forest habitat within home ranges using the original land cover map was less than 50% for all home range estimators (Table 4.2). Additionally, forest habitat was greater in its relative extent between the MCP and the fixed kernel estimators, with the highest values recorded in the core areas (50% kernel). However, results varied after adding the buffer zone to the forest, as the amount of habitat used within home ranges became larger than 90% for all home range estimates (Table 4.2).

4.4.3 Population density estimates

Densities estimates for each area followed by 95% confidence intervals, coefficients of variation and probabilities of detection are presented in Table 4.3. Model evaluation based on AIC scores supported the half-normal key function with two cosine adjustments as the best model for surveys carried out in Aurora and Monte Alegre, and also for the overall density estimate after all surveys were pooled. The uniform model with one cosine term was the best fit for surveys carried out in the north part of Terra Ronca State Park. We used right truncation to discard 10% of the largest distances and reduce the influence of a few outliers. The effective number of encounters per site was 34 for Aurora, 48 for Monte Alegre, 33 for Terra Ronca State

Park and 116 for the analysis of pooled areas. Except for an overall estimate using pooled data, the number of encounters was very close to the minimum recommended (n = 40) for reliable population density estimations (Buckland et al. 2001). The coefficients of variation with large values in all cases indicate high levels of model uncertainty, which was also evident by the range of 95% confidence intervals for all areas (Table 4.3).

The relative abundance of parakeets differed significantly among visited sites (Table 4.4, Figure 4.1). Minimum sampling effort per site, defined as four hours, was approximately twice the average time elapsed between the start of our search until the first detection. Three areas below that threshold were removed from the analysis (Guarani de Goiás, 13°58'S 46°26'W; Novo Jardim, 11°47'S 46°38'W; Ponte Alta do Bom Jesus, 11°55'S 46°33'W). Despite the existence of suitable habitat, we failed to find the species in three of the 12 remaining areas: Dianópolis (11°38'S 46°41'W), Natividade (11°36'S 47°38'W) and São Desidério (12°26'S 44°54'W). We found the parakeets in nine other locations, with temporal relative abundance ranging between 88 and 2053 birds (Table 4.4), although the results were significantly associated with the sampling effort (number of hours surveyed per sites: *mean* = 14.9; *SD* = 9.2; range 4.3-29.0; linear regression model; $F_{1,10}$= 6.33, P = 0.030, r^2= 0.387).

4.5 DISCUSSION

The results of this study represent a multi-faceted approach that must be undertaken to more fully understand factors contributing to habitat use and movements among birds in highly fragmented ecosystems. It is the first analysis of space use by a *Pyrrhura* species, one of the largest groups of small parakeets in South America (Juniper and Parr 1998).

4.5.1 Home range

Our radiotelemetry study estimated that average home ranges of Pfrimer's ranged between 195.7 (95% kernel) and 261.8 (minimum convex polygon) km^2 and suggested that variation in size may occur depending on seasonality and habitat availability. Moreover, the use of two estimators produced complementary information about patterns of area use. The fixed kernel method has the ability to describe the internal structure (utilization distribution) of home ranges based on density probability (Powell 2000, Kernohan et al. 2001) and therefore, reflects the intensity of use of different spaces within the home range. In this study, the area comprising the highest 50% probability of use (50% kernel) had average size of 42.6 ha (Table 4.1) with 44.3% of this extent represented by forest habitat (Table 4.2). Furthermore, occasional events of parakeets flying outside areas of intense use were expected (Powell 2000, Kernohan et al. 2001) and the minimum convex polygon estimates were capable of capturing such behavior efficiently. Because this method adds all observed locations encompassed by birds' movements without estimating intensity of use, its estimated home ranges were larger than those generated by kernel estimators (Table 4.1). We recommend the average size of the 95% kernel (195.7 ha) to be used as the minimum home range estimate for the Pfrimer's Parakeet as this threshold encompasses roughly 65-70% of the range of sizes reported in this study.

We did not expect to find differences in home range sizes between males and females as parrots are gregarious birds forming flocks of varying size during most of the annual cycle (Chapman et al. 1989, Sick 1997, Juniper and Parr 1998). The flocks are composed of pairs or familial groups with similar numbers of both sexes (Sick 1997, Juniper and Parr 1998). In contrast, differences in home range estimates across study sites were expected. Home range size for parakeets in Aurora was more than three times larger than in Monte Alegre (Table 4.1). This might be explained in part because the fragments in the first are larger and more numerous than in the latter (Figure 4.2). However, home range estimates varied considerably in size. Thus, caution is recommended when assuming a direct relationship between area extent and home range size. This hypothesis could be better tested if a large continuous forest area existed in their range.

We found a significant effect of precipitation on determining home range size. This is also evident based on differences found between sites and years (Figure 4.2), with “year” accounting for cumulative precipitation. In tropical environments, the end of the dry season is known to be a critical period for many animal species, as availability of resources can be severely affected (Renton 2001). Thus, individuals might be forced to expand home ranges and increase time looking for food to cope with shortage of resources (Stone 2007, Schradin et al. 2010). Although it was not possible to dissociate site and precipitation for statistical testing because of sample size limitations (only 2 birds for 2007 in Monte Alegre), we found suggestive evidence that Pfrimer’s Parakeet might increase space use during prolonged periods of drought, particularly if more area was available. Monitoring collared individuals over the annual cycle in areas of different sizes would provide a better understanding about the influence of habitat availability and seasonality on determining home range size.

4.5.2 Habitat use

Our observations suggest that habitat loss and fragmentation are potentially affecting the way Pfrimer’s Parakeet uses its habitat. However, our ability to detect such ecological effects depends on how close the scale of our measurements matches the scale of the species given that each species observes the environment on its own spatial and temporal scale (Wiens 1989, Wiens and Milne 1989, Levin 1992). Although there is a vast literature about concepts, methods and flaws of assessing and interpreting habitat use and availability (see Garshelis 2000 for a review), the main purpose of our investigation was to have a reasonable understanding about how Pfrimer's Parakeet perceives and uses a highly fragmented landscape.

Observations of the parakeets in the field were balanced throughout the day, which allowed us to draw inferences about their behavior in relation to habitat. First, parakeets were observed flying over or within the forest canopy in 53% of the records. This supports the evidence of a strong connection with this habitat as they are found in the forest more than half of the daytime period. Second, in the remaining 47% of observations, parakeets were not found flying farther than 300 meters from the forest edge and usually were found in much shorter distances (Figure 4.3), which has also been observed for other parrot species (Marsden et al. 2000, Robinet et al. 2003). This suggests that the habitat, as seen at this species' scale, comprises non-forest areas that are within a certain range from the forest edge. It also explains their behavior of moving among fragments by using paths with higher forest cover, similar to what has been observed for hummingbirds (Hadley and Betts 2009). If, in fact, they see this additional area as useable habitat, the combination of forest plus the buffer zone of 300 m can actually be interpreted as the “functional” habitat of the species. However, the causal effect of such behavior remains unclear. For example, Marsden et al. (2000) argued that behavior of the birds rather than habitat unsuitability might be stopping other *Pyrrhura* spp. from crossing open landscapes. This explanation can find support either in behavioral components related to animal’s decision (Lima and Zollner 1996, Bélisle 2005) or in landscape characteristics such as composition (Fahrig 2003), configuration (Villard et al. 1999, Betts et al. 2006) or matrix complexity (Bender and Fahrig 2005).

The confounding effects of landscape composition, configuration and species behavior becomes more evident when home range estimates are incorporated into habitat analyses. Overlapping individual home ranges with the land cover map (Bianchi and Haig *in review b*) allowed us to estimate the percentage of habitat (forest and non-forest) that exists for each bird within its home range (Table 4.2). In the original classification, we found an average of forest habitat ranging between 34 and 44.3%, with the proportion of forest increasing towards the center of the home range (i.e., 50% kernel > 95% kernel > MCP). When the buffer zone was added as part of the parakeets’ habitat, more than 92% of the home range extent fell within this “functional habitat”. The existence of less than 45% of forest habitat within the home range of a forest bird like the Pfrimer’s Parakeet suggests a striking effect of habitat loss and fragmentation. Conversely, it implies that an additional area not necessarily represented by the ideal habitat has been incorporated into their home ranges. In our study, this additional area is suggested to be represented by the 300 m around the forest fragments. However, the degree to which the species can tolerate this change is unknown, although likely dependent on the landscape composition and configuration. A similar case was observed for the Blue-winged Macaw (*Primolius maracana*), where the landscape mosaic was represented by only 25% of the original habitat, which likely explains the cause of the observed population decline (Nunes and Galetti 2007).

The importance of dry forests and their decline have significant implications for future management and conservation practices for Pfrimer's Parakeet. For example,, observations of groups of parakeets flying over open pastures and heavily disturbed areas has been mistakenly interpreted by local farmers as the species being able to persist in harsh environments. However, it is not clear how these landscape elements play on determining the ability of the species to use and persist in a changing environment.

4.5.3 Population density estimates

Results indicated equivalent densities and probabilities of detection of Pfrimer's Parakeet in the three sites sampled, which yields an overall estimate of 11.7 individuals/km^2. In contrast, relative abundances varied significantly among sites located in many portions of the distribution range, with low estimates recorded in mosaics of fragments located in the periphery of the dry forest region.

Some limitations in our data from the line surveys must be outlined before further discussion of their value. The methods used in this study are estimates of relative abundances, based either on extent (area), where numbers can be extrapolated to estimate total population size, or time (hours), that can be used to compare different areas where systematic surveys (e.g., line counts) are lacking (Morrison et al. 2001, 2006). Thus, we combined both methods to make inferences about the current population size of the Pfrimer's Parakeet in the region. However, variations on these estimates are likely related to differences in the absolute population size, area extent, detectability of birds and sampling scheme. Therefore, inferences are limited (Gibbs 2000). The number of detections per site was below the minimum of 40-60 suggested for analysis in program Distance (Buckland et al. 2001). This may partially explain the large range of values in the coefficients of variation (CV) and in the 95% confidence intervals obtained for each area. When all surveys were pooled and the number of detections increased to 116, both CV and 95% confidence intervals were reduced (Table 4.3). Another drawback is that we should have prioritized a large number of transect lines instead of several replications per line. Although transect lines were placed to cover different habitats on each site, replications might significantly affect density estimates, causing problems such inflation in variation associated with encounter rates (Buckland et al. 2001, 2008, Jathanna et al. 2003).

Despite these limitations, density estimates obtained here were robust enough to be used as a baseline for future monitoring and represent the best information available for the species. Moreover, our density estimate (11.7 individuals/km^2) is comparable to other studies surveying *Pyrrhura* spp. at different sites in the Atlantic Forest of Brazil. Guix et al. (1999) estimated densities of Maroon-bellied Parakeet (*P. frontalis*) at 13.06 individuals/km^2 on São Sebastião island; and Marsden et al. (2000, 2001) found densities of Blue-chested Parakeet (*Pyrrhura cruentata*) and Maroon-faced Parakeet (*P. leucotis*) in the Sooretama-Linhares reserve at, respectively, 41.3 and 41.9 individuals/km^2.

The relative abundance of parakeets based on time effort varied widely among the nine sites analyzed (Table 4.4). However, if seen as an indirect indicator of population size (Pollard and Greatorex-Davies 1998, Collier et al. 2008), the index suggests that Monte Alegre, Aurora and the north part of the Terra Ronca State Park (respectively areas 3, 1 and 2 – Figure 4.1) are the sites with the largest populations of Pfrimer's Parakeet. Our surveys in these areas were carried out during a period of massive fructification of cultivated trees (e.g., mangos and guava) that attracted large groups of parrots and might have affected the local abundance of birds. As food availability tends to decrease at the end of the dry season in tropical ecosystems

(Renton 2001, Brown and Sherry 2006), large gatherings of parrots exploring temporal and abundant food resources can be expected (Roth 1984, Pizo et al. 1995, Rivera-Milán et al. 2005, Cockle et al. 2007). In contrast, despite a similar sampling effort, the sites in Divinópolis, Arraias and Posse (areas 6, 5 and 8 – Figure 4.1) have relative abundance below 50% of the average abundance of areas 1, 2 and 3. A similar trend is observed when looking at the time elapsed from the beginning of the search and the first observation. Overall, the time for the first detection was 2.6 times shorter in sites with largest abundance (mean time for areas 1, 2 and 3 = 0.93 h; and for areas 5, 6 and 8 = 2.6 h). Sites in Nova Roma (area 7) and in Iaciara (area 9) had the lowest indices of relative abundance and the longest time elapsed until the first encounter, suggesting the existence of very small populations. From a geographic perspective, it is interesting to note that sites 5 to 9 (except 6) are located in the periphery of what was once the bulk of the dry forests distribution in the Paranã River Basin. Bianchi and Haig (*in review b*) reported a displacement pattern on deforestation, with larger fragments remaining in the eastern portion of the basin where the limestone outcrops are commonly found. Thus, it is not surprising that large populations of Pfrimer's Parakeet will be found where the large fragments are located. Contrary to this pattern is the mosaic of fragments in Monte Alegre (area 3), which has been heavily deforested. Although no inference can be made about long term population persistence in the region, periodic monitoring of sampled areas could provide crucial information about trends in abundance over time, particularly on peripheral populations.

Population estimates presented here are the first for the species since Olmos et al (1997), which have estimated density to be between 60-75 individuals per square kilometer, based on surveys carried out in one site (Nova Roma – area 7 in this study) fifteen years ago. The authors stated that total population size could be ranging around 162,000–202,500 parakeets. Our estimates for all areas combined range between 9-15 individuals per square kilometer (95% confidence interval), which gives an estimate of total population size between 39,168–65,280 based on the 4,352 km^2 of forest still remaining as reported by Bianchi and Haig (*in review b*). If both of these estimates are correct, this represents a population decline of approximately 72% in 15 years. However, extrapolations to estimate absolute population size demand extra caution and numbers should be interpreted within an ecological perspective. Issues with detectability are one of the major concerns in obtaining estimates of abundance and, consequently, extrapolations of absolute population size (Pollock et al. 2002, Royle 2004, Kéry et al. 2005). One example from the Pfrimer's Parakeet, is that density estimates came from sites with high relative bird abundance possibly caused by large gatherings of parakeets visiting temporal food resources, which might have inflate overall estimates. In fact, if abundances are different among areas as suggested in our results, estimates of absolute population size as a result of direct extrapolation to a fixed number representing area extent are a subjective approximation.

This study is part of a broad approach (Bianchi and Haig *in review a, b*) to investigate the consequences of anthropogenic pressures over ecological processes on the endemic Pfrimer's Parakeet. So far, the species was known to occur in the dry forests of central Brazil, with limited information about its ecology (Olmos et al. 1997, Silva 1997). It has been listed as Endangered since 2007 because "…*the species has an extremely small range which is severely fragmented and within which habitat loss and degradation are continuing…*" (Birdlife International 2008), but no further information was available to determine the impacts of habitat loss and fragmentation in current populations. Our results have provided information about home range sizes, movement scale within forest mosaic and spatial structure of populations throughout the distribution range. Collectively, they provide a baseline to plan appropriate conservation measures for this and potentially for other species of parakeets with similar degree of habitat association. Our approach represents an innovative combination of methods needed to quickly obtain information about threatened or poorly known taxa over a short term.

Acknowledgements

We thank B. Cline, D. Kesler, and P. Laver for their assistance with methods, data analysis of radiotelemetry. P. Haggerty provided help with GIS issues. M. Huso helped with statistical analysis. A. Portella, F. Bianchi, I. Faria, M. Bizerril, M. Reis, F. Ervilha, R. Cardoso helped in fieldwork. The USGS Forest and Rangeland Ecosystem Science Center, Fundação O Boticário de Proteção à Natureza, Cleveland Metroparks Zoo (Scott Neotropical Fund), Parrots International, Canadian Parrot Symposium, Pesquisa e Conservação do Cerrado (PEQUI), Pacific Islands Conservation Research Association have provided financial support for this study. The Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) and the Centro Nacional de Pesquisa para Conservação das Aves Silvestres (CEMAVE) granted permits (16808-1; 3041/1) for the fieldwork in Brazil. CAB was supported by a CAPES/Fulbright doctoral scholarship (15053166/201604-4).

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Table 4.1. Mean home range estimates (fixed kernel density at 95% and 50% contours and 100% minimum convex polygon) for the Pfrimer's Parakeet in two areas of central Brazil using radiotelemetry during 2007 and 2008. Home range areas in hectares followed by standard deviations (*SD*).

Locality	N Birds	Kernel 95%	Kernel 50%	MCP
Aurora	10	303.4 (177.9)	66.4 (37.4)	398.2 (240.9)
Monte Alegre	10	87.97 (51.7)	18.9 (11.2)	125.4 (81.8)
Overall	20	195.7 (168.7)	42.6 (36.3)	261.8 (224.2)

Table 4.2. Mean percentage of habitat types found within home ranges of 20 Pfrimer's Parakeets using a land cover map with binary classification (see text for details). Home range estimates in hectares.

		Habitat type within HR (%)			
		Original		Buffer (300 m)	
HR Estimator	Mean size	Forest	Non-Forest	Forest + Buffer	Non-Forest
Kernel 95%	195.7	40.8	59.2	95.6	4.4
Kernel 50%	42.6	44.3	55.7	99.6	0.4
MCP	261.8	34.0	66.0	92.2	7.8

Table 4.3. Population density estimates of the Pfrimer's Parakeet at three sites and pooled for the entire region. N= number of encounters; D= Density (inds/km^2); D(CV)%= density coefficient of variation; D(95%CI)= density 95% confidence interval; and P = probability of detection.

Site	N	D	D (CV)%	D (95% CI)	P
Aurora	34	11.2	27.5	6.5-19.2	0.49
Monte Alegre	48	14.7	23.0	9.4-23.2	0.58
Terra Ronca State Park	33	10.2	19.2	7.0-15.0	0.62
All areas (pooled)	116	11.7	13.2	9.0-15.2	0.47

Table 4.4. Relative abundance of Pfrimer's Parakeet in nine sites in central Brazil. Geographical coordinates indicate specific site locations within municipalities.

Municipality	Geographical Coordinates	Relative Abund. (n/100 h)	Total Effort (hr.)	Elapsed Time (hr.)
Monte Alegre	13°16'S 46°48'W	2053	19.0	0.5
Aurora	12°39'S 46°28'W	1549	19.5	1.3
São Domingos	13°31'S 46°23'W	1396	25.0	1.0
Taguatinga	12°23'S 46°30'W	765	8.5	1.5
Divinópolis	13°13'S 46°30'W	628	19.6	3.2
Arraias	12°46'S 46°45'W	585	21.4	1.2
Posse	14°04'S 46°27'W	472	29.0	3.2
Nova Roma	13°46'S 46°51'W	143	8.4	6.2
Iaciara	14°11'S 46°46'W	88	6.8	6.1

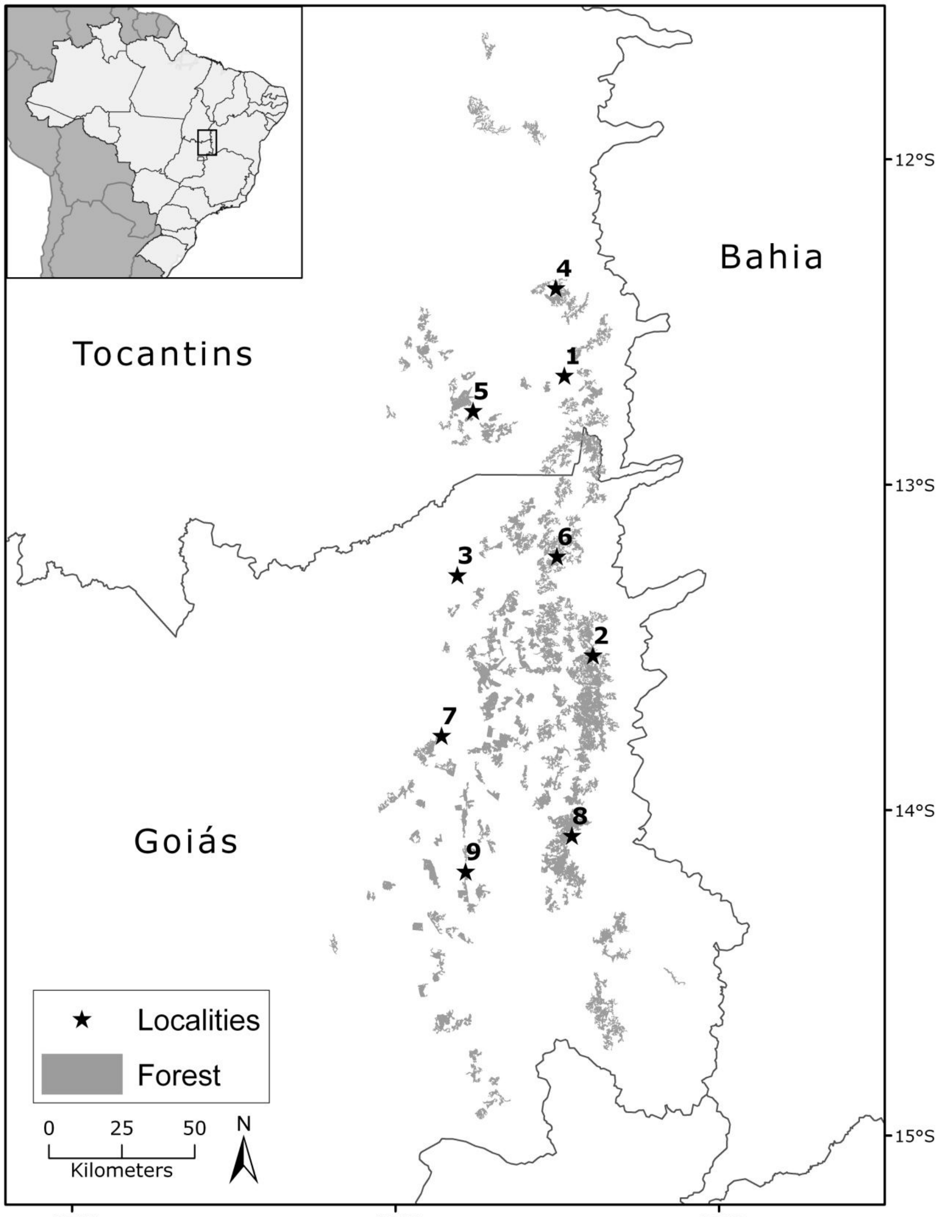

Figure 4.1. Dry-forest remnants in the Paranã River Basin (Tocantins and Goiás states), central Brazil (adapted from Bianchi and Haig *in review b*). Stars represent study sites located within the following municipalities: 1- Aurora; 2- São Domingos; 3- Monte Alegre, 4- Taguatinga; 5- Arraias; 6-Divinópolis; 7- Nova Roma; 8- Posse and 9- Iaciara.

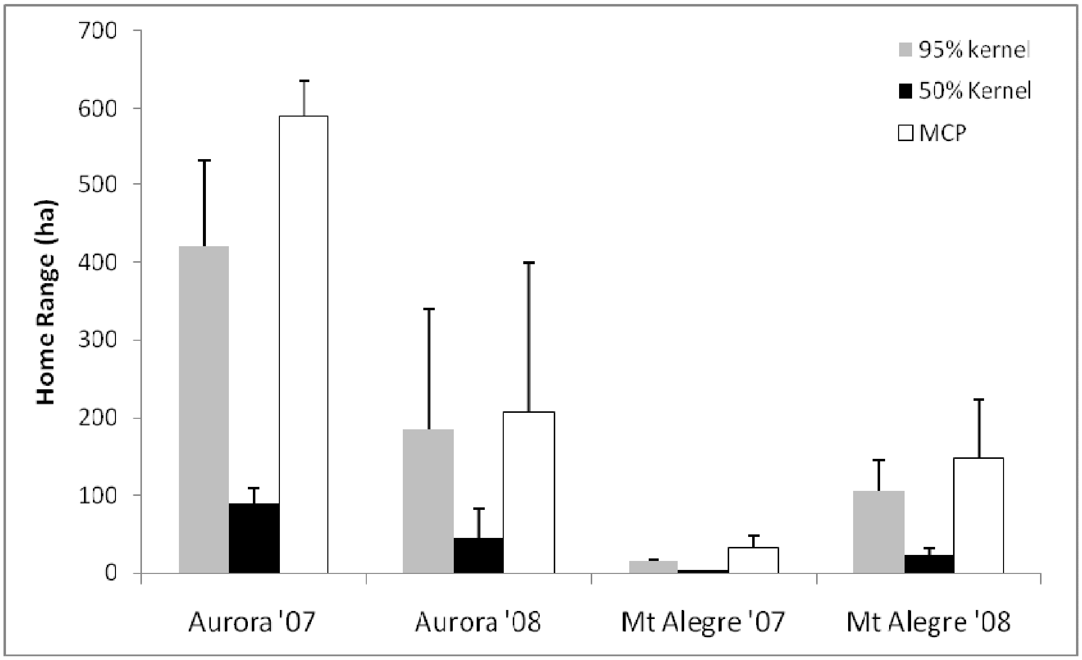

Figure 4.2. Home ranges of Pfrimer's Parakeet based on 95% kernel, 50% kernel and minimum convex polygons MCP) per study site and year (bars representing SD).

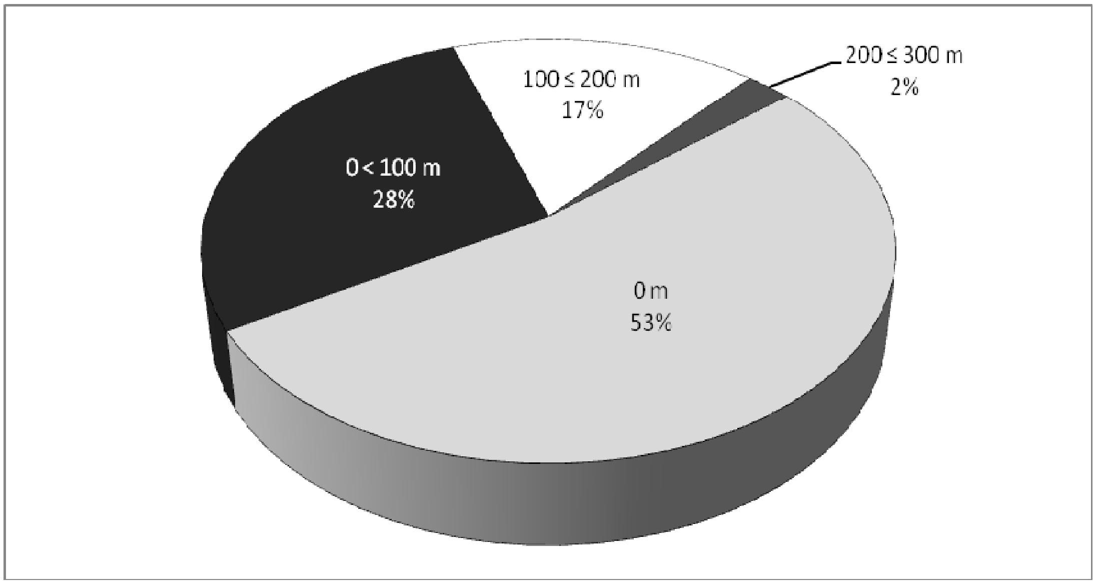

Figure 4.3. Observed distances of Pfrimer's Parakeet from the forest edge.

CHAPTER 5

CONCLUSIONS

5.1 Potential Distribution, Habitat Use and Population Structure of the Pfrimer's Parakeet in central Brazil

This dissertation presented a novel approach, the Rapid Endangered Species Assessment, as a means to improve information collection about poorly known species that demand assessment of extinction risk. The model was developed using the endemic and yet threatened Pfrimer's Parakeet that occurs in the tropical dry forests of the Cerrado biome in central Brazil. Results presented here bring a wide range of new information about the species that will significantly impact future evaluation of its conservation status.

The potential distribution of the Pfrimer's Parakeet was modeled and validated in chapter two. I used the maximum entropy method (Maxent, Phillips et al. 2006) to predict the distribution of the species through a three-step process: (1) development of an initial model, using 13 unique localities to generate the first predicted distribution range, (2) field investigation to verify the species' occurrence in the areas suggested in the initial model, (3) model refinement using a combination of previously known and new occurrence records to improve the predicted distribution. Seven environmental variables were incorporated into the model after a two-step variable selection process that included multi-colinear analysis (Buermann et al. 2008, Kumar and Stohlgren 2009) and training gain sensitivity analysis after variable removal (Yost 2008). The initial model suggested a total distribution area ranging from 40,290 (minimum training presence threshold, MTP) to 74,450 km^2 (fixed cumulative 10 percent threshold, FC10) distributed in three main regions of the Cerrado biome. Subsequent field investigation in 75 localities within the predicted areas found the species in 17 sites, all located in the range of the dry forests of the Paranã River Basin. Model refinement using 10 new occurrence points and the same set of environmental variables produced a predicted area ranging from 33,812 (MTP) to 50,864 km^2 (FC10). Although a number of inferences and applications can be drawn from the model outputs, the most practical and important result was identification of the Paranã River Basin as the core area of the species' potential distribution. These results set the boundaries and guided the subsequent analysis of habitat loss and fragmentation.

In chapter three, I presented the results about deforestation trends in the Paranã River Basin in a large spatiotemporal scale that is unique for the region. Remote sensing analysis and GIS methods were used to estimate deforestation rates in the area (59, 403 km^2) in three time intervals over 31 years (1977-2008). Unsupervised classification into two categories (forest and non-forest) of Landsat MSS 3 and TM5 satellite imagery produced binary land cover maps with high accuracy (>89% for year 2008). Reduction in forest extent was estimated to be 66% between 1977 and 2008 with high levels of fragmentation based on the increase in number of patches and reduction of area. It also indicated that forest loss was more severe in the flatlands of the western part of the basin, resulting in forest fragments being limited to areas with limestone outcrops. Deforestation processes of this magnitude are likely to cause severe impacts on rare species or species of restricted range like the Pfrimer's Parakeet (Carlson 2000, Simberloff 2000, Goodsell and Connell 2002, Manu et al. 2005). Therefore, the conservation implications of this study are many, as the dry forests of the Paranã Basin are among the largest tropical dry forest formations in Brazil (Scariot and Sevilha 2005) and have been classified as a high priority for biodiversity conservation by the Brazilian national government (Ministério do Meio Ambiente 2002). The results presented in this chapter will also serve as a baseline for future monitoring and establishment of conservation measures for this habitat, benefiting many species that are associated with these forests.

Ecological aspects of Pfrimer's Parakeet life history such as home range, habitat use and population estimates were addressed in chapter four with the goal of depicting the current spatial structure of the species' population. Specific field methods were applied over a period of eight months, including radio telemetry (Kernohan et al. 2001), systematic surveys using transect lines (Buckland et al 2001) and behavioral observations of habitat use. Home ranges were estimated to have an average size of 195.7 hectares (fixed kernel density estimate) with variations in size likely related to fragment extent and seasonality. Parakeets were seen using mostly forested areas but made brief but frequent excursions into non-forest areas distant up to 300 meters away from the forest edge. Results suggest that Pfrimer's Parakeet populations more than a few kilometers apart from each other might be demographically, if not genetically isolated. Population density was estimated in 11.7 individuals/km^2 based on surveys carried out in three areas. However, estimates of relative abundance based on time effort have shown that populations likely have different sizes among fragments, suggesting that small populations are found in the periphery of the dry forest remnants in the Paranã River Basin. The results of this chapter represent a starting point for future monitoring of Pfrimer's Parakeet population trends and genetic analyses.

5.2 The *Rapid Endangered Species Assessment* as a Conservation Tool

The approach I have proposed in this dissertation represents an innovative combination of methods needed to obtain information about poorly known or "data deficient" taxa over a short period of time, in order to provide a baseline for extinction risk assessment. I successfully tested its application using a little known species with status concern. This suite of methods has a great potential to be used as a conservation tool at multiple scales (from landscape to population structure), hence it represents an advancement for conservation science.

From a species perspective, this dissertation provides the most detailed study of Pfrimer's Parakeets to date. Until this work, the species was known to occur in the dry forests of central Brazil, with limited information about its ecology (Olmos et al. 1997, Silva 1997, Bianchi 2008). It has been listed as Endangered since 2007 because "…*the species has an extremely small range which is severely fragmented and within which habitat loss and degradation are continuing…*" (Birdlife International 2008), but no further information was available to determine the impacts of habitat loss and fragmentation in current populations. After taking the broad investigative approach described in this study, it is possible now to report that (1) although distribution modeling tools have suggested a much larger occurrence area for the species, field investigations support its presence in the Paranã River Basin and, therefore habitat protection should focus in this specific region; (2) deforestation levels in their prime habitat are extremely high in the region. I report a 66% decline in forest extent over a period of 33 years with more forest remnants being found in the eastern portion of the basin; and (3) the species has an average home range size of about $2km^2$, it is extremely limited in movements within forest mosaic and populations are potentially isolated and unbalanced in numbers throughout the distribution range. Collectively, these results provide a baseline to plan appropriate conservation measures for this and potentially for other similar species of parakeets.

From a conservation perspective, the “Rapid Endangered Species Assessment” seems to be a promising approach which can be applied in two major scenarios: (1) to provide information about poorly known species, and (2) to improve data available about species already classified as threatened. In the first scenario, extinction risk assessment demands the existence of species specific information to be contrasted against some particular reference data, through analysis of biological criteria related to population size, geographic range and area of occupancy. The process is essentially a comparison of the species’ population status in two time intervals. However, if no reference data are available or existing data is considered inadequate for a reasonable assessment, candidate species cannot be evaluated and, following the IUCN system, are classified as “data deficient”. Thus, the Rapid Endangered Species Assessment approach can be used in this case to obtain the primary information needed to set the reference data for extinction risk assessment of poorly known or “data deficient” species. In the second scenario, when enough data are available for species assessment, the evaluation process generates information about population trends that are ultimately translated into a final classification represented by different categories of threat. However, as the causes of threats are usually too broadly defined (e.g., habitat loss, illegal trade, etc.)

and do not provide information about how current populations have been affected, the establishment of effective conservation priorities is delayed. In this case, the Rapid Endangered Species Assessment approach can help in providing specific information about population aspects (e.g., demography, reproduction, genetics, etc.) that have been more severely affected by such threats, and be used to guide development of priority conservation actions. The Rapid Endangered Species Assessment is a combination of several methods carried out over a short period of time. Its working principle and the questions that can be addressed with this approach are illustrated in Figure 5.1. More specifically, potential distribution models can help researchers to make inferences about species' occurrence; spatiotemporal analysis of habitat availability can provide information about patterns of change in species' habitat and support the formulation of hypothesis about current population distributions; and investigation of population spatial structure can provide data on abundance and densities, as well as genetic variability. The application of this method will lead biologists to have a better understanding of the current level of threats and how to interpret them when defining and prioritizing conservation strategies. This represents a significant advance in the process of species listing, as it provides for status evaluation at a more detailed level than current IUCN assessments. Even considering that IUCN categories and criteria only strive to assess threat level, they have proven to be broadly applicable and reasonably defendable in the absence of other methods (Hoffman et al. 2008) because classification is based on rules that reflect demographic attributes and the degree of threat faced by each taxon (Burgman et al. 1999). Although IUCN incorporates inference based on extrapolation, no existing methods explicitly consider that the amount or quality of data used as a method for classification of conservation status involves several kinds of uncertainty (Akçakaya et al. 2000, Mrosovsky and Godfrey 2008). Among the different types of uncertainty, the one known as "measurement error" may be potentially reduced or eliminated with the acquisition of additional data (Akçakaya et al. 2000). This is exactly where the "Rapid Endangered Species Assessment" may play a fundamental role. If a comprehensive approach is carried out for a particular species over multiple scales using a set of specific methods, a reliable amount of information would be available in a relatively short time, and consequently, a better assessment could be determined. In fact, it would be possible to define more precisely what threat(s) might be leading the species to decline and what it is needed to establish priorities for conservation actions. Preferably, species assessment should be exhaustive and detailed but given the urgency of the situation and limited resources available, something minimally ideal yet still scientifically viable is urgently necessary. This minimum can be achieved through the use of Rapid Endangered Species Assessment tool.

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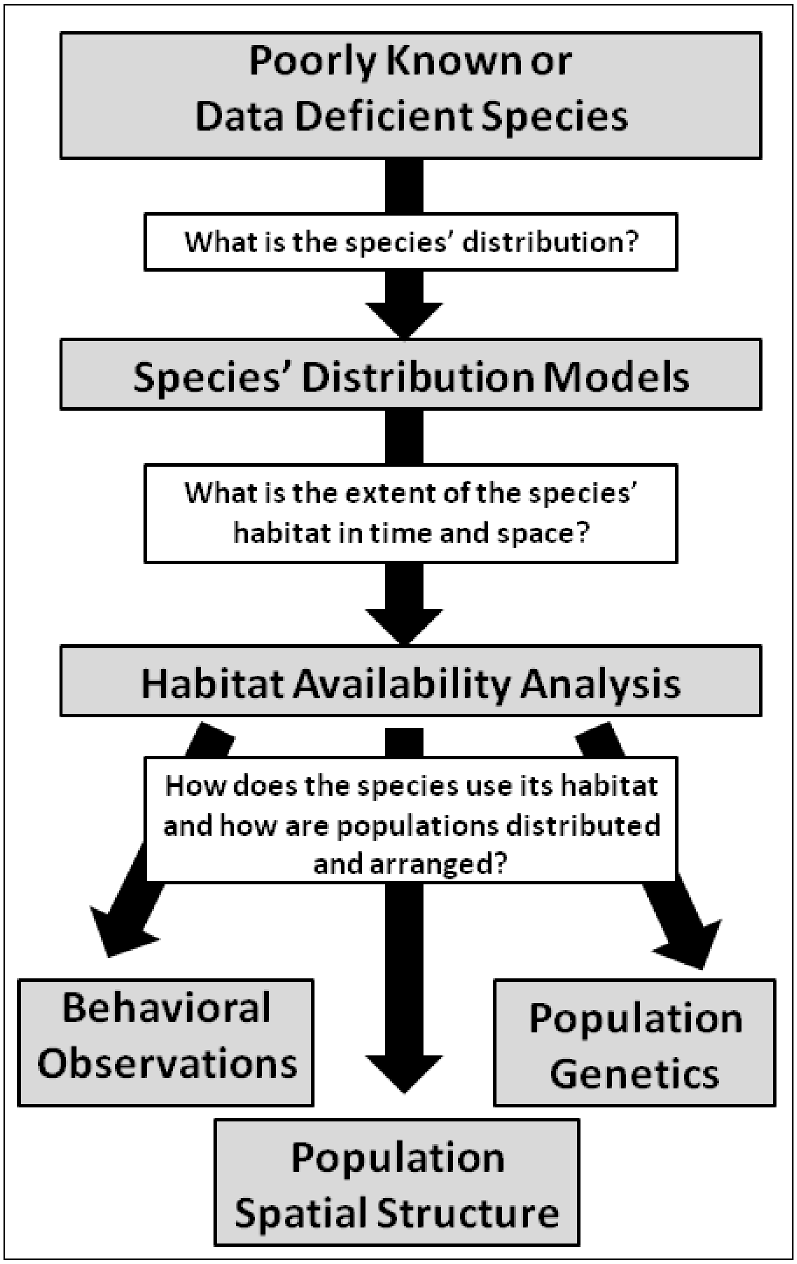

Figure 5.1. A flow chart representing the working principle of the Rapid Endangered Species Assessment approach. Each grey box represents a set of information that can be used to support extinction risk assessment of species of concern.

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