COMBINING SPATIAL MODELS AND STAKEHOLDER PRIORITIES TO GUIDE

LANDSCAPE-SCALE CONSERVATION PLANNING FOR NEOTROPICAL BIRDS

by

CODY M. COX

(Under the Direction of Nathan P. Nibbelink)

ABSTRACT

Broad-scale deforestation in the Neotropics has decreased habitat area and connectivity for forest-dwelling fauna. Costa Rica has attempted to increase forest cover and connectivity outside of protected areas to support wildlife conservation by establishing a network of biological corridors. However, reforestation within corridors, which is primarily undertaken by conservation organizations, has rarely targeted wildlife habitat requirements directly. Since conservation action within corridors is implemented by myriad organizations with different priorities, effective management within corridors requires collaboration and the identification of potential synergies and conflicts. Effective conservation also requires an increased understanding of how changes in forest cover within biological corridors affect wildlife populations, which is limited by the fact that species-habitat relationships remain poorly understood for many Neotropical species. In this dissertation, I use the upper Guacimal watershed, located within the *Corredor Biológico Pájaro Campana* (CBPC) in northwestern Costa Rica, as a case study for identifying the effects of stakeholder conservation priorities on the populations of resident forest-dwelling bird species. I conducted semi-structured interviews with key informants from 20 locally-operating conservation organizations to understand their land management practices and

conservation constraints. The interviews included a participatory mapping exercise where participants highlighted the locations of their conservation priorities. I found that organizations' priorities aligned with the CBPC goal of increasing downslope forest connectivity, but priorities linked with specific conservation themes differed in their spatial distributions. I conducted avian point counts at 301 sites within the study area and used this dataset to develop multinomial *N*-mixture abundance models for 16 forest-dwelling bird species at three focal scales. While relationships with landscape gradients were scale-dependent and species-specific, landscape composition was a more frequent driver of abundance patterns than landscape configuration. I then developed four reforestation scenarios based on theme-specific participatory mapping conservation priorities and examined predicted changes in the abundance of ten forest-dwelling bird species under each scenario. Modest increases in forest cover provided significant benefits for many species, regardless of forest configuration. However, no scenario was optimal for all focal bird species. Therefore, trade-offs must be weighed when planning reforestation initiatives in the region.

INDEX WORDS: birds, Neotropics, Costa Rica, *Corredor Biológico Pájaro Campana*, conservation planning, participatory mapping, abundance models, wildlife conservation

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DEDICATION

This dissertation is dedicated to my grandfather, James H. Cox, Sr., for inspiring my lifelong interest in tropical rainforests and for providing an incredible foundation of belief in and support for me, and to my father, Jim Cox, for being my best friend, inspiring my passion for wildlife, and constantly encouraging and challenging me to perform my best every day.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Humans have increasingly altered landscapes worldwide, ushering in an era of rapid, broad-scale habitat change (Hoekstra et al. 2005; Karimi et al. 2020). Thus, creative conservation solutions are required to balance diverse social and ecological needs that are both socially acceptable and scientifically defensible (Faith & Walker 2002; Bryan et al. 2010; Karp et al. 2015; Brown et al. 2019). However, the integration of social and ecological data for conservation planning is challenging (Knight et al. 2010), particularly for wildlife management (Whitehead et al. 2014). The Neotropical region contains the highest levels of global biodiversity across nearly all terrestrial taxa (Raven et al. 2020). However, this region is subject to broad scale deforestation, losing 3.91 million hectares of forest annually between 2000 and 2010 (Achard et al. 2014), primarily due to the expansion and intensification of agriculture (Graesser et al. 2015; Dang et al. 2019). This broad-scale deforestation has reduced habitat area and connectivity for forest-dependent wildlife, causing population declines (Schumaker 1996; Powell et al. 2000; Donald & Evans 2006).

Approximately two-thirds of Costa Rica's forest cover was cleared between 1950 and 1988 (Sánchez-Azofeifa et al. 2001), primarily for agricultural expansion (Donald & Evans 2006). However, this trend has been reversed in Costa Rica through the implementation of conservation-focused legislation and the growth of the nature-based tourism industry (Calvo-Alvorado et al. 2009). As a result, the nation has experienced net gains in forest cover since 2000

(Keenan et al. 2015) and has emerged as a model for conservation in the Neotropics (Evans 2000; Calvo-Alvorado et al. 2009; Moran et al. 2019). Costa Rica has designated 28% of its landmass as protected areas (Evans 2000; Powell et al. 2000; Sánchez-Azofeifa et al. 2003). However, high deforestation rates outside of protected areas have reduced forest connectivity, which limits the effectiveness of protected areas for maintaining viable wildlife populations (DeFries et al. 2005; DeClerck et al. 2010; Moran et al. 2019).

To increase forest connectivity between protected areas to better support wildlife, Costa Rica developed a network of 44 biological corridors in the 1990s (Sánchez-Azofeifa et al. 2003; SINAC 2009). However, these corridors are mosaics of remnant forest, agriculture, and towns (Fagan et al. 2013), and corridors rely on voluntary compliance with management objectives (Moran et al. 2019). Research suggests that the establishment of biological corridors have produced mixed results in increasing forest connectivity in Costa Rica (Morse et al. 2009; DeClerck et al. 2010; Allen 2015), since economic incentives, rather than compliance with conservation goals, remains the primary motivation for landowner participation in reforestation initiatives (Calvo-Alvorado et al. 2009; Morse et al. 2011).

Most of the research on biological corridor effectiveness has focused on how conservation policies have shaped decisions by individual landowners (Morse et al. 2009; Morse et al. 2011; Allen 2015; Allen & Padgett Vasquez 2017; Allen & Colson 2019; Brownson et al. 2021) and how stakeholder decisions have influenced patterns of regional forest cover (Allen & Padgett Vasquez 2017). However, locally-operating organizations play a large role in developing and implementing biological corridor policies, and little research has examined the conservation priorities of these organizations and their alignment with corridor goals. Understanding synergies and gaps between the objectives of different organizations is important for enhancing

collaborative co-management within corridors (Calvo-Alvorado et al. 2009; DeClerck et al. 2010). Furthermore, research is needed to determine how wildlife respond to landscape gradients in fragmented landscapes within corridors in order to forecast how occupancy and abundance of certain species are likely to respond to various management decisions. A better understanding of species-landscape relationships will permit biological corridor initiatives to better target the needs of species of concern and increase conservation effectiveness (Moran et al. 2019). Finally, integrating our understanding of species-landscape relationships with priorities of conservation organizations can facilitate the assessment of trade-offs between a range of conservation objectives, and potentially increase effectiveness and social acceptance of decisions (Bryan et al. 2010).

RESEARCH OBJECTIVES

The goal of my dissertation is to determine how conservation priorities within the upper Guacimal watershed of Costa Rica affect wildlife populations. The study area is located within a single biological corridor in northwestern Costa Rica, the *Corredor Biológico Pájaro Campana* (Bellbird Biological Corridor; CBPC), and has been the focus of extensive research on landowner conservation motivations (Allen 2015; Allen & Padgett Vasquez 2017; Allen & Colson 2019; Brownson et al. 2021), making it an ideal location to expand knowledge about conservation priorities. I selected birds as the focal taxon for identifying conservation effects on wildlife because birds play an important regional economic role in the nature-based tourism industry (Brownson et al. 2021); serve as symbols for conservation initiatives, including the CBPC, which is represented by the Three-wattled Bellbird (*Procnias tricarunculatus*) (Echeverri et al. 2021); and are key ecological indicators (Șekercioḡlu et al. 2019).

I framed my dissertation using a single integrative research question: how do stakeholder conservation priorities affect outcomes for bird species in the upper Guacimal watershed? My objectives in this dissertation are to identify how different conservation priorities of locally-operating conservation organizations affect the abundance of forest-dwelling birds, and to identify synergies and trade-offs between different priorities. In turn, this information can be considered in collaborative regional planning, shifting sometimes opportunistic reforestation initiatives to more intentional efforts that are more likely to address the needs of species. To achieve this broader goal, I identify where organizations' conservation priorities are distributed on the landscape and how they align with CBPC objectives through the use of participatory mapping-based interviews. I also demonstrate how priorities differ spatially according to conservation themes as a way of highlighting non-dominant opinions and describe how these priorities are shaped by conservation challenges. Additionally, I use abundance data collected from point counts to determine how a suite of forest-dwelling bird species respond to landscape gradients in the study area and highlight how responses differ across spatial scales.

LITERATURE REVIEW

Effects of Neotropical Deforestation

The Neotropical region contains the highest biodiversity of any global region across nearly all terrestrial taxa (Raven et al. 2020). However, this region has experienced rapid, broad-scale deforestation during recent decades. Between 2000 and 2010, 3.91 million hectares of forest were cleared annually in the Neotropics (Achard et al. 2014), primarily due to the expansion and intensification of agricultural operations (Graesser et al. 2015; Dang et al. 2019). The combination of high biodiversity and habitat destruction in this region have resulted in the designation of several locations in the Neotropics as global biodiversity hotspots, including the

Mesoamerican biodiversity hotspot, which covers much of Central America and provides habitat for 1,159 endemic vertebrate species, representing 4.2% of the global species total (Myers et al. 2000).

Deforestation due to agricultural expansion is recognized as the primary threat to wildlife in in the Neotropics (Donald & Evans 2006). It adversely affects forest-dependent fauna by reducing habitat area and connectivity (Timmers et al. 2022), since remnant forest patches are often isolated from one another (Schumaker 1996; Powell et al. 2000; Moran et al. 2019). Forest fragmentation can cause species to decline more rapidly than expected based on the reduction of forest area (Schumaker 1996) because fragmentation also decreases inter-patch dispersal, reduces access to food resources, decreases genetic diversity, alters microclimates, intensifies competition, increases predation, and exacerbates edge effects (Hunter 1996; Stratford & Stouffer 1999; Robinson 2001; Șekercioḡlu et al. 2001; Donald & Evans 2006). Effects of fragmentation on wildlife are often greatest in in the smallest and most isolated patches (Timmers et al. 2022).

Conservation in Costa Rica

The Central American nation of Costa Rica is located entirely within the Mesoamerican biodiversity hotspot (Myers 2000). It includes 4% of global biodiversity while covering only 0.03% of its terrestrial surface area, which represents 133 times more biodiversity than expected due to land area alone (Allen 2016). Similar to the trend in the Neotropical region as a whole, Costa Rica experienced significant forest loss in the latter half of the 20th century, achieving the highest deforestation rates in Central America for much of the 1960s and 1970s (Evans 2000), primarily as a result of agricultural expansion (Donald & Evans 2006). Between 1950 and 1988, Costa Rica's extensive tropical forests were reduced at a rate of 3.6% annually, resulting in the

loss of approximately two-thirds of the nation's forest cover (Guindon 1996; Sánchez-Azofeifa et al. 2001). However, Costa Rica began to reverse this trend in the 1990s through the emergence of the nature-based tourism industry and the implementation of pro-conservation legislation (Calvo-Alvorado et al. 2009). Nature-based tourism offers livelihood alternatives to agricultural production and provides financial incentives for forest protection and restoration (Almeyda et al. 2010). It has rapidly developed into the leading industry in Costa Rica (Brockett & Gottfried 2002; Allen 2016). The 1996 Forestry Law prohibited deforestation on privately-owned land nationwide (Evans 2000) and other policies eliminated federal monetary incentives for agriculture (Edelman 1999). Additional legislation has required the establishment of riparian buffers to protect water quality and implemented a scheme to provide payments for watershed ecosystem services to landowners from revenues collected within individual watersheds (Shahady & Boniface 2018; Brownson et al. 2020). As a result, Costa Rica has experienced a net gain in forest cover since 2000 (Keenan et al. 2015) and 28% of the country's landmass is currently designated as protected areas, including 12% as national parks (Figure 1.1) (Evans 2000; Powell et al. 2000; Sánchez-Azofeifa et al. 2003). Based on these successes, Costa Rica has earned a reputation as a model of successful conservation in the Neotropics (Evans 2000; Calvo-Alvorado et al. 2009; Moran et al. 2019).

However, approximately half of Costa Rica's forests remain outside of formally protected areas (Moran et al. 2019), where they remain highly fragmented and subject to ongoing deforestation (Sánchez-Azofeifa et al. 2003), which reduces their functionality as wildlife habitat. Additionally, deforestation outside of protected areas serves to decrease forest connectivity between protected forest patches, thus isolating protected areas (DeFries et al. 2005). The isolation of protected areas reduces their effectiveness for wildlife conservation

because individual reserves are rarely large enough to support viable populations on their own, particularly for species with large home ranges or low population densities (DeClerck et al. 2010; Moran et al. 2019), which are common characteristics of many Neotropical forest-dwelling birds (Stouffer & Bierregaard 1995). Population sizes of forest-dwelling wildlife often decrease as isolation of protected areas increases (Timmers et al. 2022). Therefore, conservation in landscapes surrounding reserves is critical for maintaining viable wildlife populations (Mannetti et al. 2019). Thus, improving forest connectivity outside of, and between, protected areas has emerged as a conservation priority in Costa Rica (SINAC 2009).

Because it is difficult to set aside additional large tracts of land exclusively as protected areas due to human integration with unprotected landscapes (Hoekstra et al. 2005), wildlife conservation action is increasingly focusing on improving habitat quality in surrounding mixed-use landscapes to supplement and connect protected areas (Vandermeer & Perfecto 2007; DeClerck et al. 2010). Costa Rica sought to enhance forest connectivity between its national parks by developing a network of 44 biological corridors, which cover about a third of the nation's land area, beginning in the 1990s (Figure 1.1) (Sánchez-Azofeifa et al. 2003; SINAC 2009). While this corridor system covers an extensive area and provides key linkages between national parks, individual corridors are relatively large (DeClerck et al. 2010) and consist of mixed-use landscapes that feature substantial proportions of agricultural land and communities in addition to forest (Fagan et al. 2013). Furthermore, biological corridors in Costa Rica lack the legal authority to mandate land management policies, and exist more as frameworks for conservation action than legally-supported protected areas. Therefore, the biological corridors depend on voluntary stakeholder support for initiatives to achieve conservation outcomes (Moran et al. 2019) and many individual corridors actually developed out of grassroots initiatives

(DeClerck et al. 2010). The councils that coordinate the corridors are therefore tasked with promoting effective participatory co-management and facilitating cooperation between myriad government agencies and non-government organizations that operate within each corridor to achieve conservation goals (DeClerck et al. 2010). Additionally, since the vast majority of land within biological corridors is privately owned, and much of it remains in agricultural production, biological corridor member organizations must effectively collaborate with landowners and land managers to implement conservation initiatives (Allen 2015).

Despite the widespread recognition of the conservation potential of the Costa Rican biological corridor network and its use as a model for enhancing forest connectivity throughout the Neotropical region (Evans 2000), research indicates that individual corridors have had mixed results in enhancing forest connectivity (Morse et al. 2009; DeClerck et al. 2010; Allen 2015). Due in part to their relative infancy, few corridors have shown demonstrable effects on increasing forest cover beyond the general pattern of forest increase found in Costa Rica as a whole (DeClerck et al. 2010). The primary motivations for landowners within corridors to reforest portions of their properties are economic, rather than directly related to support of corridor initiatives (Morse et al. 2011). Thus, the vulnerability of these initiatives to changing economic conditions is cause for concern (Calvo-Alvorado et al. 2009). As a result of economic influences, forest regeneration has not occurred evenly within biological corridors, but is instead shaped by patterns of land marginality and proximity to alternate income sources from tourism, which is linked to proximity to reserves (Allen 2015). Thus, forest regeneration is more likely to occur on land that is less cost effective to farm, such as steep slopes, or on land that provides more value under alternative land uses, such as places with access to tourism revenue.

Patterns of forest regeneration within biological corridors are also shaped by proximity to conservation organizations and are thus influenced by distance to roads and by conservation initiatives, which often target ecosystem services (Allen 2015). Thus, land closer to streams is more likely to be forested, since national legislation and many local initiatives have focused on establishing and maintaining riparian buffers to protect water quality while also increasing forest cover and connectivity (Townsend & Masters 2015; Shahady & Boniface 2018; Allen & Colson 2019; Brownson et al. 2020). Riparian buffers provide important habitat corridors for many wildlife species, facilitate altitudinal migration, which is performed by many frugivorous and nectarivorous bird species (Hsiung et al. 2018), and assist elevational range shifts for species affected by climate change (Townsend & Masters 2015). In addition to restoring riparian buffers, conservation organizations have targeted other ecosystem services to promote win-win solutions for reforestation and landowners. One commonly employed strategy is planting trees as windbreaks in agricultural areas (Brownson et al. 2021), which provide a range of benefits for agricultural crops and forest-dependent wildlife (Harvey et al. 2004; Schroth et al. 2004; Donald & Evans 2006; Şekercioḡlu et al. 2007; Chan & Daily 2008; Perfecto & Vandermeer 2008; Jindal et al. 2008; Baker et al. 2018). However, despite the proliferation of reforestation initiatives within biological corridors, reforestation has largely been opportunistic or in conjunction with other management goals, and there has been little effort to target habitat requirements of species of concern (Allen 2015; Brownson et al. 2021), which is needed if one of the goals is to maximize the effectiveness of the biological corridors for wildlife.

Avian Habitat Use

In Costa Rica, birds play an important economic role because birdwatching comprises a significant sector of the booming nature-based tourism industry (Brownson et al. 2021).

Additionally, birds are commonly used as symbols for forest conservation in the Neotropics (Echeverri et al. 2021), due to the fact that many species are charismatic and easily-recognized and because forest-dwelling bird species are important ecological indicators since they occupy a diversity of ecological niches, often display specialized behavior, and exhibit a range of responses to habitat change (Șekercioḡlu et al. 2019). Forest fragmentation causes declines in the abundance of many species of forest-dependent birds in the Neotropics (Robinson 2001; Ferraz et al. 2003; Laurance et al. 2011; Stouffer 2020; Timmers et al. 2022). However, individual species display unique responses to combinations of landscape gradients as a result of niche specialization and specific behavioral and physiological traits, requiring species-specific models to best predict responses to fragmentation (Miguet et al. 2016; Frishkoff & Karp 2019). Nevertheless, responses to landscape gradients may be influenced by certain behaviors (Reid et al. 2014). Foraging behavior is believed to influence bird species' responses to forest fragmentation because it is linked to mobility (Burney & Brumfield 2009; Gonthier et al. 2014). For example, food resources are more patchily distributed in the forest canopy than the understory, so species that utilize these resources must be more mobile to track them (Levey & Stiles 1992). Additionally, light and climate conditions in the forest canopy more closely resemble forest gaps than the cooler, darker, more climatically stable conditions in the understory, which may also play a role in the fact that canopy species are more likely to cross forest gaps (Levey & Stiles 1992; Șekercioḡlu et al. 2019). Thus, understory species are thought to be more vulnerable to forest fragmentation. For example, 100 hectare forest patches in the Amazon are estimated to lose approximately half of their understory bird species within fifteen years of isolation (Ferraz et al. 2003).

Diet also plays a role in shaping the responses of Neotropical forest birds to fragmentation (Reid et al. 2014; Hendershot et al. 2020; Timmers et al. 2022). Insectivorous species are often relatively sedentary because insect availability does not dramatically fluctuate seasonally (Burney & Brumfield 2009) and many species employ specialized foraging techniques, such as following army ants, which require specific microhabitats (Stouffer & Bierregaard 1995; Robinson 2001; Șekercioḡlu et al. 2001). Therefore, insectivores tend to have limited dispersal capabilities and diminished propensities for crossing forest gaps, leaving them vulnerable to forest fragmentation, which is linked to precipitous declines in richness and abundance of members of this guild (Stouffer & Bierregaard 1995; Stratford & Stouffer 1999; Șekercioḡlu et al. 2001; Ferraz et al. 2003; Laurance et al. 2011; Visco et al. 2015; Stouffer 2020).

Frugivorous birds tend to be more mobile than insectivores because they must track patchily available fruit resources, and are thus better able to move through and persist in fragmented landscapes (Burney & Brumfield 2009; Laurance et al. 2011; Gonthier et al. 2014; Hendershot et al. 2020). Due to their mobility, some frugivorous bird species can expand their home ranges in fragmented landscapes to include sufficient food resources (Hansbauer et al. 2008; Peters & Nibbelink 2011). Some species even preferentially utilize forest edges, where fruiting plants are often most abundant, and thus potentially benefit from a degree of fragmentation (Restrepo & Gomez 1998; Reid et al. 2014). Similar patterns of edge preference have also been documented in frugivorous bats in the Neotropics (Chambers et al. 2016). Nevertheless, more intensive disturbance can still cause declines in frugivorous birds because home range expansion leads to decreases in landscape-level population density (Hansbauer et al. 2008), energetic costs increase with distance between food resources, which can reduce survival

(Graham 2001; Peters & Nibbelink 2011), and decreased forest cover reduces protection from predators and camouflage for nest sites (Storch et al. 2005).

Effects of Landscape Structure

Many Neotropical bird species experience declines with decreases in forest patch size (Timmers et al. 2022) and demonstrate reduced tendencies to cross forest gaps as distance increases because predation risk increases in open areas and time spent foraging decreases as a result of increased time spent traveling between patches, thereby reducing survival (Hsiung et al. 2018). However, there is considerable variability in the responses of Neotropical forest birds to fragmentation (Frishkoff & Karp 2019), and additional research is needed to determine how landscape gradients affect their abundance in fragmented landscapes. Research in experimentally-manipulated landscapes, which are designed to best isolate the effects of individual gradients, have indicated that landscape configuration gradients are important drivers of abundance across spatial scales (Haddad et al. 2017). Studies in the Amazon have identified edge density and forest patch proximity as key drivers of patterns of avian abundance and richness across several avian feeding guilds (Laurance et al. 2011; Stouffer 2020). These findings support the theory that fragmentation causes declines in abundance that are not driven by the reduction in habitat area (Schumaker 1996). Conversely, observational research in non-experimentally manipulated fragmented Neotropical landscapes has found that landscape composition (e.g., proportion of forest cover) is primarily responsible for patterns of avian abundance (Carrara et al. 2015; Frishkoff & Karp 2019). These findings support the Habitat Amount Hypothesis, which states that amount of habitat in fragmented landscapes is the key driver of abundance patterns rather than its configuration (Fahrig 2013). Therefore, further research is needed to identify the roles of landscape composition and configuration in driving

abundance of Neotropical forest birds, since a better understanding of their habitat use can inform conservation efforts, permitting more effective targeting of species' habitat requirements (Carrara et al. 2015).

Role of Scale

Since species select habitat hierarchically, species-habitat relationships are often scale-dependent (Johnson 1980; Carrara et al. 2015; Chambers et al. 2016; Chandler & Hepinstall-Cymerman 2016). Thus, species may respond to local and landscape-scale gradients simultaneously (Frishkoff & Karp 2019) and the direction of response to the same gradient can vary across scales (Chandler & Hepinstall-Cymerman 2016). Many Neotropical bird species have relatively large home ranges and thus may select habitat at broad spatial scales (Stratford & Stouffer 1995). Other species may primarily select habitat at local scales, but abundance may be shaped by patterns occurring at broader scales that influence local demographic trends, such as high mortality or low reproduction in locally suitable habitat that is adjacent to matrix areas. Choices about the scale of analysis for identifying species-habitat relationships can influence results by determining which areas are included or excluded from analysis (Wheatley 2010). Therefore, to avoid generating misleading inferences about species-habitat relationships, it is essential to analyze responses at multiple spatial scales (Weins 1989; Thompson & McGarigal 2002; Chambers et al. 2016; McGarigal et al. 2016; Mertes & Jetz 2017; Frishkoff & Karp 2019), since the scale of relationships with gradients are often unknown *a priori* (Wheatley 2010; Chandler & Hepinstall-Cymerman 2016). More mobile species are thought to respond to landscape gradients at broader spatial scales than sedentary species (Miguet et al. 2016). However, research on Neotropical forest-dependent birds has indicated that local forest cover often has a stronger effect on patterns of abundance than broad-scale forest cover, regardless of

mobility (Frishkoff & Karp 2019). Thus, determining the characteristics that influence the scale of species' responses to the landscape require additional research.

Participatory Mapping

Stakeholder involvement in conservation decisions helps to reduce tensions and increase implementation efficiency by enhancing awareness, empowerment, and trust (Schusler et al. 2003; Treves et al. 2006; Donovan et al. 2009; Morse 2012). Human relationships with the environment are often place-specific because people ascribe unique meanings to specific locations (Stedman 2003). Thus, conflicts over management decisions are often related to place-specific meanings in addition to general opinions on an issue (Cheng et al. 2003). Participatory mapping was introduced as a tool for understanding place-specific opinions by permitting participants to identify management preferences, opinions, and landscape values directly onto a map of an area of interest (Brown 2005), which helps to increase stakeholder involvement in the planning process (Brown & Raymond 2014). Participatory mapping can aid planning by facilitating direct comparisons between participant opinions and other types of spatial data to identify locations of synergies and conflicts and assess trade-offs (Bengston et al. 2004; Theobald et al. 2005; Karimi et al. 2020). Thus, participatory mapping data can serve as an important complement to expert-generated data sources in the planning process (Sieber 2006).

Participatory mapping is particularly useful because it can be adapted to the study context and sample population size, ranging from large-scale mail-based surveys (Brown 2005) to one-on-one interviews (Bryan et al. 2010). Additionally, participant responses to non-spatial questions can be appended to spatial participatory mapping data (Tyrväinen et al. 2007) to provide context for participant preferences (Lowery & Morse 2013). Analysis of this contextual

information can help ensure that non-dominant opinions are identified and considered in the planning process (Sletto 2009; Cochrane & Corbett 2018).

Participatory mapping approaches have been used to collect data on a wide range of natural resource management topics, including wildlife conservation preferences (Cox et al. 2014; Whitehead et al. 2014; Brown et al. 2019; Cox et al. 2019), landscape values (Brown 2005), development preferences (Nielsen-Pincus 2011), ecosystem services (Raymond et al. 2009; Cox et al. 2015), and vulnerability to landscape change (Morse et al. 2020). However, wildlife-focused participatory mapping studies have focused on identifying locations where stakeholder support overlaps with high quality habitat to identify conservation targets that are publicly and scientifically supported (Cox et al. 2014; Whitehead et al. 2014; Brown et al. 2019; Cox et al. 2019). This type of analysis identifies locations that already provide high quality habitat that can be protected from degradation. Another key element of wildlife conservation is the restoration of degraded landscapes to increase suitable habitat in the landscape (Reid et al. 2014). However, participatory mapping studies have not examined how different participant priorities will alter habitat and affect wildlife populations in the future, which can enhance conservation planning effectiveness and facilitate the assessment of trade-offs.

Role of Organizations in Regional Conservation

Most previous research on conservation within Costa Rican biological corridors has focused on the opinions of individual landowners about conservation initiatives and motivations for reforestation (Morse et al. 2009; Morse et al. 2011; Allen 2015; Allen & Colson 2019; Brownson et al. 2021). However, myriad organizations involved with developing land management policies operate within each biological corridor, and many of these were instrumental in the grassroots efforts that led to the establishment of many individual corridors

(DeClerck et al. 2010). These organizations continue to play vital roles in developing and implementing conservation initiatives within biological corridors, and many are members of the councils that oversee the corridors themselves, and thus play a role in shaping corridor objectives. However, organizations often have competing conservation objectives (Moran et al. 2019) and developing tools to facilitate collaboration and identify synergies and trade-offs remains a key goal for promoting more collaborative and effective conservation within biological corridors in Costa Rica (Harvey et al. 2008; Calvo-Alvorado et al. 2009).

Assessing Trade-offs in Conservation Planning

Effective wildlife conservation requires creative solutions that balance stakeholder priorities with the habitat requirements of species (Faith & Walker 2002; Karp et al. 2015; Brown et al. 2019). While identifying synergies is an important element of collaborative conservation, due to the diversity and complexity of stakeholder priorities and wildlife habitat requirements, win-win solutions that satisfy multiple conservation objectives are difficult to accomplish (McShane et al. 2011; Karp et al. 2015) and limited by resource availability (Faith & Walker 2002). Since no single optimal solution exists in many situations, conservation planning often requires an assessment of trade-offs between myriad social and ecological objectives (Hirsch et al. 2010; Whitehead et al. 2014). Often, the best solutions are context-dependent (Karp et al. 2015). Thus, specific combinations of management objectives may require different solutions to conservation challenges. In many cases, some objectives will be prioritized over others, and it is critical to explicitly acknowledge these trade-offs to ensure transparency in the planning process (McShane et al. 2011) and produce outcomes that are socially acceptable and scientifically valid (Bryan et al. 2010).

STUDY AREA: UPPER GUACIMAL WATERSHED

For my dissertation, I used a case study approach focused on a single Costa Rican biological corridor, the *Corredor Biológico Pájaro Campana* (CBPC), which is located on the Pacific slope of northwestern Costa Rica (Figure 1.1). The CBPC was initially conceived in 1992 as a tool to promote forest connectivity along an elevation gradient between well-protected highland cloud forest and coastal mangrove forests (CBPC 2011). It uses the Three-wattled Bellbird (*Procnias tricarunculatus*), a vulnerable bird species that requires forest habitat as it migrates annually along the elevation gradient present in the CBPC tracking ripening wild avocado fruits (Family: Lauraceae) (Stiles & Skutch 1989), as a flagship species (CBPC 2011). The CBPC was formally implemented in 2007 when a local council to administer the corridor was established after the implementation of a national law that formally recognized biological corridors in 2006 (SINAC 2009; CBPC 2011).

The CBPC is a 667 km^2 area that spans 11 Holdridge life zones (Holdridge 1967; Allen 2016) and provides habitat for approximately half of Costa Rica's vertebrate species (CBPC 2011). The CBPC encompasses three watersheds: the Aranjuez, Guacimal, and Lagartos. We restricted this study to the upper portion of the central watershed, the Guacimal, which is 129 km^2 (Figure 1.1). We focused on the upper Guacimal watershed because climate, species composition, scale of agricultural production, primary crops, and conservation issues differ significantly in the lower portion of the watershed. The upper Guacimal watershed spans an elevation gradient from 1,842 to 148 m above sea level, stretching from well-protected cloud forests in the highlands to highly fragmented lowland tropical dry forest. This gradient includes Pacific slope middle elevation seasonally dry forests, which are highly fragmented and underrepresented in Costa Rica's network of protected areas (Powell et al. 2000). Precipitation

generally increases with elevation within the study area, while temperature decreases along the same gradient (Allen 2016). The orientation of the CBPC along this elevational gradient allows it to not only promote increased forest cover and wildlife habitat within individual elevation zones, but also enhance connectivity along the elevation gradient (Townsend & Masters 2015). Elevational connectivity can facilitate altitudinal migration, which is undertaken seasonally by many frugivorous and nectarivorous bird species in the region (Hsiung et al. 2018), and aid species that are shifting their ranges upslope in response to climate change (Townsend & Masters 2015).

The study area has approximately 5,000 residents (INEC 2011). However, nearly 80% of the population is concentrated in the town of Santa Elena, located at the upper extreme of the study area, which is a regional tourism hub that receives over 250,000 visitors per year (Caldas 2009). The remainder of the study area is relatively lightly populated, but includes a few small agrarian communities. Approximately 60% of the study area is forested, including several substantial reserves and remnant and regenerating forest patches located on private land (Allen 2015). The study area includes the renowned Monteverde Cloud Forest Reserve (MVCFR), which receives over 80,000 visitors annually from all over the world (Caldas 2009). The MVCR forms the core of the local tourism industry, which has become the largest economic sector of the highland zone of the study area (Burlingame 2000; Allen 2015). However, the remainder of the study area is primarily agricultural (Griffith et al. 2000). Most of the agriculture occurring within the study area is relatively small-scale, but operations increase in size as elevation decreases. Agriculture in the study area primarily revolves around cattle ranching for both dairy and beef and coffee cultivation, though subsistence crops and other cash crops, such as sugar cane, are often commonly grown (Burlingame 2014; Allen 2016).

The well-protected highland zone of the study area has a long and robust conservation history, due in part to its lush vegetation, iconic species, and high levels of endemism (Burlingame 2000). The MVCFR was established in 1972 to protect the regional water supply, but quickly became an important site for biological research, and represented the only known habitat of the charismatic and highly endemic Golden Toad (*Bufo periglenes*), which has since gone extinct (Burlingame 2000). This early interest in the area led to the growth of a scientific research community focused on the Monteverde region, which resulted in further research across the spectrum of tropical ecology and inspired additional conservation efforts in the area. The MVCFR has expanded from 554 ha to 10,500 ha and is linked with other large reserves, which provide key protection to the highland zone of the study area. When the nature-based tourism industry exploded in Costa Rica in the mid-1980s, the MVCFR became a popular tourist destination (Burlingame 2000). The concentration of scientific interest, tourism revenue, and early resident interest in conservation in this area has resulted in large amounts of land being set aside as reserves, a proliferation of locally-operating conservation organizations, and general public support for conservation initiatives (Brownson et al. 2021). However, middle and lower elevations within the study area remain primarily agricultural and have fewer ties to tourism. These elevations have few reserves and many landowners are more resistant to conservation measures that they view as conflicting with their livelihoods (Allen 2015). Thus, conservation action has been more challenging in these zones, and they are host to vastly fewer conservation-focused organizations.

DISSERTATION STRUCTURE AND OBJECTIVES

Chapter 2: Identifying Synergies and Differences in Multi-Stakeholder Conservation Priorities Using Participatory Mapping Interviews

The second chapter of this dissertation provides an assessment of the alignment of the conservation priorities of organizations operating within the study area with CBPC goals. To understand organizations' conservation priorities, I conducted semi-structured interviews about conservation priorities and challenges with key informants from 20 organizations that are involved with developing land use priorities in the study area. The interviews included a participatory mapping exercise where participants identified conservation priorities on a map of the study area. The objectives of this chapter were to (1) identify hotspots where organizations' conservation priorities clustered in the landscape, (2) determine whether organizations' conservation priorities aligned with CBPC goals by analyzing the distributions of key landscape gradients within hotspots, (3) contextualize spatial patterns with information provided by participants about conservation goals and limitations, and (4) highlight differences in the spatial distributions of participant priorities that were linked to individual conservation themes.

Chapter 3: Scale-Dependent Responses of Forest Birds to Fragmentation in Costa Rica

In the third chapter of my dissertation, I examine how forest-dwelling birds respond to a suite of landscape gradients at multiple spatial scales in the study area. To identify patterns in responses, I collected avian abundance data at 301 randomly-stratified sites that reflected important landscape gradients within the study area. I then constructed multinomial N-mixture abundance models for 16 commonly-detected species, which were grouped into four feeding guilds, at three spatial scales: 100 m, 500 m, and 1,000 m. I used these abundance models to (1) determine which landscape gradients influence the abundance of focal bird species, (2) identify

how species' responses to gradients change across spatial scales, (3) compare responses to landscape gradients between members of different feeding guilds to identify commonalities, and (4) uncover patterns in the scale of strongest response to landscape gradients across feeding guilds.

Chapter 4: Combining Multiple Stakeholder Perspectives with Species-Abundance Models Explicitly Addresses Trade-offs in Conservation Planning for Forest-Dwelling Birds in Costa Rica

In the fourth chapter of my dissertation, I forecast the effects of different reforestation scenarios for the study area on the abundance of a suite of forest-dwelling birds. I used themes derived from a participatory mapping exercise conducted with 20 participants from locally-operating organizations involved with developing land management priorities to produce four reforestation scenarios for the study area. I then developed multi-scale multinomial N-mixture abundance models for a suite of 10 forest-dwelling bird species using abundance data collected from 301 sites. The objectives of this chapter are to (1) identify places linked with different conservation themes that were prioritized by organizations using participatory mapping-based interviews, (2) develop reforestation scenarios from specific themes, (3) construct multi-scale models to predict the abundance of a diverse suite of forest-dwelling resident bird species within the study area, (4) use avian abundance models to forecast changes in abundance under each reforestation scenario, and (5), compare avian responses to scenarios to highlight trade-offs between conservation goals and avian abundance.

Chapter 5: Conclusion

The fifth chapter of this dissertation synthesizes key findings from the previous three chapters and highlights how combining participatory mapping, semi-structured interviews, and

predictions of species-specific responses to landscape gradients can enhance collaborative conservation planning in the CBPC by facilitating the identification of synergies and management trade-offs. This process aids in the development of solutions to conservation problems that are both socially supported and scientifically valid. I also highlight key avenues for future research that could expand upon the findings in my dissertation and identify challenges and lessons learned while conducting this research. Additionally, I assess the ways in which I fulfilled Integrative Conservation (ICON) PhD curriculum requirements, including strategic communication of my research and an internship with the Smithsonian Migratory Bird Center where I helped develop a manual of certification standards for bird-friendly coffee. This chapter is followed by appendices that include my semi-structured interview script, avian abundance model output, and maps of predicted abundance of focal bird species in the study area.

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Figure 1.1. The location of the upper Guacimal watershed study area within the *Corredor Biológico Pájaro Campana* (CBPC), Costa Rica.

CHAPTER 2

IDENTIFYING SYNERGIES AND DIFFERENCES IN MULTI-STAKEHOLDER

CONSERVATION PRIORITIES USING PARTICIPATORY MAPPING INTERVIEWS[1]

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[1] Cox, C.M., N.P. Nibbelink, and W.C. Morse. To be submitted to *Ecology and Society*.

ABSTRACT

Broad scale deforestation has reduced habitat area and connectivity for wildlife in the Neotropics. Costa Rica has worked to reverse this trend through the establishment of a network of biological corridors to enhance connectivity between protected areas. However, these biological corridors are mosaics of diversely-managed privately-owned land and lack the legal authority to ensure land use change. Research has shown that biological corridors have had mixed results in promoting conservation-oriented management decisions among individual landowners. However, little research has examined the role of organizations involved with setting land use priorities that operate within these biological corridors in supporting corridor objectives, despite their critical roles in implementing conservation initiatives. To explore how organizations' conservation priorities align with corridor goals and highlight synergies and constraints, we conducted semi-structured interviews about land management, conservation initiatives, and constraints to conservation with key informants from 20 organizations operating within the upper Guacimal watershed, located within the *Corredor Biológico Pájaro Campana* (CBPC) in northwestern Costa Rica. The interviews included a participatory mapping activity where participants identified up to five conservation priorities by drawing polygons on a map of the study area. An analysis of locations where significant numbers of participant-identified polygons overlapped, termed hotspots, showed that organizations' conservation priorities aligned with the CBPC goal of enhancing downslope forest connectivity by highlighting middle elevation areas of moderate to low forest cover that are downslope adjacent to the currently well-protected highland zone of the study area. Semi-structured interviews provided important context to describe why places were identified, complementing the spatial information about where priorities were located. Interviews revealed that lowland areas were not prioritized as frequently

due to conservation constraints associated with working in this zone. Qualitative analysis of interviews also ensured that non-dominant opinions were identified, revealing trade-offs between prioritizing conservation expansion and the need to allocate resources towards maintaining currently protected areas. Thus, by coupling participatory mapping with semi-structured interviews, this study provides valuable information for the CBPC that can increase both effectiveness in identifying conservation priorities and representation of diverse perspectives.

INTRODUCTION

Recognizing that humans have dramatically altered landscape structure at a global scale (Hoekstra et al. 2005), strategies that integrate the place-based perspectives of a wide array of stakeholders have become essential for effective landscape-scale conservation (Brown et al. 2019). Human activities have caused significant global habitat conversion in recent decades (Hansen et al. 2010), including the removal of 5% of global forest cover between 2000 and 2010 (Alroy 2017), leading to declines in forest-dependent wildlife (Butchart et al. 2010). In the Neotropical region, which contains the highest levels of global terrestrial biodiversity (Raven et al. 2020), 3.91 million hectares of forest were lost annually from 2000 – 2010 (Achard et al. 2014), primarily as a result of agricultural expansion (Graesser et al. 2015; Dang et al. 2019). Large-scale deforestation in the region has not only decreased forest area, thereby reducing habitat for forest-dependent species (Donald & Evans 2006), but has also left much remaining forest highly fragmented (Powell et al. 2000; Moran et al. 2019), which can further affect forest-dependent wildlife by decreasing access to mates, access to food resources, and genetic diversity, while increasing interspecific competition and predation (Donald & Evans 2006).

Costa Rica lost approximately two-thirds of its forest cover between 1950 and 1988 (Sánchez-Azofeifa et al. 2001), primarily due to agricultural expansion (Donald & Evans 2006).

However, the nation has experienced large-scale forest regeneration since the 1990s as a result of the emergence of the nature-based tourism industry and implementation of conservation-focused legislation (Calvo-Alvorado et al. 2009), which has led to the designation of 28% of the country's landmass as protected areas, including 12% as national parks (Figure 2.1) (Evans 2000; Powell et al. 2000; Sánchez-Azofeifa et al. 2003). As a result, Costa Rica has developed a reputation as a model for successful conservation in the Neotropics (Evans 2000; Calvo-Alvorado et al. 2009; Moran et al. 2019). While deforestation within Costa Rican national parks is negligible, unprotected forests, which represent nearly half of the nation's total forest cover (Moran et al. 2019), are highly fragmented (Powell et al. 2000) and are subject to ongoing degradation and deforestation (Sánchez-Azofeifa et al. 2003). Deforestation in unprotected areas threatens to isolate national parks from one another (DeFries et al. 2005), thereby reducing their effectiveness, since individual reserves are usually not large enough to support viable populations, particularly for species with large home ranges, low population densities, or migratory behavior (DeClerck et al. 2010; Moran et al. 2019). Thus, the management of landscapes surrounding reserves plays a critical role in maintaining wildlife populations (Mannetti et al. 2019), and increasing forest connectivity has emerged as a conservation priority in Costa Rica.

The amount of additional land that can be set aside exclusively for biodiversity conservation is limited by human land use (Hoekstra et al. 2005). Thus, the focus of conservation action must move beyond protected areas and onto surrounding mixed-use landscapes to supplement and connect reserves (Vandermeer & Perfecto 2007; DeClerck et al. 2010; Allen 2015). To enhance forest connectivity between and outside of reserves for more effective wildlife conservation, Costa Rica developed a network of 37 biological corridors in the 1990s

(Figure 2.1) (Sánchez-Azofeifa et al. 2003; SINAC 2009). These biological corridors are relatively large (DeClerck et al. 2010) and consist of diversely-managed privately-owned land, including protected areas, fragmented unprotected forest, agricultural operations, and sizeable towns (Fagan et al. 2013). Most of the Costa Rican biological corridors developed from grassroots initiatives and are managed by individual councils that must facilitate cooperation between myriad governmental and non-governmental organizations operating in each corridor with a goal of fostering effective participatory co-management (DeClerck et al. 2010). Conservation outcomes in Costa Rican biological corridors are particularly dependent upon stakeholder support because they are not legally protected areas and lack the legislative authority to regulate land management. Thus, conservation within biological corridors requires collaboration with private land managers and the integration of social and ecological management objectives through inclusive planning to be effective (Knight et al. 2008; Reed 2008; Allen 2015; Brown et al. 2019; Mannetti et al. 2019). Since conservation action can affect and be affected by stakeholders (Lockwood 2010), it is essential to understand stakeholder perspectives on management issues (Brown & Raymond 2014; Brown et al. 2019; Karimi et al. 2020) and assess trade-offs during the planning process (Knight et al. 2010; Mannetti et al. 2019). Including stakeholders in the planning process promotes support for management outcomes through increased trust, empowerment, and awareness of issues; reduces tensions; enhances plan implementation efficiency (Donovan et al. 2009; Morse 2012; Schusler et al. 2003; Treves et al. 2006); and promotes community involvement in conservation efforts (Bryan et al. 2010).

To determine the role of biological corridors in promoting conservation in Costa Rica, most previous research has examined the attitudes of individual landowners towards

conservation initiatives (Morse et al. 2009; Allen & Colson 2019), especially since most corridors are relatively young and have thus not had tangible effects on forest cover (DeClerck et al. 2010). Economic incentives have been found to be the primary motivators for reforestation within corridors (Morse et al. 2011). However, support for payments for ecosystem services (PES) programs varies widely between corridors (Morse et al. 2009; Morse et al. 2011; Allen & Colson 2019), and the programs themselves are unlikely to provide enough value to ensure conservation success in the face of future socioeconomic changes (Calvo-Alvarado et al. 2009). While national-scale PES programs have produced limited conservation additionality, as many participants would manage properties similarly regardless of payments, locally-focused PES programs, such as watershed-specific payments for water services, which have recently been adopted in Costa Rica, have been shown to be more effective for increasing engagement with diverse landowners (Shahady & Boniface 2018; Brownson et al. 2020).

Implementation of agroforestry practices that offer direct ecosystem services to farmers, such as restoring riparian buffers to protect water quality (Allen & Colson 2019) or planting windbreaks to protect crops (Brownson et al. 2021), have received mixed support. Furthermore, nature-based tourism, which offers opportunities for coupling conservation with livelihoods in Costa Rica, has garnered widespread support (Brownson et al. 2021), but relationships between nature-based tourism and forest regeneration are spatially variable (Allen 2015). Thus, forest regeneration has not occurred uniformly within biological corridors in Costa Rica. Instead, it has been shaped by the marginality of land, proximity to tourism infrastructure, and accessibility by conservation organizations, and is thus correlated with landscape features, such as distance to protected areas, slope, distance to roads, and distance to streams (Allen 2015). Furthermore, patterns of forest regeneration can vary even within a single biological corridor (Allen & Padgett

Vasquez 2017), indicating that they are also products of place-specific decisions, which requires an understanding of local landscape preferences (Brown 2005).

Humans develop relationships with their environments and ascribe unique meanings to specific locations (Stedman 2003). Therefore, debates about land management and conservation planning often stem as much from specific place meanings as from general attitudes towards management topics (Cheng et al. 2003). Participatory mapping allows participants to directly identify their preferences on a map of the landscape (Brown & Raymond 2014), which they have been shown to be able to do with a high degree of spatial accuracy (Cox et al. 2014; Brown et al. 2019). This approach facilitates stakeholder involvement in the planning process (Brown & Raymond 2014), while complementing expert-led conservation planning (Sieber 2006) by allowing stakeholder preferences to be visualized and directly compared with other spatial data (Bengston et al. 2004; Theobald et al. 2005) to facilitate the identification of synergies, trade-offs, and conflicts (Karimi et al. 2020). Participatory mapping has been applied to a wide range of natural resource management topics ranging from wildlife conservation (Cox et al. 2014; Brown et al. 2019; Cox et al. 2019), landscape values (Brown 2005), development preferences (Nielsen-Pincus 2011), ecosystem services (Raymond et al. 2009; Cox et al. 2015), and sea level rise vulnerability (Morse et al. 2020). The participatory mapping approach offers flexibility in implementation methodology. In previous studies, data collection has ranged from mail-based surveys (Brown 2005) to one-on-one interviews (Bryan et al. 2010). In the participatory mapping framework, participant responses to other types of questions can be appended to spatial data, allowing qualitative and quantitative methods to be mixed (Lowery & Morse 2013; Morse et al. 2020). However, the maps generated from such studies only show where participant preferences are located, but often obscure the context of why participants identified those locations (Sletto

2009). Coupling participatory mapping exercises with qualitative data collection methods (e.g., semi-structured interviews) offers insights into the context that shapes participant preferences (Lowery & Morse 2013) and provides greater participant empowerment through increased opportunities to share their opinions (Sletto 2009; Cochrane & Corbett 2018).

Since Costa Rican biological corridors include diverse stakeholders with unique management preferences, participatory mapping offers a spatially-explicit framework for identifying conservation preferences to visualize goals, synergies, and conflicts to facilitate effective and collaborative planning, which has been identified as one of the top priorities for the Costa Rican biological corridor network (DeClerck et al. 2010). Despite the proliferation of conservation organizations operating within Costa Rican biological corridors and their leading roles in shaping and implementing biological corridor policies while representing diverse stakeholder opinions, most research has focused on the conservation motivations and preferences of individual landowners (Morse et al. 2011; Allen 2015; Brownson et al. 2021). However, organizations operate at broader spatial scales than individual landowners. Thus, they can influence land management decisions across larger areas and shape corridor objectives, while also representing the interests of stakeholder groups. Therefore, it is critical to understand how organizations' management priorities align with corridor goals. Highlighting synergies and sources of conflict can help managers efficiently develop more integrated plans with greater stakeholder involvement (Harvey et al. 2008; Calvo-Alvorado et al. 2009).

Objectives

The purpose of this study was to provide insight into the ways in which biological corridors interact with organizations involved with developing land use priorities to shape private land conservation in Costa Rica. We used qualitative and quantitative data from an approach that

combined participatory mapping with semi-structured interviews to identify the locations of the conservation preferences of organizations operating within the upper Guacimal watershed, located within the *Corredor Biológico Pájaro Campana* (CBPC; Bellbird Biological Corridor) of northwestern Costa Rica, and determine how organizational missions, land management practices, and constraints shape these preferences. We assessed the landscape characteristics of places identified as conservation priorities by participants to determine their relationships with CBPC conservation goals. The primary objective of the CBPC is to increase downslope forest connectivity from the well-protected highlands (CBPC 2011). Therefore, we expected organizations to prioritize 1) middle elevations because they are downslope adjacent to highland protected areas; 2) upper elevations, since they include the base of operations of most organizations and are thus more likely to be selected due to spatial discounting (Brown et al. 2020); 3) existing reserves, since they provide critical habitat and are the focus of current management efforts; 4) areas adjacent to intact forest to increase forest connectivity; and 5) areas near streams because the restoration of riparian buffers to protect water quality has been prioritized locally as a way to use ecosystem services to improve forest connectivity (Townsend & Masters 2015; Allen & Padgett Vasquez 2017). We also hypothesized that the spatial distributions of stakeholder conservation priorities would differ based on the conservation themes that were ascribed to those places.

METHODS

Study Area

The study area consisted of the 129 km^2 upper Guacimal watershed, which is located within the CBPC on the Pacific slope of northwestern Costa Rica (Figure 2.1). The CBPC was conceived in 1992 (CBPC 2011) and formally established in 2007 with the formation of a local

administrative council (SINAC 2009; CBPC 2011). It is designed to promote forest connectivity along an elevation gradient from highland cloud forests to coastal mangrove forests using the vulnerable Three-wattled Bellbird (*Procnias tricarunculatus*) as a flagship species (CBPC 2011). Within the CBPC, the upper Guacimal watershed extends from well-protected cloud forest at the continental divide to fragmented lowland tropical dry forest, including middle elevation (500 – 1500 m) seasonally dry Pacific slope forests, which are particularly underrepresented in Costa Rica's network of protected areas (Powell et al. 2000). The study area was restricted to the upper Guacimal watershed because climate, species composition, the scale of agricultural operations, and conservation priorities differ significantly in the lower portion of the watershed. The study area is inhabited by approximately 5,000 people (INEC 2011). About 80% of the population of the study area is concentrated in the highland town of Santa Elena, while the remainder of the study area is a sparsely inhabited mosaic of small-scale agriculture, agrarian communities, and protected forest (Griffith et al. 2000), including the renowned Monteverde Cloud Forest Reserve (MVCFR), which is visited by over 80,000 people annually (Caldas 2009). Tourism has supplanted agriculture as the primary source of income for Santa Elena due to its proximity to the MVCFR, but the remainder of the study area primarily depends on agricultural production, particularly dairy cattle and coffee (Burlingame 2014). Due to its high number of endemic species and the growth of the nature-based tourism industry, the highland zone of the study area has a robust conservation history, beginning with the establishment of the MVCFR in 1972 (Burlingame 2000), and is host to many local conservation organizations, while middle and lower elevations contain fewer locally-operating organizations.

Sample Selection and Interview Protocol

We employed a case study approach (Creswell & Poth 2017) that mixed qualitative and quantitative and spatial methods to understand the interactions between organizational conservation priorities and corridor goals within a single biological corridor in Costa Rica, the CBPC. Between November 2017 and July 2018, we 20 conducted semi-structured interviews (Chambers 1998) with key informants from a range of organizations involved with developing land use priorities in the study area. Organizations' missions ranged from conservation to agricultural production and included both government agencies and non-government organizations (NGOs). An initial list of interview candidates was generated based on the authors' experience in the region. Additional candidates were identified using the snowball sampling technique, in which interview participants were asked to list other relevant organizations until no additional organizations were identified (Newing et al. 2011). Candidates were invited to participate in the study using a version of the contact approach developed by Dillman et al. (2008), which employed a pre-notice letter to describe the study and invite participation and two reminder messages to candidates who had not yet responded, that we modified for electronic correspondence (Appendix A).

Semi-structured interviews (Chambers 1998; Creswell & Poth 2017) focusing on topics related to land use and conservation within the study area (Appendix B) were conducted in either Spanish or English, based on participant preference in a one-to-one format, with the addition of a translator for Spanish language interviews. Our interview protocol was approved by the University of Georgia Institutional Review Board (STUDY00005044) and conducted under research permits approved by the Costa Rican *Ministerio de Ambiente y Energía* (Ministry of Environment and Energy: 019-2017-INV-ACAT; M-P-SINAC-PNI-ACAT-048-2018). Informed

consent was obtained prior to the start of each interview. Interviews lasted approximately 30-45 minutes. Participants were asked to respond from an organizational rather than personal perspective. The interviews included questions about the organization's mission, spatial scale of operations, length of time operating within the study area, the organization's land management practices and current conservation initiatives, positive and negative conservation experiences, and constraints to conservation action.

At the conclusion of the interviews, participants were asked to complete a participatory mapping exercise using ArcGIS 10.3 software (ESRI 2011). They were instructed to draw polygons to identify up to five places that should be prioritized for conservation on a map of the study area (Lowery & Morse 2013), which included aerial imagery and key landmarks for reference. Participants were asked to explain their rationale for each selection to provide context for analysis (Tyrväinen et al. 2007). The map of the study area was initially displayed at a 1:70,000 scale so that the entire study area was visible on the computer screen, but participants could zoom in to view areas in greater detail. While limiting participants to identifying five conservation preferences forced them to prioritize specific places, they were not limited in the area that they could include within each polygon (Lowery & Morse 2013). We used polygons for place identification in this study because they better account for small sample sizes in participatory mapping studies than points (Brown & Pullar 2012; Karimi et al. 2020).

Data Analysis

Audio recordings of the interviews were transcribed and translated. Transcript text was coded using a hierarchical scheme in MaxQDA 18 (VERBI 2017). The code list, which focused on conservation issues, was constructed from both *a priori* and emergent categories, and was subsequently grouped into broader themes (Hutchison et al. 2010). Peer validation, which was

used to ensure the accuracy and replicability of the coding scheme, was conducted by asking an experienced colleague to code 20% of the interview text (four randomly-selected interviews) with author codes not included using code list that we generated (Barber & Walczak 2009; Kvale & Brinkmann 2009). We then compared text that was coded by the peer validator and by ourselves and found >85% alignment, which provided confidence that our coding structure was consistent and replicable. Coded transcripts were analyzed to identify themes relating to conservation initiatives, priorities, and perceived constraints.

The conservation priority polygons from the participatory mapping exercise were analyzed in ArcGIS 10.3 (ESRI 2011) to identify patterns in polygon density (Lowery & Morse 2013). To highlight areas of high participant consensus for conservation, we calculated hotspots, which represented the top 33% of the polygon density values (≥9 overlapping polygons) (Brown & Pullar 2012; Ramirez-Gomez et al. 2016; Karimi et al. 2020). We then overlaid the hotspots with landscape gradients to identify spatial patterns in hotspot location (Brown 2005) and assess their alignment with the primary CBPC goal of increasing downslope forest connectivity from the well-protected highlands (CBPC 2011). We used a 5 m resolution digital elevation model (DEM) resampled from a 30 m DEM (SRTM 2014) to identify the distributions of elevations included within the study area and hotspots. Forest cover of the study area and hotspots was assessed by reclassifying 5 m resolution 2013 land cover data (INF 2014) into forest and non-forest classes and calculating the percent of forest within a 100 m buffer around each cell. We also calculated the percent forest cover in a 1 km buffer around the hotspots to determine whether hotspots were located adjacent to areas of higher or lower forest cover than the surrounding landscape. We analyzed Euclidean distances from the nearest protected area in the study area and hotspots using boundaries included in the Digital Atlas of Costa Rica (TEC 2014)

and provided by individual reserves. We also calculated Euclidean distance from the nearest stream for the entire study area and for the hotspots using stream data from the Digital Atlas of Costa Rica (TEC 2014). We used Chi-Square goodness-of-fit tests to determine whether the distribution of each landscape gradient within the hotspots differed significantly from the distribution in the study area as a whole to determine whether certain landscape features were disproportionately prioritized by organizations operating in the region. For this analysis, continuous landscape gradients were grouped into equal interval bins.

To determine whether the distributions of places identified with specific conservation themes differed from the hotspots, we appended the themes that were used to code the participant rationales for locating each polygon to its attribute table in ArcGIS (Lowery & Morse 2013). Polygons could contain multiple themes. We then developed density maps for the participant-identified polygons of three common themes and compared their distributions with the locations of the hotspots.

RESULTS

Missions of Organizations

We conducted interviews with participants from 20 organizations that are active in land management within the study area, which represented snowball sampling candidate saturation (Newing et al. 2011). Of the 24 organizations contacted, candidates from three organizations did not respond and one declined to participate in the study, resulting in a participation rate of 83%. Participant demographics were not recorded, since they were asked to answer from an organizational rather personal perspective. Interviews were coded into 30 themes (Table 2.1). The majority (55%) of organizations operated at a local scale (i.e., serving a few communities), but organizations operating at regional (i.e., CBPC) (30%) and national scales (15%) were also

represented. The temporal scale of operations within the study area ranged from 55 years to less than 1 year, but most began operations in the early 2000s, shortly before the establishment of the CBPC corridor council. The density of organizational operations varied significantly within the study area. Sixteen organizations operate in the upper portion, which is more populous, has a longer conservation history and large reserves, and is the epicenter of regional tourism, while only six organizations operate in the largely agricultural lower portion of the study area, many of which have regional or national scopes. Organizations with regional scopes were primarily based in the upper portion of the study area. Several of the organizations interviewed are members of the CBPC council, and are thus directly involved in developing corridor objectives. Nineteen of the interview participants (95%) elected to complete the participatory mapping exercise. Participants drew 74 total polygons (3.7 polygons per participant) to identify places that they believed should be prioritized for conservation, which encompassed 95.5% of the study area (123.3 km^2). Conservation hotspots, which highlighted places with high participant consensus, consisted of areas that included the top 33% of polygon density values ($\geq$9 overlapping polygons) (Karimi et al. 2020). The 24 conservation hotspots covered 10.1% of the study area (13.1 km^2) (Figure 2.2).

Conservation Initiatives

All participants (n=20) expressed support for conservation initiatives within the study area, often due to a sense of pride in Costa Rica's reputation as "a global leader and proactive country in terms of conservation initiatives," and emphasized the benefits that conservation offers for regional economics, sustainability, and human well-being. Additionally, all participants expressed support for the CBPC and its goal of increasing downslope forest connectivity to facilitate wildlife conservation and stated a desire to align management practices

with CBPC goals. Despite differences in land management priorities, none of the participants expressed a negative attitude towards general conservation efforts, and all participants noted that conservation was a key priority for their current and future land management. Every organization interviewed reported involvement in some conservation initiatives (Table 2.2), many in collaboration with local landowners, which allows implementation of initiatives over broader spatial scales and fosters community engagement in conservation initiatives. Landowner collaboration was emphasized by participants as being "essential for ensuring understanding and support for sustainable land use" within the CBPC. The most commonly reported conservation initiative undertaken by organizations was reforestation, which is critical for forest restoration, improving habitat in the agricultural matrix, and ecosystem service provisioning, and is one of the key ways that organizations support the CBPC goals of increasing forest connectivity and wildlife habitat.

Elevation

Middle elevations were significantly overrepresented within the participatory mapping hotspots, as we expected (Figure 2.3; X^2 (17) = 335306, p < .001). However, upper elevations were underrepresented with respect to their availability within the study area. Thus, our hypothesis about the prioritization of middle elevations was supported, while our hypothesis about upper elevations was not. Organizations targeted middle elevations because they believed that "it is important to focus on increasing forest connectivity downslope from cloud forest reserves" to facilitate animal movement and support CBPC goals. Many organizations chose not to prioritize highland areas during the mapping exercise because they felt that "from about 1,200 meters up, we're in pretty good shape" due to the preponderance of biological reserves, which are "already well protected, so the focus needs to be on protecting the areas outside the reserves

because animals need more habitat than that." This opinion resulted in high elevations being proportionately underrepresented in the hotspots, despite the fact that they are the epicenter of current regional conservation. This pattern in the distribution of hotspots did not support our spatial discounting hypothesis, where we expected upper elevations to be prioritized due to their proximity to the headquarters of most organizations.

Interviews revealed that organizations also tended to restrict their conservation priorities to middle elevations due to the influence of perceived constraints. Many organizations did not extend their priorities into the lowlands, as would be expected if they were solely conforming to CBPC connectivity goals. Since most organizations are headquartered in the highlands, "distance is the main limitation" to enacting conservation initiatives in the lowlands, "because it is very expensive and time consuming to transport people" to work on projects in this zone. Organizations also highlighted the distinct elevational gradient present in landowner support for conservation. Landowners in the upper and middle elevations are generally supportive of conservation initiatives, while landowners at lower elevations tend to be more resistant to conservation. One participant noted that "the middle [elevation] zone is where our major intervention is, because people there are supportive of reforestation, and the highest part [of the study area] has already been doing it," while the lower elevations are "a whole different ball game because the land ownership is completely different." The lower elevations are dominated by larger-scale agriculture, where landowners are resistant to taking land out of production for conservation because they cannot tap into nature-based tourism revenue by protecting land, unlike landowners at higher elevations. Nature-based tourism drives conservation patterns by providing economic incentives to landowners to take land out of production. However, within the study area, access to tourism-based income is unequally distributed spatially as a result of

existing infrastructure (e.g., roads), and distribution of charismatic species and ecosystems. The highland cloud forest attracts large numbers of tourists who "want to come to experience the cloud forest, see the plants, the charismatic species, like [Resplendent] Quetzals, all of the endemic" species. The lower portion of the study area, which is tropical dry forest, lacks the same charismatic ecosystem and flagship species and attracts very few tourists, so landowners must rely on other sources of income, such as cattle, which conflicts with conservation objectives. Therefore, the conservation success of the highlands "is not replicable and the idea of selling these local isolated communities around tourism is really not very realistic," especially at lower elevations and requires the development and implementation of new conservation strategies to address these challenges.

Protected Areas

Contrary to our expectations, less than 1% of the hotspot area was located within protected areas, despite the fact that reserves cover 16.4% of the study area. However, while the hotspots significantly underrepresented protected areas, they significantly overrepresented areas located within 2 km of reserves (Figure 2.4; X^2 (11) = 519928, p < .001). In interviews, several participants stated that they believed that reserves are "already well protected, so the focus needs to be on protecting the areas outside the reserves because animals need more habitat than that." They felt that "areas near protected areas should be prioritized because protecting them will increase connectivity out from protected areas," thus reinforcing the prevailing theme of participants prioritizing conservation expansion to support the connectivity goals of the CBPC. However, despite the participant consensus illustrated by the locations of the hotspots, a minority of participants presented a contrasting point of view. They explained that "currently protected areas serve as important hubs for conservation, but require continual funding to maintain their

status as being well protected. For example, if [they] don't have funding for park guards, [they] can have increased poaching and encroachment [by neighboring farms] and squatting," which can reduce their conservation effectiveness.

Forest Cover

Hotspots significantly underrepresented areas of high forest cover and overrepresented areas with moderate to low forest cover (Figure 2.5; X^2 (9) = 156481, p < .001). However, the 1 km buffers around the hotspots contained significantly greater proportions of high forest cover than the hotspots (X^2 (9) = 191305, p < .001), but still significantly overrepresented areas with moderate to low forest cover compared to the study area as a whole (Figure 2.5; X^2 (9) = 248445, p < .001). These results indicate that hotspots were located in areas of moderate to low forest cover adjacent to relatively intact forest patches, which supported our hypothesis that areas adjacent to high forest cover would be prioritized by participants. While most participants indicated that "location and the need to create forested corridors within the CBPC are more important than current land cover" for shaping conservation priorities, a strong contingent believed that "resources need to be allocated to lower quality areas to increase connectivity," since areas with high forest cover generally are already well-protected. As we found with elevation, participants generally prioritized conservation expansion into areas adjacent to current hubs as a means to support the primary CBPC objective of increasing forest connectivity between the cloud forest and coastal mangroves.

Water Quality Protection

Participant-identified hotspots significantly overrepresented areas within 1 km of streams (Figure 2.6; X^2 (11) = 30496, p < .001), and 80% of the hotspot area fell within 500 m of streams. This finding supported our hypothesis that organizations would prioritize riparian areas.

Organizations often prioritize riparian areas for reforestation because they offer an opportunity to bundle the expansion of downslope forest connectivity with water quality protection, which is beneficial to landowners and "something that everybody can agree on." Since riparian restoration is "easiest thing to get people to rally around first," it offers the opportunity to increase forest cover while supporting community needs and generating the support needed for implementation of further conservation-focused initiatives.

Conservation Constraints

The interviews revealed that organizations operating within the study area are challenged by a range of constraints to their conservation initiatives (Table 2.3). The most commonly reported constraint was a lack of adequate funding, which limits conservation initiatives and leads to understaffing. Collaboration between organizations was also noted to be a key constraint to conservation effectiveness within the CBPC, since each organization has its own initiatives and priorities. The CBPC was developed to provide greater structure for regional conservation and facilitate collaboration, but "moving resources to the corridor, for each organization, is a big challenge … [because] each organization has its own way of doing conservation." Additionally, many organizations find it difficult to invest as much time as needed to the corridor council to develop effective planning and collaboration because they are understaffed and need to focus on their own missions. Community resistance also constrains conservation initiatives, particularly at lower elevations where landowners "rely on farming because they don't have access to other sources of revenue, like tourism" and are thus "reluctant to take land out of production."

Distribution of Theme-Specific Polygons

The rationales expressed by participants for identifying their conservation priorities on the map included 14 interview themes (Table 2.1). Congruent middle elevation areas were

among the most commonly identified places across each of the selected themes (Figure 2.7).

Many of these same areas were also included within the conservation priority hotspots. However,

key differences in the distributions of polygons associated with each theme also emerged. For

example, reserve expansion/connectivity polygons were exclusively located at upper and middle

elevations, while downslope connectivity and water quality polygons included greater

proportions of the study area. Additionally, the density maps for each theme highlighted theme-

specific areas of relatively high consensus that were not included in the hotspots. For example,

lower elevation riparian areas and high elevation springs were identified as being important for

water quality protection, but were not the focus of the conservation priority hotspots. Thus, it is

evident that theme-specific analysis can provide an additional layer of context and detail for

identifying landscape-scale participant conservation priorities.

DISCUSSION

This study demonstrates that participatory mapping can provide a spatially-explicit

framework for identifying and integrating the opinions of a diverse group of stakeholders to

facilitate effective conservation planning (Brown et al. 2019), which is a top priority for the

Costa Rican biological corridor system (DeClerck et al. 2010). This approach supports regional

management by identifying locations of strong consensus for conservation action, which can

then be prioritized for future initiatives (Karimi et al. 2020). The conservation priority hotspots

identified through this study can provide organizational stakeholders greater insights into the

priorities of other organizations, which can increase opportunities for collaboration.

Additionally, since the hotspots themselves only show *where* participant conservation

preferences cluster spatially, this study demonstrates that semi-structured interviews and theme-

specific density maps are critical tools for providing additional context to describe *why* places were prioritized, and to ensure that non-dominant perspectives are identified and considered.

This case study provides key insights into the roles of land management organizations and biological corridors in shaping conservation priorities in Costa Rica. Despite the diverse missions of the organizations included in this study, we found universal support for conservation action and CBPC objectives among participants. Participant conservation priorities clustered spatially and hotspots were consistent with the primary goal of the CBPC, which is to increase downslope forest connectivity (CBPC 2011). Many participants were explicit about identifying conservation priorities that supported CBPC connectivity goals, showing the influence that corridor objectives have on organizations' agendas. Participant-identified conservation priority hotspots were concentrated at middle elevations in an attempt to expand initiatives downslope from the highland cloud forest, which is currently well-protected. Additionally, participants prioritized areas with lower forest cover that were adjacent to reserves and other areas of high forest cover in an attempt to increase forest cover outside of reserves and enhance downslope connectivity. Participants also prioritized riparian areas, which provided opportunities to bundle the enhancement of downslope forest connectivity with additional ecosystem service provisioning, such as water quality protection, which has strong landowner support (Allen & Padgett Vasquez 2017). The synergy in conservation prioritization across a range of organizations and explicit alignment of priorities with CBPC goals demonstrate that biological corridors can shape regional conservation priorities despite lacking legal authority. Thus, corridors can serve as tools to bring groups together to achieve common conservation goals.

The prioritization of discrete places for conservation by organizations helps explain why forest regeneration patterns vary within individual biological corridors in Costa Rica (Allen &

Padgett Vasquez 2017). However, organizations prioritized some of the same landscape characteristics that motivate individual landowner to permit forest regeneration, such as proximity to reserves and streams (Allen 2015). The alignment of organizations' priorities with gradients predicting forest regeneration within the CBPC (Allen & Padgett Vasquez 2017) demonstrates that organizations are achieving tangible results along some of the same gradients that they are targeting.

This study exposed key trade-offs that must be navigated for effective regional conservation by highlighting differences is organizational conservation priorities. For example, most participants prioritized expanding conservation efforts beyond protected areas, which was illustrated by only 1% of the hotspot area falling on protected land. However, interviews revealed that a minority of participants believed that reserves should remain a conservation focus to ensure that they continue to operate with maximum effectiveness, since they require considerable resources for continuous upkeep. This opinion was espoused by a small group of participants, and thus was not represented by the location of the hotspots. Without a qualitative component to this study, this breadth of opinion would not have been identified, thus underscoring the utility of mixed-methods approaches for participatory mapping research to provide context and highlight potential sources of conflict, especially where an opinion differs from that of the dominant preference in a sample (Karimi et al. 2020), which would be obscured in a strictly quantitative approach. Highlighting these viewpoints will allow CBPC leadership to better balance trade-offs between conserving new areas and increasing protection in existing conservation areas to develop more effective and collaborative conservation plans.

It is also important to understand how regional conservation is constrained by the landscape, which despite past conservation success in the CBPC (Allen 2015) and current CBPC

goals (CBPC 2011) and organizational priorities, could limit future success. For example, organizations based in the highlands face logistical hurdles, such as long travel times, to expanding operations at lower elevations. Additionally, nature-based tourism has provided significant economic incentives for conservation in the highlands, which provides direct revenues to organizations and influences landowners to adopt conservation practices. However, nature-based tourism in the highlands is driven by its charismatic species, such as the Resplendent Quetzal (*Pharomachrus mocinno*), lush vegetation, and high degree of endemism (Burlingame 2000).

At lower elevations in the study area, tourism is virtually non-existent, requiring landowners to have a greater reliance on agricultural production, which leads them to be more resistant to conservation measures that will take land out of production. Nature-based tourism is unlikely to develop as a major driver of conservation in this zone, due to its lack of infrastructure and the relative lack of charismatic and endemic species and lush vegetation in this dry forest ecosystem. Thus, conservation in this zone must shift away from a focus on charismatic species to spearhead conservation (Stotz et al. 1996), and adapt new conservation strategies. Certain agroforestry practices can provide key ecosystem services to farmers, while also increasing habitat and connectivity for forest-dependent wildlife in the Neotropics (Townsend & Masters 2015; Hendershot et al. 2020). For example, windbreaks provide direct benefits to farmers by protecting crops from damaging winds, reducing soil erosion (Jindal et al. 2008), and decreasing livestock mortality due to heat stress (Baker et al. 2018), while providing habitat for some forest bird species (Harvey & Gozalez Villalobos 2007; Brownson et al. 2021). Additionally, locally-targeted payments for watershed ecosystem services, which have recently been implemented at an individual watershed scale, can supplement stream protection legislation by providing

monetary incentives to landowners to restore riparian buffers in this zone (Townsend & Masters 2015; Shahady & Boniface 2018; Brownson et al. 2020).

These constraints played a key role in shaping the pattern of conservation prioritization of middle elevations that was highlighted in the hotspots. However, without a qualitative component to this study, important information about why areas were not prioritized would be missing, thus painting an incomplete picture of conservation prioritization in the region (Lowery & Morse 2013). The participatory mapping hotspots showed where participant conservation priorities clustered spatially, but not why those patterns emerged. The interview component of this study permitted contextual information to be analyzed to describe conservation priorities and constraints that shaped participant prioritization and illuminated areas where key stakeholders may have opinions that differ from the majority (Sletto 2009), such as in the case of prioritization of currently protected areas. Additionally, examining the spatial distribution of polygons connected to individual themes can also provide context for why places were prioritized by participants (Lowery & Morse 2013). Our analysis revealed that the hotspots included many of the most frequently identified places for each of the themes examined. Thus, the hotspots represented places that were prioritized for multiple reasons, making them a valuable tool for regional conservation planning, since they represent areas of high stakeholder support and synergy across multiple themes. However, each theme also included areas of high density that were not included in the hotspots, indicating that theme-specific analysis is also important for planning to ensure that key areas for a specific theme are not missed and provide more context to facilitate an assessment of trade-offs between prioritizing different locations (Knight et al. 2010; Lowery & Morse 2013; Karimi et al. 2020), which can lead to more effective and collaborative regional planning (DeClerck et al. 2010)

While this case study provides important insights into the ways in which biological corridors can shape the conservation priorities of constituent organizations in Costa Rica and thus drive landscape-level change, it may not be representative of the interactions in other biological corridors operating within unique contexts. Additionally, the findings of this study were shaped by the perspectives of organizations that agreed to participate. Other perspectives and priorities may not have been represented due to non-response or non-participation (Manfreda et al. 2008). Additionally, comparing regional models of species-habitat use with organizations' conservation priorities would facilitate a greater understanding of the benefits provided to wildlife under different conservation priorities, which can increase management effectiveness (Cox et al. 2014; Brown et al. 2019).

Our findings show that organizations' conservation priorities align with CBPC goals, such as increasing downslope forest connectivity, indicating that biological corridors can shape regional conservation objectives in Costa Rica despite their lack of legislative power (DeClerck et al. 2010) and function as an important way to bring groups together to achieve common conservation goals. This research highlighted places where organizational conservation priorities clustered spatially and identified some of the key drivers of those patterns. Understanding where commonly-identified conservation priorities are located spatially can increase land use planning efficiency within the CBPC (Calvo-Alvorado et al. 2009; DeClerck et al. 2010; Brown et al. 2019). However, by coupling participatory mapping with semi-structured interviews, this study was also able to provide greater context for the locations of these priorities than would be possible in a strictly quantitative study (Lowery & Morse 2013), which revealed key challenges for conservation in the lower portions of the CBPC, highlighted important minority opinions about allocating resources towards maintaining currently protected areas, and identified

synergies and differences between hotspots and the distributions of participant-identified priorities that were linked to specific themes. This contextual information can aid considerably in the assessment of trade-offs in the management planning process, increasing effectiveness and representation of diverse perspectives.

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Table 2.1. Frequency of theme occurrence in coded interview text and participatory mapping polygons.

Theme	Number of Occurrences in Interviews	Number of Polygons
Conservation	100	45
Wildlife	85	33
Birds	61	6
Spatial scale	61	0
Economics	57	0
Reforestation	57	25
Agriculture	52	0
Downslope connectivity	49	55
Water quality	49	36
Reserve management	44	9
Tourism	43	4
Reserve expansion/connectivity	42	25
Collaboration	41	0
Community engagement	37	1
Education	35	0
Constraints	27	0
Funding	24	0
Temporal scale	21	0
Ecosystem services	19	5
Positive experiences	16	0
Biodiversity	12	4
Negative experiences	11	0
Climate change	10	0
Development	10	0
Sustainability	10	3
Government	9	0
Pollution	8	0
Soil	8	2
Research	6	0
Carbon	3	0

Table 2.2. Conservation initiatives undertaken by organizations.

Conservation Initiative	Number of Organizations	Percent of Organizations
Reforestation	14	70%
Education/outreach	10	50%
Tourism	8	40%
Sustainable agriculture	7	35%
Water quality protection	7	35%
Reserve maintenance	4	20%
Research	4	20%
Land acquisition	3	15%
Direct wildlife conservation	3	15%

Table 2.3. Conservation constraints of organizations.

Conservation Constraint	Number of Organizations	Percent of Organizations
Lack of funding/staff	15	75%
Community resistance	6	30%
Current management practices	5	25%
Lack of education	5	25%
Government policies	5	25%
Lack of collaboration between organizations	4	20%
Logistics/distance between sites	2	10%
Urbanization	2	10%
Conservation saturation	2	10%
Lack of land titles	1	5%

Figure 2.1. Location of the study area within the *Corredor Biológico Pájaro Campana* (CBPC),
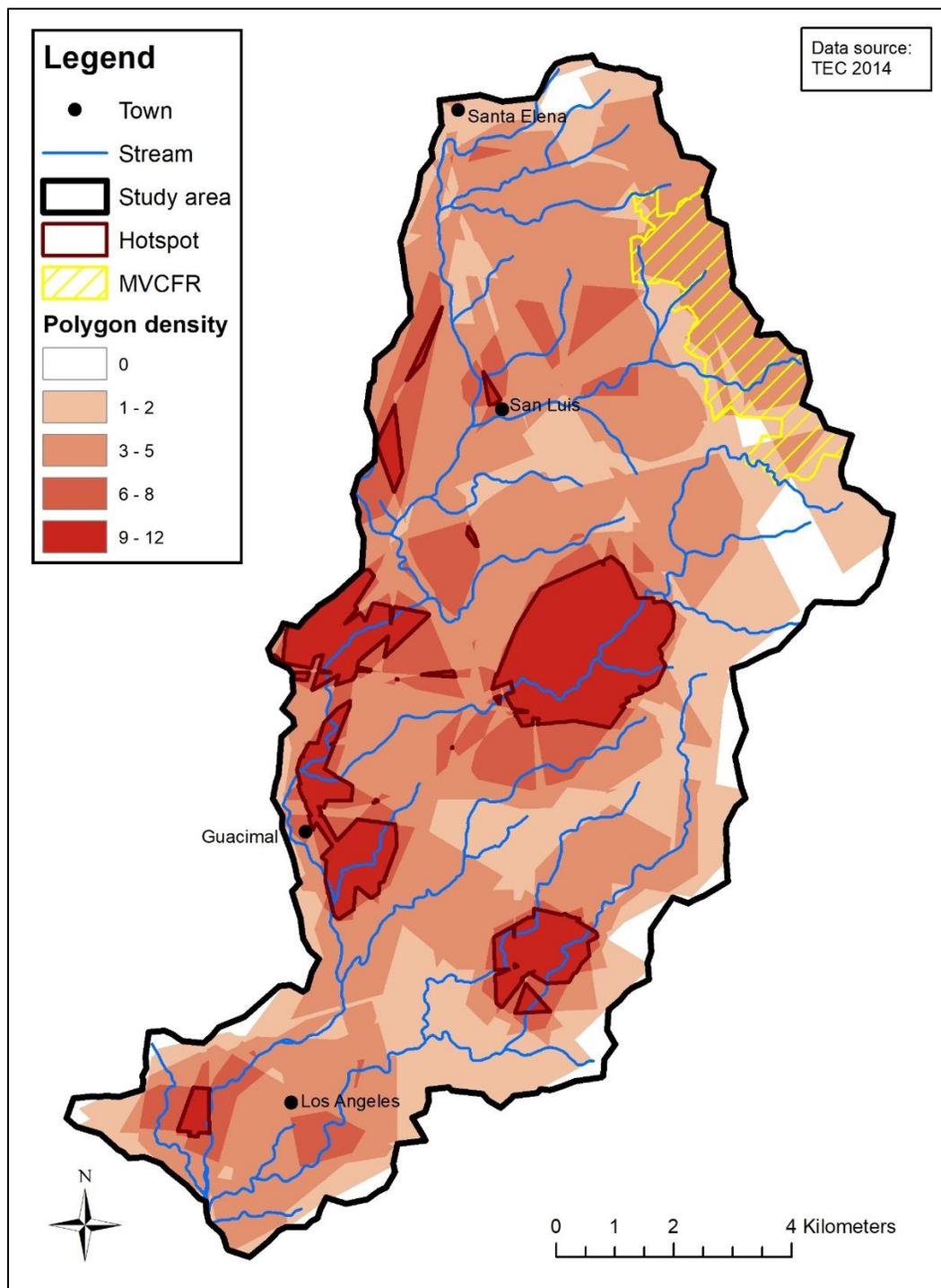
Costa Rica.

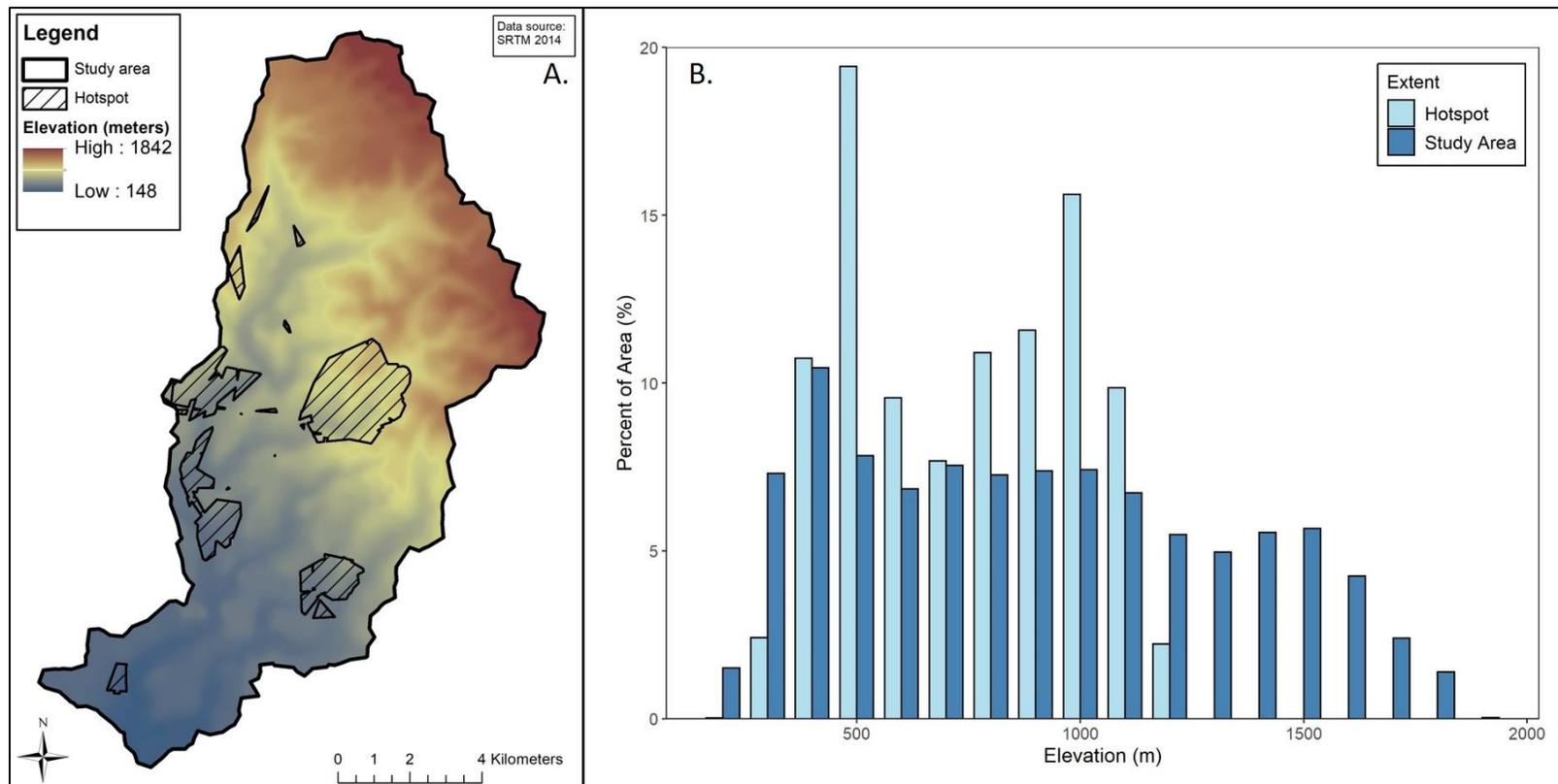Figure 2.2. Densities of conservation priority polygons from the participatory mapping exercise.

Figure 2.3. Location of hotspots along the study area elevational gradient (A.) and comparison of study area and hotspot elevation

distributions (B.).

Figure 2.4. Location of hotspots along the study area distance from protected area gradient (A.) and comparison of study area and hotspot distance from protected area distributions (B.).
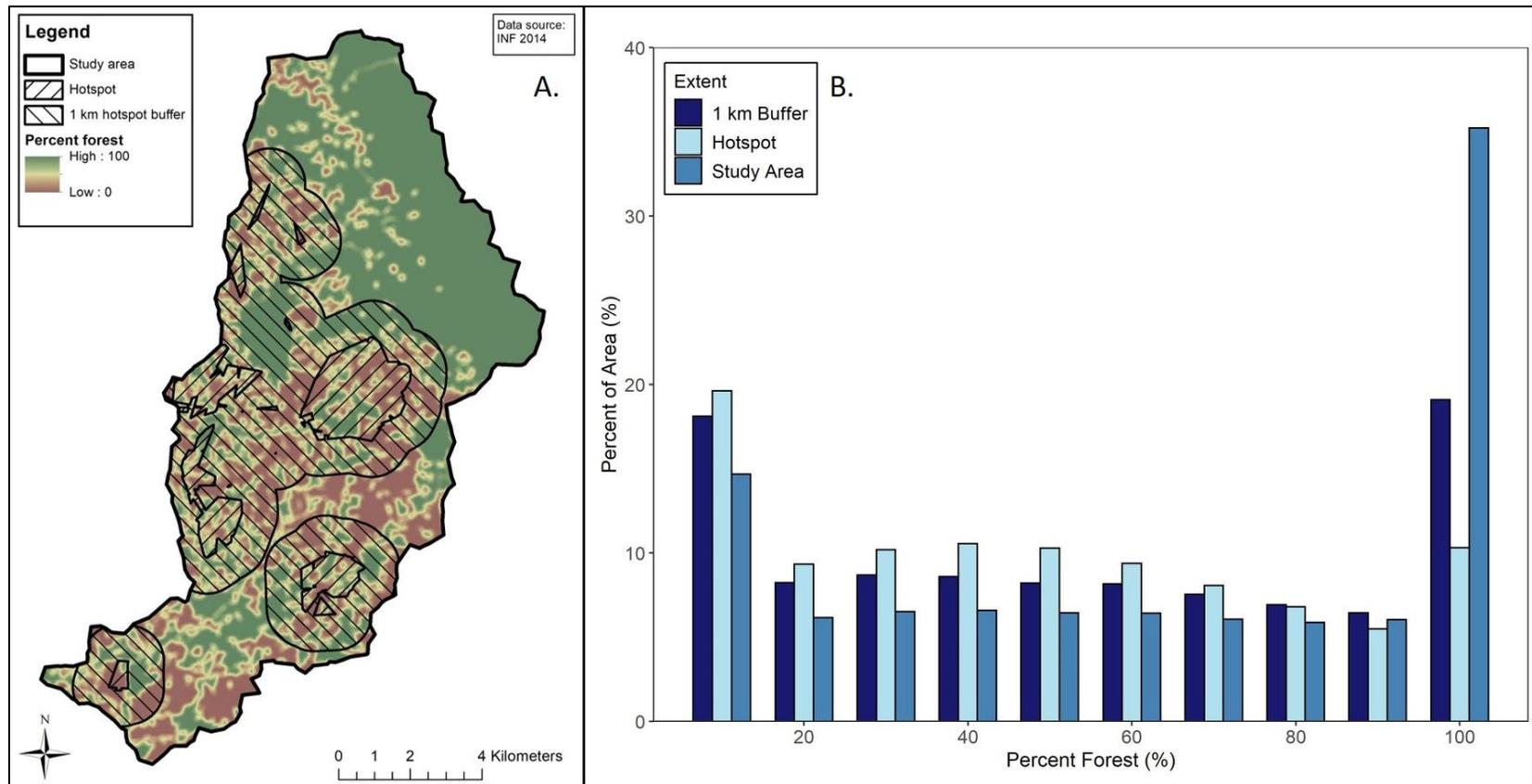
Figure 2.5. Location of hotspots along the study area percent forest gradient (A.) and comparison of study area and hotspot percent forest distributions (B.).
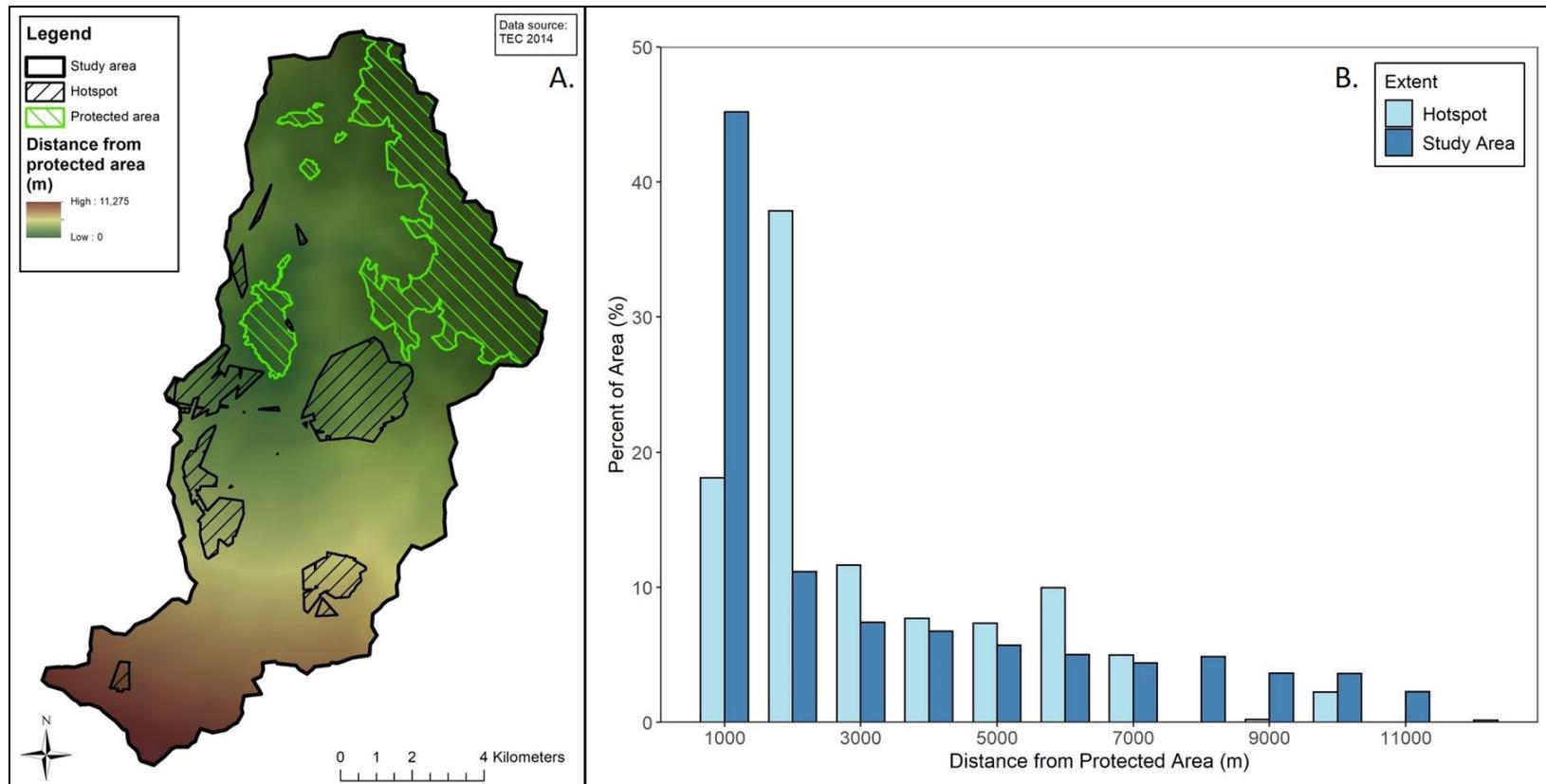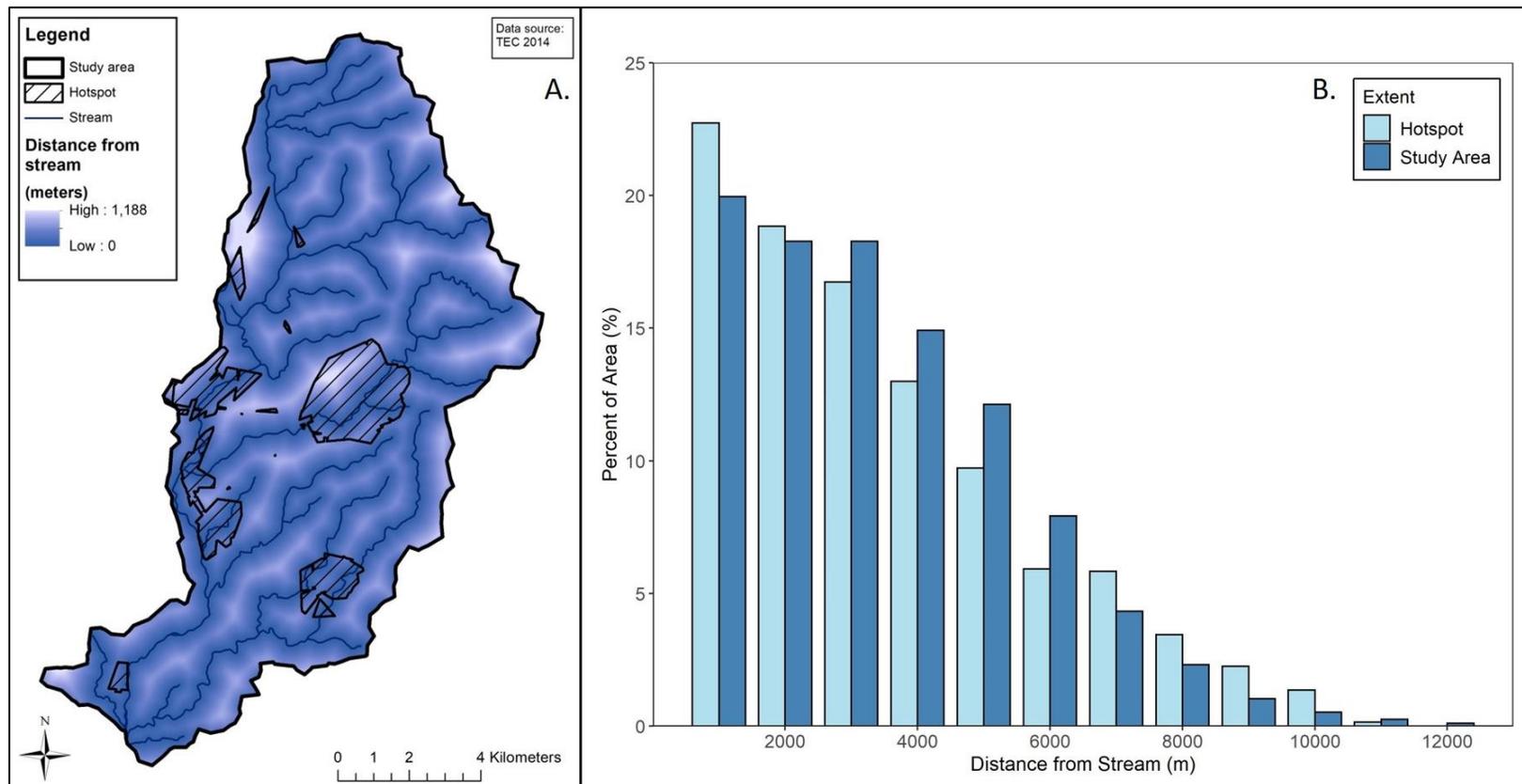
Figure 2.6. Location of hotspots along the study area distance from stream gradient (A.) and comparison of study area and hotspot distance from stream distributions (B.).
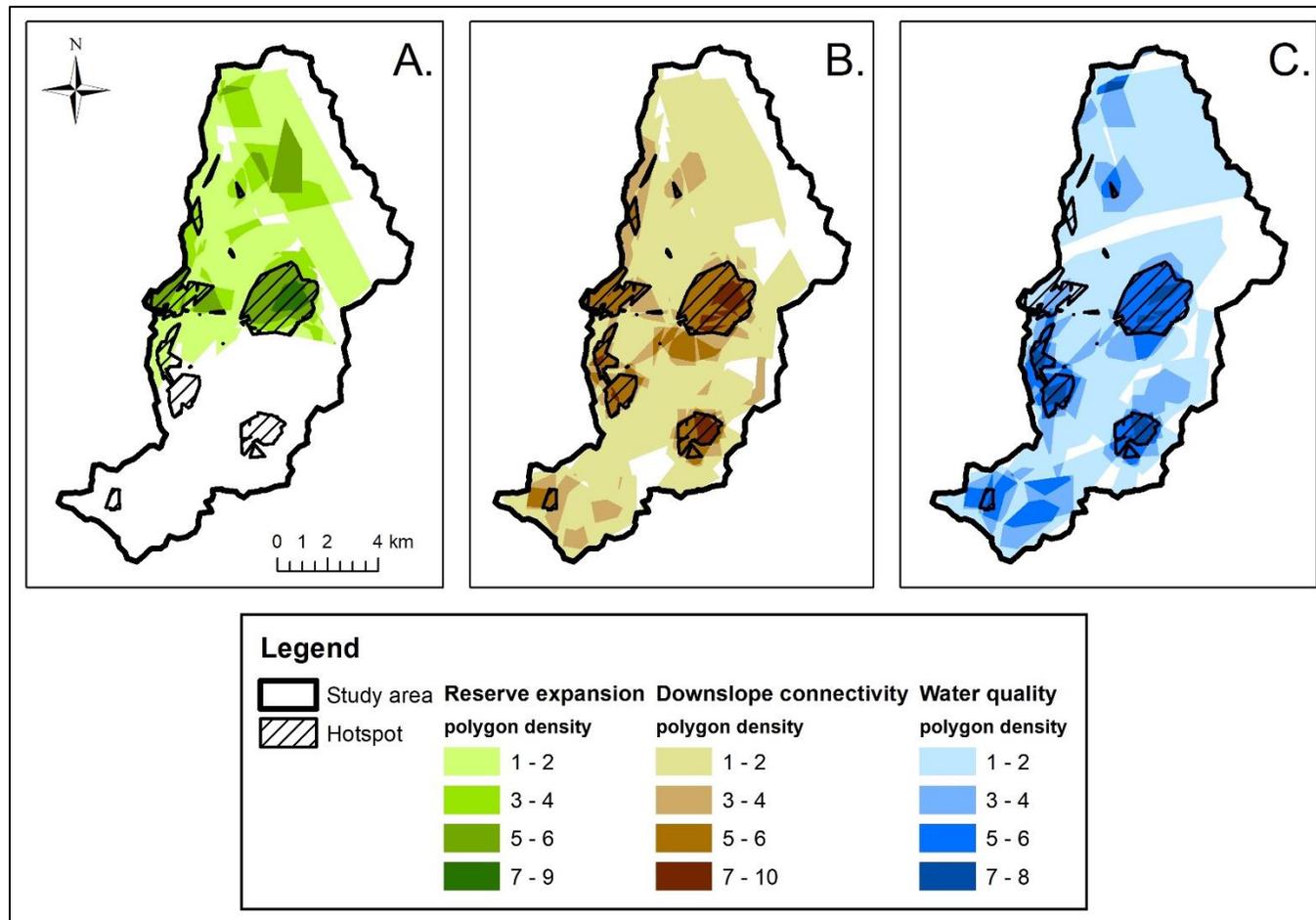
Figure 2.7. Comparison of the distribution of the hotspots and the density of polygons for three selected themes: (A.) reserve expansion/connectivity, (B.) downslope connectivity, and (C.) water quality.

CHAPTER 3

SCALE-DEPENDENT RESPONSES OF FOREST BIRDS TO FRAGMENTATION IN

COSTA RICA[2]

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[2] Cox, C.M., R.B. Chandler, R.J. Cooper, and N.P. Nibbelink. To be submitted to *Landscape Ecology*.

ABSTRACT

In the Neotropics, forest fragmentation has adversely affected many forest-dependent bird species by reducing habitat area and connectivity. Effective conservation strategies require detailed understandings of species-habitat relationships, which are complicated by the fact that species display diverse and scale-dependent responses to a range of landscape gradients. To identify which landscape gradients influence the abundance of a suite of resident forest-dependent bird species in Costa Rica, determine how responses change across spatial scales, and compare responses to landscape gradients between members of different feeding guilds, we conducted point counts at 301 randomly-stratified sites reflecting key landscape gradients in northwestern Costa Rica. We used this dataset to construct multinomial *N*-mixture abundance models for 16 commonly detected species at three spatial extents: 100 m, 500 m, and 1,000 m. We found that both landscape composition and configuration had effects on the abundance of Neotropical forest birds. For example, edge density was significantly related to abundance of canopy frugivores, and core forest area was significantly related to abundance of understory insectivores, but response varied by species and scale. As seen in other recent work, composition (percent forest) was a much more frequent driver of abundance patterns. This result indicates that many bird species will benefit from reforestation in a landscape, regardless of location and arrangement. However, many focal species displayed scale-dependent responses to landscape gradients, highlighting the need to consider habitat-use at multiple spatial scales. While we found some differences in responses to gradients between guilds, strong patterns did not emerge, reinforcing the idea that habitat use should best be understood through the development of species-specific models.

INTRODUCTION

Understanding how animals respond to landscape gradients is a critical component of effective conservation planning in an era of rapid, broad-scale habitat change (Frishkoff & Karp 2019). In the Neotropical region, which contains the highest levels of global terrestrial biodiversity (Raven et al. 2020), 3.91 million hectares of forest were lost annually between 2000 and 2010 (Achard et al. 2014), primarily as a result of agricultural expansion and intensification (Graesser et al. 2015; Dang et al. 2019). Deforestation in the Neotropics has not only reduced habitat area for forest-dependent species (Donald & Evans 2006), but has also fragmented remaining forest into isolated patches (Powell et al. 2000; Moran et al. 2019). Forest fragmentation decreases habitat connectivity (Schumaker 1996), which can adversely affect forest-dependent fauna by altering microclimates; decreasing inter-patch dispersal, access to food resources, and genetic diversity; and increasing competition, predation, and proportion of forest edge (Hunter 1996; Stratford & Stouffer 1999; Robinson 2001; Şekercioḡlu et al. 2001; Donald & Evans 2006). As a result, forest fragmentation can cause species to decline more quickly than would be expected based solely on the reduction of landscape-scale habitat area (Schumaker 1996).

The effects of forest fragmentation have been linked to declines in the abundance and richness of Neotropical forest-dependent bird species across a range of feeding guilds (Robinson 2001; Ferraz et al. 2003; Laurance et al. 2011; Stouffer 2020). However, there is considerable variability in the responses of individual species to fragmentation (Frishkoff & Karp 2019; Brownson et al. 2021) because species respond to unique combinations of landscape gradients as a result of specific behavioral and physiological traits. Thus, species-specific habitat models are required for effective conservation planning (Frishkoff & Karp 2019). Studies utilizing

experimentally-manipulated fragmented landscapes, which can better isolate the effects of individual landscape gradients than observational studies, have demonstrated that landscape configuration gradients play key roles in driving habitat use patterns across multiple taxa and spatial scales independent of the reduction of habitat area (Haddad et al. 2017). For example, edge density and forest patch proximity are two key drivers of declines in avian abundance and richness across several feeding guilds in a fragmented Amazonian landscape (Laurance et al. 2011), which highlights the additional negative consequences of forest fragmentation beyond the reduction of habitat area.

While the role of landscape configuration in driving declines of forest bird species has been supported in experimentally fragmented landscapes, observational research in non-experimentally altered fragmented landscapes has largely supported the Habitat Amount Hypothesis (Fahrig 2013), which concludes that landscape composition (e.g., proportion of forest cover) is the primary driver of species abundance patterns in fragmented landscapes and has a much stronger effect on the abundance of forest bird species than landscape configuration gradients (Villard et al. 1999; Cushman & McGarigal 2002; Grand et al. 2004; Carrara et al. 2015; Frishkoff & Karp 2019). However, the responses of many Neotropical forest bird species to forest proportion are not linear due to species peaking at different amounts of forest cover as a means of specialization (Frishkoff & Karp 2019). Thus, further research is needed to examine the roles of landscape composition and configuration in driving patterns of Neotropical avian abundance, since the findings have important implications for optimizing conservation planning (Carrara et al. 2015).

Different avian responses to landscape composition and configuration may be driven by behavioral traits (Reid et al. 2014). Foraging behavior is thought to play a key role in

determining the fragmentation tolerance of forest-dwelling bird species because the distribution of food resources often drives species' movement patterns (Burney & Brumfield 2009; Gonthier et al. 2014). Spatial and temporal variation in food resources are often greater in the forest canopy than the understory, causing canopy species to travel long distances (Levey & Stiles 1992). Species that forage in the forest canopy are also more likely to cross forest gaps than understory species (Şekercioḡlu et al. 2019) because the well-lit, open forest canopy more closely resembles non-forest conditions than the darker, cooler, and more densely vegetated forest understory (Levey & Stiles 1992) and because understory species tend to differ in wing morphology, which reduces their flight capacities and restricts gap-crossing behavior (Lees & Peres 2009).

Diet also plays an important role in driving Neotropical forest-dwelling bird species' responses to fragmentation (Reid et al. 2014; Hendershot et al. 2020). Insectivorous species tend to be relatively sedentary, since there is little seasonal difference in insect availability (Burney & Brumfield 2009). Diversity and abundance of Neotropical understory insectivorous birds decline precipitously in fragmented landscapes (Stouffer & Bierregaard 1995; Stratford & Stouffer 1999; Şekercioḡlu et al. 2001; Ferraz et al. 2003; Laurance et al. 2011; Stouffer 2020). Species of this guild tend to be particularly sensitive to forest fragmentation due to their poor dispersal capabilities and diminished propensies for crossing forest gaps (Visco et al. 2015), which are the result of employing specialized foraging techniques (e.g., following army ants) that require narrow microhabitats (Stouffer & Bierregaard 1995; Robinson 2001; Şekercioḡlu et al. 2001). However, frugivorous birds, which must constantly move to track patchily available fruit resources, are better able to persist in fragmented landscapes (Burney & Brumfield 2009; Laurance et al. 2011; Hendershot et al. 2020). Due to their mobility (Gonthier et al. 2014), many

frugivores readily permeate the non-forest matrix in fragmented landscapes, where they are known to expand their home ranges to incorporate sufficient food resources (Hansbauer et al. 2008; Peters & Nibbelink 2011). Many frugivorous forest birds even preferentially visit forest edges, where fruiting plants are often most abundant (Restrepo & Gomez 1998) and can thus potentially benefit from local-scale fragmentation (Reid et al. 2014), as has been documented in Neotropical frugivorous bats (Chambers et al. 2016). However, frugivorous birds are still likely to decline as a result of more intensive or broader scale disturbance because home range expansion can decrease population density within a landscape (Hansbauer et al. 2008) and energetic costs grow as distance between food resources increases, which can reduce survival (Graham 2001; Peters & Nibbelink 2011).

Species-habitat relationships are often scale-dependent due to the hierarchical nature of habitat selection (Johnson 1980; Carrara et al. 2015; Chambers et al. 2016). Thus, local and landscape level gradients can simultaneously affect species' abundances (Frishkoff & Karp 2019), making it necessary to consider responses to landscape gradients at multiple spatial scales (Weins 1989; Chambers et al. 2016; Mertes & Jetz 2017; Frishkoff & Karp 2019) to avoid generating misleading inferences about species-habitat relationships (Thompson & McGarigal 2002; McGarigal et al. 2016). Scale may play a role in driving the different effects of landscape configuration found in previous fragmentation studies. Additionally, local forest cover has a much stronger effect on the abundance of many Neotropical forest bird species than regional forest cover, even for mobile species that would be expected to respond more strongly to forest cover at broader spatial scales (Frishkoff & Karp 2019).

Objectives and Hypotheses

Costa Rica has become a model for successful conservation in the Neotropics (Evans 2000; Moran et al. 2019) by reversing a trend that saw the nation lose two-thirds of its forest cover between 1950 and 1988 (Sánchez-Azofeifa et al. 2001). While Costa Rica has experienced a net increase in forest cover since 2000 (Moran et al. 2019) through the implementation of conservation-focused legislation and growth of the nature-based tourism industry (Calvo-Alvorado et al. 2009), little reforestation has directly targeted the habitat requirements of species of concern. Instead, forest regeneration has largely been opportunistic or influenced by other management goals (Allen 2015; Brownson et al. 2021). An understanding of species-habitat relationships is required to optimize habitat augmentation initiatives, especially in fragmented landscapes. The goals of this study were to (1) identify which landscape gradients influence the abundance of a suite of resident forest-dependent bird species in Costa Rica, (2) determine how responses change across spatial scales, (3) compare responses to landscape gradients between members of different feeding guilds, and (4) identify the scale at which species most strongly respond.

We hypothesized that diet and foraging stratum would drive patterns of habitat use in Neotropical forest-dependent birds (Reid et al. 2014). We focused on forest-associated species, and we expected all species to respond positively to forest cover at broad spatial scales. However, we predicted that members of less sensitive guilds would display non-linear responses at finer scales. We predicted that canopy-dwelling species would be less sensitive to fragmentation than understory species (Ṣekercioḡlu et al. 2019) because food resources are more heterogeneously distributed in the canopy, and climatic and light conditions more closely resemble non-forest conditions (Burney & Brumfield 2009). Additionally, we predicted that

frugivorous species would respond positively to edge density, since fruiting plants are often most abundant along the forest edge (Restrepo & Gomez 1998). We expected understory insectivores to be the most sensitive guild to fragmentation (Laurance et al. 2011) and thus respond positively to the amount of core forest habitat and negatively to distance between patches and number of patches. We also predicted that understory species, which are more sensitive to fragmentation and less mobile, would respond most strongly to landscape gradients at local scales, while canopy species would respond more strongly at broader spatial scales (Miguet et al. 2016).

METHODS

Study Area

The study area comprised the 129 km^2 upper Guacimal watershed, which is located within the *Corredor Biológico Pájaro Campana* (CBPC; Bellbird Biological Corridor) on the Pacific slope of northwestern Costa Rica (Figure 3.1). The CBPC was established to promote forest connectivity between highland cloud forests and coastal mangroves (CBPC 2011). Within the CBPC, the upper Guacimal watershed spans a gradient from well-protected highland cloud forest to highly fragmented lowland tropical dry forest (1842 m - 148 m above sea level), including middle elevation (500 m - 1500 m) Pacific slope forests, which are highly fragmented in Costa Rica and underrepresented in the nation's reserve system (Powell et al. 2000). The upper Guacimal watershed is a mosaic of biological reserves, including the renowned Monteverde Cloud Forest Reserve, which receives over 80,000 visitors annually (Caldas 2009); small-scale agriculture, which primarily consists of cattle and coffee (Griffith et al. 2000; Burlingame 2014); and small agrarian communities. The study area has approximately 5,000 inhabitants, nearly 80% of whom live in the town of Santa Elena, which is a regional tourism hub (INEC 2011). We included only the upper portion of the Guacimal watershed in the study

area because climate, species composition, and the scale of agricultural operations differ

substantially in the lower portion of the watershed.

Sampling Design

We conducted point counts using a stratified-random sampling design to ensure adequate

coverage across the ranges of focal landscape gradients within the study area (Matseur et al.

2019). To develop our sampling strata, we calculated a suite of landscape gradients that we

hypothesized would be key predictors of avian abundance (Table 3.1) using a 250 m circular

moving window around each cell in FRAGSTATS v4 (McGarigal et al. 2012). These gradients

included measures of landscape composition and configuration. While not related to

fragmentation, elevation and distance to stream were also included in our analysis to ensure that

key gradients that shape habitat selection beyond land cover were considered. We used three data

sources to calculate landscape gradients: 2013 five-meter resolution land cover data (INF 2014)

for Costa Rica, which we reclassified into forest and non-forest classes; a 30 m resolution digital

elevation model (DEM) (SRTM 2014), which we resampled to five-meter cells to match the

grain of the land cover data; and a Costa Rican stream dataset (TEC 2014). We then used an

isocluster tool to group the landscape into 10 strata based on similarities across the landscape

gradients and generated an equal number of random points within each stratum, which were used

as sites for avian point counts. Points were located at least 250 meters apart to prevent

overlapping surveys and increase sampling independence (Blake & Loiselle 2001; Carrara et al.

2015).

Avian Surveys

We navigated to the randomly generated points using a handheld global positioning

system (GPS) unit. When sites were unreachable due to topography or land ownership, we

discarded the site and proceeded to an alternate site within the same stratum. We surveyed avian abundance at 301 sites from May – December in 2016 and 2017 and May – July in 2018. Sites were revisited up to five times, but not more than twice per year. We used a dependent double-observer approach (Nichols et al. 2000) to record the species and abundance of all birds seen and heard within a 50 m radius of each point count site during a 10-minute interval (Robbins et al. 1986; Blake & Loiselle 2001; Duclos et al. 2019). At the start of each point count, we recorded the site name, visit number, point count start time, temperature, wind speed, weather conditions, observers, and the location of the site using a handheld GPS unit (Robbins et al. 1986; Matseur et al. 2019). We restricted point count sampling to a window from 20 minutes before dawn until two hours after dawn on days with light to moderate wind speeds and little to no precipitation to facilitate detection (Blake & Loiselle 2001). Avian data collection methods were approved by the University of Georgia's Institutional Animal Care and Use Committee (A2015 02-008-Y3-A0; A2018 04-015-Y1-A0) and conducted under research permits approved by the Costa Rican *Ministerio de Ambiente y Energía* (Ministry of Environment and Energy: 037-2016-INV-ACAT; 019-2017-INV-ACAT; M-P-SINAC-PNI-ACAT-048-2018).

Analytical Methods

We focused our statistical analysis on resident forest-dependent bird species (Stiles & Skutch 1989; Stotz et al. 1996) that were detected at 30 or more sites (Wenger & Freeman 2008). We then grouped species that met these criteria into feeding guilds according to diet and foraging stratum and selected four guilds for analysis: understory insectivores, understory frugivores, canopy insectivores, and canopy frugivores. For each focal species, we developed a candidate set of hierarchical *N*-mixture models (Royle 2004; Chandler et al. 2011) to determine which landscape gradients best predict abundance at each of three spatial scales: 100 m, 500 m, and

1,000 m. Since animal count data can be affected by the probabilities that an individual is present at a site, produces a signal that allows it to be detected, and that the signal is detected by an observer (Chandler et al. 2011; Alexander & Hepp 2014), we included variables thought to affect avian abundance (eight landscape gradients listed in Table 3.1), availability (date, year, time of day, temperature, and wind speed) and detection probability (observer) in our models. Thus, we developed three-level hierarchical models to estimate abundance (λ) for each species while simultaneously accounting for availability of an individual to be detected (φ) and detection probability (p) (Chandler et al. 2011):

$$M_i \sim \text{Poisson}(\lambda)$$

$$N_{it} \sim \text{Binomial}(M_i, \varphi)$$

$$y_{it} \sim \text{Multinomial}(N_{it}, \pi_{it})$$

where M_i represents the total number of individuals that used site i during the study period, N_{it} represents the subset of individuals present at site i at time t, y_{it} is the vector of counts of individuals detected at site i at time t, and π_{it} is the vector of multinomial cell probabilities calculated from a detection probability function (p) (Chandler et al. 2011; Alexander & Hepp 2014). The multinomial cell probabilities for dependent double-observer point counts that we used for each site visit were (1) the probability that observer 1 detected an individual and (2) the probability of observer 2 detecting an individual that was not detected by observer 1:

$$\pi_1 = p_1, \pi_2 = p_2(1\text{-}p_1)$$

The probability of an individual not being observed by either observer is $\pi_3 = (1-p_1)(1-p_2)$. Hierarchical models were implemented using the 'gmultmix' function in the 'unmarked' package (Fiske & Chandler 2011) for the statistical software program, R (R Core Team 2020).

We used a multi-stage approach to develop a candidate set of models for each focal species at each focal scale. All model covariates were standardized to facilitate model convergence (Alexander & Hepp 2014). We began by fitting candidate models with combinations of detection and availability covariates and selected the top-ranked model to use as a foundation for including abundance covariates (Matseur et al. 2019). We then developed a candidate set of abundance models that each contained only a single landscape gradient for each species and scale combination. This set included linear terms for each of our eight focal landscape gradients and quadratic terms for five gradients that we hypothesized might have non-linear relationships with avian abundance in the study area. We then ran these candidate models and excluded gradients that did not have a significant effect on abundance ($p<0.05$). We then ranked the remaining single-gradient models using a model selection framework and compared the Akaike's Information Criterion (AIC) weights (Burnham & Anderson 2002) of gradients where both linear and quadratic models were produced and removed the version with the lower AIC weight. The remaining gradients were used for development of a final set of candidate abundance models.

Construction of the final candidate set of models from available gradients followed a series of rules. Gradients with greater than 0.9 AIC weight in the ranking of single gradient models were included in all candidate models to limit the number of potential candidate models. Additionally, gradients with a Pearson's R correlation score of >0.7 were not allowed to occur in the same model, except in cases when gradients were correlated with elevation. Additive models

were then constructed using all combinations of landscape gradients available based on our criteria. Finally, we ranked competing candidate models using a model selection framework and interpreted the model that received the highest AIC weight (Burnham & Anderson 2002).

To validate top-ranked models, we plotted semivariograms of model residuals using kriging with a maximum lag of 4,000 m (approximately 50% of the study area diameter) using the ArcGIS 10.2 geostatistical analyst tool (ESRI 2011) and examined the plots to identify evidence of spatial structure in the model residuals. We also examined the goodness-of-fit for the top-ranked models using a chi-square test with a parametric bootstrap for 100 simulations (Fiske & Chandler 2015) and used an overdispersion ratio (c-hat) to adjust standard errors of poorly fitting models (Kéry & Royle 2016). Additionally, we compared parameter estimates of all top-ranked models that included gradients that were correlated with elevation with models excluding elevation to ensure that the inclusion of a correlated gradient did not change the direction or magnitude of relationships. We then used the top-ranked models to develop five-meter resolution raster maps predicting abundance within the study area for each species at each focal scale. Cell values in these maps represented the predicted number of individuals in a 50-m radius circle around the cell center.

Subsequently, we compared the frequency of gradient appearance in top-ranked models and directionality of response across species, guilds, and scales. For one metric of landscape composition, percent forest, and two frequently occurring metrics of landscape configuration, core forest area and edge density, we used the top-ranked model to generate response curves for abundance across the entire range of the focal gradient that occurred within the study area, while holding other landscape gradients constant at their means (Kéry & Royle 2016). Due to the strong effects of elevation on defining suitable habitat, we held this gradient constant at its

optimal value instead of the mean. We then scaled the predicted abundance values in the response curves to standardize for differences in relative abundance between species using the raster abundance layer generated for the study area. We set the minimum and maximum values present in the raster layer to zero and one, respectively, in the response curve plots. We then examined the curves to identify patterns in responses to focal gradients across guilds, species, and scales.

To assess the relative effects of scale on species' abundance, we ranked the top-ranked abundance model for each species from each focal scale using a model selection framework and identified the scale of the model with the highest AIC weight for each species. We then examined patterns in frequency of top-ranked scales across guilds to determine whether members of feeding guilds shared similar scales of strongest response to landscape gradients.

RESULTS

Point Count Results

We detected 10,405 individuals representing 280 bird species, 189 genera, and 44 families during 404 total point counts, which were conducted at 301 sites within the study area. From this dataset, we selected 16 species for analysis because they were forest-dependent year-round residents (Stotz et al. 1996) that fit into our four feeding guilds (Stiles & Skutch 1989) and were detected at ≥30 sites, which we deemed necessary for constructing robust models (Wenger & Freeman 2008) (Table 3.2).

Model Results and Validation

We fit abundance models for all 16 focal species at all three spatial scales (Appendix D). Wind speed, temperature, and time of day significantly affected the availabilities of some species to be detected, and the individual observer significantly affected the detection of certain species

(Appendix E). The top-ranked abundance models for all species at all focal scales included at least one landscape gradient. Our inspection of the semivariograms of model residuals revealed no evidence of spatial structure in the model residuals for any focal species across all three spatial scales. However, goodness-of-fit tests revealed that model fit varied between species, with some top-ranked models falling outside the acceptable range for interpretation (Appendix E). However, when 1-2 outlying points were excluded and goodness-of-fit statistics were recalculated, model fit was improved for the poorly fitting models, ensuring that all model results were interpretable. Inclusion of gradients correlated with elevation did not cause changes in the direction of relationships with other significant model variables or substantial changes in the size of coefficients. Thus, we do not believe that including elevation in the models significantly altered our interpretation of the importance of other model variables.

Frequency of Gradient Appearance in Top-Ranked Models

While not related to fragmentation, elevation and distance to stream were included in our analysis to ensure that key gradients that shape habitat selection beyond land cover were considered. Elevation, which appeared in 96% of the top-ranked models for scale-specific species abundance, had the highest frequency of inclusion of any landscape gradient (Figure 3.2) and elevation alone often carried >0.9 AIC weight when ranking individual gradients for candidate model construction and it played a key role in shaping patterns of predicted abundance on the study area landscape (Figure 3.3; Appendix F). Conversely, distance to stream appeared in only 21% of the top scale-specific species abundance models, primarily at the 1,000 m scale.

Landscape composition, represented by percent forest, appeared in 71% of the top-ranked models. It was the most frequently occurring fragmentation gradient in top models by a large margin. Percent forest was consistent in its frequency across scale, appearing in the top model

for 75% of the focal species at both the 100 m and 500 m scales, and 63% of the species at the

1,000 m scale (Figure 3.2). However, percent forest appeared in the top-ranked models of canopy

insectivores less frequently than other feeding guilds.

Landscape configuration gradients appeared in the top-ranked models for species far less

frequently than elevation and percent forest (Figure 3.2). The most frequently appearing

configuration gradient, core forest area, was included in only 33% of the top-ranked models,

while edge density appeared in only 31% of the top-ranked models. The remaining configuration

gradients (patch density, patch shape, and patch proximity) occurred less frequently in top-

ranked models, even for sensitive understory insectivores, contrary to their predicted importance

as drivers of forest bird abundance. While core forest area appeared in the top-ranked 100 m

scale model for all but one understory species, where all responses were either positive or non-

linear, it only appeared in the top model for two canopy species, and the relationship was

negative in both cases. At the 1,000 m scale, core forest area appeared in the top-ranked model

for all but one understory insectivore species, where all responses were non-linear, but did not

appear in the top model for a single member of another guild. Edge density appeared in the top-

ranked models for 50% of the species at the 100 m scale, which included members of all focal

guilds. However, edge density decreased in its frequency of appearance as scale increased. At the

1,000 m scale, edge density only occurred in the top-ranked model of a single species, the Social

Flycatcher.

Responses to Percent Forest

Percent forest cover was included in the top-ranked model of all species except the

Dusky-capped Flycatcher. Species' responses to percent forest cover were almost exclusively

positive or non-linear across all scales, with the few exceptions occurring in certain canopy

species (Figure 3.4). However, 63% of species' abundances increased linearly with percent forest at the 100 m scale compared with only 19% at the 1,000 m scale, where responses were much more likely to be non-linear. Notable exceptions to this pattern were the canopy-dwelling Social Flycatcher and Red-billed Pigeon, which both responded negatively to percent forest at the 100 m scale. Two key patterns emerged across all focal species. The abundance of some species increased with percent forest similarly across multiple spatial scales (e.g., Black-faced Solitaire, Common Chlorospingus), while the abundance of others increased with percent forest at fine scales but peaked at intermediate amounts of forest cover at broader scales (e.g., Long-tailed Manakin, White-eared Ground-Sparrow).

Responses to Core Forest Area

Core forest area was most frequently included in the top-ranked models of understory species. However, it appeared only at the 100 m scale for understory frugivores, while it appeared in 83% of top-ranked models for understory insectivores at both the 100 m and 1,000 m scales (Figure 3.5). Understory insectivores were the only guild where core forest area appeared in top-ranked models at the 1,000 m scale. Understory insectivores were the only guild where core forest area appeared at multiple scales for the same species. The abundances of some understory insectivores peaked at intermediate amounts of core forest area across scales (e.g., Rufous-and-white Wren, White-eared Ground-Sparrow), while others switched from increasing abundance with core forest area at fine scales to displaying abundance peaks at intermediate amounts of core forest area at broader scales (e.g., Gray-breasted Wood-Wren). However, no focal species' abundance increased with core forest area across multiple spatial scales. Core forest area appeared very infrequently in the top models of canopy species, and responses were negative in all cases.

Responses to Edge Density

Edge density appeared in the top-ranked model for 31% of the focal species-scale combinations. However, no species displayed negative relationships between abundance and edge density where it appeared in the top model (Figure 3.6). In the infrequent cases where edge density appeared in the top model for a species at multiple focal scales, the species' responses were largely consistent across scales. Edge density appeared in the top-ranked model at ≥ 1 scale for all frugivores, but was entirely absent in the top models of 50% of the focal insectivorous species.

Ranking of Scales

A ranking of the AIC values of the top model for each species at each scale did not reveal any strong patterns in the top-ranked scale by guild, contrary to our predictions (Figure 3.7). All four guilds included species-level heterogeneity in the top-ranked scale. Notably, the most predictive scale for understory insectivores was never 100 m, while the most predictive scale for three species of canopy frugivores (75% of focal species in this guild) was 100 m.

DISCUSSION

This analysis provides key information about the responses of a diverse group of resident Neotropical forest bird species to forest fragmentation. Assigning species to guilds required qualitative decision-making since many species' behaviors do not fit neatly within categorical guilds (Reid et al. 2014). Additionally, model fit was somewhat variable across species. Nonetheless, key patterns emerged from our data that have important implications for Neotropical conservation. Despite the focus of this study on avian responses to forest fragmentation, elevation was the most frequently occurring and strongest individual predictor of avian abundance across our suite of focal species, since our study area occurred along a steep

elevational gradient. Elevation had a strong influence on shaping suitable habitat for many focal

species (Figure 3.3). In our study area, temperature and precipitation were highly correlated with

elevation and are likely the true drivers of abundance patterns because many Neotropical species

have narrow thermal tolerances, restricting them to narrow elevational zones (Forero-Medina et

al. 2011). We used elevation as a proxy for climatic gradients in our models because of its utility

for management and our access to higher resolution data. Elevation is an essential consideration

for management because restoring forest outside of a species' suitable elevational range will not

provide additional habitat for that species. However, the other non-fragmentation gradient that

we included in our analysis, distance to stream, rarely appeared in the top-ranked abundances

models of our focal species. While this finding indicates that distance to streams is likely not a

key management concern for many bird species in this landscape, riparian buffers have

conservation value for birds by increasing landscape forest cover and provide key habitat for

other taxa and movement corridors to facilitate seasonal (Hsiung et al. 2018) and climate change-

driven altitudinal migration (Townsend & Masters 2015).

Frequency of Landscape Composition and Configuration

Landscape composition, which we measured using percent forest, appeared in 71% of the

top-ranked models across all scales, while at least one landscape configuration gradient appeared

in 69% of the top-ranked models. However, no individual configuration gradients appeared in

more than 33% of models. The relative infrequency of key configuration gradients in top-ranked

models compared to percent forest did not support our hypotheses. However, this pattern did

support previous findings that landscape composition is a much stronger driver of Neotropical

avian abundance and diversity patterns in non-experimentally manipulated fragmented

landscapes than landscape configuration (Carrara et al. 2015; Frishkoff & Karp 2019). These

findings align with the Habitat Amount Hypothesis (Fahrig 2013), which states that the amount of habitat in the landscape, in this case forest cover, is the primary driver of species abundance patterns, regardless of configuration. Thus, our results suggest that adding forest cover within the proper elevational zones for focal species can have significant positive effects on many forest species, regardless of configuration.

There are other explanations as to why we did not find strong effects of landscape configuration on species abundance, in contrast to some previous studies that used experimentally fragmented landscapes (Laurance et al. 2011; Haddad et al. 2015). Landscape composition may be a stronger driver of avian abundance than configuration in non-experimentally manipulated landscapes (Carrara et al. 2015, Frishkoff & Karp 2019) because they do not isolate configuration gradients as fully from other confounding gradients or sample across as broad a range of gradient values (Haddad et al. 2017). Furthermore, edge density was correlated with percent forest at the 1,000 m scale and core forest area was correlated with percent forest at the 500 m scale. Thus, these gradients may have occurred less frequently in broader scale models because significant effects on abundance could not be teased out in this landscape as a result of the correlations with percent forest, which was a stronger driver of abundance patterns.

Additionally, the degree of fragmentation within our study area was modest compared with other landscapes. The maximum distance between forest patches in the study area was only 199 m, and the non-forest matrix in this region is characterized by relatively permeable shade-grown coffee, windbreaks, and pastures with remnant trees (Brownson et al. 2021). The lack of broad-scale patch isolation in our study area may have obscured some responses to configuration gradients, since specific habitat selection patterns are often context-dependent (McGarigal et al.

2016). Thus, patch proximity may have occurred so infrequently in our top-ranked models, contrary to our expectations, because forest patches were not isolated enough from one another in our study area to detect the effects of distance (Carrara et al. 2015; Haddad et al 2017), since the effects of landscape configuration are greatest in the most isolated patches (Haddad et al 2015). These landscape patterns may hold relatively true for Costa Rica as a nation, leading to similar findings in other studies in Costa Rica (Frishkoff & Karp 2019) and other relatively intact Neotropical landscapes (Carrara et al. 2015), contrasting with the broad-scale fragmentation observed in experimental studies in the Amazon, where configuration played a larger role in predicting abundance (Laurance et al. 2011; Stouffer 2020). In a landscape with more isolated patches we would expect different results (Carrara et al. 2015). Additionally, our findings may be biased towards more tolerant species since we did not detect any highly sensitive species (Stotz et al. 1996) at enough sites to include in our analysis. We expect sensitive understory insectivores to respond more strongly to landscape configuration and be strongly linked to core forest area and forest patch proximity (Laurance et al. 2011).

Responses to Landscape Composition

These models illustrate that the amount of forest in the landscape is an important driver of abundance for forest-dependent Neotropical bird species across a range of feeding guilds, as we expected. However, the direction of the relationships was often species- and scale-specific. At the 100 m scale, abundance of all understory species increased with percent forest, while responses were more variable for canopy species, indicating that canopy species are less sensitive to habitat proportion at local scales than understory species (Levey & Stiles 1992), as we hypothesized. However, while some species displayed similar increases with forest cover across scales, abundance for many species peaked at intermediate amounts of forest cover at

broader spatial scales (Figure 3.4). However, differences in responses across scales were not

detectable between guilds. Species that respond positively to percent forest at all spatial scales

may be more sensitive to fragmentation than species that exhibit peaks at intermediate amounts

of forest cover at broader spatial scales, which are likely better able to persist in moderately

fragmented landscapes because they are able to exploit resources along the forest edge and

permeate the non-forest matrix.

Non-linear responses to landscape gradients are relatively common in Neotropical birds

(Frishkoff & Karp 2019), and indicate specialization along particular gradients, perhaps as a

mechanism for niche partitioning in a region of high biodiversity. A common pattern in our

results was that of species' abundance increasing with local forest cover, but peaking at

intermediate levels of broad scale forest cover (e.g., Long-tailed Manakin; Figure 3.4). Similarly,

Frishkoff and Karp (2019) found non-linear relationships between responses to local and

landscape-scale forest cover in Neotropical birds, with only the abundance of forest interior

specialists consistently increasing with landscape-scale forest cover. We expected some species

to be tolerant of fragmentation at fine scales, but require increased forest habitat at broad scales,

but instead found the inverse, which indicates that many forest species can utilize fragmented

landscapes at broad scales, but still depend on local forest cover. This pattern may be driven by

the fact that individuals require local forest cover for protection from predators and camouflage

for nest sites (Storch et al. 2005), but choose areas near enough to the forest edge to exploit its

abundant food resources (Restrepo & Gomez 1998). Additionally, many Neotropical forest bird

species respond more strongly to local forest cover than landscape-level forest cover (Carrara et

al. 2015; Frishkoff & Karp 2019) and can intensively utilize even small forest patches within an

agricultural matrix (Şekercioḡlu et al. 2007). Therefore, birds may not be actively selecting areas

of intermediate forest cover in the landscape, but simply not avoiding forest patches located within fragmented landscapes. Importantly, these scale-dependent responses would be missed if relationships between abundance and forest cover were only examined at a single focal scale, leading to incorrect inferences about habitat use patterns (McGarigal et al. 2016).

Responses to Landscape Configuration

While landscape composition appeared much more frequently than configuration gradients, we found some potentially important effects of landscape configuration on avian abundance. As we hypothesized, responses to core forest were linked to species' foraging strata. Core forest area appeared in the top-ranked models of understory species at ≥1 scale, where responses were almost universally positive or non-linear, but appeared infrequently in the models of canopy species, where relationships were always negative (Figure 3.5). This pattern highlights the fact that understory species are more linked with the amount of interior forest in the landscape than canopy species and are consequently more sensitive to fragmentation (Levey & Stiles 1992). Additionally, 83% of our focal understory insectivores responded to core forest area at the 1,000 m scale, while none of the understory frugivores responded to this gradient at this scale, which supports our hypothesis that understory insectivores are more sensitive to fragmentation than understory frugivores due to their greater reliance on interior forest habitat. Understory frugivores can likely make better use of forest patches in fragmented landscapes because of their greater mobility, arising from their need to track patchily available food resources (Burney & Brumfield 2009), than understory insectivores, which require more intact landscapes. However, most understory insectivores in this study displayed non-linear relationships with core forest area, especially at broad scales. This pattern of responses, coupled with the fact that none of these species were classified as highly sensitive to disturbance by Stotz

et al. (1996), indicates that our focal understory insectivores may not be representative of the most sensitive members of the guild, which likely have stronger positive associations with core forest area (Laurance et al. 2011; Stouffer 2020). However, we did not detect any highly sensitive understory insectivores at enough sites to construct robust models.

While edge density only appeared in 31% of our top-ranked models, we did find evidence of certain species maximizing their abundance along the forest edge density gradient, unlike Frishkoff and Karp (2019), indicating a degree of edge specialization. For example, Social Flycatcher abundance increased with edge density at both the 100 m and 1,000 m scales (Figure 3.6), likely due to the increased visibility provided by perches along the forest edge for sallying to catch insects, while Slate-throated Redstarts, another canopy insectivore, may not have responded to edge density because they forage differently, gleaning insects from denser vegetation (Stiles & Skutch 1989). However, while only 50% of focal insectivorous species responded to edge density at any scale, all focal frugivores responded to edge density at ≥1 scale. This difference in response supports the idea that frugivores are more tolerant of forest fragmentation than insectivores (Burney & Brumfield 2009; Carrara et al. 2015; Hendershot et al. 2020), and positive relationships between frugivore abundance and edge density suggest preferential use of the forest edge, where fruiting plants are often most abundant (Restrepo & Gomez 1998), similar to patterns of habitat use observed in Neotropical frugivorous bats (Chambers et al. 2016). Furthermore, some focal understory insectivores (e.g., Orange-billed Nightingale-Thrush, Slaty-backed Nightingale-Thrush) also include a significant amount of fruit in their diets (Stiles & Skutch 1989), which may explain their associations with edge density.

Forest generalist birds tend to have positive relationships with edge density because of increased access to resources along the edge in heterogeneous landscapes (Carrara et al. 2015),

unlike interior specialists, which require tracts of continuous forest. None of the focal species in our study displayed negative relationships with edge density, indicating that edge was not a significant limiting factor for any of these species. Other studies on Neotropical birds have uncovered strong edge effects on sensitive forest specialists (Laurance et al. 2011), further indicating that our focal species may not be representative of the responses of this suite of species. However, core forest area and edge density in our study area were correlated at both the 500 m and 1,000 m scales and could not appear in the same model. Thus, for more sensitive species, the positive associations with core forest area may have outweighed the negative effects of edge density, thus obscuring the relationship.

Scale of Response

While individual species select habitat at different spatial scales (McGarigal et al. 2016), research on Neotropical birds has indicated that local forest cover has a stronger effect on community structure and species diversity than landscape-scale forest cover (Carrara et al. 2015; Frishkoff & Karp 2019). Thus, we expected the more sensitive guilds in our study to respond most strongly at local scales, but predicted that highly mobile species (e.g., canopy frugivores) would respond more strongly at broader spatial scales (Gonthier et al. 2014; Miguet et al. 2016). However, even highly mobile Neotropical birds often respond most strongly to local conditions (Frishkoff & Karp 2019). We found considerable variability in the top-ranked scales within guilds (Figure 3.7), but in general, results did not support our hypotheses. No understory insectivores responded most strongly at the 100 m scale, while 75% of the focal canopy frugivores responded most strongly to local conditions, despite their mobility. Our results highlight the fact that the scale at which species most strongly respond to habitat characteristics can be highly variable and requires species-level examination (McGarigal et al. 2016).

Conclusions

While our models illustrate the effects of key landscape gradients on avian abundance, further research is needed to determine how these gradients relate to species' persistence in the landscape, since these abundance models cannot identify areas that represent sink habitats, are experiencing extinction lags, or support only specific behaviors (e.g., feeding but not reproduction) (Daily et al. 2001; Carrara et al. 2015; Şekercioḡlu et al. 2019). Thus, our findings should be validated with long-term studies on population dynamics to ensure that species can persist in the same landscapes where they are abundantly detected (McGarigal et al. 2016). Additionally, understanding avian movement patterns in fragmented landscapes would provide greater insight into how birds access patchily-distributed resources and their tolerances for moving across forest gaps (Hansbauer et al. 2008; Peters & Nibbelink 2011). Matrix quality has also been shown to be a key driver of patterns of avian abundance and diversity in the Neotropics (Laurance et al. 2011; Hendershot et al. 2020; Stouffer 2020), but was not considered in this study. Furthermore, since landscape context can affect local-scale responses to gradients (Reid et al. 2014; Frishkoff & Karp 2019), additional work should be undertaken to determine how landscape composition at one scale influences responses at another. The goal of this study was to examine responses to landscape gradients across a range of scales. However, to create the most realistic predictions of species' abundance within the study area to best determine how management action might affect abundance, models that combine gradients from multiple spatial scales should be used (McGarigal et al. 2016).

This study showed that both landscape composition and configuration have effects on the abundance of Neotropical forest birds (Laurance et al. 2011; Carrara et al. 2015). However, landscape composition was a much more frequent driver of abundance patterns (Frishkoff &

Karp 2019). Since many bird species will benefit from additional forest added to the landscape, regardless of configuration, opportunistic reforestation (Allen 2015; Brownson et al. 2021) can be an effective strategy for augmenting habitat in Costa Rica. The fact that many focal species responded both positively to local forest cover and non-linearly to landscape-scale forest cover provides an encouraging sign that local conservation projects can create habitat for many forest bird species by restoring forest in agricultural landscapes (Şekercioḡlu et al. 2007; Frishkoff & Karp 2019; Karp et al. 2019), since even moderate restoration could reverse long-term declines and greatly benefit forest species (Şekercioḡlu et al. 2019). While we found some differences in responses to gradients between guilds, the lack of definitive patterns reinforces the idea that habitat use should best be understood through the development of species-specific models and that groups of species that respond to fragmentation similarly are best defined *post hoc* (Frishkoff & Karp 2019). Developing models of habitat use in individual species remains complex, since responses are often context-dependent and results are difficult to transfer across species' ranges and to other taxa (McGarigal et al. 2016; Frishkoff & Karp 2019). Nevertheless, many of our key findings about avian responses to forest fragmentation align with conclusions from other studies on the habitat use of Neotropical birds in similar landscapes (Carrara et al. 2015; Frishkoff & Karp 2019). Finally, the differences in response by species across scales underscores the necessity of considering habitat use at multiple spatial scales for informed conservation planning (McGarigal et al. 2016).

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Table 3.1. Landscape gradients included in candidate abundance models. Descriptions adapted from McGarigal et al. (2012). Each gradient was calculated within circular focal windows around each cell in the landscape of three radii: 100 m, 500 m, and 1,000 m.

Landscape gradient	Gradient type	Description	Units	Range	Data source
Elevation	General	Mean elevation within focal window.	meters	*100 m:* 151.5 – 1,826.5 *500 m:* 179.6 – 1,742.6 *1,000 m:* 188.5 – 1,703.9	Resampled 30 m DEM (SRTM 2014)
Distance to stream	General	Mean Euclidean distance to nearest stream within focal window.	meters	*100 m:* 15.6 – 1,187.9 *500 m:* 76 – 985 *1,000 m:* 136.9 – 757.4	Stream polyline (TEC 2014)
Percent forest	Composition	Percent forest cover within focal window.	percent	*100 m:* 0 – 99.6 *500 m:* 3.5 – 100 *1,000 m:* 18.7 – 100	Reclassified 5 m land cover (INF 2014)
Core forest area	Configuration	Amount of forest cover located ≥ 100 m from forest edge within focal window.	hectares	*100 m:* 0 – 3.1 *500 m:* 0 – 78.5 *1,000 m:* 0 – 314.1	Reclassified 5 m land cover (INF 2014)
Edge density	Configuration	Sum of lengths of all forest edge (m) within focal window divided by the total forest area (ha) within the focal window.	meters/ hectare	*100 m:* 0 – 766.4 *500 m:* 0 – 298 *1,000 m:* 0 – 225.8	Reclassified 5 m land cover (INF 2014)
Patch density	Configuration	Number of forest patches divided by focal window area (m^2), multiplied by 1,000,000.	number/ 100 hectares	*100 m:* 31.8 – 446 *500 m:* 1.3 – 35.6 *1,000 m:* 0.3 – 14	Reclassified 5 m land cover (INF 2014)
Patch shape	Configuration	Inverse of mean perimeter-area ratio of forest patches (m:m^2) within focal window.	none	*100 m:* 0 – 7,746.6 *500 m:* 140.1 – 6,964.1 *1,000 m:* 197.5 – 7,183.8	Reclassified 5 m land cover (INF 2014)
Proximity index	Configuration	Mean sum of forest patch area (m^2) divided by the squared nearest edge-to-edge distance to each forest patch (m^2) within focal window.	none	*100 m:* 0 – 227.7 *500 m:* 0 – 5,775.2 *1,000 m:* 0 – 22,722.6	Reclassified 5 m land cover (INF 2014)

Table 3.2. Forest-dependent bird species included in analysis.

Common name	Scientific name	Family	Guild	# sites occupied	# individuals detected
Keel-billed Toucan	*Ramphastos sulfuratus*	Ramphastidae	Canopy frugivore	81	166
Northern Emerald-Toucanet	*Aulacorhynchus prasinus*	Ramphastidae	Canopy frugivore	53	105
Black-faced Solitaire	*Myadestes melanops*	Turdidae	Canopy frugivore	33	69
Red-billed Pigeon	*Patagioenas flavirostris*	Columbidae	Canopy frugivore	66	158
Squirrel Cuckoo	*Piaya cayana*	Cuculidae	Canopy insectivore	36	47
Slate-throated Redstart	*Myioborus miniatus*	Parulidae	Canopy insectivore	33	74
Social Flycatcher	*Myiozetetes similis*	Tyrannidae	Canopy insectivore	46	99
Dusky-capped Flycatcher	*Myiarchus tuberculifer*	Tyrannidae	Canopy insectivore	52	70
Long-tailed Manakin	*Chiroxiphia linearis*	Pipridae	Understory frugivore	65	173
Common Chlorospingus	*Chlorospingus flavopectus*	Emberizidae	Understory frugivore	32	118
Lesson's Motmot	*Momotus lessonii*	Momotidae	Understory insectivore	62	134
White-eared Ground-Sparrow	*Melozone leucotis*	Emberizidae	Understory insectivore	48	95
Orange-billed Nightingale-Thrush	*Catharus aurantiirostris*	Turdidae	Understory insectivore	37	57
Slaty-backed Nightingale Thrush	*Catharus fuscater*	Turdidae	Understory insectivore	35	53
Rufous-and-white Wren	*Thryophilus rufalbus*	Troglodytidae	Understory insectivore	97	181
Gray-breasted Wood-Wren	*Henicorhina leucophrys*	Troglodytidae	Understory insectivore	40	90
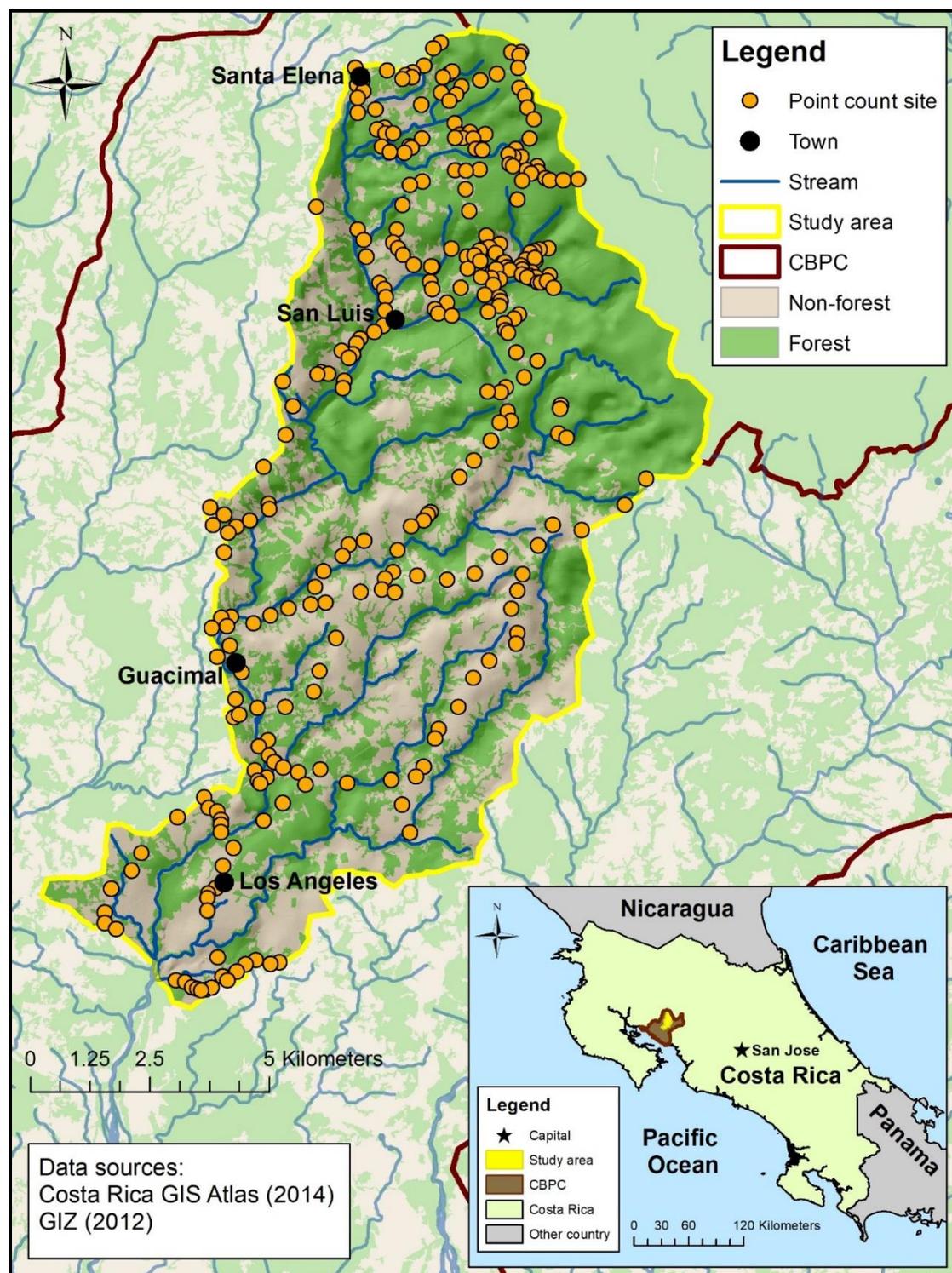
Figure 3.1. Location of the study area and point count sites within the *Corredor Biológico Pájaro Campana*, Costa Rica.
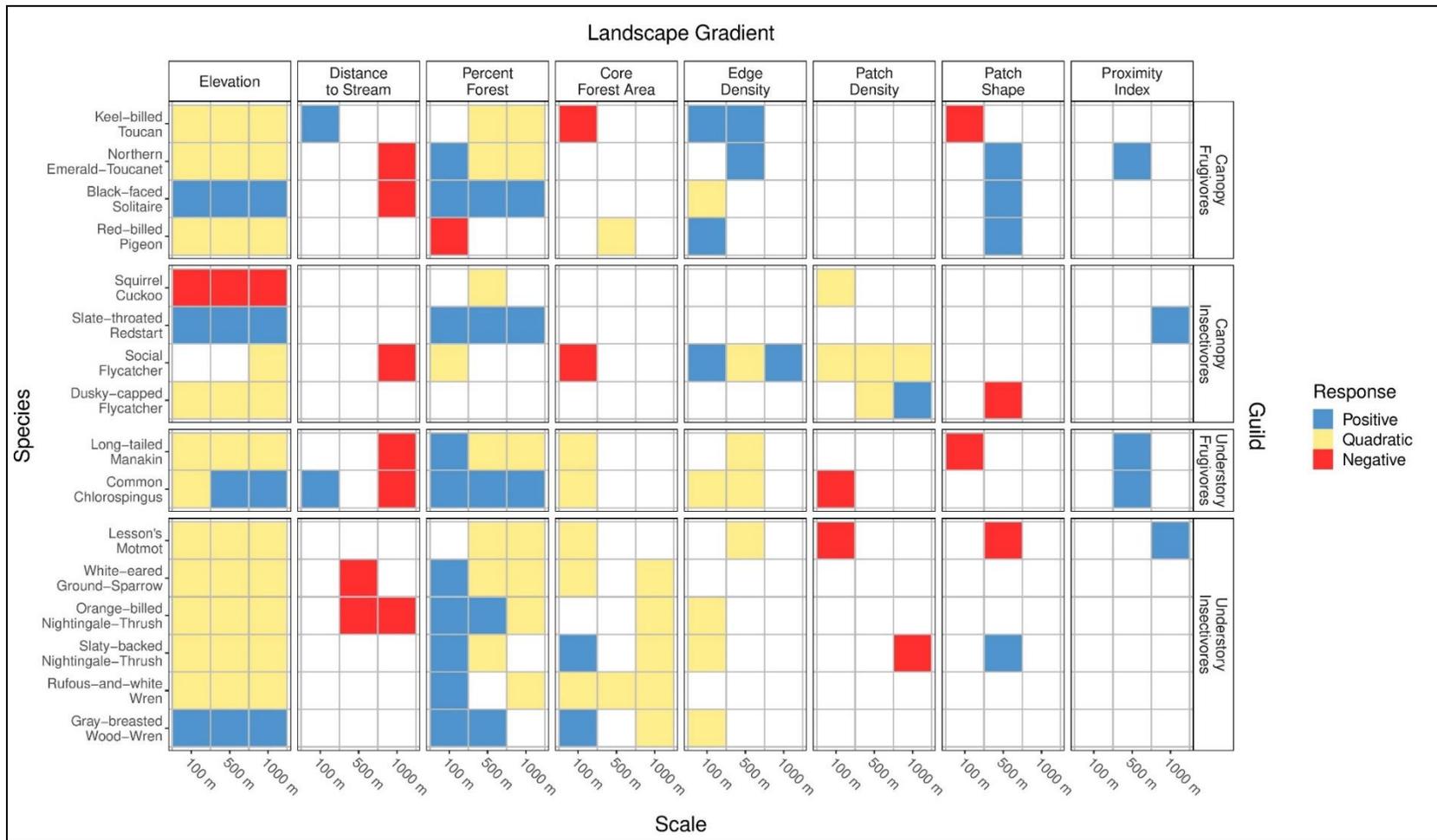
Figure 3.2. Direction of abundance response to landscape gradients included in the top-ranked model for each focal species at each focal scale. Empty cells indicate gradients not included in the top-ranked model at that scale.
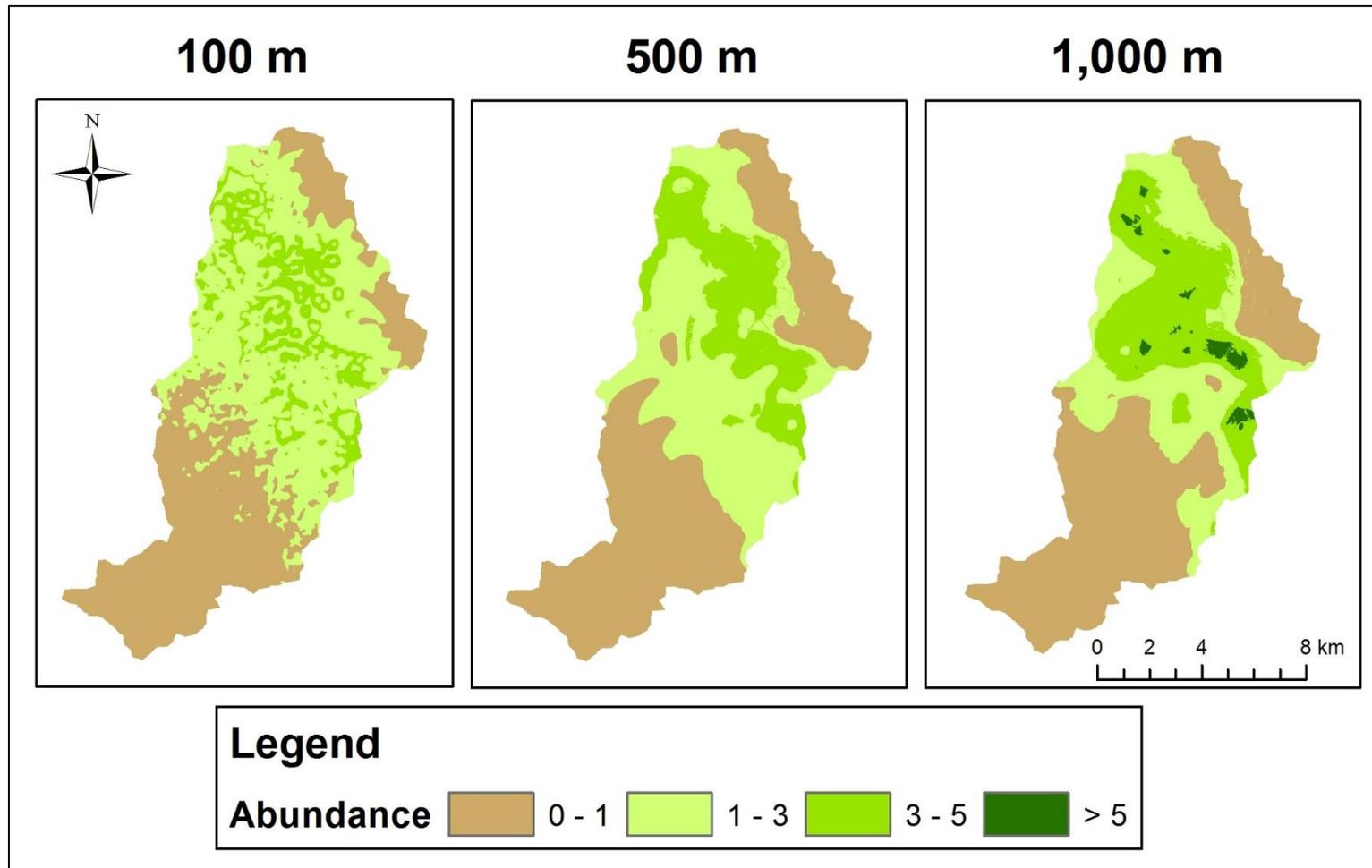
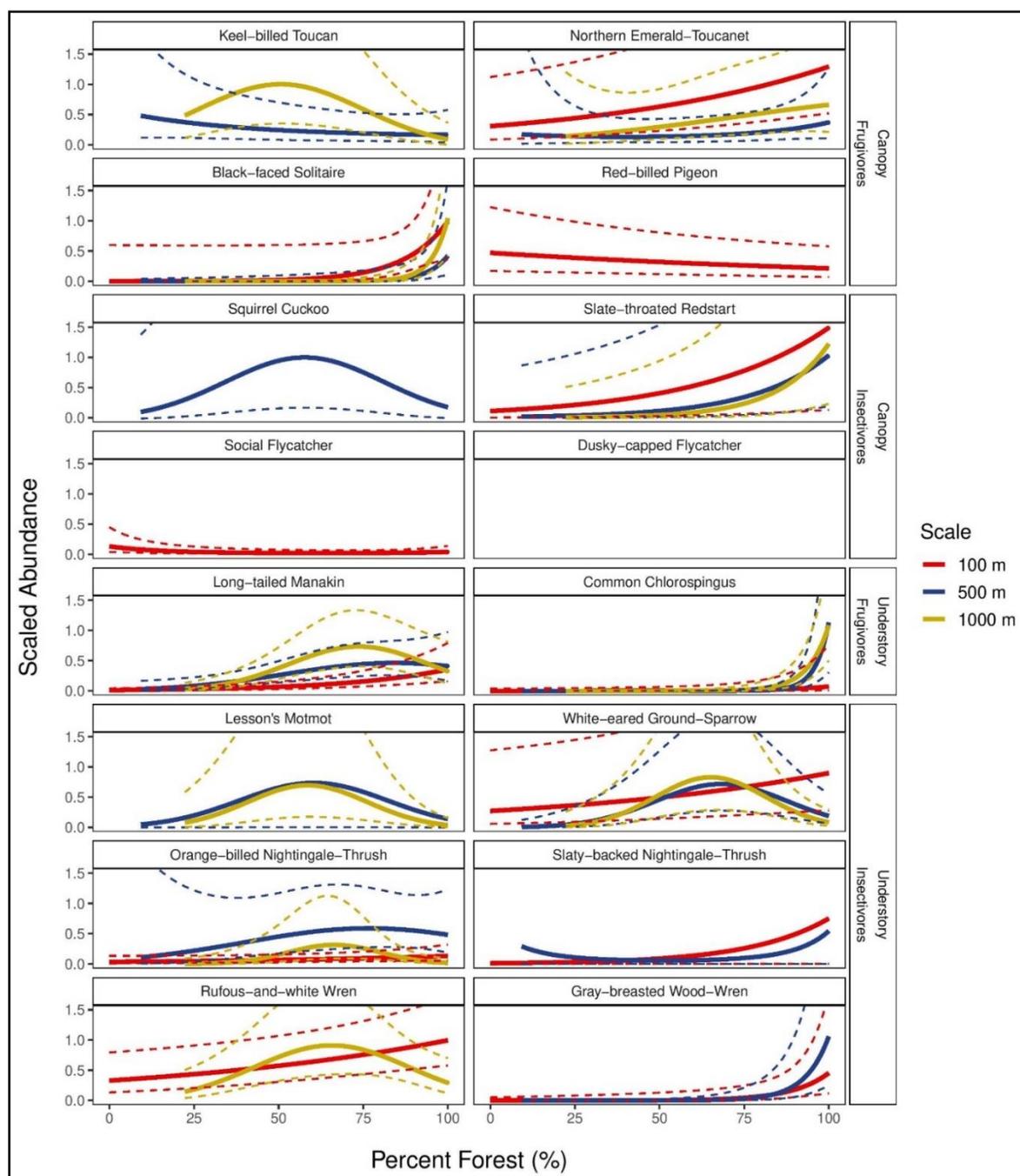Figure 3.3. Predicted abundance of Rufous-and-white Wrens under the top-ranked model at each focal scale.

Figure 3.4. Abundance of species across the range of percent forest found within the study area at each focal scale. Abundance was scaled to account for differences between species. 95% confidence intervals are illustrated with dashed lines. Missing lines within a plot indicate that percent forest did not appear in the top-ranked model for that species at that scale.
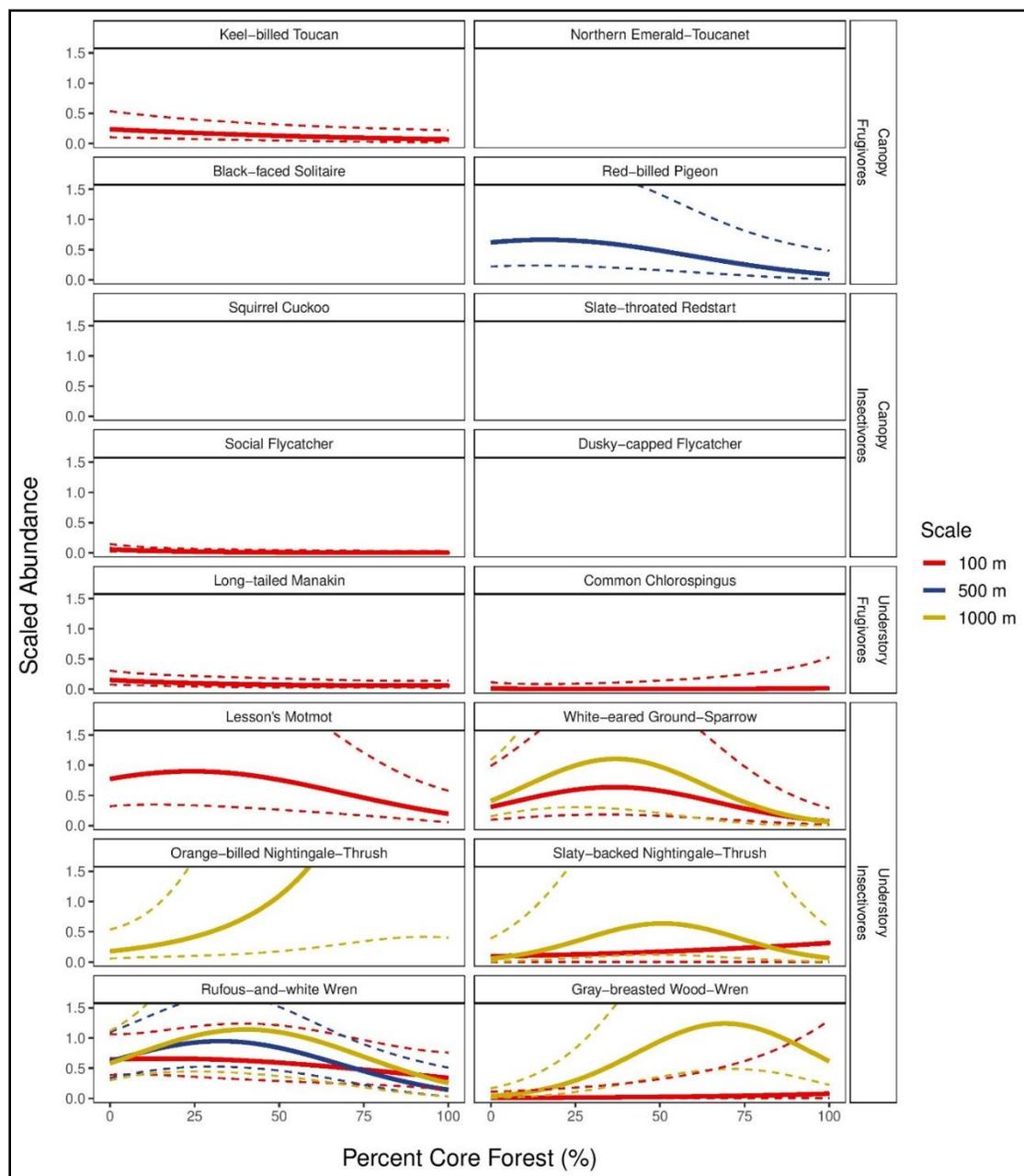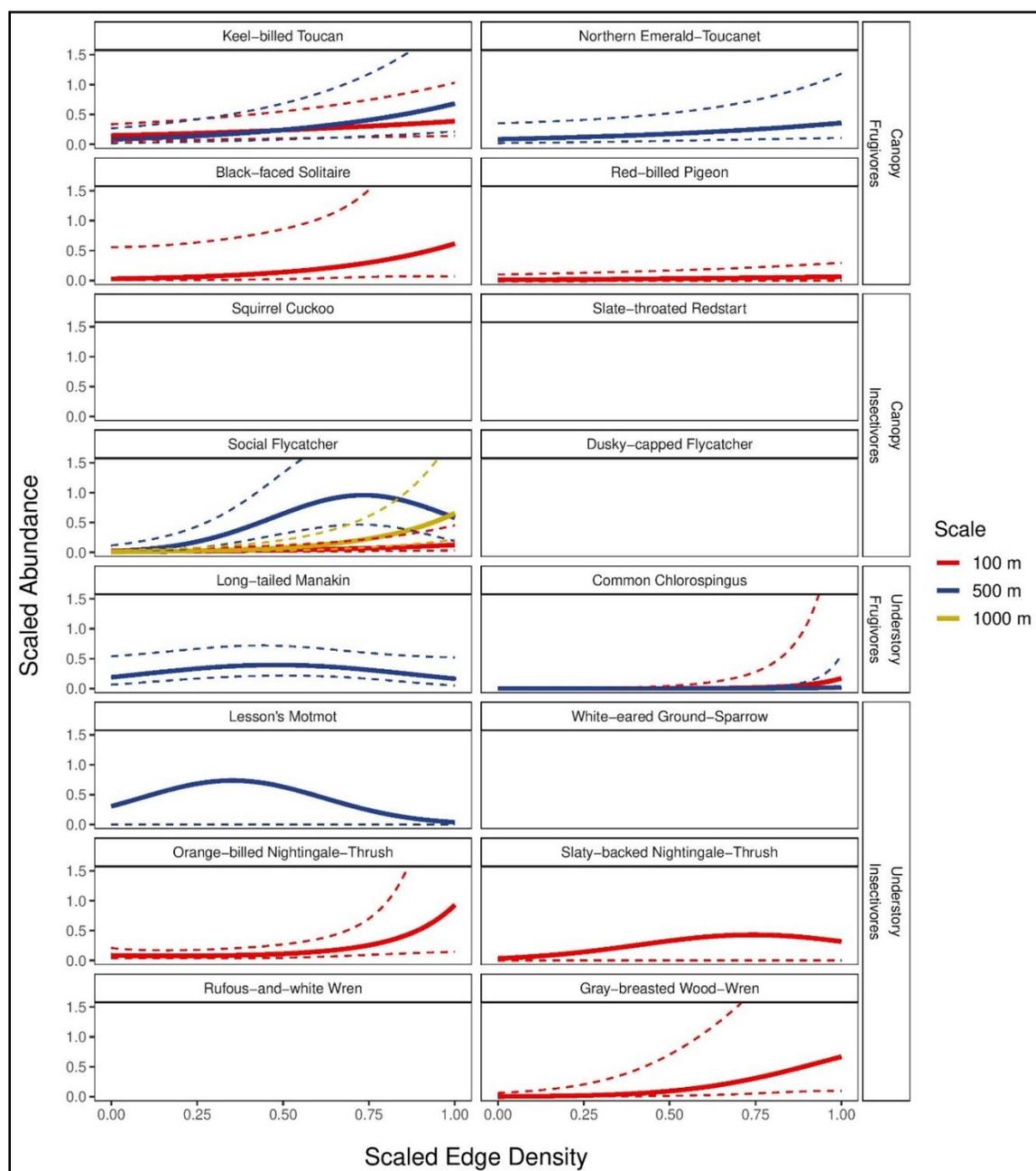
Figure 3.5. Abundance of species across the range of percent of core forest (≥100 m from edge) found within the study area at each focal scale. Abundance was scaled to account for differences between species. 95% confidence intervals are illustrated with dashed lines. Missing lines within a plot indicate that percent forest did not appear in the top-ranked model for that species at that scale.

Figure 3.6. Abundance of species across the range of edge density found within the study area at each focal scale. Edge density values were rescaled from 0 to 1 to facilitate comparison across scales. Abundance was scaled to account for differences between species. 95% confidence intervals are illustrated with dashed lines. Missing lines within a plot indicate that percent forest did not appear in the top-ranked model for that species at that scale.
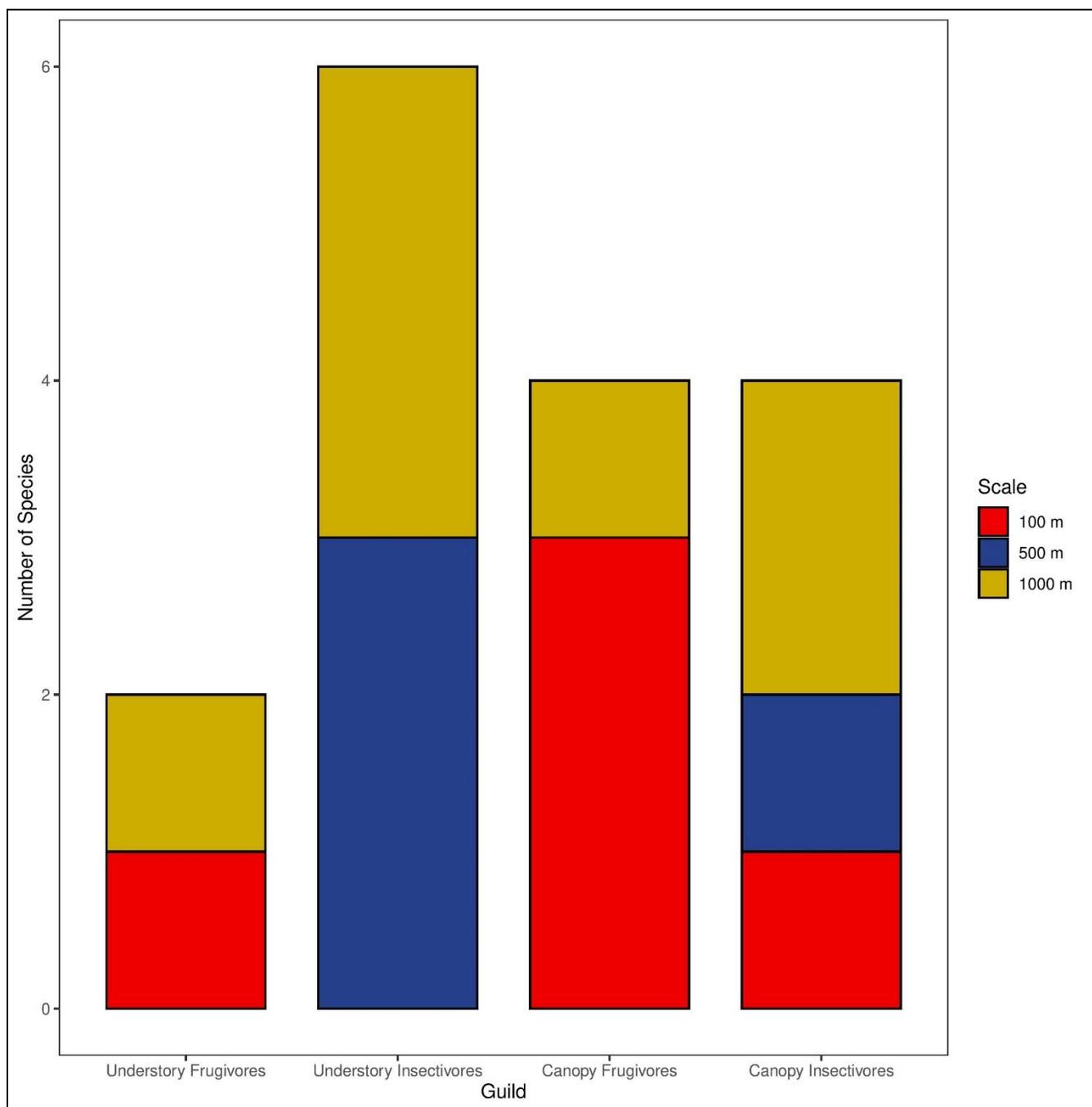
Figure 3.7. Scale of top-ranked abundance model for each focal species grouped by guild.

CHAPTER 4

COMBINING MULTIPLE STAKEHOLDER PERSPECTIVES WITH SPECIES-

ABUNDANCE MODELS EXPLICITLY ADDRESSES TRADE-OFFS IN CONSERVATION

PLANNING FOR FOREST-DWELLING BIRDS IN COSTA RICA[3]

ABSTRACT

Effective conservation planning requires the integration of social and ecological data. However, the degree of complexity inherent in achieving multiple conservation objectives often requires an assessment of trade-offs between different outcomes. Participatory mapping has been used as a tool for identifying stakeholder conservation preferences spatially, which can facilitate their comparison with ecological data to identify synergies and trade-offs in the planning process. While participatory mapping has previously been used to identify locations with high quality wildlife habitat and high stakeholder conservation support, to the best of our knowledge it has not been used to forecast how management options derived from participant preferences might affect wildlife in the future. We used a case study approach focused on the upper Guacimal watershed, located in northwestern Costa Rica, to forecast changes in the abundances of forest-dwelling bird species under reforestation scenarios developed from a participatory mapping exercise. We asked participants from 20 organizations involved with developing land use priorities within the study area to identify conservation priorities on a map of the region and explain their selections. We grouped priorities by themes and developed four theme-specific reforestation scenarios. Concurrently, we conducted avian point counts at 301 sites within the study area and used this dataset to develop multinomial N-mixture abundance models for 10 forest-dwelling bird species to determine which landscape gradients drive abundance patterns for each species. We then applied the abundance models to each reforestation scenario, thus forecasting the potential change in abundance of each species under each scenario. Our results indicate that even modest increases in forest cover within the study area can provide significant benefits for many forest-dwelling bird species, regardless of configuration. However, the responses of individual species to scenarios were somewhat variable, and no scenario emerged as

optimal for all focal species. Thus, trade-offs between species must be assessed when implementing reforestation initiatives in the region. While we focused on identifying trade-offs between avian species, this approach could be applied to other conservation objectives and thus has broad utility for conservation planning.

INTRODUCTION

Since humans have increasingly become integrated parts of landscapes globally (Hoekstra et al. 2005; Karimi et al. 2020), creative solutions are needed for conservation planning that balance diverse stakeholder objectives with wildlife habitat requirements (Faith & Walker 2002; Karp et al. 2015; Brown et al. 2019). Consideration of both human values and biological data are essential for developing effective conservation plans (Bryan et al. 2010), but the integration of these two data sources remains challenging (Knight et al. 2010; Whitehead et al. 2014). While win-win solutions that accomplish multiple conservation goals are attractive, they can be difficult to achieve, given the degree of complexity associated with many management objectives (Karp et al. 2015) and limited resource availability (Faith & Walker 2002). Instead, conservation planning often requires trade-offs between myriad competing social and ecological objectives (Hirsch et al. 2010; Whitehead et al. 2014), which requires assessments of different outcomes (Karp et al. 2015). Therefore, optimal conservation strategies are context-specific and may produce different solutions based on specific management objectives (Karp et al. 2015).

The Neotropical region is increasingly a focus of conservation action because it contains the greatest global biodiversity across nearly all terrestrial taxa (Raven et al. 2020), but is subject to rapid, broad-scale deforestation. Between 2000 and 2010, 3.91 million hectares of forest were cleared annually in the region (Achard et al. 2014), primarily for the expansion and

intensification of agriculture (Graesser et al. 2015; Dang et al. 2019). This broad-scale

deforestation has reduced habitat area for forest-dwelling species (Donald & Evans 2006).

Deforestation has also fragmented remaining forest patches (Powell et al. 2000; Moran et al.

2019), which decreases habitat connectivity for forest-dwelling fauna, causing declines due to

decreased access to food resources, decreased genetic diversity, decreased inter-patch dispersal,

altered microclimates, increased competition, increased predation, and increased edge effects

(Hunter 1996; Stratford & Stouffer 1999; Robinson 2001; Șekercioḡlu et al. 2001; Donald &

Evans 2006).

In Costa Rica, approximately two-thirds of the forested area was cleared between 1950

and 1988 (Sánchez-Azofeifa et al. 2001), primarily for the expansion of agriculture (Donald &

Evans 2006). However, Costa Rica has reversed this trend through the implementation of

conservation-oriented legislation, the growth of the nation's nature-based tourism industry, and

the initiatives of conservation organizations (Calvo-Alvorado et al. 2009). The result has been a

net gain in forest cover since 2000 (Keenan et al. 2015) and a reputation as a model for

conservation in the Neotropical region (Evans 2000; Calvo-Alvorado et al. 2009; Moran et al.

2019). Costa Rica has developed an extensive reserve system that encompasses 28% of the

country's landmass, including 12% designated as national parks (Figure 4.1) (Evans 2000;

Powell et al. 2000; Sánchez-Azofeifa et al. 2003). However, unprotected forests in Costa Rica

remain highly fragmented (Powell et al. 2000), and continue to experience deforestation and

degradation (Sánchez-Azofeifa et al. 2003), which increasingly isolates protected areas (DeFries

et al. 2005). Isolation reduces the effectiveness of protected areas for wildlife conservation since

few reserves are large enough to support viable populations of most species on their own

(DeClerck et al. 2010; Moran et al. 2019). Therefore, management outside of protected areas to

supplement reserves is critical for wildlife conservation (Vandermeer & Perfecto 2007; Mannetti et al. 2019).

Enhancing forest connectivity between protected areas has become a major conservation priority in Costa Rica. As a mechanism to work towards this goal, Costa Rica developed a network of 44 biological corridors in the 1990s, which cover a third of the nation's land area (Figure 4.1) (Sánchez-Azofeifa et al. 2003; SINAC 2009). However, these corridors are relatively large (DeClerck et al. 2010; Moran et al. 2019) and consist almost entirely of privately-owned land, including reserves, unprotected forest patches, agriculture, and towns (Fagan et al. 2013). Management within corridors remains challenging since the corridors do not have the legal authority to implement land management regulations, and instead must rely on support from diverse stakeholders that often have competing objectives, including those of locally-operating conservation organizations (DeClerck et al. 2010). Since most corridors were established relatively recently, few have demonstrated positive effects on regional forest cover (DeClerck et al. 2010). Instead, most forest regeneration in Costa Rica over the past two decades has occurred opportunistically (Morse et al. 2011; Allen 2015) or has been shaped by the goals of local conservation organizations (Allen 2015), which have often focused on trying to accomplish win-win scenarios by prioritizing areas that provide key ecosystem services (Townsend & Masters 2015; Karp et al. 2015; Cox Chapter 2). Few forest restoration efforts directly target the habitat requirements of species of concern, despite the fact that enhancing forest connectivity to facilitate wildlife conservation is a primary goal of the Costa Rican biological corridor network (SINAC 2009).

Targeting species requirements is challenging, since species-habitat relationships are poorly known for many Neotropical species (Young & Zuchowski 2003). Resident forest-

dwelling bird species are important ecological indicators because they occupy diversity of ecological niches and display a range of responses to habitat change (Șekercioḡlu et al. 2019) and are economically important due to the growth of birdwatching-based tourism (Brownson et al. 2021). Many Neotropical understory-dwelling insectivorous bird species are particularly vulnerable to forest fragmentation due to their reduced capacities for crossing forest gaps (Ferraz et al. 2003; Hendershot et al. 2020; Stouffer 2020). However, species that forage in the forest canopy, those that feed primarily on fruit, and insectivores that have greater dietary breadth or specialize in edge habitats are often less sensitive to forest fragmentation (Levey & Stiles 1992; Restrepo & Gomez 1998; Burney & Brumfield 2009; Frishkoff & Karp 2019; Hendershot et al. 2020; Cox Chapter 3). While many sensitive understory insectivores require large contiguous forest patches, many of these less sensitive species can benefit from even modest forest restoration in agricultural landscapes (Șekercioḡlu et al. 2019).

However, since species-habitat relationships are often scale-dependent (Johnson 1980; Carrara et al. 2015; Chambers et al. 2016), local and landscape-level patterns can simultaneously affect species' abundances (Chandler & Hepinstall-Cymerman 2016; Frishkoff & Karp 2019). Many Neotropical forest-dwelling birds respond positively to forest cover at local scales, but non-linearly at broad scales (Cox Chapter 3). Thus, it is necessary to examine responses to landscape gradients at multiple spatial scales (Weins 1989; Chambers et al. 2016; Mertes & Jetz 2017; Frishkoff & Karp 2019) to avoid generating misleading inferences about species-habitat relationships (Thompson & McGarigal 2002; McGarigal et al. 2016). Thus, multi-scale models are necessary to best predict the abundance of species in a landscape (McGarigal et al. 2016).

Effective wildlife conservation requires the integration of habitat assessments and human values (Bryan et al. 2010). Participatory mapping offers an approach that allows respondents to

map their management opinions and values (Brown & Raymond 2014), which can then be directly compared to ecological data to identify synergies and potential conflicts for conservation (Theobald et al. 2005; Cox et al. 2014; Brown et al. 2019). This method facilitates participant involvement in the planning process (Brown & Raymond 2014), which can increase the effectiveness of conservation initiatives by improving community trust, empowerment, and awareness of management issues; promoting community involvement in management efforts (Bryan et al. 2010); reducing tensions; and enhancing plan implementation efficiency (Schusler et al. 2003; Treves et al. 2006; Donovan et al. 2009; Morse 2012). Participatory mapping has been used to spatially identify stakeholder preferences on conservation priorities for a range of wildlife species (Cox et al. 2014; Whitehead et al. 2014; Brown et al. 2019; Cox et al. 2019). These studies have focused primarily on examining the intersection of areas with high quality habitat and high public conservation support to identify conservation targets. Thus, the focus has been on identifying priority areas for conservation or management action, but to our knowledge, participatory mapping exercises have not yet been applied to the evaluation of multiple alternative future scenarios for wildlife.

Participatory mapping has the potential to serve as an alternative (or supplement) to optimization tools for combining social and ecological data for the development of management plans (Whitehead et al. 2014). This approach offers an advantage over traditional optimization because it can illuminate the context surrounding stakeholders' spatial priorities (Lowery & Morse 2013) and ensure that non-dominant opinions, which can be obscured in optimization-focused approaches, are considered in the planning process (Sletto 2009).

Objectives and Hypotheses

The goal of this study was to understand how different conservation priorities of organizations operating within the study area will affect avian abundance in a fragmented landscape in northwestern Costa Rica. The specific research objectives were to (1) identify a suite of alternative reforestation scenarios based on participatory mapping interviews with organizations that are involved in developing local land use priorities, (2) forecast potential impacts of each scenario on the distribution and abundance of forest-dependent bird species, and (3) use forecasts to examine trade-offs between conservation goals and avian abundance. We hypothesized that the abundance of all focal bird species would increase under each reforestation scenario, since all focal species are forest-associated (Stiles & Skutch 1989; Stotz et al. 1996). However, since Neotropical birds are confined to limited elevational zones due to their narrow thermal tolerances (Forero-Medina et al. 2011), we predicted that reforestation scenarios that increased lateral forest connectivity would have greater effects on abundance than scenarios that improved downslope connectivity (Townsend & Masters 2015). We also expected that the amount of forest edge created in each scenario would have varying effects on the abundance of focal species due to differences in edge sensitivity, since some species can exploit the abundant resources in the forest edge, while others are restricted to the forest interior (Frishoff & Karp 2019; Cox Chapter 3).

METHODS

Study Area

This study was conducted in the 129 km^2 upper Guacimal watershed, which is located within the *Corredor Biológico Pájaro Campana* (CBPC) on the Pacific slope of northwestern Costa Rica (Figure 4.1). The CBPC was established in 2007 (SINAC 2009) to promote forest

connectivity between highland cloud forests and coastal mangrove forests (CBPC 2011). The

upper Guacimal watershed, which is located entirely within the CBPC, spans a gradient from

well-protected cloud forest to fragmented lowland tropical dry forest. We restricted the study

area to the upper portion of the Guacimal watershed because climate, species composition, the

scale of agricultural operations, and conservation priorities differ significantly in the lower

portion of the watershed. The study area has approximately 5,000 residents, nearly 80% of whom

are concentrated in the town of Santa Elena (INEC 2011). The rest of the study area is relatively

lightly populated, consisting of a patchwork of protected forest reserves, small-scale agriculture

focused on cattle and coffee production, and small agrarian communities (Griffith et al. 2000).

The highland zone of the study area is well-protected and includes the Monteverde Cloud Forest

Reserve (MVCFR), which is a major tourist destination that attracts over 80,000 visitors

annually (Caldas 2009). As a result, this area hosts many local conservation-focused

organizations. Lower and middle elevations in the study area are primarily agricultural, contain

few protected areas, and host few conservation organizations. However, these zones are

increasingly becoming the focus of regional conservation planning to facilitate downslope

connectivity from the highland reserves (CBPC 2011; Cox Chapter 2).

Participatory Mapping Interviews

We used a case study approach (Creswell & Poth 2017) to assess trade-offs for resident

bird species based on different conservation priorities of organizations operating within a single

biological corridor in Costa Rica, the CBPC. To understand regional conservation priorities, we

conducted 20 semi-structured interviews (Chambers 1998) with key informants from a range of

organizations involved with developing land use priorities in the study area, including

government agencies and non-government organizations (NGOs), operating within the study

area between November 2017 and July 2018. We developed the initial interview candidate list

from our experience in the study area, and identified additional candidates during interviews

using the snowball sampling technique (Newing et al. 2011). We invited candidates to participate

in this study using an approach modified from Dillman et al. (2008), which employed an

invitation letter and two reminders for candidates who had not yet responded to the invitation

(Appendix A). Semi-structured interviews (Chambers 1998; Creswell & Poth 2017), which

lasted approximately 30-45 minutes, were conducted in a one-on-one format, with the addition of

a translator for Spanish language interviews. Interview participants were asked to answer from

an organizational, rather than personal perspective. Our interview protocol was approved by the

University of Georgia Institutional Review Board (STUDY00005044) and conducted under

research permits approved by the Costa Rican *Ministerio de Ambiente y Energía* (Ministry of

Environment and Energy: 019-2017-INV-ACAT; M-P-SINAC-PNI-ACAT-048-2018). Informed

consent was obtained prior to the start of each interview. Audio of all interviews was recorded.

The interviews covered a range of topics about land management practices, perspectives

on conservation, current involvement in conservation initiatives, and perceived constraints to

regional conservation (Appendix B). The interviews also included a participatory mapping

exercise where participants were asked to draw polygons on a map of the study area using

ArcGIS 10.2 software (ESRI 2011) to identify up to five places that they thought should be

prioritized for conservation (Lowery & Morse 2013). The map included aerial imagery and key

landmarks for reference and was initially displayed at a 1:70,000 scale, but participants could

zoom to view areas in greater detail. We used polygons for place identification because they best

account for small sample sizes in participatory mapping studies (Brown & Pullar 2012; Karimi et

al. 2020). We asked participants to identify no more than five places so that they would highlight

discrete places in the landscape (as in Lowery & Morse 2013), but participants were not restricted in the size of polygons that they could draw. During the mapping exercise, participants were asked to explain their rationale for each polygon that they drew on the map to provide context for their selections (Tyrväinen et al. 2007).

Participatory Mapping Analysis

The audio recordings of the interviews were transcribed and translated. We coded all interview text into themes using a hierarchical coding scheme (Hutchison et al. 2010) focused on land management and conservation topics in MaxQDA 18 (VERBI 2017). The coding scheme was peer validated to ensure accuracy and replicability (Kvale & Brinkmann 2009). We then linked the themes used to describe rationales for locating each polygon with the corresponding polygon (Lowery & Morse 2013) in ArcGIS 10.2 (ESRI 2014). We filtered polygons by theme and produced theme-specific density maps to show where polygons related to specific conservation priorities clustered in the landscape (Figure 4.2) (Cox Chapter 2).

Reforestation Scenario Construction

From our theme-specific participatory mapping polygon density layers, we selected three commonly-identified themes with differences in polygon distributions for analysis: reserve expansion/connectivity, downslope connectivity, and water quality (Cox Chapter 2). Since all three themes emphasized connectivity between different elevation zones, we developed a fourth polygon layer focused on lateral connectivity by selecting participant-identified polygons that included similar elevation ranges to test our hypothesis about the increased benefits provided by lateral connectivity to forest-dwelling birds. We then used the polygon density layers for each theme to develop corresponding reforestation scenarios. We classified a 5 m resolution land cover map of the study area (INF 2014) into forest and non-forest. Using the statistical software

program, R (R Core Team 2020), we then created new raster layers that semi-randomly added forest to landscape under each theme-based scenario. Reforested cells were required to occur in non-forest land cover that was included in at least one theme-specific polygon. Areas with higher polygon density were weighted to increase the likelihood that they were reforested. We then randomly placed 10 cells, termed seeds, in locations in the landscape that met these criteria, and contiguous cells were randomly added around these seeds to generate forest cover. Added cells were required to be located in non-forest area included in one theme-specific polygon. Forest cells were added iteratively, and the values of the non-forest cells were re-weighted at each step. Thus, cells closer to currently added forest cells were prioritized to minimize gaps in the reforestation raster. Each scenario increased forest cover in the study area from 60.2% to 67.7% to standardize the effects of reforestation.

Avian Surveys

We conducted point counts to collect avian abundance data. We used a stratified-random sampling design to locate our sites to ensure adequate sampling across the ranges eight focal landscape gradients that we predicted to be key drivers of avian abundance patterns in the study area (Cox Chapter 3; Table 4.1). We placed an equal number of randomly generated point count sites within each stratum. Sites were located a minimum of 250 m apart to increase sampling independence and ensure that sampling areas did not overlap (Blake & Loiselle 2001; Carrara et al. 2015). We conducted point counts at 301 sites within the study area from May – December in 2016 and 2017 and May – July in 2018 (Cox Chapter 3). We used a dependent double-observer point count method (Nichols et al. 2000) to record the abundance of all bird species detected during a 10 minute interval within a 50 m radius of each site (Robbins et al. 1986; Blake & Loiselle 2001; Duclos et al. 2019). All point counts were conducted between 20 minutes before

dawn and two hours after dawn on days with little to no precipitation and light to moderate wind speeds (Blake & Loiselle 2001). We recorded the site name, visit number, start time, temperature, wind speed, weather conditions, observers, and site location using a handheld GPS unit at the start of each point count (Robbins et al. 1986; Matseur et al. 2019). Avian data collection methods were approved by the University of Georgia's Institutional Animal Care and Use Committee (A2015 02-008-Y3-A0; A2018 04-015-Y1-A0) and conducted under research permits approved by the Costa Rican *Ministerio de Ambiente y Energía* (Ministry of Environment and Energy: 037-2016-INV-ACAT; 019-2017-INV-ACAT; M-P-SINAC-PNI-ACAT-048-2018).

Avian Abundance Modeling

We selected ten resident forest-dependent bird species that were detected at ≥30 sites with varied diets, foraging strata, elevational preferences, and responses to forest fragmentation to represent the breadth of potential responses to reforestation scenarios (Stiles & Skutch 1989; Stotz et al. 1996; Cox Chapter 3). We developed a candidate set of hierarchical *N*-mixture models (Royle 2004; Chandler et al. 2011) for each focal species to determine which combinations of landscape gradients best predict abundance. These three-level hierarchical models included variables that we predicted would affect avian abundance (λ; eight landscape gradients listed in Table 4.1), while accounting for variables thought to affect the availability of an individual to be detected (φ; date, year, time of day, temperature, and wind speed) and detection probability (p; observer) (Chandler et al. 2011). The hierarchical model formula that we used was:

$$M_i \sim \text{Poisson}(\lambda)$$

$$N_{it} \sim \text{Binomial}(M_i, \varphi)$$

$$y_{it} \sim \text{Multinomial}(N_{it}, \pi_{it})$$

where M_i signifies the total number of individuals that used site i during the study period, N_{it} signifies the subset of individuals that were present at site i at time t, y_{it} represents a vector of counts of individuals that were detected at site i at time t, and π_{it} represents the vector of multinomial cell probabilities that was calculated using a detection probability function (p) (Chandler et al. 2011; Alexander & Hepp 2014). The detection probability function that we used for dependent double-observer point counts for each visit to a site included: (1) the probability of observer 1 detecting an individual and (2) the probability that observer 2 detected an individual that observer 1 did not detect, which used the formula:

$$\pi_1 = p_1, \pi_2 = p_2(1\text{-}p_1)$$

The probability that an individual was not detected by either observer is $\pi_3 = (1\text{-}p_1)(1\text{-}p_2)$. We implemented the hierarchical models using the 'gmultmix' function the R statistical software program (R Core Team 2020) package 'unmarked' (Fiske & Chandler 2011).

Since species-habitat relationships are often scale-dependent (Johnson 1980; Weins 1989; Carrara et al. 2015; Chambers et al. 2016; McGarigal et al. 2016), and species' responses to a single gradient can vary across scales (Cox Chapter 3), we calculated each of the eight landscape gradients included in the hierarchical models using three moving window radii in FRAGSTATS v4 (McGarigal et al. 2012): 100 m, 500 m, and 1,000 m. Gradients calculated at each focal scale

were included in the models. We used a multi-stage process to develop a set of candidate models for each species (Matseur et al. 2019). We began by standardizing all model variables to facilitate model convergence (Alexander & Hepp 2014). Then, we fit candidate models containing combinations of availability and detection variables. We ranked these models using a model selection framework and selected the model with the highest AIC weight (Burnham & Anderson 2002) to use as a foundation for constructing models that included abundance variables (Matseur et al. 2019). We then constructed a set of abundance models that included individual landscape gradients for each focal species calculated at each focal scale. We also included models with quadratic terms for five of the landscape gradients (Table 4.1), since species often respond non-linearly to habitat characteristics (Chandler & Hepinstall-Cymerman 2015; Frishkoff & Karp 2019; Cox Chapter 3). We examined model output and excluded gradients that did not have significant effects on abundance ($p<0.05$) from the candidate set of univariate models. Then, we used a model selection framework to rank the remaining candidate models by AIC weight (Burnham & Anderson 2002).

We used the rankings of univariate models to develop a candidate set of abundance models for each species. To reduce the size of the candidate sets of models, we compared the AIC ranks of gradients where both linear and quadratic models were included and removing the lower ranked model at each scale. Additionally, individual gradients that received ≥0.9 AIC weight were included in all candidate abundance models. We then calculated a Pearson's correlation coefficient matrix for all landscape gradients and did not permit gradients with a correlation coefficient of >0.7 to appear in the same model, except where gradients were correlated with elevation. When a gradient was correlated with itself at multiple scales, we selected only the top-ranked scale for inclusion in candidate abundance models. We then

constructed additive abundance models based on these criteria and ranked the candidate set using a model selection framework. We interpreted the model that received the highest AIC weight for each species, which was considered to be the best-fitting model of its abundance in the study area (Burnham & Anderson 2002).

We validated the top-ranked model for each species by checking the parameter estimates of variables in models that included gradients that were correlated with elevation to ensure that the correlation did not cause the direction or magnitude of relationships to change. Then, we plotted semivariograms of the model residuals using kriging with a maximum lag of 4,000 m (which represented approximately 50% of the diameter of the study area) using the ArcGIS 10.2 geostatistical analyst tool (ESRI 2011) and examined the plots for evidence of spatial structure in the model residuals. We also used a chi-square test with a parametric bootstrap for 100 simulations (Fiske & Chandler 2015) and employed an overdispersion ratio (c-hat) to adjust standard errors of poorly fitting models (Kéry & Royle 2016) to calculate the goodness-of-fit of each of the top-ranked models.

Scenario Comparison

To determine how each of the four reforestation scenarios would affect abundance for each focal bird species, we calculated each landscape gradient used to develop the avian abundance models (Table 4.1) at each of the same focal scales (100 m, 500 m, 1,000 m) for each scenario landscape using FRAGSTATS v4 software (McGarigal et al. 2012). We then used the top-ranked abundance model for each species to generate 5 m resolution maps of predicted abundance in the current study area landscape and under each reforestation scenario. We then calculated the percent change in abundance for each species under each scenario, and developed

a series of 5 m resolution maps to allow an inspection of the spatial patterns of abundance change for each species under each scenario.

RESULTS

Participatory Mapping Interviews

Our semi-structured interviews with participants from 20 organizations operating in the study area represented snowball sampling candidate saturation (Newing et al. 2011). Four additional candidates did not respond or declined to participate, leaving us with a participation rate of 83%. We did not record participant demographics, since they were asked to respond from the perspective of their organizations rather than as individuals. The participatory mapping exercise was completed by 19 of the interview participants (95%), who drew 74 total polygons (3.7 polygons per participant) to identify places that they believed should be prioritized for conservation. These polygons covered 95.5% of the study area and were linked to 14 conservation-related themes (Cox Chapter 2). We focused our analysis on three commonly-identified themes that included large portions of the study area and had previously been demonstrated to have different spatial distributions: reserve expansion/connectivity, downslope connectivity, and water quality (Figure 4.2; Table 4.2). We compared a fourth theme, lateral connectivity, that did not emerge from interviews, but was hypothesized to be important for regional wildlife conservation (Townsend & Masters 2015). While none of the themes included in this analysis directly focused on avian conservation because few organizations (n=3) reported directly targeting birds in their conservation initiatives, many organizations expressed a "hope and [belief] that [their] reforestation efforts will increase forest habitat for birds."

Avian Point Counts

We conducted 404 total point counts at 301 sampling sites within the study area. During the point counts, we detected 10,405 total individuals representing 280 different bird species in 189 genera and 44 families (Cox Chapter 3). From this dataset, we selected ten forest-dependent resident bird species (Stiles & Skutch 1989; Stotz et al. 1996) that were detected at ≥30 sites, which we deemed necessary to develop robust models (Wenger & Freeman 2008). We selected species that represented different dietary preferences, foraging strata, edge tolerances, and elevational zones to highlight the diversity of potential species responses to reforestation scenarios (Table 4.3).

Avian Abundance Model Results

We fit hierarchical abundance models that accounted for availability and detection for the ten focal bird species (Appendix G). Temperature, wind speed, and time of day had significant effects on the availabilities of many species to be detected, and the identity of observers also had significant effects on detection for some species (Appendix H). The inclusion of elevation and correlated landscape gradients in models did not change the direction or magnitude of the relationships of any model variables. Semivariograms plotted for the top-ranked model for each species did not reveal spatial structure in the model residuals, but chi-square goodness-of-fit tests produced c-hat scores for a few species that fell outside the acceptable range for interpretation (Appendix H). We were able to improve model fit to an acceptable level for these species by removing ≤2 outlying points.

The top-ranked abundance model for each species included multiple landscape gradients, but there was considerable variation in the gradients, scales, and direction of responses by individual species (Figure 4.3). Elevation was a component of the top-ranked models of all focal

species, though there was variation in the scale at which elevation was selected. Percent forest cover was also included in the top-ranked model of every focal species, primarily at broader spatial scales, except the Social Flycatcher, which is an edge specialist. However, many species responded non-linearly to percent forest cover, and their abundance peaked at intermediate amounts of forest cover. Responses to gradients associated with landscape configuration were more varied. Many understory species displayed non-linear relationships with core forest area, which was absent or negatively related to abundance in the models of canopy-dwelling species. The abundance of only a few species was linked directly to edge density.

Reforestation Scenario Comparison Results

All four reforestation scenarios increased forest cover in the study area by 7.5%, but the locations of added forest cover varied across scenarios (Figure 4.4), with at least 34% of the reforested area in each scenario not included in any of the other scenarios (Table 4.2). Predicted abundance across the landscape varied based on scenario (Figure 4.5; Appendix I). Abundance increased for all species under most scenarios (Figure 4.6). While responses of individual species to specific scenarios were somewhat variable, the magnitude of abundance change was relatively high across virtually all species and scenario combinations. No single scenario offered the greatest increases to abundance for all focal species. Scenario R (reserve expansion/connectivity) was the only scenario that resulted in declines in abundance for any species outside of Keel-billed Toucans. Both White-eared Ground-Sparrows and Rufous-and-white Wrens experienced declines under this scenario. Species that inhabit broader elevation zones (e.g., Long-tailed Manakins and Lesson's Motmots) experienced greater percent increases in abundance than species that are restricted to narrower elevation zones across all scenarios, with the exception of the small increases predicted for Lesson's Motmots under Scenario R. The magnitude of change

under scenarios was relatively similar for both middle elevation and highland specialists.

Highland species benefitted least from Scenario L (lateral connectivity). However, patterns in

response to scenarios based on diet or foraging stratum did not emerge. Maps of changes in

abundance from the current landscape under each scenario revealed place-specific gains and

losses that were linked to the locations of added forest cover (Figure 4.7; Appendix J).

DISCUSSION

This study provides a template for landscape-scale conservation planning that relies on

the diverse perspectives of multiple stakeholders to forecast potential effects of four land

management scenarios on avian abundance. This approach facilitates the assessment of trade-offs

between different management objectives by not only predicting changes in abundance for a

suite of bird species under different reforestation scenarios (Figure 4.6), but also highlighting

where changes are likely to occur in the landscape (Figure 4.7; Appendix J). As expected, no

single reforestation scenario provided maximal gains for all focal bird species. Thus, trade-offs

between different conservation objectives must be considered when evaluating reforestation

scenarios. However, the substantial increase in abundance for most species across nearly all

reforestation scenarios indicates that even moderate forest restoration in agricultural areas can

greatly benefit Neotropical forest bird species (Şekercioḡlu et al. 2019) and that reforestation

associated with unrelated conservation goals can benefit birds (Karp et al. 2015).

Participatory Mapping

Places prioritized by participants in the participatory mapping exercise aligned with the

primary goal of the CBPC, which is to increase downslope connectivity from protected highland

areas (CBPC 2011; Cox Chapter 2). However, the distribution of conservation priority polygons

identified in the participatory mapping exercise differed considerably by theme (Table 4.2),

illustrating the benefit of including qualitative information in participatory mapping studies to provide increased context about the motivations for place selection (Lowery & Morse 2013; Cox Chapter 2). This contextual information played a key role in allowing us to group places that were identified for similar reasons (Tyrväinen et al. 2007), aiding in the construction of theme-based reforestation scenarios that include both participant spatial preferences and motivations. Filtering by theme also can highlight non-dominant perspectives (Sletto 2009) and allow scenarios based around less frequently reported themes to be developed. Comparison of theme-specific results permits an assessment of trade-offs between priorities associated with different themes (Knight et al. 2010; Lowery & Morse 2013; Karimi et al. 2020), which can facilitate the identification of synergies and potential sources of conflict, leading to more effective and collaborative regional management (DeClerck et al. 2010).

Integrating stakeholder preferences and assessments of wildlife habitat using participatory mapping approaches have aided conservation planning by highlighting places with high quality habitat and high public conservation support (Cox et al. 2014; Whitehead et al. 2014; Brown et al. 2019; Cox et al. 2019). While prioritizing areas that offer high quality habitat is an important component of conservation, another critical component of conservation is habitat restoration to expand suitable habitat in degraded landscapes (Reid et al. 2014). However, to the best of our knowledge, no previous participatory mapping studies have forecasted the effects of participant management preferences into the future to examine how improving habitat quality on areas with public conservation support would affect species of concern. This study demonstrates the utility of this approach for assessing trade-offs between different management priorities, which highlights the complexity of stakeholder opinions and identifies how different preferences will affect conservation outcomes (Hirsch et al. 2010). In areas with ongoing habitat restoration

initiatives, such as the CBPC, quantifying the effects of different stakeholder-supported priorities on species of concern can help effectively target initiatives and identify areas of synergy with other goals (Karp et al. 2015).

Avian Abundance Models

The top-ranked models for all focal species included gradients calculated at different spatial scales, highlighting the importance of developing multi-scale models to best predict abundance across the landscape and avoid incorrect inferences (Miguet et al. 2016; McGarigal et al. 2016), since responses to landscape gradients in this landscape have been shown to vary across scales (Cox Chapter 3). While not related to fragmentation, elevation was included in the top-ranked model of all focal species, due to the fact that many Neotropical bird species have limited thermal tolerances and thus inhabit narrow elevation zones with suitable climatic conditions (Forero-Medina et al. 2011). Therefore, elevation must be considered in conservation planning in the CBPC because restoring habitat outside of the suitable elevation zone will not benefit that species. All species responded to percent forest cover except for the Social Flycatcher, which is an edge specialist. However, only the Gray-breasted Wood-Wren displayed a positive relationship between abundance and percent forest cover. The remaining species all had non-linear relationships, with a peak in abundance at intermediate amounts of forest cover, likely because the forest edge contains abundant food resources (Restrepo & Gomez 1998). This pattern appears to be common in forest-dwelling Neotropical bird species that are not highly sensitive to fragmentation (Frishkoff & Karp 2019; Cox Chapter 3). Focal species responded less frequently and with more variety to landscape configuration gradients. However, many understory insectivores responded to core forest area in the landscape, indicating a need for some interior forest habitat, and some canopy species, such as the Social Flycatcher and Keel-billed

Toucan, had positive relationships with edge density. Nevertheless, the lack of strong patterns in the responses of species with similar behaviors suggests a need for species-specific abundance models (Miguet et al. 2016; Frishkoff & Karp 2019; Cox Chapter 3).

Avian Responses to Reforestation Scenarios

Due to the diverse responses of our focal species to landscape gradients and the different locations of reforested area under each of our scenarios, no single best scenario for increasing avian abundance in the study area emerged (Figure 4.6). While the abundance of most species increased under each reforestation scenario, as hypothesized, four species exhibited declines under one or more scenarios. Notably, Keel-billed Toucan abundance decreased under all scenarios, likely due to its positive relationship with edge density, which was reduced when forest cover was added to the landscape. This finding aligns with observational research documenting declines of Neotropical frugivorous bird species in areas where reforestation increased tree cover (Reid et al. 2014). However, Keel-billed Toucans were the only frugivorous species in this study to exhibit such a response, and their relatively high abundance in fragmented areas throughout the study area (Appendix I) means that they are likely not of conservation concern. Other frugivores, such as Long-tailed Manakins and Northern Emerald-Toucanets, increased in abundance under all scenarios. Social Flycatchers, which were also positively associated with edge density, and White-eared Ground-Sparrows and Rufous-and-white Wrens, which responded non-linearly to percent forest cover, all experienced declines under Scenario R, which added more core forest area than the other scenarios, but increased under other scenarios, illustrating variation in scenario-specific responses.

Our hypothesis that Scenario L would produce the greatest increases in abundance proved correct for only two focal species. This result likely occurred because the added forest cover

within distinct elevation zones increased beyond the optimum values for many species with parabolic relationships to forest cover (Frishkoff & Karp 2019; Cox Chapter 3). Thus, Scenarios D (downslope connectivity) and W (water quality) may have performed better than expected because of the high amount of forest edge that they added to the landscape in each elevation zone. However, species that are highly sensitive to disturbance, which were not included in this analysis due to a lack of sufficient detections, likely would show the greatest increases under Scenario L because it added more core forest area within elevational zones than other scenarios (Laurance et al. 2011). We did not detect strong patterns in response to scenarios based on diet, foraging stratum, or elevation inhabited, likely due to the fact that responses to landscape gradients are largely species-specific and are often difficult to categorize into groups based on behavioral characteristics (Miguet et al. 2016; McGarigal et al. 2016; Frishkoff & Karp 2019; Cox Chapter 3). Thus, species-specific models are required to develop the most accurate predictions of responses to landscape change.

Although clear patterns did not emerge in the responses of species to individual scenarios, the overall increases in abundance across species and scenarios was generally quite high, which has important implications for regional conservation. This result indicates that adding even a relatively modest amount of forest cover to the landscape, regardless of location and configuration, can provide substantial benefits to forest-dwelling birds. Thus, local reforestation initiatives can create tangible benefits for many forest birds by restoring even relatively small amounts of forest habitat within agricultural areas (Şekercioḡlu et al. 2007; Frishkoff & Karp 2019; Karp et al. 2019; Şekercioḡlu et al. 2019; Cox Chapter 3). Since three of these scenarios (Scenarios R, D, and W) targeted conservation priorities other than avian habitat augmentation, increases in abundance under these scenarios indicate that expanding forest cover

in agricultural landscapes to meet other conservation objectives, such as ecosystem services, can also benefit forest-dwelling bird species (Karp et al. 2015). Therefore, while not directly targeting the needs of individual bird species, organizations operating within the CBPC appear to be increasing habitat for forest-dwelling birds through reforestation initiatives, as they intend (Townsend & Masters 2015; Cox Chapter 2), and even opportunistic forest restoration occurring in the CBPC (Allen 2015) can provide benefits to many forest-dwelling birds.

Conservation efforts that focus solely on ecosystem services may not adequately protect sensitive species. Thus, predictive modeling remains important for evaluating diverse conservation solutions (Karp et al. 2015). This incongruence may have been obscured in our study because none of our focal species have been shown to be highly sensitive to disturbance (Stotz et al. 1996). Low detection rates of sensitive species prevented the development of robust models for these species. Therefore, our results may not be representative of highly sensitive species, which are more likely to be affected by forest configuration, particularly core area (Laurance et al. 2011; Stouffer et al. 2020), and likely would show stronger responses to Scenario L than our suite of focal species. Furthermore, the study area contains relatively high existing forest cover (60.2%), and the relative lack of isolation of forest patches in the landscape might have obscured some patterns in responses to land cover change (Carrara et al. 2015; Haddad et al. 2017) because effects of configuration are often greatest in the most isolated patches (Haddad et al. 2015).

While the abundance models used in this study provide valuable insights into potential effects of reforestation on avian abundance, they only identify gradients that drive avian presence. Therefore, they cannot isolate gradients that will not support species' persistence in the landscape, such as sink habitats or gradients that support only limited portions of a life cycle

(Daily et al. 2001; Reid et al. 2014; Carrara et al. 2015; Şekercioḡlu et al. 2019), which require studies on population dynamics (McGarigal et al. 2016). Additionally, predictions of abundance under reforestation scenarios in this study were based solely on changes to suitable habitat and assume that all suitable areas are occupied, but research on species-specific movement patterns is required to accurately predict colonization of newly created forest patches, which would increase the accuracy of these predictions (Hansbauer et al. 2008; Peters & Nibbelink 2011). Furthermore, the abundance forecasts assume that reforested areas consist of mature forest of comparable age to remnant forest patches, which will take decades of forest succession to achieve (Kricher 2011). Our forecasts also assumed that land cover would change while rest of the study area system would remain static. However, dynamic models that account for changing environmental conditions and stochastic variability are often able produce more accurate forecasts of species' abundance (Dietze et al. 2018; Harris et al. 2018). Therefore, dynamic forecasting models may predict different estimates and patterns of abundance than our static models. Abundance of forest-dwelling Neotropical birds is also strongly linked to matrix quality (Laurance et al. 2011; Hendershot et al. 2020; Stouffer 2020), which was not included in this study, and may have affected results.

Since scenarios represent different conservation objectives and no scenario provided the greatest benefits for all focal species, regional conservation planning will require an assessment of trade-offs between benefits for different species and other conservation objectives (Hirsch et al. 2010). The best conservation decision will likely differ depending on the primary management objectives (Karp et al. 2015). However, understanding the effects of different scenarios on the abundance of multiple species can better inform planning and aid in decision-making when assessing trade-offs (Reid et al. 2014). While birds were used in this example, the

same approach could be used to incorporate other taxa and management objectives, making it

broadly applicable for wildlife conservation. Identifying outcomes and trade-offs from different

conservation priorities within the CBPC can help identify synergies and reduce management

inefficiency in a situation where multiple organizations must cooperate to enact their agendas

and meet common conservation goals (Moran et al. 2019). While embracing this level of

complexity can be challenging for management, it can ultimately produce outcomes that are

more socially and scientifically acceptable, increasing support for management actions (Bryan et

al. 2010; Hirsch et al. 2010; Karp et al. 2015). Identifying trade-offs can provide a valuable

alternative to optimization tools that produce a single management solution based on

conservation objectives, since the optimization process often obscures details and reduces

transparency (Whitehead et al. 2014).

Conclusions

This study combines results from participatory mapping and species abundance modeling

to evaluate trade-offs between multiple alternative conservation scenarios. While a single

reforestation scenario did not yield an optimal solution for increasing avian abundance in the

study area, our predictions reinforced prior work showing that many forest-dwelling Neotropical

bird species can benefit from adding modest amounts of forest cover to fragmented landscapes,

regardless of configuration (Șekercioḡlu et al. 2007; Frishkoff & Karp 2019; Karp et al. 2019;

Șekercioḡlu et al. 2019; Cox Chapter 3). Our results also indicate that many ongoing regional

forest restoration initiatives (Allen 2015; Townsend & Masters 2015) that have prioritized non-

avian conservation goals in the CBPC can benefit forest-dwelling birds. The diversity of species'

responses to individual scenarios also highlights the difficulty in grouping species into *a priori*

categories based on behavioral traits (Miguet et al. 2016; Frishkoff & Karp 2019; Cox Chapter 3)

and underscores the importance of constructing species-specific models for assessment of conservation effects (McGarigal et al. 2016). Finally, our framework presents a novel way to inform and analyze trade-offs between alternate conservation priorities. While we focused on identifying trade-offs between avian species, this approach could be applied to other conservation objectives that were not directly considered in this study. Therefore, this approach has wide-ranging utility for conservation planning.

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Table 4.1. Descriptions (adapted from McGarigal et al. 2012) of the landscape gradients that were included in the candidate avian abundance models. Each gradient was calculated at three scales: 100 m, 500 m, and 1,000 m.

Landscape gradient	Description	Units	Data source
Elevation	Mean elevation within focal window.	meters	Resampled 30 m DEM (SRTM 2014)
Distance to stream	Mean Euclidean distance to nearest stream within focal window.	meters	Stream polyline (TEC 2014)
Percent forest	Percent forest cover within focal window.	percent	Reclassified 5 m land cover (INF 2014)
Core forest area	Amount of forest cover located $\geq$ 100 m from forest edge within focal window.	hectares	Reclassified 5 m land cover (INF 2014)
Edge density	Sum of lengths of all forest edge (m) within focal window divided by the total forest area (ha) within the focal window.	meters/ hectare	Reclassified 5 m land cover (INF 2014)
Patch density	Number of forest patches divided by focal window area (m^2), multiplied by 1,000,000.	number/ 100 hectares	Reclassified 5 m land cover (INF 2014)
Patch shape	Mean perimeter-area ratio of forest patches ($m:m^2$) within focal window.	none	Reclassified 5 m land cover (INF 2014)
Proximity index	Mean sum of forest patch area (m^2) divided by the squared nearest edge-to-edge distance to each forest patch (m^2) within focal window.	none	Reclassified 5 m land cover (INF 2014)

Table 4.2. Area covered by focal themes and percentage of reforested area unique to each scenario.

Scenario	Theme	# of polygons	% study area in polygons	% unique reforested area
R	Reserve expansion/connectivity	25	48.24	36.04
D	Downslope connectivity	49	80.85	44.62
W	Water quality	49	83.35	40.15
L	Lateral connectivity	----	----	34.25

Table 4.3. Forest-dwelling bird species included in analysis.

Common name	Scientific name	Foraging stratum	Diet	Elevation	# sites occupied	# individuals detected
Keel-billed Toucan	*Ramphastos sulfuratus*	Canopy	Frugivore	General	81	166
Northern Emerald-Toucanet	*Aulacorhynchus prasinus*	Canopy	Frugivore	Highland	53	105
Social Flycatcher	*Myiozetetes similis*	Canopy	Insectivore	General	46	99
Long-tailed Manakin	*Chiroxiphia linearis*	Understory	Frugivore	General	65	173
Lesson's Motmot	*Momotus lessonii*	Understory	Insectivore	General	62	134
White-eared Ground-Sparrow	*Melozone leucotis*	Understory	Insectivore	Middle	48	95
Orange-billed Nightingale-Thrush	*Catharus aurantiirostris*	Understory	Insectivore	Middle	37	57
Slaty-backed Nightingale Thrush	*Catharus fuscater*	Understory	Insectivore	Highland	35	53
Rufous-and-white Wren	*Thryophilus rufalbus*	Understory	Insectivore	Middle	97	181
Gray-breasted Wood-Wren	*Henicorhina leucophrys*	Understory	Insectivore	Highland	40	90
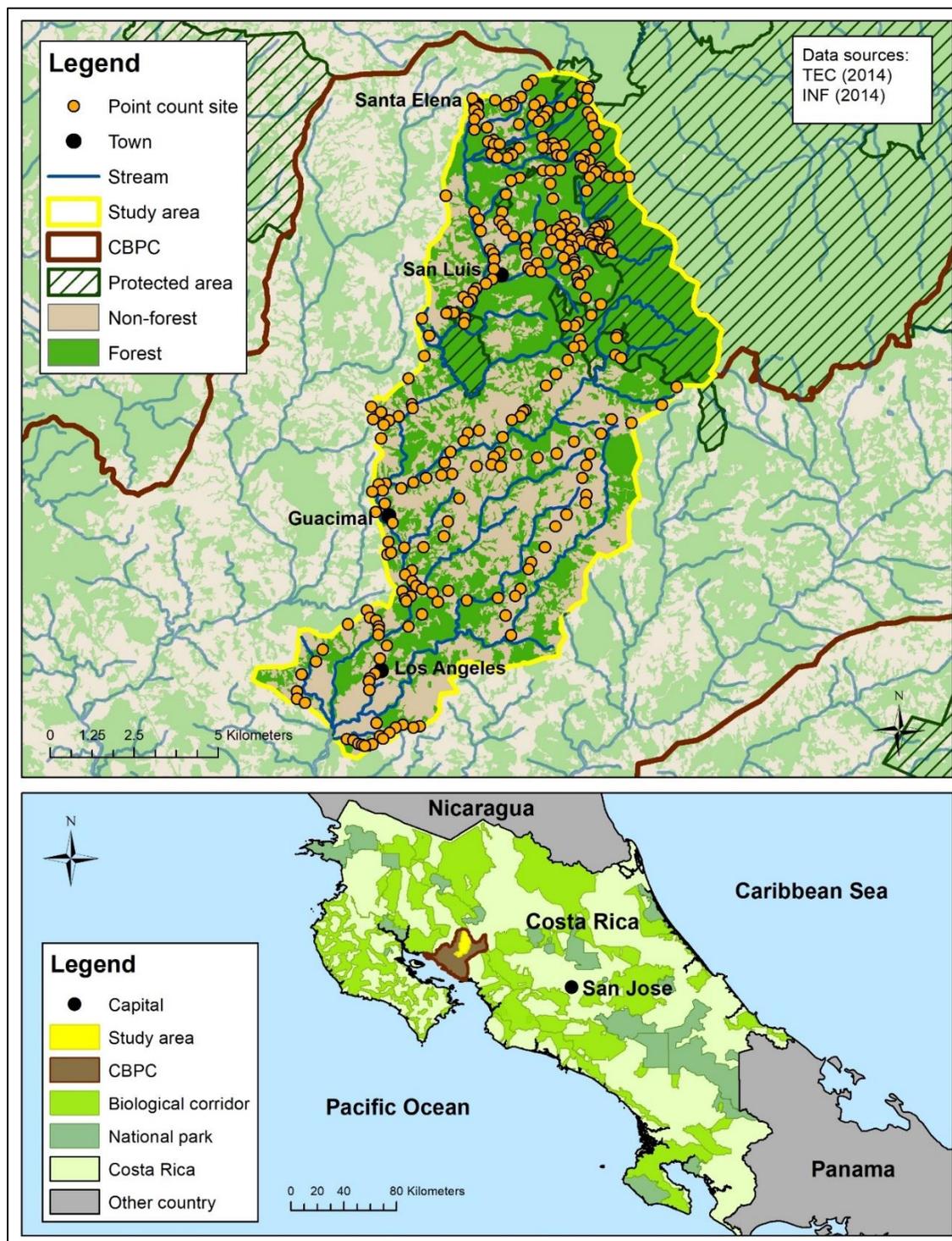
Figure 4.1. Location of the point count sites within the upper Guacimal watershed study area, situated within the *Corredor Biológico Pájaro Campana*, Costa Rica.
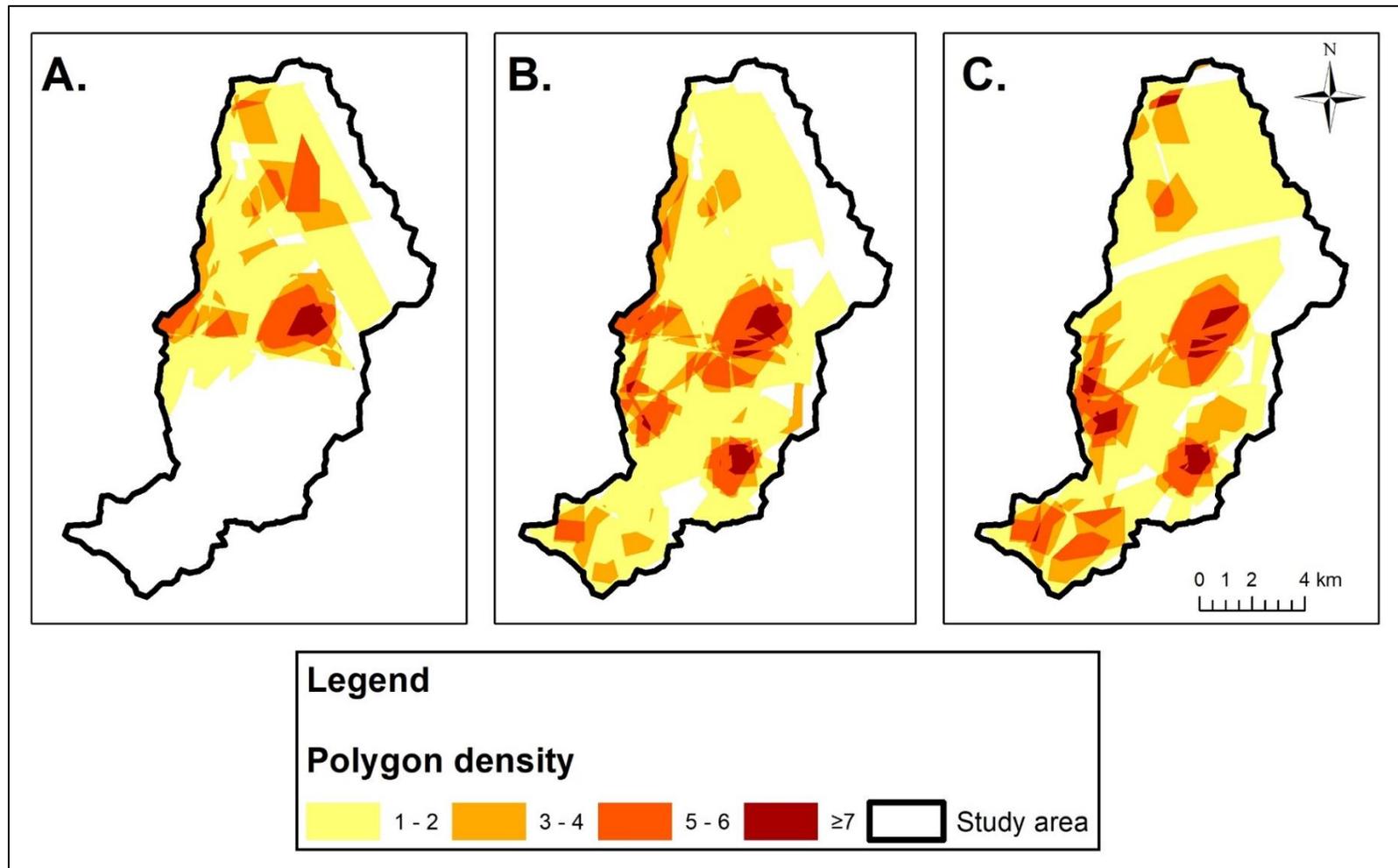
Figure 4.2. Density maps of the polygons used by participants to identify conservation priorities that were associated with three focal themes: A. Reserve expansion/connectivity, B. Downslope connectivity, and C. Water quality.
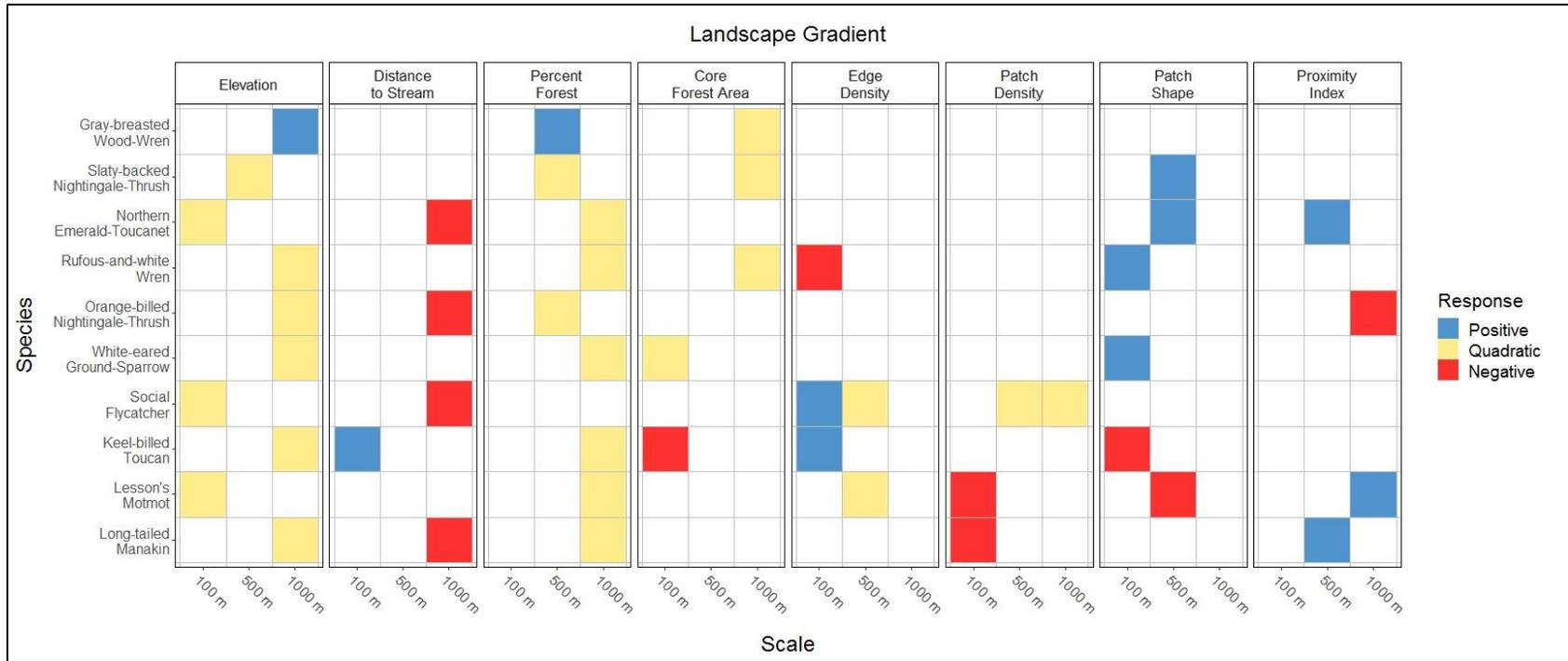
Figure 4.3. The landscape gradients and scales that were included in the top-ranked model for each focal species. Cells colored to correspond to direction of response. Empty cells indicate gradients that were not included in the top-ranked model for that species.
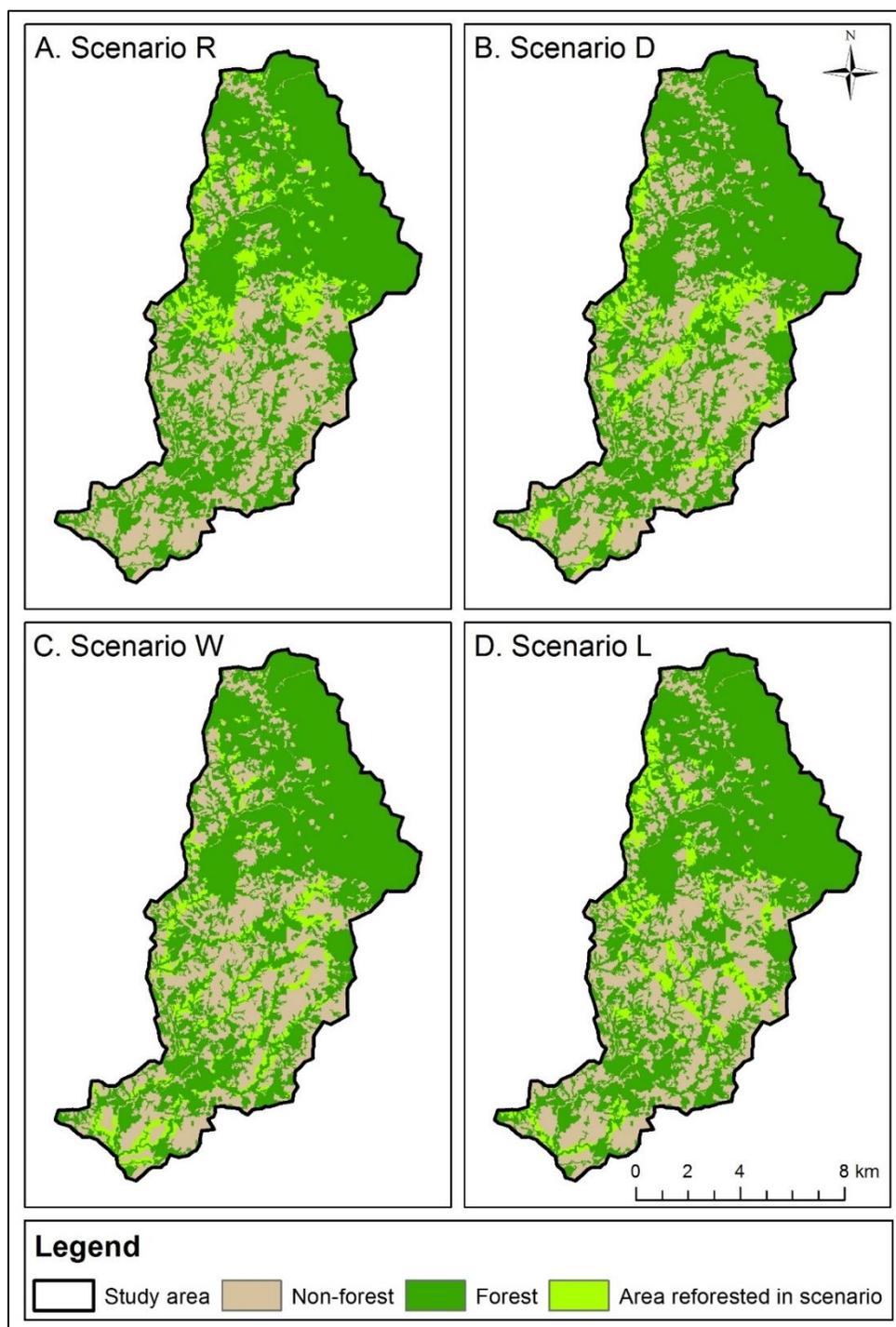
Figure 4.4. Location of added forest cover in the study area under each of the four reforestation scenarios: A. Scenario R: reserve expansion/connectivity, B. Scenario D: downslope connectivity, C. Scenario W: water quality, D. Scenario L: lateral connectivity.
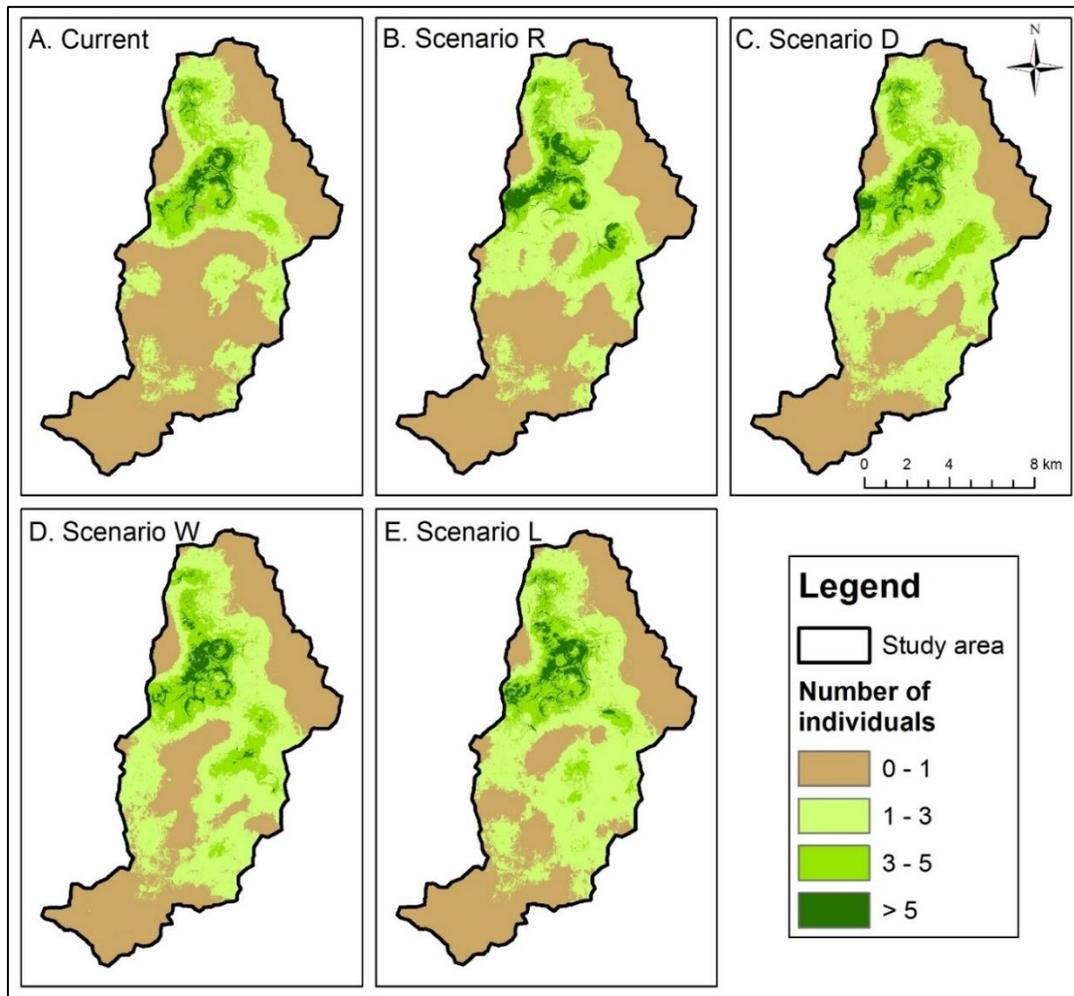
Figure 4.5. Predicted Long-tailed Manakin abundance in the current study area landscape and under each reforestation scenario.

Abundance was calculated as the number of individuals present in a 50 m radius around each 5 m cell.
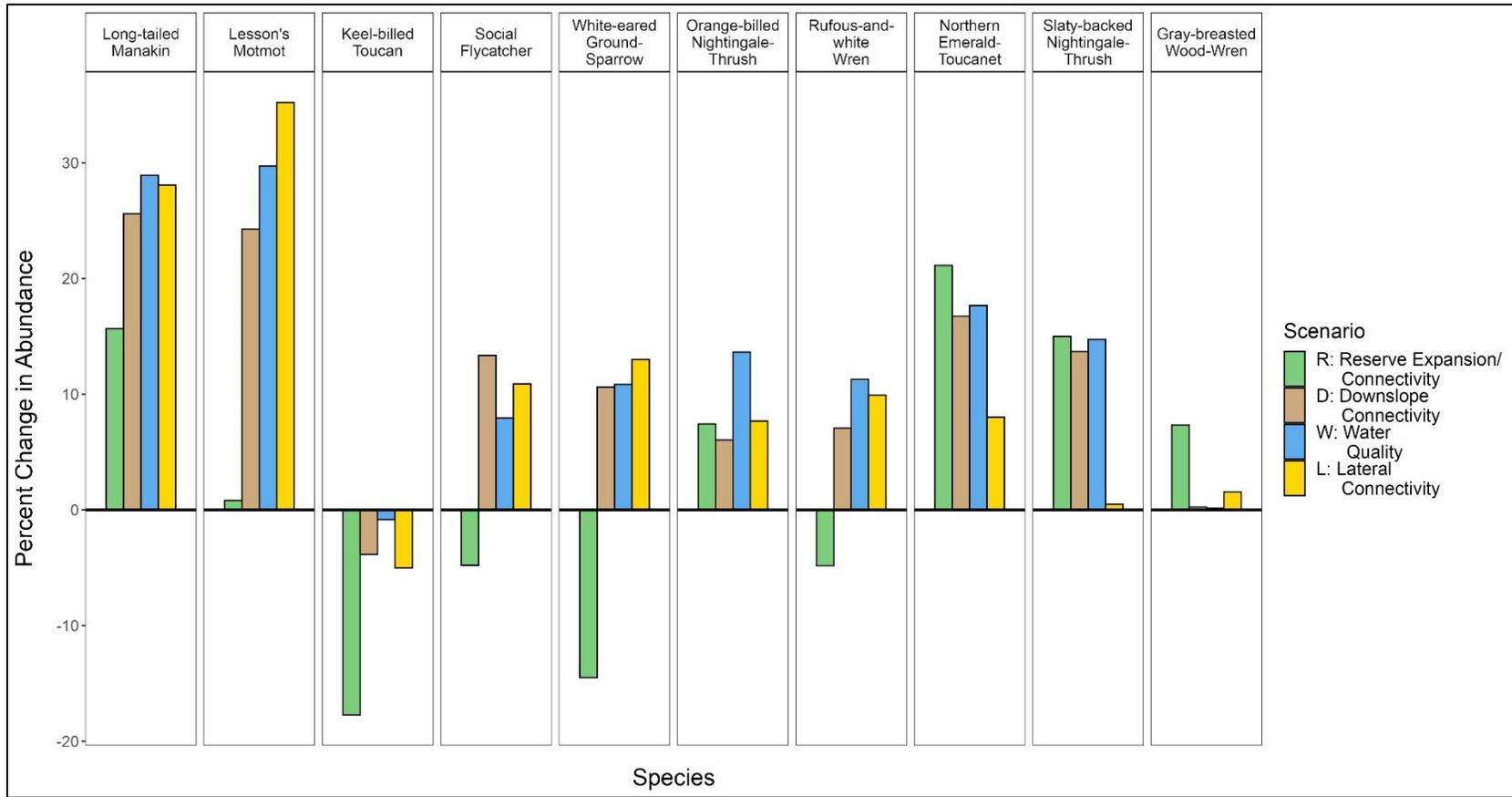
Figure 4.6. Percent change in the abundance of focal species from the current predicted population within the study area under each reforestation scenario.
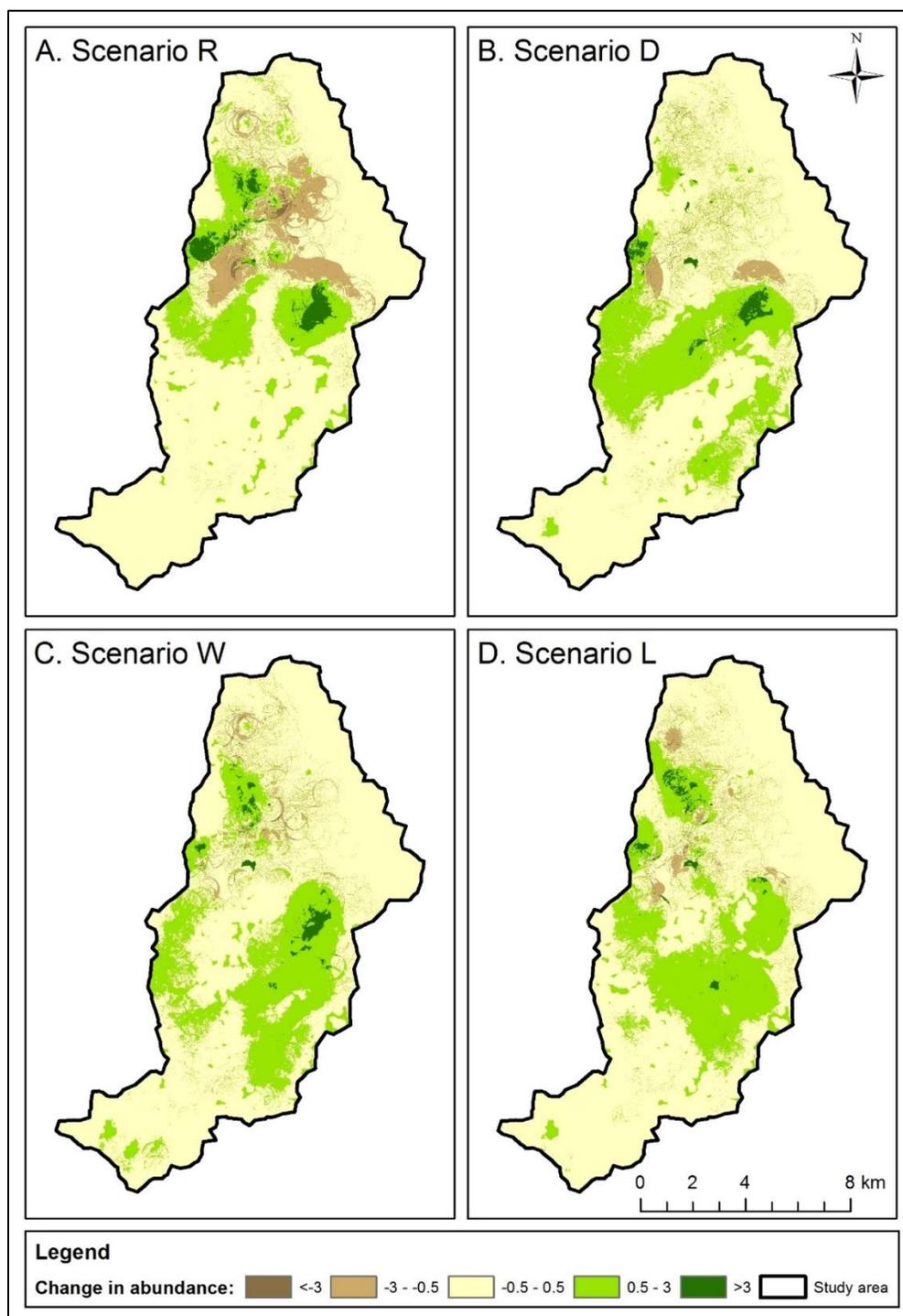
Figure 4.7. Predicted changes in Long-tailed Manakin abundance from present under each reforestation scenario. Abundance was calculated as the number of individuals present in a 50 m radius around each 5 m cell.

CHAPTER 5

CONCLUSION

SUMMARY OF FINDINGS

Chapter 2: Identifying Synergies and Differences in Multi-Stakeholder Conservation

Priorities Using Participatory Mapping Interviews

Semi-structured interviews with participants from locally-operating conservation

organizations indicated universal support for conservation action in the region (Cox Chapter 2).

Furthermore, the conservation priorities of these organizations generally supported the primary

goal of the *Corredor Biológico Pájaro Campana* (CBPC), which is increasing downslope forest

connectivity (CBPC 2011). This result suggests that biological corridors can influence regional

conservation objectives in Costa Rica, despite their lack of legislative authority (DeClerck et al.

2010). In Chapter 2, I highlighted locations where the conservation priorities of organizations

clustered spatially to identify synergies (Brown et al. 2019), which can increase management

efficiency within the CBPC (Calvo-Alvorado et al. 2009; DeClerck et al. 2010). In this chapter, I

also showed how coupling participatory mapping with contextual information gathered from

semi-structured interviews can provide a more holistic representation of regional conservation

priorities and reveal key patterns that would not appear in a strictly quantitative study (Lowery &

Morse 2013). Interviews revealed that conservation priorities were primarily located at middle

elevations because of challenges to conservation action at lower elevations due to lack of

landowner support and increased transportation time and cost. Additionally, this contextual

information helped to highlight non-dominant perspectives, such as the preference for focusing

conservation resources on maintaining currently protected areas instead of expanding initiatives into new locations. Incorporating this contextual information can facilitate the representation of diverse perspectives in the planning process (Sletto 2009) and enhance the assessment of trade-offs between management priorities (Hirsch et al. 2010; Whitehead et al. 2014). The findings in this chapter highlight where stakeholders prioritize conservation action as well as why they selected those locations. This information can inform conservation planning to increase efficiency in implementing initiatives and representation of diverse opinions.

Chapter 3: Scale-Dependent Responses of Forest Birds to Fragmentation in Costa Rica

The results from Chapter 3 indicate that many forest-dwelling bird species will benefit from increased forest cover within the study area. These findings suggest that landscape configuration plays an important role in driving abundance patterns of some species, but landscape composition (i.e., proportion of forest cover) has a much stronger effect on the abundance of most species. These results align with the findings of other observational studies on Neotropical birds in non-experimentally manipulated landscapes (Carrara et al. 2015; Frishkoff & Karp 2019). Thus, opportunistic reforestation, regardless of configuration, will likely benefit many species. Additionally, I found that many focal bird species responded linearly to local forest cover, but non-linearly to landscape-scale forest cover, which indicates that local-scale restoration can benefit many forest-dwelling bird species (Șekercioḡlu et al. 2007; Frishkoff & Karp 2019; Șekercioḡlu et al. 2019). These results can inform regional conservation planning by demonstrating that increasing forest cover in fragmented agricultural landscapes can benefit many forest-dependent bird species, though species that are highly sensitive to disturbance were not included in this analysis due to insufficient data and likely require greater amounts of forest cover. However, this analysis revealed key differences in

responses across species and scales, highlighting the need to develop species-specific models (Frishkoff & Karp 2019) and incorporate multiple spatial scales in analysis to produce accurate models to inform conservation planning (McGarigal et al. 2016).

Chapter 4: Combining Multiple Stakeholder Perspectives with Species-Abundance Models Explicitly Addresses Trade-offs in Conservation Planning for Forest-Dwelling Birds in Costa Rica

My findings in Chapter 4 illustrate the necessity of considering trade-offs in conservation planning, since incorporating social and wildlife objectives into conservation planning often creates complexity (Whitehead et al. 2014), as illustrated by the fact that different reforestation scenarios considered in this chapter benefitted different bird species. Therefore, win-win solutions that provide maximum benefits across a range of objectives are unlikely to occur (Karp et al. 2015). Thus, assessments of trade-offs are required in the decision-making process (Hirsch et al. 2010). In this case, a single reforestation scenario did not provide optimal benefits for all focal bird species, and thus trade-offs between different species and other management objectives must be weighed when selecting a scenario for implementation. However, the forecasts from the models in Chapter 4 showed that many Neotropical forest-dwelling bird species can significantly benefit from the addition of modest amounts of forest cover to fragmented landscapes, regardless of configuration (Șekercioḡlu et al. 2007; Frishkoff & Karp 2019; Șekercioḡlu et al. 2019), which underscores the value of local-scale habitat restoration for many species. These findings also indicate that local forest restoration initiatives that target non-avian objectives, such as ecosystem services, can provide benefits for many forest-dwelling birds. The approach used in this chapter provides a novel framework for identifying the potential effects of stakeholder conservation priorities on wildlife populations to facilitate trade-off

identification. Forecasting effects on wildlife as a result of stakeholder priorities provides an alternative to traditional analysis, which has focused on identifying areas with high conservation support that offer high quality wildlife habitat (Cox et al. 2014; Brown et al. 2019) and considering multiple stakeholder-derived scenarios offers an alternative to optimization that increases complexity, transparency, and stakeholder input (Whitehead et al. 2014). While the results in this chapter were focused on identifying trade-offs between avian species, this approach could be applied to other taxa and conservation objectives. Therefore, it has wide-ranging utility for wildlife conservation planning.

Management Implications and Recommendations

While very few reforestation initiatives within the study area directly target the habitat requirements of individual bird species, the findings in my dissertation indicate that even opportunistically adding forest cover within the region can provide significant benefits to many forest-dwelling bird species. However, more sensitive species require greater amounts of core forest area, which can be difficult to create through reforestation on individual properties. Therefore, conservation organizations can play an important role in landscape-scale wildlife conservation by facilitating coordination between landowners to reforest contiguous portions of adjacent properties to maximize the amount of core forest area added to the landscape. Utilizing participatory mapping to identify synergies can increase management efficiency by allowing organizations to identify opportunities for collaboration. These efforts to increase reforestation efficiency and effectiveness are especially important since the study area is approaching saturation in landowner willingness to reforest after decades of targeted reforestation initiatives. Increased monitoring of reforested areas can also help to ensure that habitat restoration is effective and forests mature as intended to increase wildlife habitat since forest quality is an

important predictor of species richness in fragmented landscapes, particularly in smaller forest patches (Timmers et al. 2022). Developing economic incentives may help increase landowner willingness to participate in reforestation initiatives. While national-scale payments for ecosystem services (PES) have produced limited conservation additionality in Costa Rica, local-scale PES programs, such as the intra-watershed payments for watershed services that have recently been adopted in Costa Rica (Shahady & Boniface 2018), can incentivize reforestation in diverse landowners, particularly those with smaller properties (Brownson et al. 2020). Encouragement of landowners to incorporate agroforestry practices, such as windbreaks that increase agricultural production and wildlife habitat (Brownson et al. 2021). Land-sparing agricultural strategies, which maximize yield in cultivated areas while allowing forested areas on farmland to be set aside for conservation, have been shown to be effective for maintaining biodiversity in Neotropical agricultural landscapes (Chandler et al. 2013), and could also be promoted as a mechanism for balancing livelihoods with conservation in the region.

My findings indicate that forest cover that is added to support other management objectives, such as improving water quality through the restoration of riparian buffers, can benefit many forest-dwelling bird species in the CBPC. However, since there was considerable variability in species-specific responses, the most effective conservation solutions will examine predicted responses during the planning stage and identify trade-offs between species and other conservation goals (Karp et al. 2015). Due to the variability in avian responses to individual reforestation scenarios, focusing on riparian corridors may serve as a valuable framework for conservation within the study area, since riparian restoration has high public and conservation organization support and can accomplish a range of conservation objectives, including water quality protection, increased forest cover and wildlife habitat, and creation of forested corridors

to facilitate seasonal altitudinal migration and upslope range shifts as a result of climate change (Townsend & Masters 2015; Hsiung et al. 2018). Therefore, emphasizing riparian restoration would accomplish both social and ecological conservation goals and address the primary objective of the CBPC, which is increasing downslope forest connectivity to facilitate wildlife conservation (CBPC 2011).

Bird species that are highly sensitive to disturbance were not detected frequently enough to construct robust models, but likely require larger tracts of contiguous forest within elevation bands than provided solely by riparian buffers, which often create linear strips of forest cover with a high proportion of forest edge. Thus, this group of species likely will benefit most from increasing core forest area (Laurance et al. 2011; Stouffer 2020). Lattice-work corridors that increase connectivity both between elevation zones along riparian corridors and within individual elevation zones (Townsend & Masters 2015) present a hybrid solution that could serve as an important framework for future regional conservation. Since the findings of my dissertation indicate that even relatively modest increases in forest cover can provide substantial benefits to many forest-dwelling birds in this landscape, using the strategies outlined to increase landscape-scale collaboration and better target reforestation efforts can increase conservation effectiveness and provide substantial benefits to regional avifauna.

INTEGRATIVE APPROACH

Research

In my approach to this research, I tried to embrace the local complexity of differing stakeholder values and priorities, as well as divergent species-environment relationships, in order to highlight uncertainties and trade-offs and avoid developing over-simplified solutions to the multi-dimensional conservation issues (McShane et al. 2011) in the CBPC of Costa Rica. In

Chapter 2, I moved beyond identifying only where participant conservation priorities clustered, and also demonstrated how spatial patterns differed by individual themes. Additionally, I highlighted instances where alternate perspectives emerged in interviews that were not depicted by the hotspot patterns, such as the need to continue allocating resources to maintain currently protected areas. In Chapter 4, rather than attempting to develop an optimal reforestation solution that balanced stakeholder priorities and avian abundance, I instead created scenarios based on a suite of themes that emerged from participant interviews and then assessed trade-offs between different scenarios.

I sought to incorporate pluralism in my research to highlight a range of perspectives on conservation issues (McShane et al. 2011). Thus, I interviewed personnel from a range of organizations and gathered perspectives on conservation priorities and challenges within the study area from a diverse group of stakeholders. Additionally, my research produced a framework that allows for iterative stakeholder input. Conservation priorities were identified by stakeholders at the outset of the process. This framework then allows stakeholders to weigh trade-offs based on scenarios derived from their input and implement the solutions that best fit their goals, rather than recommending a single optimal solution for targeting social and wildlife conservation objectives. This method of developing scenarios using stakeholder-identified conservation priorities and forecasting effects on local bird populations in the study area landscape helped make my findings context-specific. However, this framework can be adapted to fit other local contexts wherever it is applied, since it is based on priorities developed by local stakeholders.

I engaged with multiple epistemologies through the development of the research objective for my dissertation, which was to examine how local conservation priorities affect

avian populations. This objective required incorporating social and natural science methods to understand what local priorities are, where they are located, what landscape gradients drive avian abundance, and how changes to those gradients as a result of reforestation targeting local conservation priorities will affect future bird populations. Chapter 4 of my dissertation presents a mixed methods approach that produces a novel framework for conservation planning. In this chapter, I used social science methods to conduct interviews and code interview themes, which I used to generate reforestation scenarios that were derived from participant priorities. Then, I employed ecological sampling and modeling techniques to identify avian responses to landscape gradients within the study area. I used these models to forecast changes in abundance of bird species under the participant-derived reforestation scenarios to predict how different conservation priorities would affect the abundance of individual species, which facilitated an assessment of trade-offs. To the best of my knowledge, the combination of these discipline-specific methods resulted in a new application of participatory mapping. Participatory mapping has previously been used to identify where participant conservation support and high quality habitat align (Cox et al. 2014; Brown et al. 2019), but not how management decisions will affect future wildlife populations. While this analysis focused on identifying trade-offs between avian species, this approach could be applied to other taxa and conservation objectives. Therefore, it has wide-ranging utility for wildlife conservation planning.

Furthermore, I mixed quantitative and qualitative participatory mapping methods in Chapter 2 to highlight not only where participant conservation priorities clustered spatially within the study area, but also how spatial patterns differed according to themes, how patterns of priorities were shaped by conservation challenges, and highlight key non-dominant opinions for consideration in the planning process. Additionally, I helped develop a collaborative peer-

reviewed journal article with other Integrative Conservation (ICON) students who were also conducting research within the CBPC that integrated multiple disciplines (Brownson et al. 2021). This paper analyzed the role of agricultural windbreaks in providing ecosystem service benefits to farmers and avian habitat in agricultural landscapes. Conclusions were drawn from a combination of interviews with farmers, measurements of ecological conditions, such as temperature, soil, and water quality, and calculations of avian community composition.

All three data chapters of my dissertation focus on applied research that is particularly relevant to practice. I interviewed key informants from local organizations to identify the conservation priorities and limitations that were used as the foundation for my analysis in Chapters 2 and 4 of my dissertation. Chapter 3 focused on responses of avian species to landscape gradients in the same study area and highlights where 16 forest-dependent bird species are predicted to be most abundant in the landscape. Additionally, my entire dissertation was framed as a case study using a sub-watershed within a single biological corridor in Costa Rica. All of my findings are framed in a way that can inform ongoing local management within my study area in addition to the broader scientific community. I also am developing a bilingual summary of the key findings of my dissertation to distribute to local practitioners to help inform management.

Strategic Communication

Throughout the course of my PhD, I had numerous opportunities to communicate my research to a wide range of audiences. In 2015, I collaborated to produce a four minute video explaining my research to a general public audience, which utilized footage of me conducting bird research in Costa Rica (Appendix K). This video was used in a crowdfunding campaign designed to raise money to support my research. Thus, it was strategically designed to capture

general public interest. The focus of my ICON internship with the Smithsonian Migratory Bird Center (SMBC) was also an exercise in strategic communication. In my internship, I compiled SMBC bird friendly coffee certification standards and measurement methods. I then produced a manual that organized and presented standards and methods in accessible language for both inspectors and coffee growers in Latin America to facilitate participation and compliance with the program.

I also gave invited presentations on my research at an annual Georgia Ornithological Society meeting and at seminars at the University of North Georgia, Portland Community College, and the Oconee Rivers Audubon Society. I also have presented my research at numerous academic conferences with a broad range of focuses, including integrative conservation, landscape ecology, and ornithology. Additionally, while I was conducting fieldwork in Costa Rica, I gave presentations about my research to numerous student groups of different education levels, ranging from middle school to graduate school, who were involved in study abroad courses in Costa Rica. Through these experiences, I learned to tailor my explanations of my research to different education levels and engage audiences of different ages and areas of interest.

In addition to presentations about my research, I led student groups, tourists, and local landowners on interactive tours of my research on numerous occasions. These tours primarily consisted of checking mist nets and observing bird banding techniques. During these activities, I had the opportunity to engage groups of different education levels in fieldwork, teach them about ecological research, and show them my sampling methods. I also brought intern naturalists from the nearby University of Georgia – Costa Rica field station along during sampling efforts and taught them about my research, providing them exposure to ecological sampling techniques.

These outings also allowed me to share my research with them, so that they could provide information with visiting student and tourist groups. Additionally, I hired several field technicians to assist with fieldwork, which provided me the opportunity to communicate project objectives, teach sampling methods, and mentor young scientists as they began their careers. I also co-mentored two undergraduate senior thesis students in the Warnell School of Forestry and Natural Resources at the University of Georgia, who used data that I collected during my fieldwork for their theses. These experiences provided me with opportunities to help students learn to analyze data and interpret and communicate their results. This process taught me how to communicate with students about data analysis methods and interpretation of results.

Strategic communication was also a key element of conducting my fieldwork because I had to explain my research methods and objectives to myriad landowners to secure permission to sample on their properties, which was essential for establishing a sufficient number of sites in each of the sampling strata within my study area, since it consisted almost entirely of privately-owned land. This process required me to learn to explain my research to a non-technical audience, usually in Spanish. Additionally, I had to effectively and concisely communicate my research objectives to engage and recruit interview participants and ask effective questions during semi-structured interviews. In addition to communicating my research to a scientific audience through the publication of my dissertation chapters in peer-reviewed scientific journals, I am also developing a bilingual document summarizing key findings from my dissertation, which I will distribute to collaborators in Costa Rica. This document will permit my findings to be used to inform regional conservation planning.

While much of the strategic communication that I engaged in was focused on communicating my research to audiences using a more traditional science communication

approach, I also attempted to engage in bi-directional communication through the design of my semi-structured interviews with stakeholders. These interviews allowed me to take a listening role and learn about the conservation priorities and challenges that were identified by local stakeholders. This approach allowed me to develop reforestation scenarios that reflected the values and priorities of the local conservation community, in contrast to the common approach of using a suite of expert-developed scenarios for landscape-scale planning. Therefore, stakeholder perspectives directly informed the future reforestation scenarios. Thus, the findings that I will be returning to the local conservation community will be directly relevant to their current priorities.

Internship

I satisfied my ICON internship requirement (ICON 8111E) by working with the Smithsonian Migratory Bird Center (SMBC) during the spring and summer of 2018 under the supervision of Justine Bowe, the manager of the SMBC's bird friendly coffee program, and Dr. Peter Marra, the (former) director of the SMBC. The SMBC bird friendly coffee program incentivizes shade-grown coffee practices, which improve habitat quality in agricultural landscapes for many forest-associated bird species, particularly Nearctic-Neotropical migrants, while supporting farmers by providing certifications that allow their coffee to be sold at higher prices. My primary task during this internship was to develop a manual of certification methods and standards for SMBC bird friendly coffee inspectors and growers in Latin America, which was published in English and Spanish versions (Cox et al. 2019). This report provided a comprehensive synthesis of SMBC standards for farm characteristics, such as amount of forest cover, canopy height, and floristic diversity. It required compiling criteria from an array of sources and working collaboratively with SMBC personnel to develop new standards and measuring protocols. I wrote the bulk of the English version of the report, but worked with

SMBC personnel to revise and translate the document, insert illustrations, and format the report. This document greatly enhances the SMBC's ability to strategically communicate standards to both farmers and inspectors in a single organized document, which should facilitate engagement and compliance with the SMBC bird friendly program, thus enhancing the conservation potential of agricultural landscapes for Neotropical birds. This internship allowed me to contribute to an important Neotropical conservation initiative that aligns with ICON values of supporting biodiversity and human livelihoods by increasing sustainability in coffee production. It provided me with experience in strategic communication of technical certification standards to a non-technical audience. Working with the SMBC also provided me with valuable insight into the roles and responsibilities of different personnel within the SMBC and helped me envision career opportunities in conservation outside of academia.

LIMITATIONS AND CHALLENGES

I faced many obstacles during the course of my PhD, particularly during fieldwork, which provided me with excellent learning opportunities and chances to grow as a scientist. These experiences taught me how to be adaptable to changing conditions during scientific research and provided me with insights that will allow me to consider alternative ideas if conducting similar research in the future. The topography and pattern of land ownership in my study area proved to be a significant hurdle. All of the land in my study area is privately owned, and with the exception of a few large reserves, primarily consists of relatively small parcels. Thus, adequately sampling across landscape gradients in the study area required coordinating with myriad landowners to gain permission to access properties on specific dates. While landowners were incredibly generous and accommodating in permitting me to sample on their properties, this process required a substantial time commitment because I had to determine who

owned properties where sites were located and coordinate with them about times for sampling. Often, I had to schedule with multiple landowners simultaneously to visit nearby sites within a single morning of sampling. Additionally, access to many sites was difficult due to the limited road network and steep terrain within the study area. The combination of topography and difficulty in identifying land ownership rendered certain sites inaccessible, which required me to locate alternative sites while still maintaining a balanced stratified random sampling study design.

The biggest challenge that I experienced during my research also limited accessibility to many of my sampling sites. In October 2017, Hurricane Nate caused numerous landslides and flash flooding within my study area, forcing me to evacuate from my field house for 10 days and blocking roads and trails and destroying bridges, all of which provided key access corridors, oftentimes singularly, to sampling sites. I was able to maintain access to some sites using much longer alternate routes and regain access to others when debris was cleared from roads and bridges were rebuilt, but certain remote sites remained inaccessible for the duration of my fieldwork, which forced me to adjust my sampling design and find alternate sites. Additionally, the damage from the hurricane required considerable attention and energy from conservation organization personnel, leading me to postpone several interviews out of respect for the priorities and high volume of work for many key informants. These delays played an important role in my decision to undertake an additional short field season in the summer of 2018, which allowed me to complete my interviews, as well as supplement my avian dataset.

I also experienced challenges in modeling the distributions of many relatively common bird species due to the steep elevation of my study area. Many Neotropical bird species have narrow thermal tolerances, restricting them to narrow elevational zones (Forero-Medina et al.

2011). Thus, I did not detect some species that were locally relatively common at enough sites (≥30; Wenger & Freeman 2008) to construct robust models, often due to a paucity of suitable sites within their inhabitable elevation zone. While reflecting on this challenge, I have considered whether I would recommend future research in similar landscapes include multiple adjacent watersheds to increase the sampling area within elevation zones. While this solution would be attractive from an ecological modeling standpoint, in my study area it would have posed significant logistical challenges because there are no direct routes between adjacent watersheds. Thus, sampling an additional watershed would have required long travel times or alternate housing arrangements. However, future studies should consider this issue at their outset to minimize modeling and logistical challenges.

Additionally, I had originally proposed to analyze the movement patterns of two bird species, Lesson's Motmots (*Momotus lessonii*) and Northern Emerald-Toucanets (*Aulacorhynchus prasinus*). I tracked individuals of these two species using GPS transmitters during my fieldwork in Costa Rica. However, I faced technological issues due to malfunctioning transmitters, which took many months to be repaired by the manufacturer, that limited my sample size. However, this challenge led me to prioritize other components of my research and gave birth to the idea to split the analysis included in Chapters 2 and 4 of my dissertation into separate chapters, which allowed me to better emphasize the integrative aspects of my research in my dissertation. This experience showed me the value of developing backup plans and collecting multiple sources of data. For example, by collecting point count data, I still had sufficient avian data to analyze for my dissertation, even though the movement data was more limited than I had anticipated at the outset of my research.

I also struggled to incorporate new perspectives that I was exposed to through the ICON program into my research. When I entered the program, I had recently completed my MS research, which was focused on human dimensions of natural resources. Therefore, I arrived with a naïve confidence that I had a solid social science foundation and would be well-prepared and comfortable as I dove into the ICON curriculum. I quickly learned that social science perspectives in other departments were very different than what I had previously been exposed to, and I was challenged to view my research, and conservation in general, through very different lenses than I was expecting, which was not always easy or comfortable. While I find many of these alternate ways of viewing conservation challenges to be interesting and incredibly valuable for developing holistic solutions to conservation problems, I have often struggled to think from some perspectives that do not come as naturally to me. Despite the struggle, I think that the exposure to alternate perspectives that I gained through the ICON program has made me a much better informed scientist and conservationist, and has improved my ability to consider multiple perspectives when examining conservation problems, which will help me for the duration of my career by shaping my personal research objectives, allowing me to identify situations where I need to collaborate with others who have more experience with certain perspectives and methods, and enhancing my ability to communicate with collaborators across disciplines.

Finally, I faced the challenge of balancing pursuing new passions with maintaining commitments as I grew as a scientist during the course of my PhD. When I began my PhD program, my background was in human dimensions of natural resources and Geographic Information Systems (GIS) analysis. As I began to frame my dissertation and identify research gaps within the CBPC, I noticed that while other ongoing research projects were making headway in understanding spatial patterns and motivations for reforestation in the region (Allen

2015; Allen & Padgett Vasquez 2017; Allen & Colson 2019; Brownson et al. 2020; Brownson et al. 2021), there was a notable gap in quantifying the responses of fauna to habitat restoration. Thus, I set out to address this research gap so that the effects of habitat restoration on forest-dependent wildlife could be better understood, since increasing habitat for wildlife is one of the primary goals of conservation within the CBPC (CBPC 2011). While I had little previous experience in conducting wildlife research, it was an essential component of the integrative research question that I wanted to address, so I was given the opportunity to pursue it, and I quickly settled on birds as a focal taxon. I immediately fell in love with all components of this portion of my research, including ornithology, fieldwork, and statistical modeling, and desired to develop the greatest depth of knowledge and experience in these areas that I possibly could during the course of my PhD. This newfound love altered my vision of my career trajectory and long-term research objectives, as I shifted from being centered in the human dimensions of wildlife to becoming an ornithologist and spatial ecologist at my core. The growth of my interest in these fields pulled my attention away from enhancing my social science skillset for a time. However, I continued to feel a commitment to the ICON program, both because I believe strongly in its core philosophy and because I felt a personal conviction to honor my commitment to the program and see that aspect of my research to completion. These feelings inspired me to continue to push to develop and complete the social science elements of my dissertation. Nevertheless, it took time, restlessness, reflection, and personal growth to learn to balance my commitments with my passions and develop a dissertation that unites the two.

FUTURE RESEARCH DIRECTIONS

There are several lines of research that I would like to pursue using the data that I collected during my fieldwork in Costa Rica that would provide valuable supplements to the

findings included in my dissertation. My predictions about avian responses to reforestation scenarios would be greatly enhanced by an understanding of how individuals move through fragmented landscapes (Peters & Nibbelink 2011). While conducting fieldwork in Costa Rica, I attached GPS transmitters to 17 Lesson's Motmots (*Momotus lessonii*) and 7 Northern Emerald-Toucanets (*Aulacorhynchus prasinus*), two of the focal species in my analysis in Chapters 3 and 4, to track their movements through the landscape at five minute intervals. I plan to analyze movement data from these two species to determine how landscape gradients affect movement patterns and home range size. This analysis would be particularly valuable since there is virtually no published information about the movements or home ranges of Lesson's Motmots, nor any other members of the family Momotidae. This research will enhance our understanding of functional connectivity requirements for these species and allow us to better estimate which landscape characteristics will facilitate colonization of restored forest patches. I also plan to use this movement data to parameterize an agent-based model that will allow an investigation of responses of individuals of these two species to experimental changes to landscape gradients.

Additionally, I plan to compare the abundance and richness of species detected using the point counts that I used for my dissertation analysis and mist netting efforts that I conducted concurrently to determine how the two sampling methods provide different pictures of community composition. I also plan to compare models of abundance for a suite of species that were commonly detected using both sampling methods to determine how predicted responses to landscape gradients differ based on sampling method, which can have important implications for future efforts to build accurate species distribution models for Neotropical birds. Additionally, I plan to model responses of bird species to individual landscape gradients at regular intervals over a broad range of scales to identify domains of scale where response patterns change (Wheatley

2010). Finally, I plan to use my study area as a case study to examine how the presence of charismatic species shapes patterns of nature-based tourism, which provides critical funding and incentives for conservation action. As a result, conservation action is often concentrated in areas with charismatic species and more challenging to implement in landscapes that lack iconic species (Stotz et al. 1996). This theme emerged in some of my interviews with conservation organizations. This case study will be part of a broader paper examining wildlife-based tourism and conservation in Costa Rica through a social-ecological systems lens. All of these avenues for future research will provide important information that will increase regional conservation planning efficiency and effectiveness.

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APPENDIX A

INTERVIEW RECRUITMENT AND REMINDER MATERIALS

Pre-notice Letter

<Date>

Dear <participant>,

We are writing to ask for your help with an important study being conducted by the University of Georgia about bird conservation in the Bellbird Biological Corridor, Costa Rica. The information you provide will be used as an input to regional planning processes. We have identified you as a key member of an organization that is active in the area, and would like to conduct an approximately 45 minute interview with you about your organization's views on conservation and management strategies. The interview will also contain a participatory mapping exercise where you can identify places that your organization views as important for conservation or alternative uses.

This research can only be successful with the generous help of people like you. Therefore, we would like to do everything we can to make it easy and enjoyable for you to participate. Please take a moment to reply to this email and let us know whether or not you are willing to participate. If you indicate that you do not wish to participate, we will not contact you again. Choosing not to participate will not jeopardize your relationship with the University of Georgia or the researchers on this project. If you are willing to participate, we will work to set up a time and location to conduct the interview that is most convenient for you. We greatly appreciate your help with this project and hope that you will take the opportunity to share some of your organization's approaches to and opinions about conservation in the Bellbird Biological Corridor.

Best Wishes,

Nate Nibbelink   *Cody Cox*

Dr. Nate Nibbelink   Cody Cox
Professor and Researcher,   PhD Candidate and Researcher
Warnell School of Forestry and Natural Resources   Integrative Conservation and
Director,   Warnell School of Forestry and
Center for Integrative Conservation Research   Natural Resources
University of Georgia   University of Georgia

First Reminder Letter

Dear <participant>,

A few weeks ago we emailed you because you were selected as part of a small sample of organizational leaders to help in a study about bird conservation in the Bellbird Biological Corridor. However, to the best of our knowledge, we have not received a reply about whether you are interested in participating. We are writing again because of the importance that your answers have for helping us to get accurate results. If you are willing to participate in an approximately 45 minute interview about your organization's approach to management and conservation, including a participatory mapping exercise, please respond and we will schedule a time and location that is most convenient for you. If you do not wish to participate, please let us know and we will not contact you again. We are extremely grateful for your help with this important study.

Sincerely,

Nate Nibbelink   Cody Cox
Professor, University of Georgia   PhD Candidate, University of Georgia

Second Reminder Letter

Dear <participant>,

About a month ago we emailed you because you were selected as part of a small sample of organizational leaders to help in a study about bird conservation in the Bellbird Biological Corridor. However, to the best of our knowledge, we have not received a reply about whether you are interested in participating. We are writing again because of the importance that your answers have for helping us to get accurate results. If you are willing to participate in an approximately 45 minute interview about your organization's approach to management and conservation, including a participatory mapping exercise, please respond and we will schedule a time and location that is most convenient for you. If you do not wish to participate, please let us know and we will not contact you again. We are extremely grateful for your help with this important study.

Sincerely,

Nate Nibbelink   Cody Cox
Professor, University of Georgia   PhD Candidate, University of Georgia

APPENDIX B

SEMI-STRUCTURED INTERVIEW SCRIPT

I. Introduction

    1. What is your organization's mission?

    2. What is the scale (e.g. local, regional, national) of your organization's activities?

    3. Approximately how many employees/volunteers does your organization have?

    4. How long has your organization been active in the Bellbird Biological Corridor?

II. Management

    1. Is your organization involved in any conservation initiatives?

    2. Are any of these initiatives bird-related?

    3. Has your organization had particular positive or negative experiences with conservation?

    4. What factors limit your organization's conservation initiatives?

III. Participatory Mapping

    1. Please identify up to 5 places on the map that you think are most important for bird

        conservation. Why did you select these places?

    2. Please identify up to 5 places on the map that you think are important for other (non-

        conservation) reasons. Why did you select these places?

IV. Landscape

    1. Does the quality of a landscape affect your organization's opinions about whether or not

        avian conservation action should occur there?

2. Does your organization think avian conservation efforts should be focused on areas that are already well-protected or are in close proximity to well-protected areas?

3. Does your organization think avian conservation efforts within the region should occur exclusively within the Bellbird Biological Corridor?

4. Does your organization think that avian conservation provides economic opportunities in certain areas?

5. Does your organization think that avian conservation limits economic opportunities in certain areas?

APPENDIX C

LIST OF ABUNDANCE MODEL VARIABLE ABBREVIATIONS

Variable	Abbreviation
Elevation	elevMn
Distance to stream	distStrm
Percent forest	pfor
Core forest area	coreFor
Edge density	ed
Patch density	patchDens
Patch shape	mnPARiFor
Proximity index	proxFor
Temperature	Temp.
Observer A	Obs. A
Observer B	Obs. B
Observer C	Obs. C
Observer D	Obs. D
Observer E	Obs. E
Observer F	Obs. F

APPENDIX D

AIC RANKINGS FOR ABUNDANCE MODELS FOR EACH FOCAL SPECIES AT EACH

FOCAL SCALE

ΔAIC = difference in AIC relative to the top-ranked model, w = AIC weight, K = number of

model parameters.

Long-tailed Manakin: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor100+mnPARiFor100+ coreFor100²	0	9.10E-01	18
elevMn100+ elevMn100²+pfor100+coreFor100²	6.13	4.30E-02	17
elevMn100+elevMn100²+pfor100+mnPARiFor100	6.92	2.90E-02	16
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²+ patchDens100	8.04	1.60E-02	18
elevMn100+elevMn100²+pfor100	12.22	2.00E-03	15
elevMn100+elevMn100²+pfor100+patchDens100	14.2	7.50E-04	16
elevMn100+elevMn100²	37.73	5.80E-09	14
null	87.91	7.40E-20	12

Common Chlorospingus: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor100+ed100+ed100²+distStrm100+ coreFor100+coreFor100²+patchDens100	0	0.28	16
elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ mnPARiFor100+distStrm100+coreFor100+coreFor100²	0.56	0.21	17
elevMn100+elevMn100²+pfor100+ed100+ed100²+ mnPARiFor100+distStrm100+coreFor100+coreFor100²	1.63	0.12	16
elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ distStrm100+coreFor100+coreFor100²+patchDens100	2	0.1	17
elevMn100+elevMn100²+ed100+ed100²+mnPARiFor100+ distStrm100+coreFor100+coreFor100²	2.58	0.078	15
elevMn100+elevMn100²+proxFor100+ed100+ed100²+ mnPARiFor100+distStrm100+coreFor100+coreFor100²	3.38	0.052	16

elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ distStrm100+coreFor100+coreFor100²	3.52	0.048	16
elevMn100+elevMn100²+pfor100+ed100+ed100²+coreFor100+ coreFor100²+patchDens100	4.96	0.024	15
elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ mnPARiFor100+coreFor100+coreFor100²	6.14	0.013	16
elevMn100+elevMn100²+ed100+ed100²+distStrm100+ coreFor100+coreFor100²+patchDens100	6.2	0.013	15
elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ coreFor100+coreFor100²+patchDens100	6.95	0.0087	16
elevMn100+elevMn100²+ed100+ed100²+mnPARiFor100+ coreFor100+coreFor100²	7.14	0.0079	14
elevMn100+elevMn100²+pfor100+ed100+ed100²+ mnPARiFor100+coreFor100+coreFor100²	7.49	0.0066	15
elevMn100+elevMn100²+pfor100+ed100+ed100²+distStrm100+ coreFor100+coreFor100²	7.54	0.0065	15
elevMn100+elevMn100²+proxFor100+ed100+ed100²+ mnPARiFor100+coreFor100+coreFor100²	7.72	0.0059	15
elevMn100+elevMn100²+proxFor100+ed100+ed100²+ distStrm100+coreFor100+coreFor100²+patchDens100	7.86	0.0055	16
elevMn100+elevMn100²+pfor100+proxFor100+ed100+ed100²+ coreFor100+coreFor100²	8.5	0.004	15
elevMn100+elevMn100²+ed100+ed100²+coreFor100+ coreFor100²+patchDens100	9.48	0.0025	14
elevMn100+elevMn100²+proxFor100+ed100+ed100²+ coreFor100+coreFor100²+patchDens100	10.86	0.0012	15
elevMn100+elevMn100²+pfor100+ed100+ed100²+coreFor100+ coreFor100²	13.45	0.00034	14
elevMn100+elevMn100²+pfor100+mnPARiFor100+distStrm100+ coreFor100+coreFor100²	15.1	0.00015	14
elevMn100+elevMn100²+pfor100+proxFor100+mnPARiFor100+ distStrm100+coreFor100+coreFor100²	16.47	0.000075	15
elevMn100+elevMn100²+mnPARiFor100+distStrm100+ coreFor100+coreFor100²	17.24	0.000051	13
elevMn100+elevMn100²+pfor100+distStrm100+coreFor100+ coreFor100²+patchDens100	17.45	0.000046	14
elevMn100+elevMn100²+pfor100+distStrm100+coreFor100+ coreFor100²	17.55	0.000043	13
elevMn100+elevMn100²+pfor100+proxFor100+distStrm100+ coreFor100+coreFor100²	18.37	0.000029	14
elevMn100+elevMn100²+pfor100+mnPARiFor100+coreFor100+ coreFor100²	18.45	0.000028	13
elevMn100+elevMn100²+proxFor100+mnPARiFor100+ distStrm100+coreFor100+coreFor100²	19.16	0.000019	14

Model			
elevMn100+elevMn100^2+pfor100+proxFor100+distStrm100+coreFor100+coreFor100^2+patchDens100	19.27	0.000018	15
elevMn100+elevMn100^2+pfor100+proxFor100+mnPARiFor100+coreFor100+coreFor100^2	19.43	0.000017	14
elevMn100+elevMn100^2+mnPARiFor100+coreFor100+coreFor100^2	19.65	0.000015	12
elevMn100+elevMn100^2+pfor100+coreFor100+coreFor100^2+patchDens100	20.05	0.000012	13
elevMn100+elevMn100^2+pfor100+coreFor100+coreFor100^2	20.2	0.000012	12
elevMn100+elevMn100^2+pfor100+proxFor100+coreFor100+coreFor100^2	20.45	0.00001	13
elevMn100+elevMn100^2+distStrm100+coreFor100+coreFor100^2+patchDens100	21.39	6.4E-06	13
elevMn100+elevMn100^2+proxFor100+mnPARiFor100+coreFor100+coreFor100^2	21.45	6.2E-06	13
elevMn100+elevMn100^2+pfor100+proxFor100+coreFor100+coreFor100^2+patchDens100	21.71	5.4E-06	14
elevMn100+elevMn100^2+coreFor100+coreFor100^2+patchDens100	23.12	2.7E-06	12
elevMn100+elevMn100^2+proxFor100+distStrm100+coreFor100+coreFor100^2+patchDens100	23.34	2.4E-06	14
elevMn100+elevMn100^2+proxFor100+coreFor100+coreFor100^2+patchDens100	25.06	0.000001	13
elevMn100+elevMn100^2+ed100+ed100^2+distStrm100+coreFor100+coreFor100^2	26.54	4.8E-07	14
elevMn100+elevMn100^2+distStrm100+coreFor100+coreFor100^2	26.85	4.2E-07	12
elevMn100+elevMn100^2+proxFor100+ed100+ed100^2+distStrm100+coreFor100+coreFor100^2	26.88	4.1E-07	15
elevMn100+elevMn100^2+proxFor100+distStrm100+coreFor100+coreFor100^2	28.42	1.9E-07	13
elevMn100+elevMn100^2+coreFor100+coreFor100^2	28.79	1.6E-07	11
elevMn100+elevMn100^2+ed100+ed100^2+coreFor100+coreFor100^2	29.49	1.1E-07	13
elevMn100+elevMn100^2+proxFor100+ed100+ed100^2+coreFor100+coreFor100^2	29.52	1.1E-07	14
elevMn100+elevMn100^2+proxFor100+coreFor100+coreFor100^2	30.12	8.1E-08	12
elevMn100+elevMn100^2	38.52	1.2E-09	9
null	304.06	2.7E-67	7

Lesson's Motmot: 100 m

Model	ΔAIC	*w*	*K*
elevMn100+elevMn100²+coreFor100+coreFor100²+ patchDens100	0	4.40E-01	17
elevMn100+elevMn100²+coreFor100+coreFor100²	1.06	2.60E-01	16
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²+ patchDens100	1.93	1.70E-01	18
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²	2.61	1.20E-01	17
elevMn100+elevMn100²	9.07	4.70E-03	14
elevMn100+elevMn100²+patchDens100	9.18	4.50E-03	15
elevMn100+elevMn100²+pfor100+patchDens100	10.01	3.00E-03	16
elevMn100+elevMn100²+pfor100	11.03	1.80E-03	15
null	30.35	1.10E-07	12

White-eared Ground-Sparrow: 100 m

Model	ΔAIC	*w*	*K*
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²	0	1.80E-01	17
elevMn100+elevMn100²+coreFor100+coreFor100²+ patchDens100	0.29	1.60E-01	17
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²+ patchDens100	0.65	1.30E-01	18
elevMn100+elevMn100²+mnPARiFor100+coreFor100+ coreFor100²	0.97	1.10E-01	17
elevMn100+elevMn100²+pfor100+mnPARiFor100+ coreFor100+coreFor100²	1.13	1.00E-01	18
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²	1.87	7.20E-02	18
elevMn100+elevMn100²+ed100+coreFor100+coreFor100²+ patchDens100	2.09	6.40E-02	18
elevMn100+elevMn100²+ed100+mnPARiFor100+coreFor100+ coreFor100²	2.69	4.80E-02	18
elevMn100+elevMn100²+coreFor100+coreFor100²	2.7	4.70E-02	16
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100+ coreFor100+coreFor100²	2.89	4.30E-02	19
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²+patchDens100	4.39	2.00E-02	20
elevMn100+elevMn100²+ed100+coreFor100+coreFor100²	4.65	1.80E-02	17
elevMn100+elevMn100²	20.68	5.90E-06	14
null	81.74	3.30E-19	12

Orange-billed Nightingale-Thrush: 100 m

Model	ΔAIC	*w*	*K*
elevMn100+elevMn100²+pfor100+ed100+ed100²	0	3.50E-01	17
elevMn100+elevMn100²+pfor100+ed100+ed100²+ coreFor100+coreFor100²	0.73	2.40E-01	19
elevMn100+elevMn100²+pfor100	1.1	2.00E-01	15
elevMn100+elevMn100²+pfor100+coreFor100+ coreFor100²	2.29	1.10E-01	17
elevMn100+elevMn100²	2.6	9.50E-02	14
null	45.87	3.80E-11	12

Slaty-backed Nightingale-Thrush: 100 m

Model	ΔAIC	*w*	*K*
elevMn100+elevMn100²+pfor100+ed100+ed100²+coreFor100	0	1.40E-01	18
elevMn100+elevMn100²+pfor100+ed100+ed100²	0.14	1.30E-01	17
elevMn100+elevMn100²+pfor100	0.14	1.30E-01	15
elevMn100+elevMn100²+pfor100+ed100+ed100²+ mnPARiFor100	0.2	1.30E-01	18
elevMn100+elevMn100²+pfor100+ed100+ed100²+ mnPARiFor100+coreFor100	0.59	1.10E-01	19
elevMn100+elevMn100²+pfor100+mnPARiFor100	0.8	9.50E-02	16
elevMn100+elevMn100²+pfor100+ed100+ed100²+ patchDens100	1.89	5.50E-02	18
elevMn100+elevMn100²+pfor100+ed100+ed100²+ coreFor100+patchDens100	1.95	5.30E-02	19
elevMn100+elevMn100²+pfor100+patchDens100	2.09	5.00E-02	16
elevMn100+elevMn100²+pfor100+coreFor100	2.14	4.80E-02	16
elevMn100+elevMn100²+pfor100+mnPARiFor100+ coreFor100	2.73	3.60E-02	17
elevMn100+elevMn100²+pfor100+coreFor100+patchDens100	4.08	1.80E-02	17
elevMn100+elevMn100²	5.73	8.00E-03	14
null	93.28	7.80E-22	12

Rufous-and-white Wren: 100 m

Model	ΔAIC	*w*	K
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²	0	1.40E-01	17
elevMn100+elevMn100²+pfor100	0.44	1.10E-01	15
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²+ patchDens100	1.03	8.10E-02	18
elevMn100+elevMn100²+pfor100+mnPARiFor100+ coreFor100+coreFor100²	1.03	8.10E-02	18
elevMn100+elevMn100²+pfor100+patchDens100	1.27	7.20E-02	16
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²	1.62	6.00E-02	18
elevMn100+elevMn100²+pfor100+mnPARiFor100	1.67	5.90E-02	16
elevMn100+elevMn100²+mnPARiFor100+coreFor100+ coreFor100²	2.25	4.40E-02	17
elevMn100+elevMn100²+pfor100+ed100	2.44	4.00E-02	16
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²+patchDens100	2.45	4.00E-02	19
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100+ coreFor100+coreFor100²	2.46	4.00E-02	19
elevMn100+elevMn100²+mnPARiFor100	2.54	3.80E-02	15
elevMn100+elevMn100²+patchDens100	2.7	3.50E-02	15
elevMn100+elevMn100²+coreFor100+coreFor100²+ patchDens100	2.8	3.30E-02	17
elevMn100+elevMn100²+pfor100+ed100+patchDens100	3.23	2.70E-02	17
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100	3.65	2.20E-02	17
elevMn100+elevMn100²+ed100+mnPARiFor100+coreFor100+ coreFor100²	3.66	2.20E-02	18
elevMn100+elevMn100²+ed100+mnPARiFor100	4.11	1.70E-02	16
elevMn100+elevMn100²+ed100+patchDens100	4.13	1.70E-02	16
elevMn100+elevMn100²+ed100+coreFor100+coreFor100²+ patchDens100	4.31	1.60E-02	18
elevMn100+elevMn100²+coreFor100+coreFor100²	6.69	4.80E-03	16
elevMn100+elevMn100²	7.37	3.40E-03	14
elevMn100+elevMn100²+ed100	8.89	1.60E-03	15
elevMn100+elevMn100²+ed100+coreFor100+coreFor100²	12.5	2.60E-04	17
null	90.51	3.00E-21	12

Gray-breasted Wood-Wren: 100 m

Model	ΔAIC	*w*	*K*
elevMn100+pfor100+ed100+ed100²+coreFor100	0	3.10E-01	17
elevMn100+pfor100+ed100+ed100²+distStrm100+coreFor100	0.39	2.50E-01	18
elevMn100+pfor100+ed100+ed100²+mnPARiFor100+coreFor100	1.98	1.10E-01	18
elevMn100+pfor100+ed100+ed100²+coreFor100+patchDens100	2	1.10E-01	18
elevMn100+pfor100+ed100+ed100²+mnPARiFor100+distStrm100+coreFor100	2.37	9.40E-02	19
elevMn100+pfor100+ed100+ed100²+distStrm100+coreFor100+patchDens100	2.37	9.40E-02	19
elevMn100+ed100+ed100²+mnPARiFor100+coreFor100	6.68	1.10E-02	17
elevMn100+ed100+ed100²+mnPARiFor100+distStrm100+coreFor100	8.05	5.50E-03	18
elevMn100+ed100+ed100²+coreFor100+patchDens100	9.87	2.20E-03	17
elevMn100+ed100+ed100²+coreFor100	10.87	1.30E-03	16
elevMn100+ed100+ed100²+distStrm100+coreFor100+patchDens100	11.35	1.10E-03	18
elevMn100+pfor100+coreFor100	11.9	8.00E-04	15
elevMn100+ed100+ed100²+distStrm100+coreFor100	12.39	6.30E-04	17
elevMn100+coreFor100	13.03	4.60E-04	14
elevMn100+pfor100+coreFor100+patchDens100	13.07	4.50E-04	16
elevMn100+pfor100+distStrm100+coreFor100	13.37	3.80E-04	16
elevMn100+pfor100+mnPARiFor100+coreFor100	13.9	2.90E-04	16
elevMn100+mnPARiFor100+coreFor100	14.14	2.60E-04	15
elevMn100+pfor100+distStrm100+coreFor100+patchDens100	14.53	2.10E-04	17
elevMn100+distStrm100+coreFor100	14.7	2.00E-04	15
elevMn100+coreFor100+patchDens100	14.93	1.80E-04	15
elevMn100+pfor100+mnPARiFor100+distStrm100+coreFor100	15.36	1.40E-04	17
elevMn100+mnPARiFor100+distStrm100+coreFor100	15.74	1.20E-04	16
elevMn100+distStrm100+coreFor100+patchDens100	16.61	7.60E-05	16
elevMn100	23.41	2.50E-06	13
null	216.41	3.10E-48	12

Social Flycatcher: 100 m

Model	ΔAIC	*w*	*K*
pfor100+pfor100²+ed100+coreFor100+patchDens100+patchDens100²	0	3.40E-01	18
pfor100+pfor100²+proxFor100+ed100+coreFor100+patchDens100+patchDens100²	0.96	2.10E-01	19

Model	ΔAIC	Weight	K
elevMn100+elevMn100²+pfor100+pfor100²+ed100+coreFor100+ patchDens100+patchDens100²	1.5	1.60E-01	20
elevMn100+elevMn100²+pfor100+pfor100²proxFor100+ed100+ coreFor100+patchDens100+patchDens100²	2.45	9.90E-02	21
pfor100+pfor100²ed100+coreFor100	4.29	4.00E-02	16
elevMn100+elevMn100²+pfor100+pfor100²+ed100+coreFor100	5.47	2.20E-02	18
ed100+coreFor100	5.55	2.10E-02	14
pfor100+pfor100²+proxFor100+ed100+coreFor100	5.86	1.80E-02	17
elevMn100+elevMn100²+ed100+coreFor100	6.11	1.60E-02	16
elevMn100+elevMn100²+pfor100+pfor100²+proxFor100+ed100+ coreFor100	6.96	1.00E-02	19
proxFor100+ed100+coreFor100	7.38	8.50E-03	15
pfor100+pfor100²+proxFor100+coreFor100+patchDens100+ patchDens100²	7.48	8.00E-03	18
elevMn100+elevMn100²+proxFor100+ed100+coreFor100	7.75	7.00E-03	17
ed100+coreFor100+patchDens100+patchDens100²	8.17	5.70E-03	16
elevMn100+elevMn100²+ed100+coreFor100+patchDens100+ patchDens100²	8.66	4.50E-03	18
elevMn100+elevMn100²+pfor100+pfor100²+proxFor100+ coreFor100+patchDens100+patchDens100²	9.07	3.60E-03	20
pfor100+pfor100²+coreFor100+patchDens100+patchDens100²	9.13	3.50E-03	17
coreFor100	9.82	2.50E-03	13
proxFor100+coreFor100	9.87	2.40E-03	14
proxFor100+ed100+coreFor100+patchDens100+patchDens100²	9.89	2.40E-03	17
elevMn100+elevMn100²+proxFor100+ed100+coreFor100+ patchDens100+patchDens100²	10.16	2.10E-03	19
pfor100+pfor100²+proxFor100+coreFor100	10.19	2.10E-03	16
coreFor100+patchDens100+patchDens100²	10.24	2.00E-03	15
elevMn100+elevMn100²+proxFor100+coreFor100	10.32	1.90E-03	16
elevMn100+elevMn100²+coreFor100+patchDens100+ patchDens100²	11	1.40E-03	17
pfor100+pfor100²+coreFor100	11.05	1.30E-03	15
proxFor100+coreFor100+patchDens100+patchDens100²	11.07	1.30E-03	16
elevMn100+elevMn100²+coreFor100	11.17	1.30E-03	15
elevMn100+elevMn100²+proxFor100+coreFor100+ patchDens100+patchDens100²	11.19	1.30E-03	18
elevMn100+elevMn100²+pfor100+pfor100²+coreFor100+ patchDens100+patchDens100²	11.19	1.30E-03	19
elevMn100+elevMn100²+pfor100+pfor100²+proxFor100+ coreFor100	11.65	1.00E-03	18
elevMn100+elevMn100²+pfor100+pfor100²+coreFor100	13.07	4.90E-04	17
null	57.97	8.70E-14	12

Squirrel Cuckoo: 100 m

Model	ΔAIC	w	K
elevMn100+patchDens100+patchDens100²	0	2.90E-01	10
elevMn100+ed100+ed100²+patchDens100+patchDens100²	1.04	1.70E-01	12
elevMn100+coreFor100+patchDens100+patchDens100²	1.65	1.30E-01	11
elevMn100+pfor100+pfor100²+patchDens100+patchDens100²	1.88	1.10E-01	12
elevMn100+ed100+ed100²+coreFor100+patchDens100+ patchDens100²	2.95	6.60E-02	13
elevMn100	3.58	4.80E-02	8
elevMn100+pfor100+pfor100²+coreFor100+patchDens100+ patchDens100²	3.8	4.30E-02	13
elevMn100+pfor100+pfor100²+ed100+ed100²+patchDens100+ patchDens100²	3.82	4.30E-02	14
elevMn100+pfor100+pfor100²	4.93	2.50E-02	10
elevMn100+coreFor100	5.54	1.80E-02	9
elevMn100+ed100+ed100²	5.68	1.70E-02	10
elevMn100+pfor100+pfor100²+ed100+ed100²+coreFor100+ patchDens100+patchDens100²	5.78	1.60E-02	15
elevMn100+pfor100+pfor100²+coreFor100	6.93	9.00E-03	11
elevMn100+ed100+ed100²+coreFor100	7.35	7.30E-03	11
elevMn100+pfor100+pfor100²+ed100+ed100²	7.46	6.90E-03	12
elevMn100+pfor100+pfor100²+ed100+ed100²+coreFor100	9.45	2.60E-03	13
null	27.89	2.50E-07	7

Slate-throated Redstart: 100 m

Model	ΔAIC	w	K
elevMn100+pfor100	0	2.10E-01	14
elevMn100+pfor100+distStrm100	1.59	9.50E-02	15
elevMn100+pfor100+mnPARiFor100	1.62	9.30E-02	15
elevMn100+pfor100+patchDens100	1.7	9.00E-02	15
elevMn100+pfor100+coreFor100	2	7.70E-02	15
elevMn100+pfor100+ed100+ed100²	2.73	5.40E-02	16
elevMn100+pfor100+mnPARiFor100+distStrm100	3.16	4.30E-02	16
elevMn100+pfor100+distStrm100+patchDens100	3.3	4.00E-02	16
elevMn100+pfor100+distStrm100+coreFor100	3.59	3.50E-02	16
elevMn100+pfor100+mnPARiFor100+coreFor100	3.6	3.50E-02	16
elevMn100+pfor100+coreFor100+patchDens100	3.69	3.30E-02	16
elevMn100+pfor100+ed100+ed100²+mnPARiFor100	4.05	2.80E-02	17
elevMn100+pfor100+ed100+ed100²+distStrm100	4.31	2.40E-02	17
elevMn100+pfor100+ed100+ed100²+coreFor100	4.58	2.10E-02	17
elevMn100+pfor100+ed100+ed100²+patchDens100	4.63	2.10E-02	17

Model			
elevMn100+pfor100+mnPARiFor100+distStrm100+coreFor100	5.14	1.60E-02	17
elevMn100+pfor100+distStrm100+coreFor100+patchDens100	5.31	1.50E-02	17
elevMn100+pfor100+ed100+ed100²+mnPARiFor100+ distStrm100	5.56	1.30E-02	18
elevMn100+pfor100+ed100+ed100²+mnPARiFor100+ coreFor100	5.72	1.20E-02	18
elevMn100+pfor100+ed100+ed100²+distStrm100+patchDens100	6.21	9.40E-03	18
elevMn100+pfor100+ed100+ed100²+distStrm100+coreFor100	6.21	9.40E-03	18
elevMn100	6.23	9.30E-03	13
elevMn100+pfor100+ed100+ed100²+coreFor100+patchDens100	6.49	8.20E-03	18
elevMn100+pfor100+ed100+ed100²+mnPARiFor100+ distStrm100+coreFor100	7.29	5.50E-03	19
elevMn100+pfor100+ed100+ed100²+distStrm100+coreFor100+ patchDens100	8.12	3.60E-03	19
null	111.69	1.20E-25	12

Dusky-capped Flycatcher: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²	0	1.00E+00	14
null	24.65	4.40E-06	12

Keel-billed Toucan: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²+ed100+mnPARiFor100+distStrm100+ coreFor100	0	2.50E-01	18
elevMn100+elevMn100²+ed100+mnPARiFor100+coreFor100	0.72	1.80E-01	17
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100+ distStrm100+coreFor100	1.99	9.30E-02	19
elevMn100+elevMn100²+pfor100+ed100+distStrm100+coreFor100	2.64	6.70E-02	18
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100+ coreFor100	2.64	6.70E-02	18
elevMn100+elevMn100²+ed100+distStrm100+coreFor100	2.86	6.10E-02	17
elevMn100+elevMn100²+pfor100+ed100+coreFor100	3.21	5.10E-02	17
elevMn100+elevMn100²+ed100+coreFor100	4.07	3.30E-02	16
elevMn100+elevMn100²+mnPARiFor100+coreFor100	4.23	3.00E-02	16
elevMn100+elevMn100²+mnPARiFor100+distStrm100+ coreFor100	4.94	2.10E-02	17
elevMn100+elevMn100²+ed100+coreFor100+patchDens100	4.98	2.10E-02	17
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ patchDens100	5.19	1.90E-02	18
elevMn100+elevMn100²+coreFor100	5.34	1.70E-02	15

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor100+coreFor100	5.46	1.60E-02	16
elevMn100+elevMn100²+distStrm100+coreFor100	5.47	1.60E-02	16
elevMn100+elevMn100²+pfor100+distStrm100+coreFor100	6.11	1.20E-02	17
elevMn100+elevMn100²+pfor100+mnPARiFor100+coreFor100	6.16	1.20E-02	17
elevMn100+elevMn100²+pfor100+mnPARiFor100+distStrm100+ coreFor100	6.92	8.00E-03	18
elevMn100+elevMn100²+coreFor100+patchDens100	7.04	7.50E-03	16
elevMn100+elevMn100²+distStrm100+coreFor100+patchDens100	7.35	6.40E-03	17
elevMn100+elevMn100²+pfor100+coreFor100+patchDens100	7.39	6.30E-03	17
elevMn100+elevMn100²+pfor100+distStrm100+coreFor100+ patchDens100	7.98	4.70E-03	18
elevMn100+elevMn100²	31.54	3.60E-08	14
null	62.63	6.40E-15	12

Northern Emerald-Toucanet: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor100	0	2.20E-01	15
elevMn100+elevMn100²+pfor100+ed100	0.32	1.90E-01	16
elevMn100+elevMn100²+pfor100+mnPARiFor100	1.65	9.60E-02	16
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²	1.66	9.50E-02	17
elevMn100+elevMn100²+pfor100+patchDens100	1.9	8.40E-02	16
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100	1.95	8.30E-02	17
elevMn100+elevMn100²+pfor100+ed100+patchDens100	2.29	6.90E-02	17
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²	3.09	4.70E-02	18
elevMn100+elevMn100²+pfor100+mnPARiFor100+coreFor100+ coreFor100²	3.43	3.90E-02	18
elevMn100+elevMn100²+pfor100+coreFor100+coreFor100²+ patchDens100	3.63	3.60E-02	18
elevMn100+elevMn100²+pfor100+ed100+mnPARiFor100+ coreFor100+coreFor100²	4.83	2.00E-02	19
elevMn100+elevMn100²+pfor100+ed100+coreFor100+ coreFor100²+patchDens100	5.08	1.70E-02	19
elevMn100+elevMn100²	6.37	9.00E-03	14
null	95.54	3.90E-22	12

Red-billed Pigeon: 100 m

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor100+ed100	0	5.20E-01	16
elevMn100+elevMn100²+pfor100+ed100+coreFor100	1.72	2.20E-01	17
elevMn100+elevMn100²+ed100+coreFor100	3.63	8.40E-02	16
elevMn100+elevMn100²+ed100	4.26	6.20E-02	15
elevMn100+elevMn100²+pfor100+coreFor100	4.7	5.00E-02	16
elevMn100+elevMn100²+coreFor100	5.35	3.60E-02	15
elevMn100+elevMn100²+pfor100	5.82	2.80E-02	15
elevMn100+elevMn100²+	10.9	2.20E-03	14
null	39.67	1.30E-09	12

Long-tailed Manakin: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ed500+ ed500²	0	3.90E-01	19
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500	0.17	3.60E-01	17
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²	1.95	1.50E-01	18
elevMn500+elevMn500²+pfor500+pfor500²	2.62	1.10E-01	16
elevMn500+elevMn500²	25.15	1.30E-06	14
null	75.54	1.50E-17	12

Common Chlorospingus: 500 m

Model	ΔAIC	w	K
elevMn500+pfor500+proxFor500+ed500+ed500²	0	2.60E-01	12
elevMn500+pfor500+proxFor500	1.02	1.60E-01	10
elevMn500+pfor500+proxFor500+ed500+ed500²+mnPARiFor500	1.42	1.30E-01	13
elevMn500+pfor500+proxFor500+mnPARiFor500	1.69	1.10E-01	11
elevMn500+pfor500+proxFor500+ed500+ed500²+distStrm500	1.89	1.00E-01	13
elevMn500+pfor500+proxFor500+distStrm500	3.02	5.70E-02	11
elevMn500+pfor500+proxFor500+ed500+ed500²+ mnPARiFor500+distStrm500	3.35	4.90E-02	14
elevMn500+pfor500+proxFor500+mnPARiFor500+distStrm500	3.69	4.10E-02	12
elevMn500+pfor500	3.9	3.70E-02	9
elevMn500+pfor500+ed500+ed500²	5.74	1.50E-02	11
elevMn500+pfor500+distStrm500	5.78	1.40E-02	10
elevMn500+pfor500+mnPARiFor500	5.88	1.40E-02	10
elevMn500+pfor500+ed500+ed500²+distStrm500	7.39	6.40E-03	12
elevMn500+pfor500+ed500+ed500²+mnPARiFor500	7.65	5.70E-03	12

Model	ΔAIC	w	K
elevMn500+pfor500+mnPARiFor500+distStrm500	7.76	5.30E-03	11
elevMn500+pfor500+ed500+ed500²+mnPARiFor500+distStrm500	9.28	2.50E-03	13
elevMn500	32.06	2.80E-08	8
null	314.2	1.50E-69	7

Lesson's Motmot: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²+ mnPARiFor500	0	6.70E-01	19
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ed500+ ed500²+mnPARiFor500	1.85	2.70E-01	20
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²	6.3	2.90E-02	18
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ed500+ ed500²	8	1.20E-02	19
elevMn500+elevMn500²+ed500+ed500²+mnPARiFor500	8.21	1.10E-02	17
elevMn500+elevMn500²+proxFor500+ed500+ed500²+ mnPARiFor500	9.02	7.40E-03	18
pfor500+pfor500²+ed500+ed500²+mnPARiFor500	14.17	5.60E-04	17
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500	14.63	4.50E-04	17
pfor500+pfor500²+proxFor500+ed500+ed500²+mnPARiFor500	15.81	2.50E-04	18
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ mnPARiFor500	16.54	1.70E-04	18
pfor500+pfor500²+ed500+ed500²	19.1	4.80E-05	16
elevMn500+elevMn500²+mnPARiFor500+coreFor500²	19.23	4.50E-05	17
elevMn500+elevMn500²+pfor500+pfor500²	19.52	3.90E-05	16
pfor500+pfor500²+proxFor500+ed500+ed500²	20.29	2.60E-05	17
elevMn500+elevMn500²+proxFor500+mnPARiFor500+ coreFor500²	20.66	2.20E-05	18
elevMn500+elevMn500²+proxFor500+ed500+ed500²	20.72	2.10E-05	17
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500	21.15	1.70E-05	17
elevMn500+elevMn500²+ed500+ed500²	21.84	1.20E-05	16
elevMn500+elevMn500²+coreFor500²	25.01	2.50E-06	16
elevMn500+elevMn500²+proxFor500+coreFor500²	25.66	1.80E-06	17
elevMn500+elevMn500²+mnPARiFor500	26.15	1.40E-06	15
elevMn500+elevMn500²+proxFor500+mnPARiFor500	26.59	1.10E-06	16
proxFor500+ed500+ed500²+mnPARiFor500	31.31	1.10E-07	16
ed500+ed500²+mnPARiFor500	34.78	1.90E-08	15
pfor500+pfor500²+mnPARiFor500	35.8	1.10E-08	15
proxFor500+ed500+ed500²	36.71	7.20E-09	15
pfor500+pfor500²+proxFor500+mnPARiFor500	37.56	4.70E-09	16
elevMn500+elevMn500²+proxFor500	37.6	4.60E-09	15
pfor500+pfor500²	39.5	1.80E-09	14

Model	ΔAIC	w	K
elevMn500+elevMn500²	40.52	1.10E-09	14
pfor500+pfor500²+proxFor500	40.68	9.80E-10	15
ed500+ed500²	42.24	4.50E-10	14
proxFor500+mnPARiFor500+coreFor500²	47.53	3.20E-11	16
mnPARiFor500+coreFor500²	48.73	1.80E-11	15
proxFor500+coreFor500²	49.91	9.80E-12	15
proxFor500+mnPARiFor500	51.69	4.00E-12	14
coreFor500²	52.86	2.20E-12	14
mnPARiFor500	54.52	9.70E-13	13
proxFor500	55.48	6.00E-13	13
null	60.71	4.40E-14	12

White-eared Ground-Sparrow: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+distStrm500	0	6.70E-01	17
elevMn500+elevMn500²+pfor500+pfor500²	2.98	1.50E-01	16
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²+ distStrm500	3.04	1.50E-01	19
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²	6.33	2.80E-02	18
elevMn500+elevMn500²	15.79	2.50E-04	14
null	81.49	1.40E-18	12

Orange-billed Nightingale-Thrush: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+distStrm500	0	6.90E-01	17
elevMn500+elevMn500²	2.27	2.20E-01	14
elevMn500+elevMn500²+pfor500+pfor500²	3.98	9.40E-02	16
null	50.38	7.90E-12	12

Slaty-backed Nightingale-Thrush: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500	0	4.40E-01	17
elevMn500+elevMn500²+pfor500+pfor500²	0.95	2.70E-01	16
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ mnPARiFor500	1.87	1.70E-01	18
elevMn500+elevMn500²+pfor500+pfor500²+ed500	2.62	1.20E-01	17
elevMn500+elevMn500²	18.32	4.60E-05	14
null	106.41	3.40E-24	12

Rufous-and-white Wren: 500 m

Model	ΔAIC	*w*	K
elevMn500+elevMn500²+coreFor500+coreFor500²	0	5.80E-01	16
elevMn500+elevMn500²+coreFor500+coreFor500²+patchDens500	0.76	3.90E-01	17
elevMn500+elevMn500²	5.95	2.90E-02	14
null	91.36	8.40E-21	12

Gray-breasted Wood-Wren: 500 m

Model	ΔAIC	*w*	K
elevMn500+pfor500	0	2.60E-01	14
elevMn500+pfor500+mnPARiFor500	0.043	2.50E-01	15
elevMn500+pfor500+ed500	1.583	1.20E-01	15
elevMn500+pfor500+distStrm500	1.927	9.90E-02	15
elevMn500+pfor500+ed500+mnPARiFor500	1.987	9.60E-02	16
elevMn500+pfor500+mnPARiFor500+distStrm500	2.002	9.50E-02	16
elevMn500+pfor500+ed500+distStrm500	3.44	4.60E-02	16
elevMn500+pfor500+ed500+mnPARiFor500+distStrm500	3.922	3.60E-02	17
pfor500	16.76	5.90E-05	13
null	227.587	9.80E-51	12

Social Flycatcher: 500 m

Model	ΔAIC	*w*	K
ed500+ed500²+patchDens500+patchDens500²	0	3.50E-01	16
pfor500+pfor500²+ed500+ed500²	0.7	2.40E-01	16
elevMn500+elevMn500²+ed500+ed500²+patchDens500+patchDens500²	1.58	1.60E-01	18
elevMn500+elevMn500²+pfor500+pfor500²+ed500+ed500²	3.03	7.60E-02	18
ed500+ed500²	3.61	5.70E-02	14
elevMn500+elevMn500²+ed500+ed500²	4.54	3.60E-02	16
pfor500+pfor500²	4.6	3.50E-02	14
coreFor500+patchDens500+patchDens500²	5.48	2.20E-02	15
elevMn500+elevMn500²+pfor500+pfor500²	7.02	1.00E-02	16
coreFor500	7.73	7.30E-03	13
elevMn500+elevMn500²+coreFor500+patchDens500+patchDens500²	8.71	4.50E-03	17
elevMn500+elevMn500²+coreFor500	11.16	1.30E-03	15
elevMn500+elevMn500²+patchDens500+patchDens500²	26.29	6.80E-07	16
patchDens500+patchDens500²	33.02	2.30E-08	14

	ΔAIC	w	K
elevMn500+elevMn500²	34.24	1.30E-08	14
null	55.66	2.80E-13	12

Squirrel Cuckoo: 500 m

Model	ΔAIC	*w*	*K*
elevMn500+pfor500+pfor500²	0	4.80E-01	10
elevMn500+pfor500+pfor500²+mnPARiFor500	1.9	1.90E-01	11
elevMn500+pfor500+pfor500²+ed500	1.95	1.80E-01	11
elevMn500	3.48	8.40E-02	8
elevMn500+pfor500+pfor500²+ed500+mnPARiFor500	3.85	7.00E-02	12
null	26.58	8.10E-07	7

Slate-throated Redstart: 500 m

Model	ΔAIC	*w*	*K*
elevMn500+pfor500	0	4.10E-01	14
elevMn500+pfor500+mnPARiFor500	1.78	1.70E-01	15
elevMn500+pfor500+distStrm500	1.84	1.60E-01	15
elevMn500+pfor500+ed500+ed500²	3.2	8.40E-02	16
elevMn500+pfor500+mnPARiFor500+distStrm500	3.67	6.60E-02	16
elevMn500+pfor500+ed500+ed500²+mnPARiFor500	4.86	3.60E-02	17
elevMn500+pfor500+ed500+ed500²+distStrm500	4.99	3.40E-02	17
elevMn500	6.3	1.80E-02	13
elevMn500+pfor500+ed500+ed500²+mnPARiFor500+ distStrm500	6.74	1.40E-02	18
null	114.92	4.60E-26	12

Dusky-capped Flycatcher: 500 m

Model	ΔAIC	*w*	*K*
elevMn500+elevMn500²+mnPARiFor500+patchDens500+ patchDens500²	0	3.20E-01	17
elevMn500+elevMn500²+mnPARiFor500+coreFor500+ patchDens500+patchDens500²	0.77	2.20E-01	18
elevMn500+elevMn500²+pfor500+mnPARiFor500	2.29	1.00E-01	16
elevMn500+elevMn500²+mnPARiFor500	2.53	9.10E-02	15
elevMn500+elevMn500²+mnPARiFor500+coreFor500	2.69	8.30E-02	16
elevMn500+elevMn500²+patchDens500+patchDens500²	3.03	7.00E-02	16
elevMn500+elevMn500²+coreFor500+patchDens500+ patchDens500²	3.25	6.30E-02	17
elevMn500+elevMn500²+coreFor500	5.09	2.50E-02	15
elevMn500+elevMn500²+pfor500	5.78	1.80E-02	15

| elevMn500+elevMn500² | 7.17 | 8.90E-03 | 14 |
| null | 32.44 | 2.90E-08 | 12 |

Keel-billed Toucan: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+ed500	0	7.00E-01	17
elevMn500+elevMn500²+ed500	1.65	3.00E-01	15
elevMn500+elevMn500²+pfor500+pfor500²	15.46	3.10E-04	16
elevMn500+elevMn500²+coreFor500+coreFor500²	15.85	2.50E-04	16
elevMn500+elevMn500²	29.39	2.90E-07	14
null	60.02	6.40E-14	12

Black-faced Solitaire: 500 m

Model	ΔAIC	w	K
elevMn500+pfor500+mnPARiFor500	0	2.40E-01	15
elevMn500+pfor500	0.91	1.50E-01	14
elevMn500+pfor500+mnPARiFor500+distStrm500	1.03	1.40E-01	16
elevMn500+pfor500+ed500	1.19	1.30E-01	15
elevMn500+pfor500+ed500+mnPARiFor500	1.22	1.30E-01	16
elevMn500+pfor500+distStrm500	1.9	9.10E-02	15
elevMn500+pfor500+ed500+mnPARiFor500+distStrm500	2.58	6.50E-02	17
elevMn500+pfor500+ed500+distStrm500	2.69	6.10E-02	16
pfor500	15.16	1.20E-04	13
null	171.72	1.20E-38	12

Northern Emerald-Toucanet: 500 m

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ed500+mnPARiFor500	0	4.20E-01	19
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+mnPARiFor500	1.71	1.80E-01	18
elevMn500+elevMn500²+pfor500+pfor500²+ed500+mnPARiFor500	3.03	9.30E-02	18
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500+ed500	3.39	7.80E-02	18
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500	3.8	6.30E-02	17
elevMn500+elevMn500²+pfor500+pfor500²+ed500	4.16	5.30E-02	17
elevMn500+elevMn500²	4.24	5.10E-02	14
elevMn500+elevMn500²+pfor500+pfor500²+proxFor500	5.38	2.90E-02	17
elevMn500+elevMn500²+pfor500+pfor500²	5.48	2.70E-02	16
null	92.33	3.80E-21	12

Red-billed Pigeon: 500 m

Model	ΔAIC	*w*	*K*
elevMn500+elevMn500²+mnPARiFor500+coreFor500+ coreFor500²	0	5.30E-01	17
elevMn500+elevMn500²+ed500+mnPARiFor500	0.46	4.20E-01	16
elevMn500+elevMn500²+ed500	6.52	2.00E-02	15
elevMn500+elevMn500²+mnPARiFor500	6.91	1.70E-02	15
elevMn500+elevMn500²+coreFor500+coreFor500²	8.63	7.10E-03	16
elevMn500+elevMn500²	10.61	2.60E-03	14
null	38.64	2.20E-09	12

Long-tailed Manakin: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k	0	4.00E-01	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k	0.52	3.10E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k+ coreFor1k+coreFor1k²	2.91	9.30E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k+coreFor1k+ coreFor1k²	3.44	7.20E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²	4.65	3.90E-02	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	4.79	3.60E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	4.84	3.50E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	6.29	1.70E-02	18
elevMn1k+elevMn1k²+	31.9	4.70E-08	14
null	83.89	2.40E-19	12

Common Chlorospingus: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+pfor1k+distStrm1k	0	3.30E-01	10
elevMn1k+pfor1k+mnPARiFor1k+distStrm1k	1.2	1.80E-01	11
elevMn1k+pfor1k+proxFor1k+distStrm1k	1.99	1.20E-01	11
elevMn1k+pfor1k+distStrm1k+coreFor1k+coreFor1k²	2.4	9.90E-02	12
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+distStrm1k	2.53	9.20E-02	12
elevMn1k+pfor1k+mnPARiFor1k+distStrm1k+coreFor1k+ coreFor1k²	3.03	7.20E-02	13
elevMn1k+pfor1k+proxFor1k+distStrm1k+coreFor1k+coreFor1k²	4.24	3.90E-02	13
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+distStrm1k+ coreFor1k+coreFor1k²	4.67	3.20E-02	14
elevMn1k+pfor1k	6.46	1.30E-02	9

Model	ΔAIC	w	K
elevMn1k+pfor1k+proxFor1k	7.71	6.90E-03	10
elevMn1k+pfor1k+coreFor1k+coreFor1k²	8.1	5.70E-03	11
elevMn1k+pfor1k+mnPARiFor1k	8.42	4.80E-03	10
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k	9.21	3.30E-03	11
elevMn1k+pfor1k+mnPARiFor1k+coreFor1k+coreFor1k²	9.92	2.30E-03	12
elevMn1k+pfor1k+proxFor1k+coreFor1k+coreFor1k²	9.96	2.20E-03	12
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+coreFor1k+ coreFor1k²	10.95	1.40E-03	13
elevMn1k	31.16	5.60E-08	8
null	325.8	5.90E-72	7

Lesson's Motmot: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	0	4.30E-01	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²	1.84	1.70E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k	1.98	1.60E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	3.13	9.10E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k	3.84	6.40E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k+ coreFor1k+coreFor1k²	4.86	3.80E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	5.47	2.80E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k+coreFor1k+ coreFor1k²	7.44	1.10E-02	19
pfor1k+pfor1k²+proxFor1k	22.2	6.60E-06	15
pfor1k+pfor1k²	22.69	5.10E-06	14
pfor1k+pfor1k²+proxFor1k+coreFor1k+coreFor1k²	23.46	3.50E-06	17
pfor1k+pfor1k²+proxFor1k+distStrm1k	24.04	2.60E-06	16
pfor1k+pfor1k²+distStrm1k	24.47	2.10E-06	15
pfor1k+pfor1k²+coreFor1k+coreFor1k²	25.01	1.60E-06	16
pfor1k+pfor1k²+proxFor1k+distStrm1k+coreFor1k+coreFor1k²	25.37	1.30E-06	18
pfor1k+pfor1k²+distStrm1k+coreFor1k+coreFor1k²	27.01	5.90E-07	17
null	52.16	2.00E-12	12

White-eared Ground Sparrow: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	0	3.90E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²	0.74	2.70E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	0.96	2.40E-01	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	2.56	1.10E-01	17
elevMn1k+elevMn1k²	12.36	8.00E-04	14
null	82.45	4.80E-19	12

Orange-billed Nightingale-Thrush: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k+coreFor1k+ coreFor1k²	0	8.30E-01	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	3.57	1.40E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k	6.38	3.40E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²	12.37	1.70E-03	16
elevMn1k+elevMn1k²+	15.06	4.40E-04	14
null	65.7	4.50E-15	12

Slaty-backed Nightingale-Thrush: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens1k	0	5.40E-01	17
elevMn1k+elevMn1k²+pfor1k+coreFor1k+coreFor1k²	1.37	2.70E-01	17
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²	2.74	1.40E-01	16
elevMn1k+elevMn1k²+ed1k	5.74	3.10E-02	15
elevMn1k+elevMn1k²+ed1k+patchDens1k	7.72	1.10E-02	16
elevMn1k+elevMn1k²+pfor1k	12.07	1.30E-03	15
elevMn1k+elevMn1k²+patchDens1k	16.47	1.40E-04	15
elevMn1k+elevMn1k²	19.94	2.50E-05	14
null	105.8	5.80E-24	12

Rufous-and-white Wren: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	0	3.20E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²	0.56	2.40E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	1.58	1.50E-01	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	1.62	1.40E-01	19
elevMn1k+elevMn1k²+ed1k+ed1k²+coreFor1k+coreFor1k²	4.07	4.20E-02	18
elevMn1k+elevMn1k²+ed1k+ed1k²	4.31	3.70E-02	16
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²	5.53	2.00E-02	16
elevMn1k+elevMn1k²+proxFor1k+ed1k+ed1k²+coreFor1k+ coreFor1k²	6.06	1.60E-02	19
elevMn1k+elevMn1k²+proxFor1k+ed1k+ed1k²	6.31	1.40E-02	17
elevMn1k+elevMn1k²+proxFor1k+coreFor1k+coreFor1k²	7.33	8.30E-03	17
elevMn1k+elevMn1k²	8.96	3.70E-03	14
elevMn1k+elevMn1k²+proxFor1k	10.27	1.90E-03	15
null	94.38	1.00E-21	12

Gray-breasted Wood-Wren: 1,000 m

Model	ΔAIC	w	K
elevMn1k+coreFor1k+coreFor1k²	0	1.20E-01	15
elevMn1k+proxFor1k+coreFor1k+coreFor1k²	0.28	1.10E-01	16
elevMn1k+proxFor1k+distStrm1k+coreFor1k+coreFor1k²	0.87	7.80E-02	17
elevMn1k+coreFor1k+coreFor1k²+patchDens1k+patchDens1k²	1.04	7.20E-02	17
elevMn1k+distStrm1k+coreFor1k+coreFor1k²	1.53	5.60E-02	16
elevMn1k+proxFor1k+mnPARiFor1k+coreFor1k+coreFor1k²	1.53	5.60E-02	17
elevMn1k+mnPARiFor1k+coreFor1k+coreFor1k²	1.84	4.80E-02	16
elevMn1k+proxFor1k+coreFor1k+coreFor1k²+patchDens1k+ patchDens1k²	1.89	4.70E-02	18
elevMn1k+pfor1k+coreFor1k+coreFor1k²	2	4.40E-02	16
elevMn1k+pfor1k+proxFor1k+coreFor1k+coreFor1k²	2.14	4.10E-02	17
elevMn1k+distStrm1k+coreFor1k+coreFor1k²+patchDens1k+ patchDens1k²	2.23	4.00E-02	18
elevMn1k+proxFor1k+mnPARiFor1k+distStrm1k+coreFor1k+ coreFor1k²	2.32	3.80E-02	18
elevMn1k+proxFor1k+distStrm1k+coreFor1k+coreFor1k²+ patchDens1k+patchDens1k²	2.71	3.10E-02	19
elevMn1k+pfor1k+proxFor1k+distStrm1k+coreFor1k+ coreFor1k²	2.86	2.90E-02	18

Model	ΔAIC	w	K
elevMn1k+mnPARiFor1k+coreFor1k+coreFor1k²+ patchDens1k+patchDens1k²	2.98	2.70E-02	18
elevMn1k+mnPARiFor1k+distStrm1k+coreFor1k+coreFor1k²	3.13	2.50E-02	17
elevMn1k+proxFor1k+mnPARiFor1k+coreFor1k+coreFor1k²+ patchDens1k+patchDens1k²	3.3	2.30E-02	19
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+coreFor1k+ coreFor1k²	3.49	2.10E-02	18
elevMn1k+pfor1k+distStrm1k+coreFor1k+coreFor1k²	3.5	2.10E-02	17
elevMn1k+pfor1k+mnPARiFor1k+coreFor1k+coreFor1k²	3.82	1.80E-02	17
elevMn1k+proxFor1k+mnPARiFor1k+distStrm1k+coreFor1k+ coreFor1k²+patchDens1k+patchDens1k²	3.86	1.80E-02	20
elevMn1k+mnPARiFor1k+distStrm1k+coreFor1k+coreFor1k²+ patchDens1k+patchDens1k²	4.16	1.50E-02	19
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+distStrm1k+ coreFor1k+coreFor1k²	4.31	1.40E-02	19
elevMn1k+pfor1k+mnPARiFor1k+distStrm1k+coreFor1k+ coreFor1k²	5.13	9.30E-03	18
coreFor1k+coreFor1k²	25.45	3.60E-07	14
null	226.92	6.40E-51	12

Social Flycatcher: 1,000 m

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+ed1k+distStrm1k+patchDens1k+ patchDens1k²	0	5.90E-01	18
elevMn1k+elevMn1k²+proxFor1k+ed1k+distStrm1k+ patchDens1k+patchDens1k²	2	2.20E-01	19
elevMn1k+elevMn1k²+ed1k+patchDens1k+patchDens1k²	5.12	4.60E-02	17
elevMn1k+elevMn1k²+proxFor1k+ed1k+distStrm1k	5.87	3.10E-02	17
ed1k+distStrm1k+patchDens1k+patchDens1k²	6.03	2.90E-02	16
elevMn1k+elevMn1k²+proxFor1k+ed1k+patchDens1k+ patchDens1k²	7.04	1.70E-02	18
ed1k+patchDens1k+patchDens1k²	7.14	1.70E-02	15
elevMn1k+elevMn1k²+ed1k+distStrm1k	7.62	1.30E-02	16
proxFor1k+ed1k+distStrm1k+patchDens1k+patchDens1k²	7.77	1.20E-02	17
proxFor1k+ed1k+distStrm1k	8.18	9.90E-03	15
proxFor1k+ed1k+patchDens1k+patchDens1k²	8.65	7.80E-03	16
ed1k+distStrm1k	9.92	4.20E-03	14
proxFor1k+ed1k	10.87	2.60E-03	14
elevMn1k+elevMn1k²+proxFor1k+ed1k	12.57	1.10E-03	16
ed1k	14.92	3.40E-04	13
elevMn1k+elevMn1k²+ed1k	16.89	1.30E-04	15
null	65.16	4.20E-15	12

Squirrel Cuckoo: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k	0	7.20E-01	8
elevMn1k+pfor1k+pfor1k²	2.58	2.00E-01	10
elevMn1k+pfor1k+pfor1k²+coreFor1k	4.45	7.80E-02	11
null	21.91	1.30E-05	7

Slate-throated Redstart: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+pfor1k+proxFor1k	0	7.20E-01	15
elevMn1k+pfor1k+proxFor1k+coreFor1k+coreFor1k²	1.97	2.70E-01	17
elevMn1k+pfor1k+coreFor1k+coreFor1k²	9.04	7.80E-03	16
elevMn1k+pfor1k	11	2.90E-03	14
elevMn1k	14.53	5.10E-04	13
null	123.99	8.60E-28	12

Dusky-capped Flycatcher: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²+patchDens1k	0	2.70E-01	15
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens1k	0.27	2.40E-01	17
elevMn1k+elevMn1k²+coreFor1k+patchDens1k	0.42	2.20E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²	1.87	1.10E-01	16
elevMn1k+elevMn1k²+coreFor1k	2.9	6.30E-02	15
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k	3.76	4.10E-02	17
elevMn1k+elevMn1k²+ed1k+ed1k²	4.19	3.30E-02	16
elevMn1k+elevMn1k²	4.49	2.90E-02	14
null	30.08	8.00E-08	12

Keel-billed Toucan: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²+pfor1k+pfor1k²	0	6.00E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k	1.99	2.20E-01	17
elevMn1k+elevMn1k²+patchDens1k+patchDens1k²	4.47	6.40E-02	16
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens1k+patchDens1k²	4.8	5.40E-02	18
elevMn1k+elevMn1k²+coreFor1k+patchDens1k+patchDens1k²	4.99	4.90E-02	17
elevMn1k+elevMn1k²+ed1k+ed1k²	7.44	1.40E-02	16
elevMn1k+elevMn1k²+coreFor1k	10.91	2.60E-03	15
elevMn1k+elevMn1k²	16.31	1.70E-04	14
null	49.76	9.30E-12	12

Black-faced Solitaire: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+pfor1k+distStrm1k	0	2.80E-01	15
elevMn1k+pfor1k+proxFor1k+distStrm1k	1.88	1.10E-01	16
elevMn1k+pfor1k+mnPARiFor1k+distStrm1k	1.99	1.00E-01	16
elevMn1k+pfor1k	2.02	1.00E-01	14
elevMn1k+pfor1k+distStrm1k+coreFor1k+coreFor1k²	2.65	7.50E-02	17
elevMn1k+pfor1k+coreFor1k+coreFor1k²	3.45	5.00E-02	16
elevMn1k+pfor1k+mnPARiFor1k	3.69	4.50E-02	15
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+distStrm1k	3.82	4.20E-02	17
elevMn1k+pfor1k+proxFor1k	3.91	4.00E-02	15
elevMn1k+pfor1k+proxFor1k+distStrm1k+coreFor1k+ coreFor1k²	4.05	3.70E-02	18
elevMn1k+pfor1k+mnPARiFor1k+distStrm1k+coreFor1k+ coreFor1k²	4.27	3.30E-02	18
elevMn1k+pfor1k+proxFor1k+coreFor1k+coreFor1k²	5.39	1.90E-02	17
elevMn1k+pfor1k+mnPARiFor1k+coreFor1k+coreFor1k²	5.42	1.90E-02	17
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k	5.66	1.70E-02	16
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+distStrm1k+ coreFor1k+coreFor1k²	6.04	1.40E-02	19
elevMn1k+pfor1k+proxFor1k+mnPARiFor1k+coreFor1k+ coreFor1k²	7.39	7.00E-03	18
pfor1k	11.08	1.10E-03	13
null	172.24	1.10E-38	12

Northern Emerald-Toucanet: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k	0	4.00E-01	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k	0.51	3.10E-01	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ distStrm1k+coreFor1k+coreFor1k²	3.59	6.60E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k+coreFor1k+ coreFor1k²	3.68	6.40E-02	19
elevMn1k+elevMn1k²	4.14	5.10E-02	14
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	4.36	4.50E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	5.21	3.00E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²	5.64	2.40E-02	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	7.24	1.10E-02	18
null	89.79	1.30E-20	12

Red-billed Pigeon: 1,000 m

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²	0	5.90E-01	14
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²	1.27	3.10E-01	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	3.49	1.00E-01	18
null	28.97	3.00E-07	12

APPENDIX E

PARAMETER ESTIMATES WITH STANDARD ERRORS FOR COVARIATES IN TOP-

RANKED MODELS FOR EACH FOCAL SPECIES AT EACH FOCAL SCALE

Understory species: 100 m

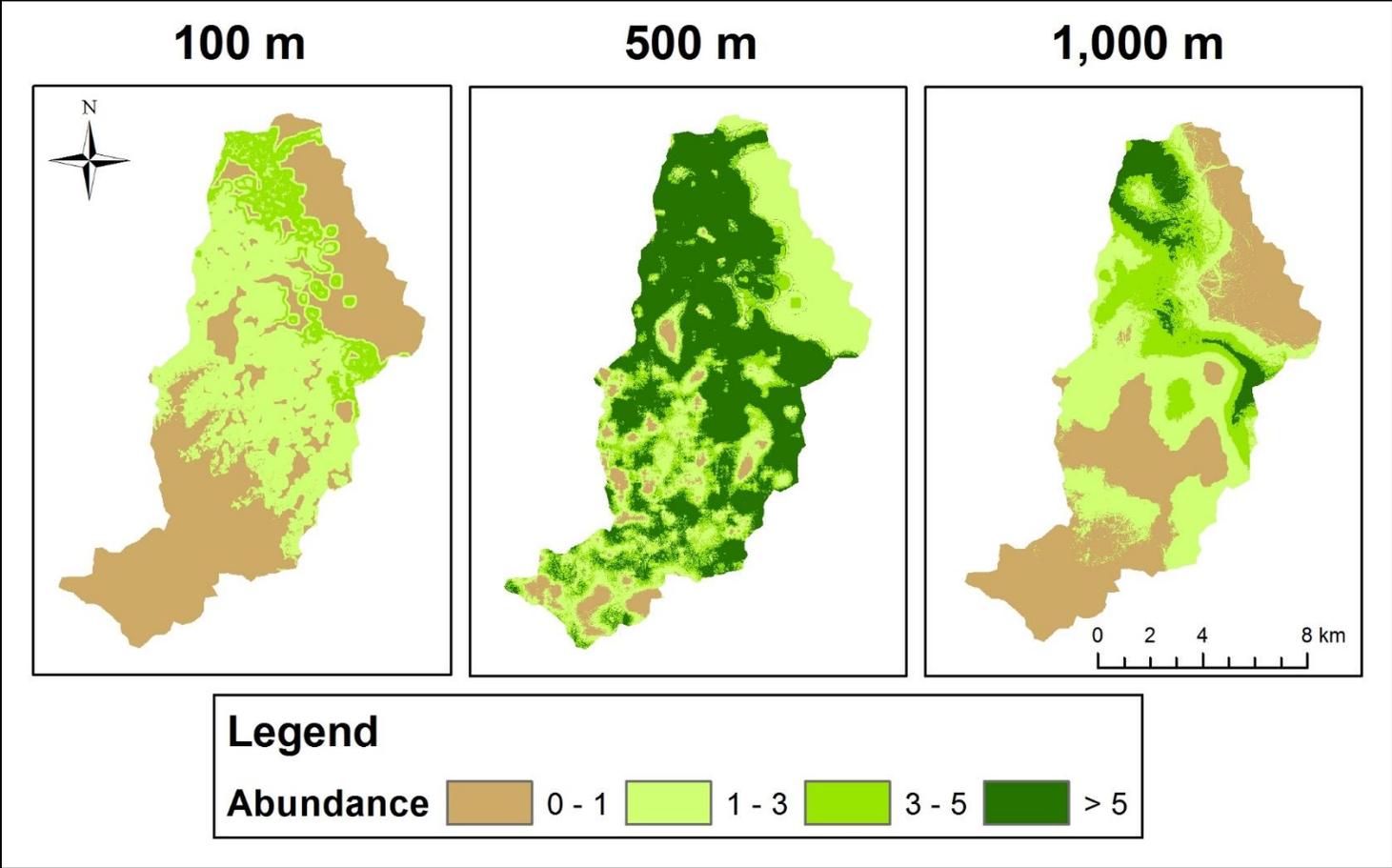| Covariate	Long-tailed Manakin	Common Chlorospingus	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren
Intercept	0.5950±0.392	±-8.012±1.594	0.934±0.444	1.060±0.605	-0.8970±0.440	-4.535±3.335	1.1436±0.296	-5.128±1.178
elevMn	-0.0375±0.152	4.755±1.535	0.626±0.146	1.139±0.335	1.9345±0.748	8.386±2.295	0.4015±0.167	2.078±0.378
elevMn²	-0.8214±0.147	-1.069±0.609	-0.270±0.147	-0.985±0.272	-2.3036±0.634	-3.399±1.036	-0.9468±0.154	
pfor	1.1217±0.184	2.499±1.206	0.409±0.199	0.4641±0.272	1.464±0.654	0.3731±0.132	3.182±1.347	
pfor²								
proxFor								
ed		1.425±0.645		0.0543±0.252	1.124±0.498	1.801±0.608		
ed²		0.144±0.232		0.2053±0.133	-0.250±0.185	-0.191±0.166		
coreFor	-0.5917±0.280	-0.751±1.098	0.035±0.273	0.587±0.329	0.474±0.343	-0.0465±0.260	0.865±0.367	
coreFor²	0.1595±0.191	0.698±0.523	-0.368±0.211	-0.806±0.248		-0.1359±0.177		
patchDens	-4.150±1.472	-0.368±0.211						
patchDens²								
mnPARiFor	-0.3906±0.130							
distStrm		0.285±0.111						
Temp.	-0.9040±0.489	-0.548±0.605	-1.8002±0.473	-1.6915±0.701	-0.6210±0.560	-2.2083±3.507	-1.279±0.342	-0.143±0.774
Day	-0.0709±0.189	1.017±0.460	-0.4142±0.191	0.3832±0.203	-0.1772±0.349	0.2029±0.267	-0.547±0.184	-0.410±0.363
Year	-0.1163±0.156	0.768±0.329	-0.0813±0.164	0.8189±0.250	-0.0305±0.285	0.4347±0.297	0.289±0.157	-0.737±0.397
Time	-0.1839±0.133	0.175±0.192	-0.8533±0.167	-0.4913±0.182	-0.2722±0.246	0.0738±0.187	-0.326±0.125	-0.318±0.231
Wind	-0.4202±0.181	-0.677±0.257	-0.5539±0.206	-0.0487±0.166	-0.1333±0.339	0.1287±0.193	-0.525±0.216	-0.597±0.300
Obs. A	1.082±0.305	1.176±0.607	1.5875±0.380	1.140±0.421	1.201±0.641	1.176±0.607	2.482±0.431	1.149±0.477
Obs. B	0.108±1.058	-8.683±81.153	11.0712±236.982	-11.987±98.861	-11.852±149.965	-8.683±81.153	9.533±248.886	7.610±67.201
Obs. C	-0.699±0.586	-0.283±1.253	-0.9503±0.878	-12.819±368.397	8.301±59.652	-0.283±1.253	-1.203±1.182	0.484±0.846
Obs. D	-0.747±0.502	-1.340±1.153	-0.7358±0.576	0.278±1.070	8.301±59.652	-1.340±1.153	-0.938±0.653	-0.898±0.635
Obs. E	1.727±1.023	0.285±0.845	0.0613±0.663	-1.969±0.537	0.820±1.094	0.285±0.845	-1.403±0.731	-0.651±0.629
Obs. F	-1.566±0.455	0.799±1.101	-0.4763±0.667	1.351±1.041	0.934±7.642	0.799±1.101	-1.403±0.731	-0.369±0.800

Canopy species: 100 m

Covariate	Social Flycatcher	Squirrel Cuckoo	Slate-throated Redstart	Dusky-capped Flycatcher	Keel-billed Toucan	Black-faced Solitaire	Northern Emerald-Toucanet	Red-billed Pigeon
Intercept	-1.33757±0.597	2.845±0.861	-0.977±1.260	4.217±1.037	0.930±0.4078	-5.7633±1.180	-0.141±0.544	1.555±0.4537
elevMn		-0.795±0.179	1.591±0.323	-0.135±0.186	0.179±0.1269	2.7251±0.431	2.628±0.691	0.134±0.1263
elevMn²				-0.974±0.212	-0.527±0.1306	-1.628±0.414	-0.604±0.1285	
pfor	-0.01559±0.277	0.889±0.374		2.6353±1.361	0.403±0.151	-0.250±0.0977		
pfor²	0.54762±0.269							
proxFor								
ed	0.54082±0.157			0.222±0.0824	0.7909±0.434	0.222±0.0777		
ed²						0.0195±0.130		
coreFor	-1.72769±0.724			-0.451±0.1720				
coreFor²								
patchDens	-0.40788±0.399	0.758±0.440						
patchDens²	0.00376±0.128	-0.335±0.144						
mnPARiFor				-0.177±0.0784				
distStrm					0.143±0.0856			
Temp.	-1.266±0.509	-5.2660±0.915	-2.679±1.304	-5.1426±1.061	-1.399±0.537	0.400±0.626	-1.48571±0.632	-1.967±0.514
Day	-0.351±0.210	-0.5575±0.227	0.101±0.197	-0.1905±0.190	-0.210±0.167	0.485±0.487	0.25625±0.195	-0.323±0.158
Year	-0.479±0.202	-0.4002±0.233	-0.367±0.197	-0.0207±0.169	-0.535±0.167	0.491±0.463	0.58361±0.180	0.138±0.137
Time	-0.030±0.156	0.0298±0.171	0.540±0.167	-0.0568±0.129	-0.243±0.120	0.332±0.386	-0.00702±0.131	-0.313±0.104
Wind	-0.294±0.217	-0.9774±0.955	-0.112±0.202	0.0301±0.129	-0.577±0.212	-0.582±0.294	-0.11504±0.157	0.176±0.105
Obs. A	1.053±0.421	0.977±0.640	3.44±1.02	0.977±0.640	2.122±0.445	0.886±0.433	2.45±0.619	0.6551±0.314
Obs. B	-1.211±1.141	-10.988±101.930	-14.70±262.95	-10.988±101.930	-14.101±248.886	-6.927±39.815	-15.93±735.730	-10.9528±121.753
Obs. C	-0.527±0.710	-0.718±0.880	-3.50±1.38	-0.718±0.880	-4.368±0.848	-2.453±1.177	7.08±61.773	-0.8305±0.695
Obs. D	0.798±1.012	-1.438±0.705	10.32±319.41	-1.438±0.705	-0.716±0.605	9.731±105.023	-2.05±0.815	0.2732±0.499
Obs. E	0.514±0.803	-0.999±0.786	-3.49±1.16	-0.999±0.786	-1.032±1.094	-0.352±0.554	-2.25±0.675	0.4725±0.458
Obs. F	-0.635±0.561	-0.892±0.654	-1.58±1.42	-0.892±0.654	-1.183±0.541	-0.413±0.705	-1.18±0.910	-0.0418±0.568

Understory species: 500 m

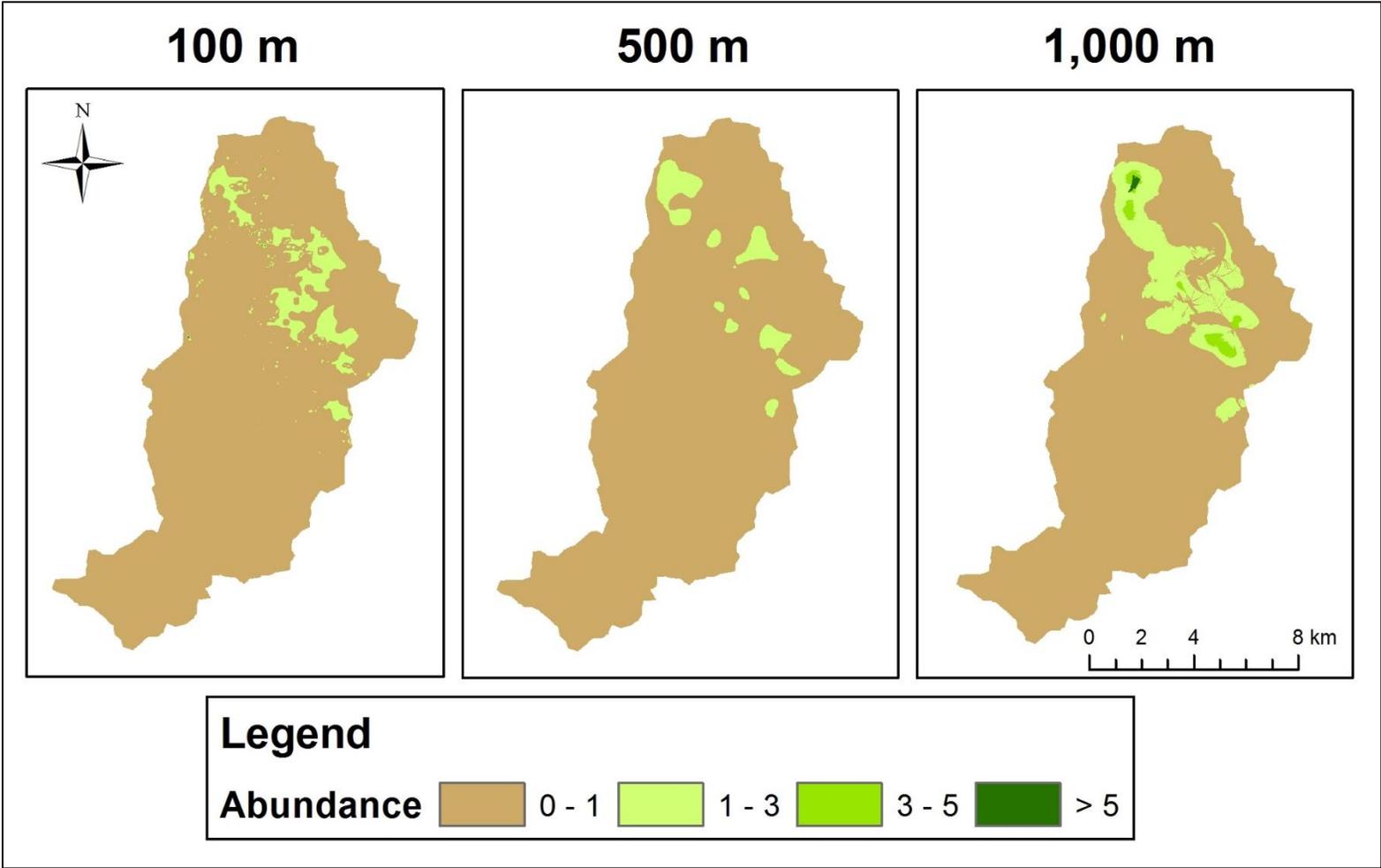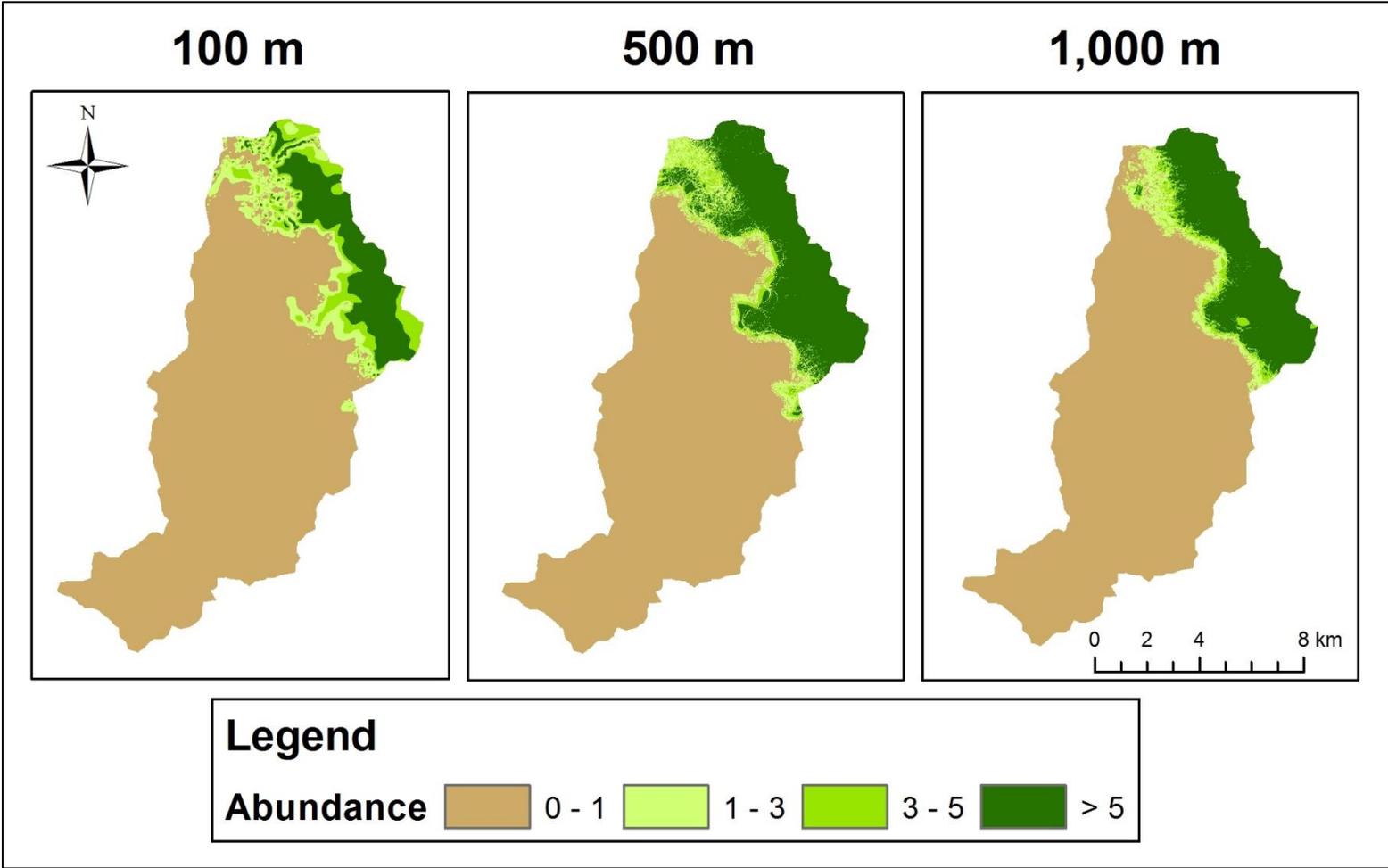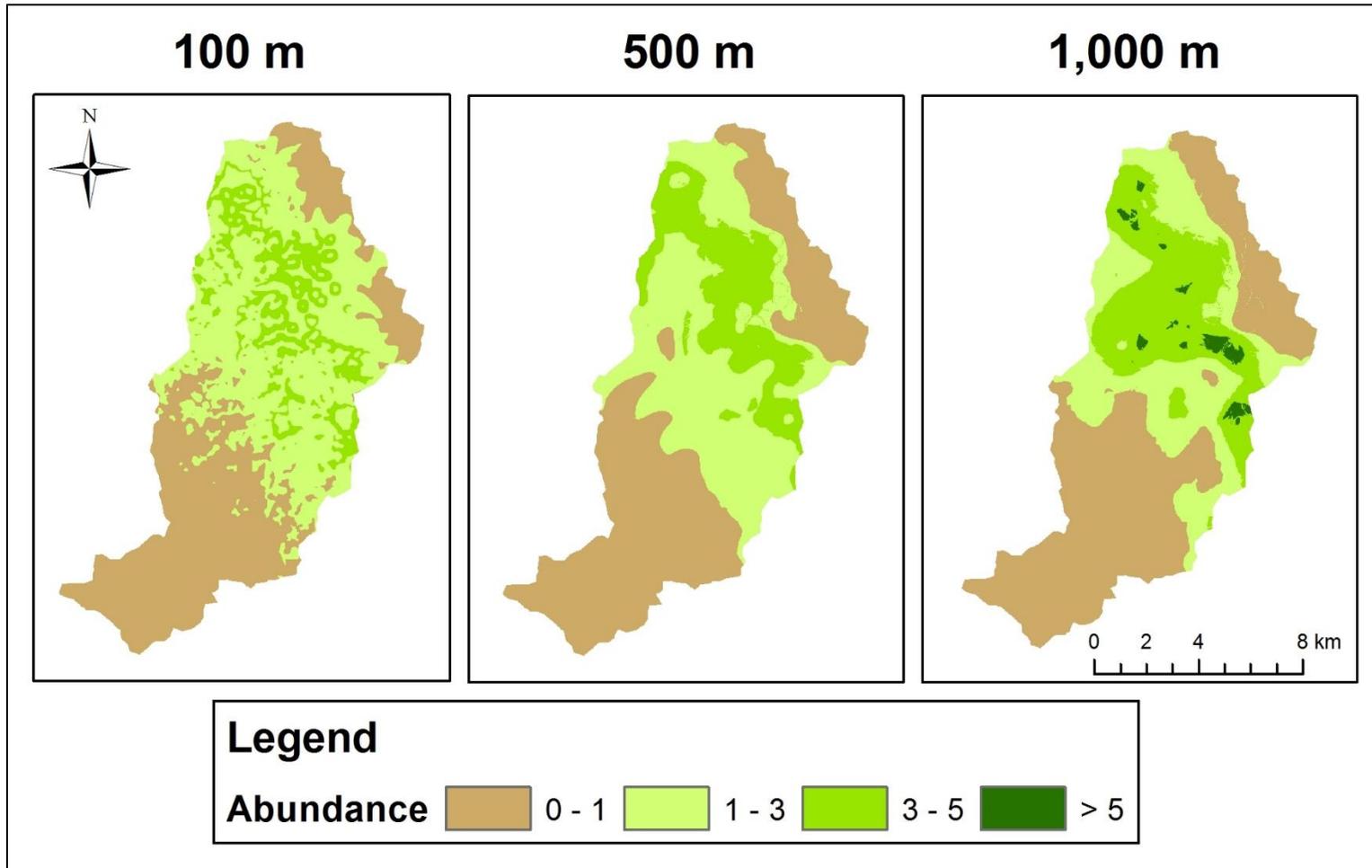| Covariate	Long-tailed Manakin	Common Chlorospingus	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren
Intercept	1.0819±0.3127	-8.382±1.5408	3.029±2.875	0.988±0.500	-0.567±0.449	-4.051±5.014	1.437±0.294	-5.41±1.016
elevMn	-0.0422±0.1629	1.669±0.4544	0.629±0.168	1.354±0.406	2.078±0.807	9.303±2.351	0.540±0.165	1.65±0.413
elevMn²	-0.7415±0.1458	0.195±0.151	-1.317±0.332	-2.435±0.684	-3.882±1.066	-0.941±0.154		
pfor	0.4651±0.1712	6.501±1.5917	-0.283±0.189	0.187±0.231	0.212±0.265	0.704±0.563	3.69±0.889	
pfor²	-0.3186±0.1939	-0.690±0.209	-0.869±0.242	-0.244±0.267	0.619±0.467			
proxFor	0.1475±0.0719	0.231±0.0829						
ed	0.1100±0.1621	1.247±0.5464	-0.244±0.187					
ed²	-0.2372±0.1205	0.428±0.2625	-0.522±0.158					
coreFor							0.238±0.170	
coreFor²							-0.423±0.157	
patchDens								
patchDens²								
mnPARiFor		-0.295±0.100		0.619±0.467				
distStrm				-0.869±0.242	-0.457±0.202			
Temp.	-0.6382±0.415	-0.624±0.715	-3.468±2.926	-1.5211±0.605	-0.5491±0.572	-3.995±4.880	-1.366±0.367	-0.819±1.088
Day	-0.0173±0.208	1.039±0.524	-0.226±0.161	0.4270±0.214	-0.2128±0.356	0.168±0.225	-0.504±0.180	-0.305±0.265
Year	-0.0308±0.170	0.640±0.336	0.113±0.131	1.0098±0.268	-0.0753±0.292	0.375±0.214	0.328±0.154	-0.542±0.298
Time	-0.1771±0.143	0.177±0.176	-0.651±0.159	-0.4994±0.189	-0.2029±0.262	-0.133±0.152	-0.297±0.123	-0.366±0.177
Wind	-0.3913±0.185	-0.799±0.270	-0.451±0.189	-0.0389±0.178	-0.1827±0.342	0.234±0.165	-0.556±0.220	-0.535±0.259
Obs. A	1.091±0.303	1.189±0.609	1.5815±0.380	1.174±0.419	1.206±0.643	1.189±0.609	2.482±0.431	1.150±0.476
Obs. B	0.103±1.058	-4.437±15.153	9.1279±90.344	-12.081±104.809	-16.321±1369.857	-4.437±15.153	8.440±144.012	12.801±814.774
Obs. C	-0.733±0.582	-0.318±1.249	-0.9289±0.880	-10.642±118.794	10.402±118.741	-0.318±1.249	-1.203±1.182	0.425±0.834
Obs. D	-0.699±0.509	-1.376±1.147	-0.7604±0.570	0.215±1.065	10.603±186.024	-1.376±1.147	-0.937±0.653	-0.877±0.639
Obs. E	1.709±1.022	0.278±0.847	0.0746±0.664	-1.975±0.541	0.809±1.094	0.278±0.847	-0.253±0.639	-0.661±0.626
Obs. F	-1.580±0.454	0.798±1.105	-0.4584±0.669	1.330±1.042	1.344±11.423	0.798±1.105	-1.407±0.731	-0.349±0.804

Canopy species: 500 m

Covariate	Social Flycatcher	Squirrel Cuckoo	Slate-throated Redstart	Dusky-capped Flycatcher	Keel-billed Toucan	Black-faced Solitaire	Northern Emerald-Toucanet	Red-billed Pigeon
Intercept	0.221±0.375	3.245±0.923	-1.44±0.959	3.8769±1.522	1.2122±0.519	-8.731±2.073	-0.448±0.602	1.7042±0.518
elevMn		-0.626±0.245	1.35±0.393	-0.1202±0.204	0.3611±0.152	2.150±0.542	2.918±0.733	0.0432±0.133
elevMn²				-1.0165±0.220	-0.5988±0.134	-1.851±0.446	-0.4441±0.123	
pfor		-0.371±0.322	1.13±0.467	-0.2400±0.166	4.278±1.923	0.381±0.229		
pfor²		-0.604±0.246		0.0626±0.137	0.193±0.258			
proxFor							0.213±0.091	
ed	1.231±0.267			0.5479±0.131	0.386±0.199			
ed²	-0.525±0.180							
coreFor								-0.1310±0.199
coreFor²								-0.2770±0.168
patchDens	0.275±0.188		0.0694±0.180					
patchDens²	-0.333±0.138		-0.3660±0.172					
mnPARiFor			-0.3209±0.139	0.792±0.538	0.309±0.140	0.3568±0.115		
distStrm								
Temp.	-1.161±0.451	-5.455±0.959	-2.300±0.940	-4.5300±1.545	-1.716±0.642	0.354±0.884	-1.3788±0.647	-2.032±0.570
Day	-0.406±0.213	-0.619±0.231	0.134±0.209	-0.2037±0.189	-0.350±0.158	0.521±0.458	0.2766±0.206	-0.237±0.155
Year	-0.347±0.206	-0.442±0.236	-0.392±0.205	0.0290±0.171	-0.493±0.156	0.636±0.429	0.4651±0.188	0.183±0.134
Time	-0.143±0.162	0.109±0.173	0.551±0.176	-0.0821±0.135	-0.330±0.119	-0.265±0.298	0.0829±0.138	-0.232±0.103
Wind	-0.203±0.201	-1.039±1.025	-0.180±0.205	0.0310±0.141	-0.538±0.203	-0.506±0.324	-0.1315±0.162	0.182±0.105
Obs. A	1.071±0.421	0.975±0.641	3.46±1.02	0.975±0.641	2.125±0.445	0.778±0.458	2.46±0.618	0.6443±0.315
Obs. B	-1.069±1.177	-9.016±38.369	-11.87±64.18	-9.016±38.369	-12.914±139.520	-11.299±973.513	-11.38±76.439	-11.3888±143.927
Obs. C	-0.550±0.709	-0.714±0.881	-3.52±1.38	-0.714±0.881	-4.373±0.848	-2.436±1.173	8.00±98.136	-0.8472±0.692
Obs. D	0.717±1.003	-1.451±0.701	-3.52±1.38	-1.451±0.701	-0.718±0.605	13.561±629.638	-2.06±0.816	0.3028±0.502
Obs. E	0.532±0.808	-0.991±0.788	-3.51±1.16	-0.991±0.788	-1.038±1.093	-0.313±0.547	-2.26±0.676	0.4690±0.456
Obs. F	-0.651±0.561	-0.889±0.655	-1.60±1.42	-0.889±0.655	-1.185±0.541	-0.461±0.682	-1.20±0.908	-0.0364±0.567

Understory species: 1,000 m

Covariate	Long-tailed Manakin	Common Chlorospingus	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren
Intercept	1.258±0.312	-6.90±1.0422	1.434±0.529	1.494±0.560	0.7522±0.653	-4.422±1.952	1.8439±0.378	-2.906±0.657
elevMn	-0.134±0.178	2.66±0.5172	0.808±0.179	1.390±0.447	2.1350±0.918	10.287±2.940	0.3606±0.185	1.967±0.439
elevMn²	-0.898±0.159	-0.225±0.155	-1.359±0.382	-3.4165±0.901	-4.032±1.361	-0.9279±0.162		
pfor	0.365±0.163	3.68±0.7673	-0.583±0.194	-0.130±0.252	-0.0306±0.387	-0.0436±0.176		
pfor²	-0.582±0.171	-0.792±0.182	-0.928±0.294	-1.3216±0.477	-0.4727±0.174			
proxFored			0.201±0.101					
proxФored²								
coreFor				0.808±0.472	0.9750±0.502	1.771±0.454	0.5369±0.331	2.129±0.457
coreFor²				-0.560±0.284	0.0642±0.247	-0.730±0.165	-0.3207±0.157	-0.568±0.150
patchDens					-0.906±0.450			
patchDens²								
mnPARiFor								
distStrm	-0.356±0.144	-0.28±0.0966		-0.7002±0.308				
Temp.	-0.7371±0.415	-0.645±0.683	-2.077±0.574	-1.5238±0.557	-1.0139±0.604	-3.457±0.734	-1.443±0.385	-0.377±0.885
Day	-0.0771±0.196	1.163±0.512	-0.363±0.182	0.4113±0.215	-0.1743±0.302	0.132±0.228	-0.526±0.180	-0.538±0.369
Year	0.0090±0.162	0.818±0.327	0.102±0.152	1.0393±0.265	0.2230±0.259	0.365±0.222	0.358±0.151	-0.945±0.479
Time	-0.1545±0.141	0.167±0.170	-0.847±0.158	-0.5561±0.187	-0.1701±0.232	±0.209±0.169	-0.302±0.122	-0.223±0.198
Wind	-0.3425±0.178	-0.774±0.254	-0.473±0.199	-0.0526±0.179	-0.0187±0.310	0.163±0.166	-0.475±0.220	-0.720±0.279
Obs. A	1.075±0.304	1.195±0.606	1.5714±0.382	1.165±0.42	1.317±0.46	1.195±0.606	2.483±0.431	1.175±0.470
Obs. B	0.168±1.065	-14.421±1686.174	10.7056±192.246	-12.869±157.69	-14.770±695.44	-14.421±1686.174	9.865±291.525	12.876±879.365
Obs. C	-0.740±0.580	-0.304±1.252	-1.0025±0.868	-13.099±368.40	11.620±237.17	-0.304±1.252	-1.222±1.179	0.383±0.828
Obs. D	-0.721±0.504	-1.344±1.157	-0.7275±0.575	0.223±1.06	10.334±165.65	-1.344±1.157	-0.939±0.653	-0.852±0.648
Obs. E	1.731±1.023	0.275±0.846	0.0774±0.663	-1.970±0.54	0.747±1.07	0.275±0.846	-0.255±0.639	-0.681±0.627
Obs. F	-1.570±0.454	0.779±1.101	-0.4590±0.668	1.342±1.04	10.616±809.08	0.779±1.101	-1.398±0.733	-0.362±0.806

Canopy species: 1,000 m

Covariate	Social Flycatcher	Squirrel Cuckoo	Slate-throated Redstart	Dusky-capped Flycatcher	Keel-billed Toucan	Black-faced Solitaire	Northern Emerald-Toucanet	Red-billed Pigeon
Intercept	0.0927±0.488	2.970±1.039	-2.024±1.024	3.454±1.020	1.528±0.487	-8.562±1.543	0.0400±0.573	1.7565±0.483
elevMn	-0.3538±0.212	-0.763±0.164	1.496±0.453	0.104±0.212	0.256±0.159	2.177±0.669	1.8019±0.595	-0.0465±0.113
elevMn²	-0.6319±0.208		-0.893±0.214	-0.546±0.133	-1.1536±0.372	-0.6057±0.125		
pfor			1.466±0.560	-0.607±0.150	4.699±1.259	0.4114±0.216		
pfor²			0.395±0.106	-0.420±0.123	-0.0696±0.209			
proxFor								
ed	1.0787±0.186							
ed²								
coreFor								
coreFor²								
patchDens	-0.6133±0.203		0.347±0.133					
patchDens²	0.0998±0.141							
mnPARiFor								
distStrm	-0.4949±0.193				-0.266±0.134	-0.4065±0.154		
Temp.	-1.3301±0.565	-5.6121±1.070	-2.389±0.934	-4.4882±1.029	-1.516±0.606	0.2374±0.845	-1.489±0.646	-2.108±0.546
Day	-0.3667±0.209	-0.5442±0.223	0.243±0.208	-0.2887±0.197	-0.293±0.160	0.7314±0.424	0.286±0.195	-0.294±0.153
Year	-0.3372±0.199	-0.4106±0.233	-0.322±0.203	-0.0609±0.174	-0.424±0.158	0.7473±0.402	0.602±0.182	0.192±0.132
Time	0.0793±0.167	0.0222±0.164	0.601±0.179	-0.1337±0.126	-0.290±0.121	-0.0733±0.300	0.149±0.140	-0.332±0.102
Wind	-0.1629±0.200	-0.9968±0.932	-0.295±0.201	0.0304±0.130	-0.473±0.206	-0.5656±0.297	-0.113±0.158	0.191±0.105
Obs. A	1.066±0.422	0.991±0.636	3.46±1.02	0.991±0.636	2.096±0.447	0.806±0.450±	2.46±0.619	0.6550±0.312
Obs. B	-1.028±1.186	-8.997±38.334	-17.31±973.51	-8.997±38.334	-12.523±114.292	-12.426±1133.709	-13.37±205.736	-9.6902±64.056
Obs. C	-0.549±0.709	-0.731±0.879	-3.53±1.38	-0.731±0.879	-4.354±0.846	-2.437±1.174	6.99±58.907	-0.8564±0.692
Obs. D	0.730±1.004	-1.446±0.705	13.21±1365.31	-1.446±0.705	-0.693±0.605	14.565±1038.493	-2.07±0.813	0.2781±0.500
Obs. E	0.541±0.809	-0.994±0.790	-3.51±1.16	-0.994±0.790	-1.057±1.084	-0.318±0.550	-2.25±0.678	0.4674±0.457
Obs. F	-0.665±0.558	-0.908±0.652	-1.60±1.41	-0.908±0.652	-1.152±0.543	-0.463±0.685	-1.20±0.909	-0.0192±0.571

APPENDIX F

MAPS OF PREDICTED ABUNDANCE OF FOCAL SPECIES IN THE STUDY AREA AT

EACH FOCAL SCALE

UNDERSTORY INSECTIVORES

Lesson's Motmot

White-eared Ground-Sparrow
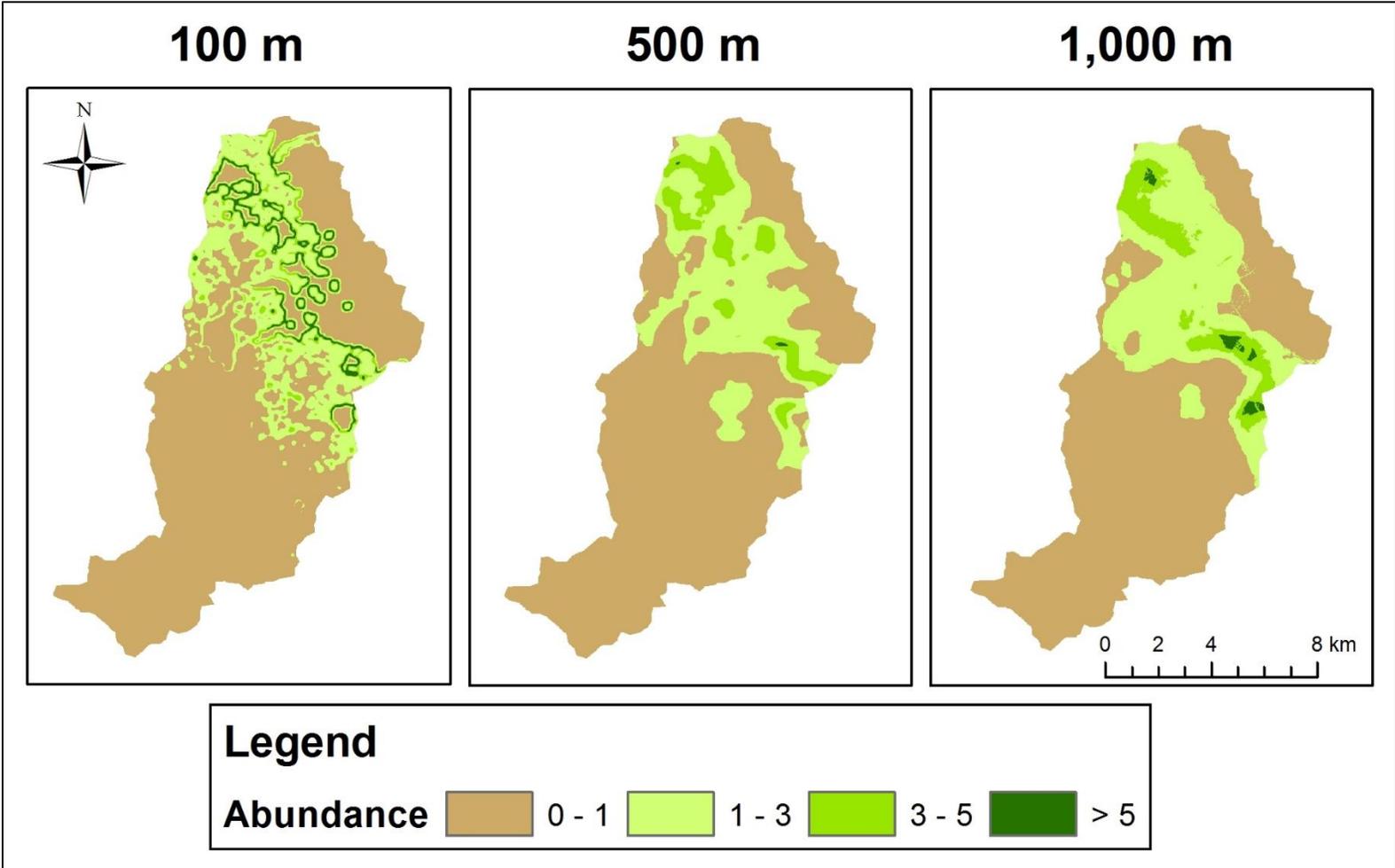
Orange-billed Nightingale-Thrush

Slaty-backed Nightingale-Thrush

Rufous-and-white Wren

| Abundance | 0 - 1 | 1 - 3 | 3 - 5 | > 5 |

Gray-breasted Wood-Wren

100 m   500 m   1,000 m

Legend

Abundance   0 - 1   1 - 3   3 - 5   > 5
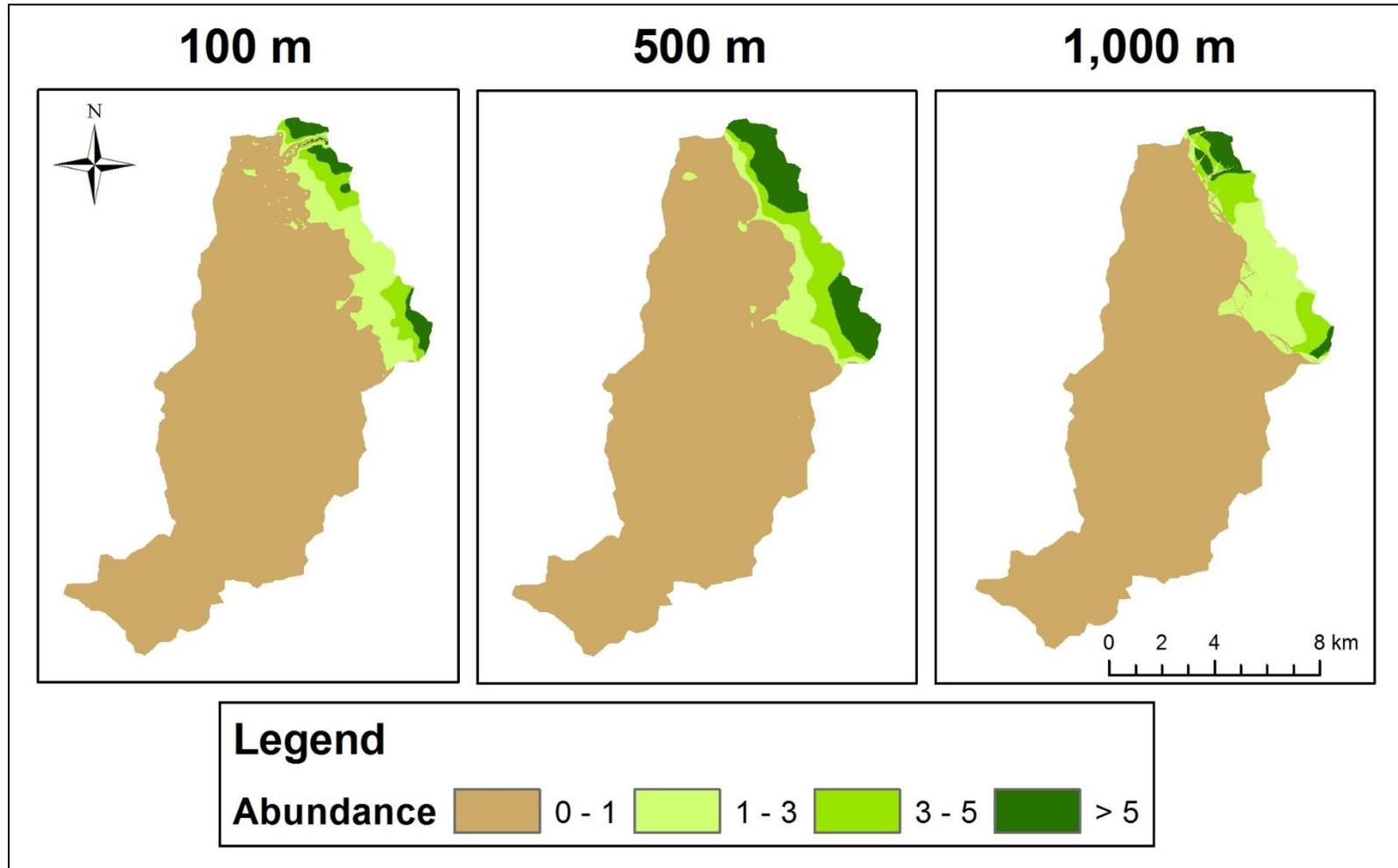
UNDERSTORY FRUGIVORES

Long-tailed Manakin
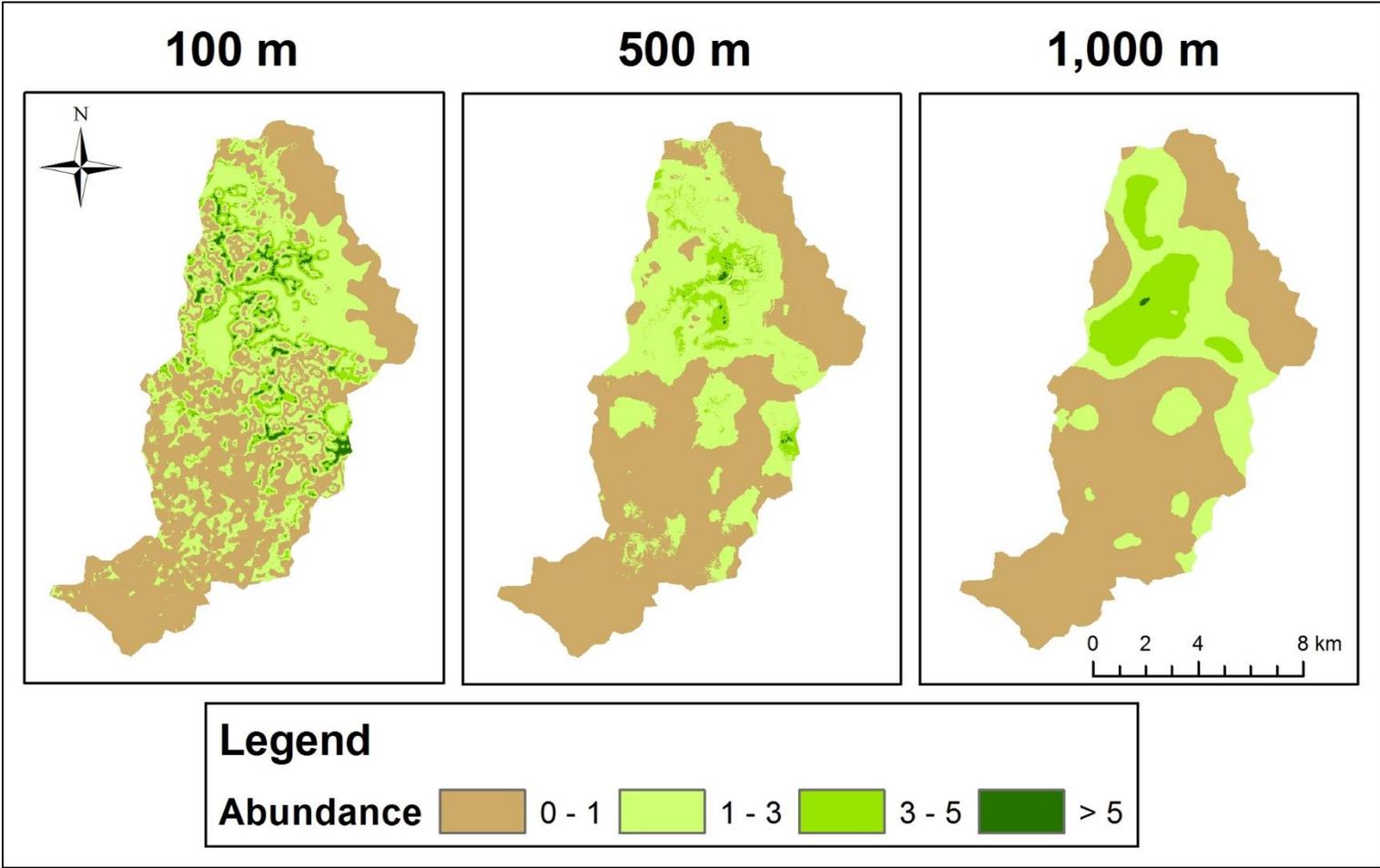
Common Chlorospingus
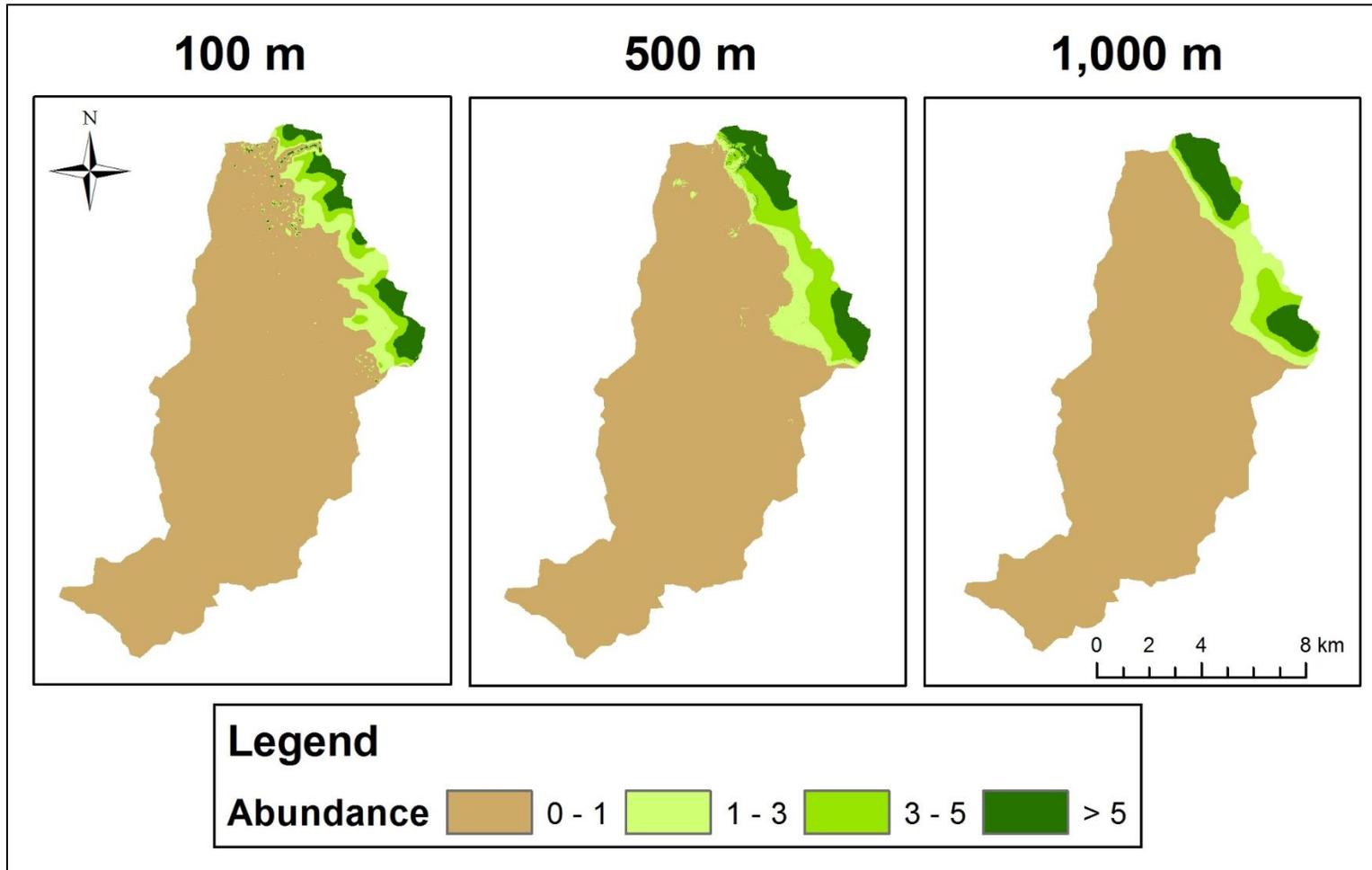
CANOPY INSECTIVORES

Squirrel Cuckoo
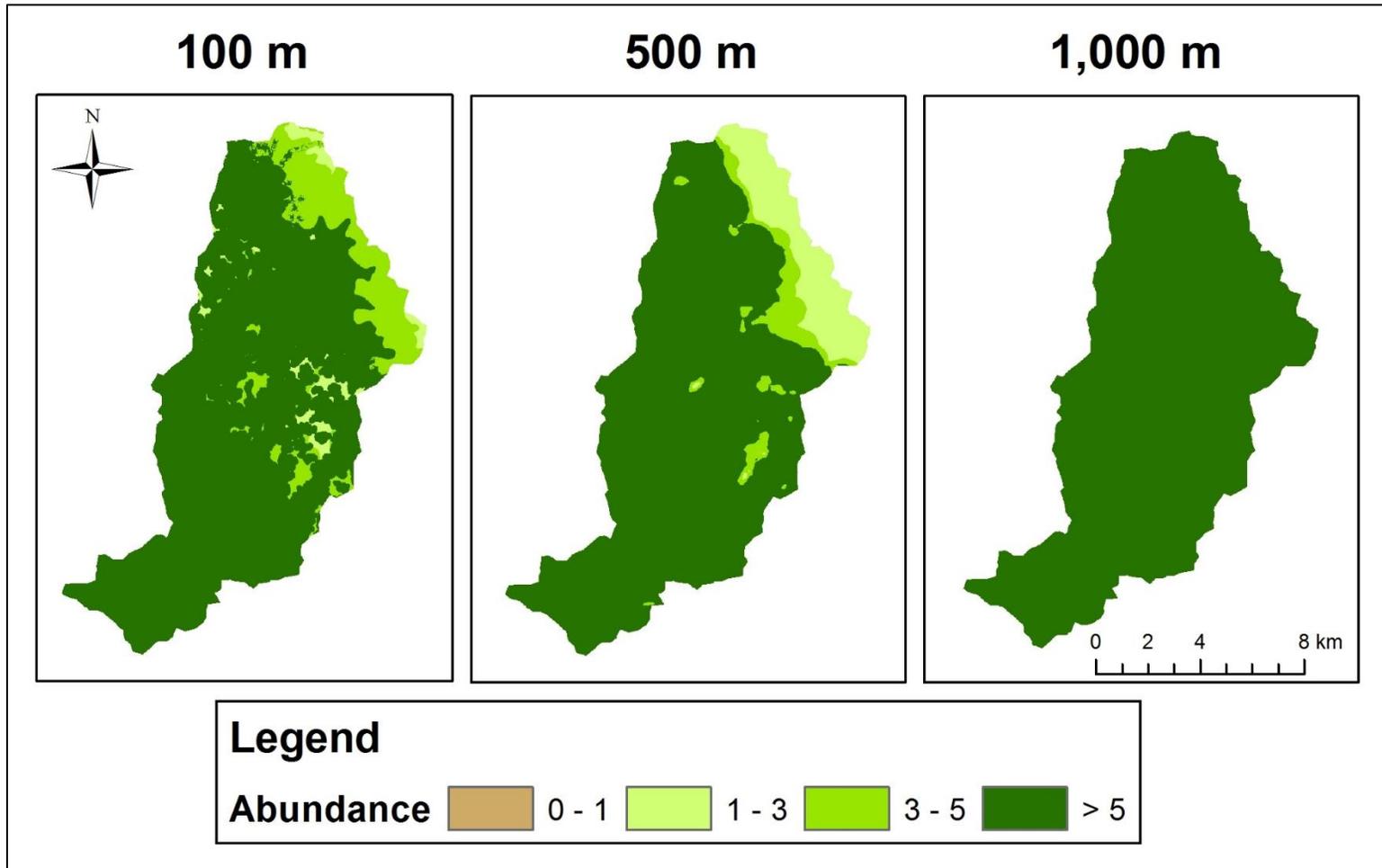
Slate-throated Redstart
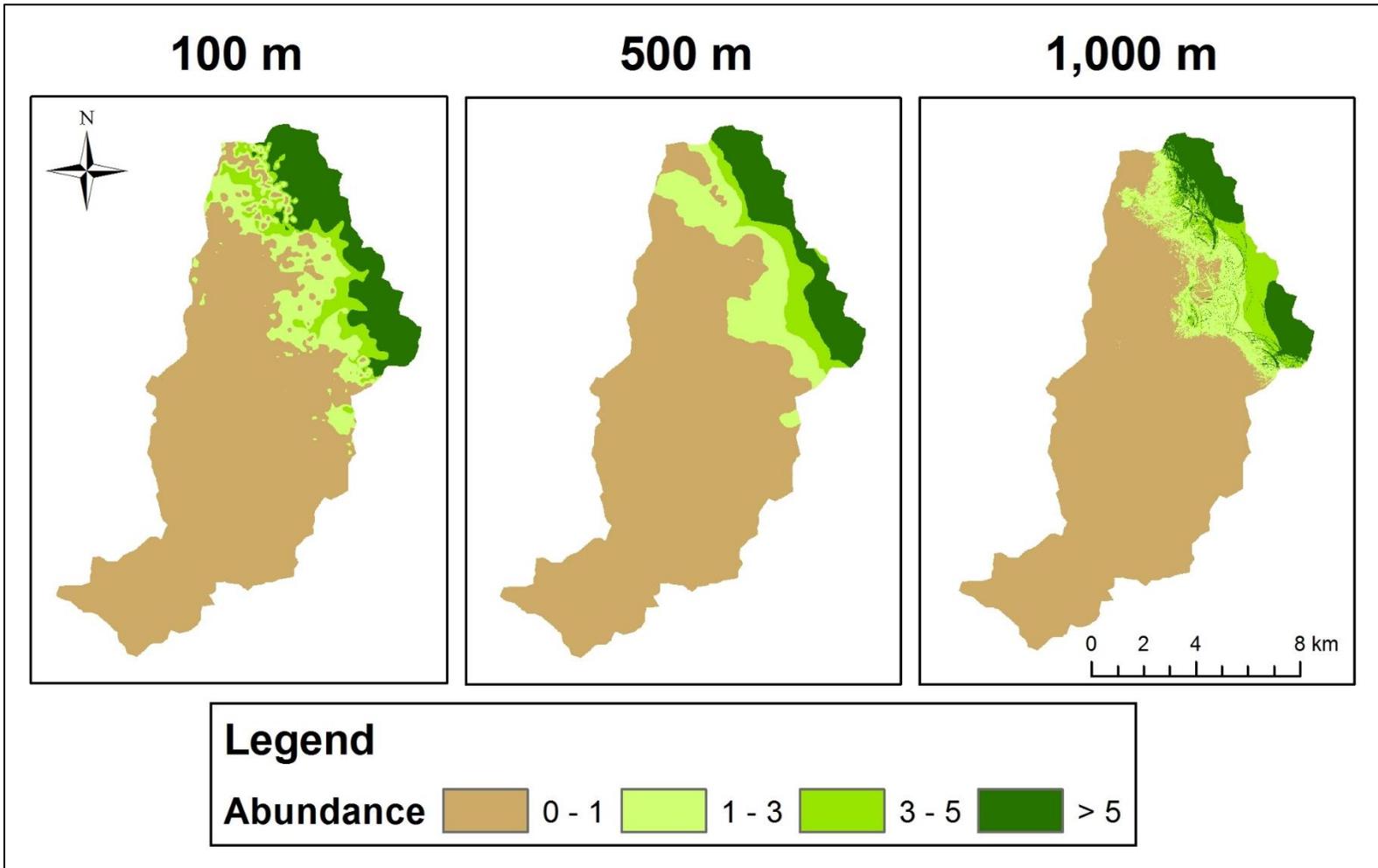
Social Flycatcher
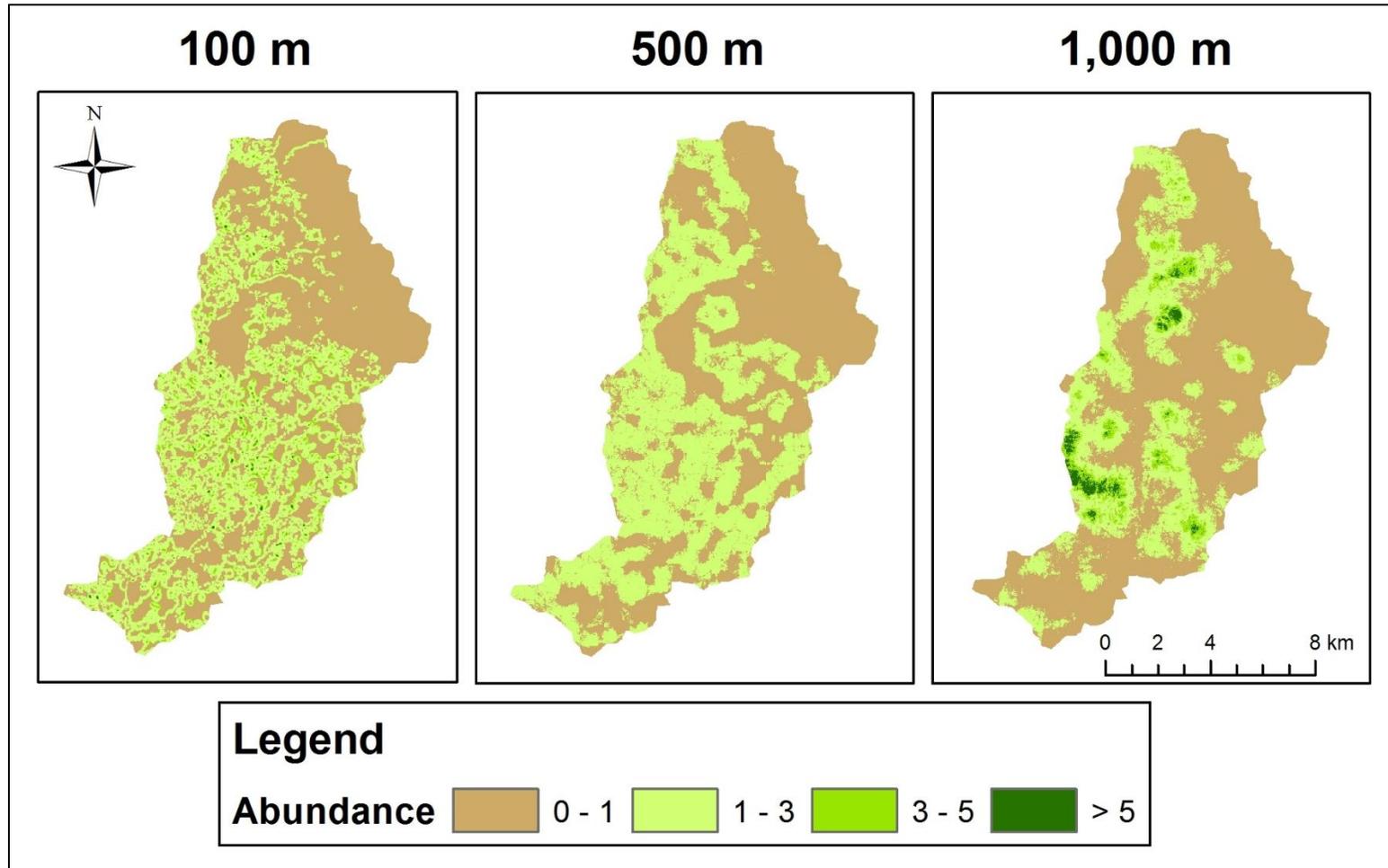
Dusky-capped Flycatcher
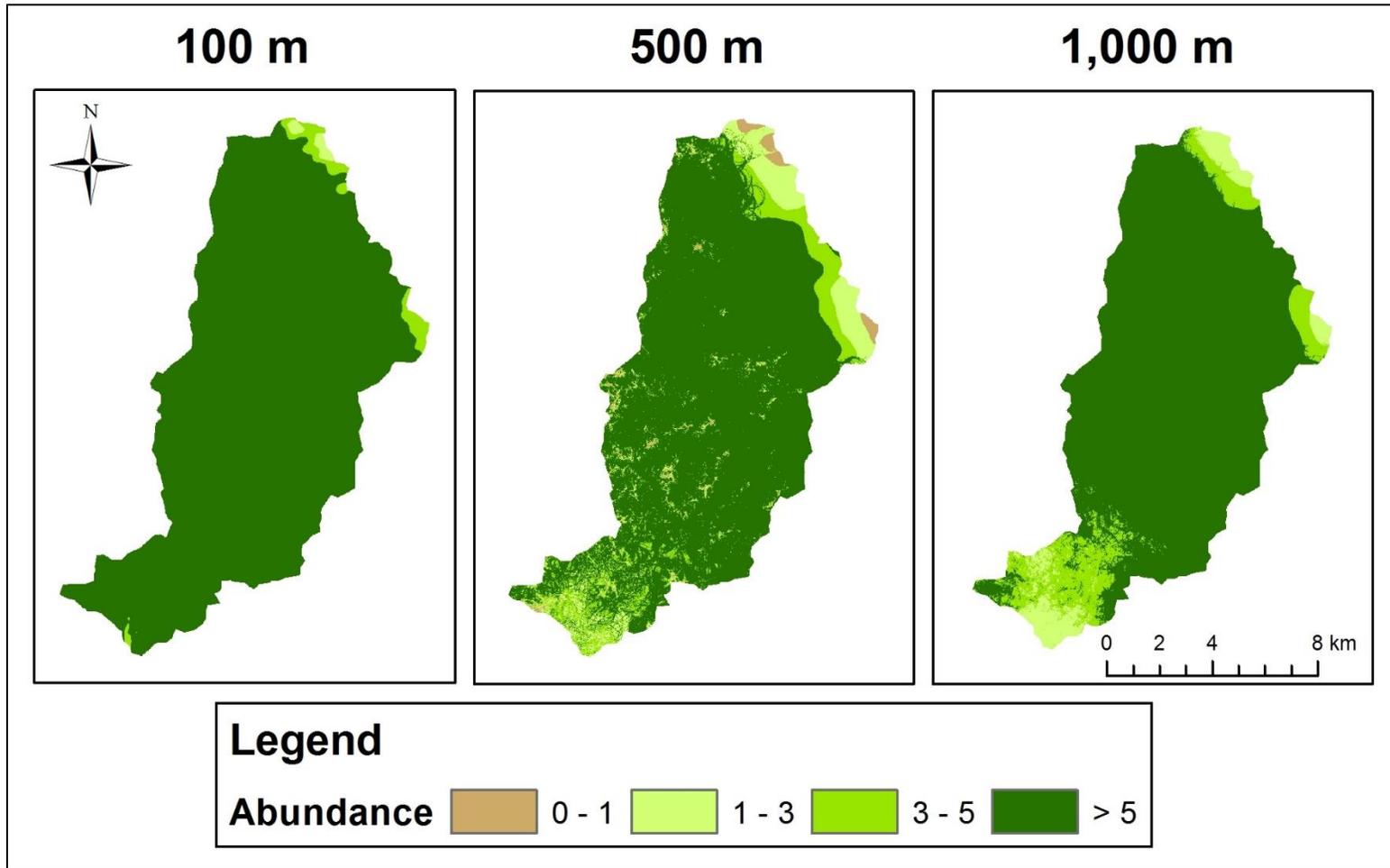
CANOPY FRUGIVORES

Keel-billed Toucan
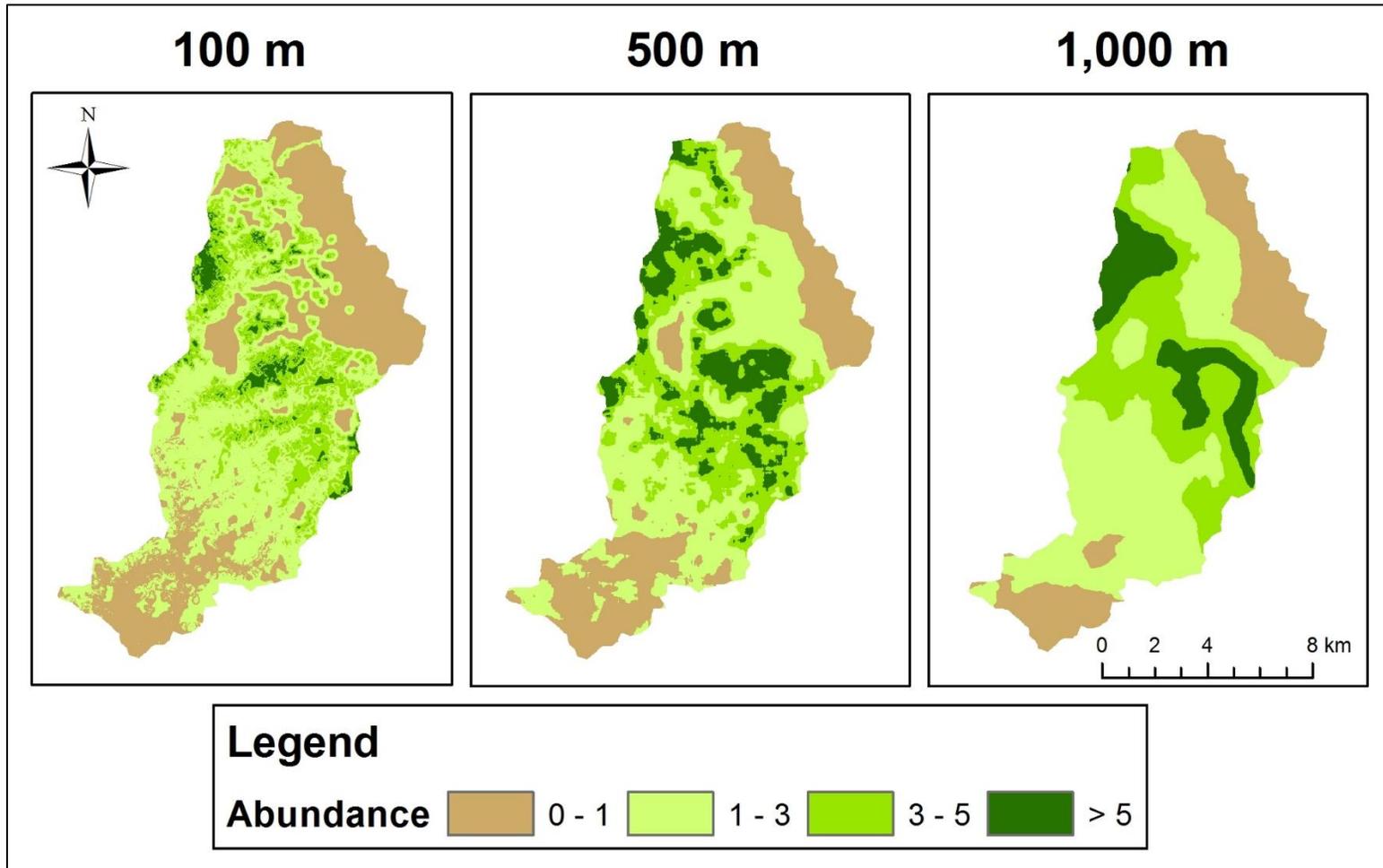
Northern Emerald-Toucanet
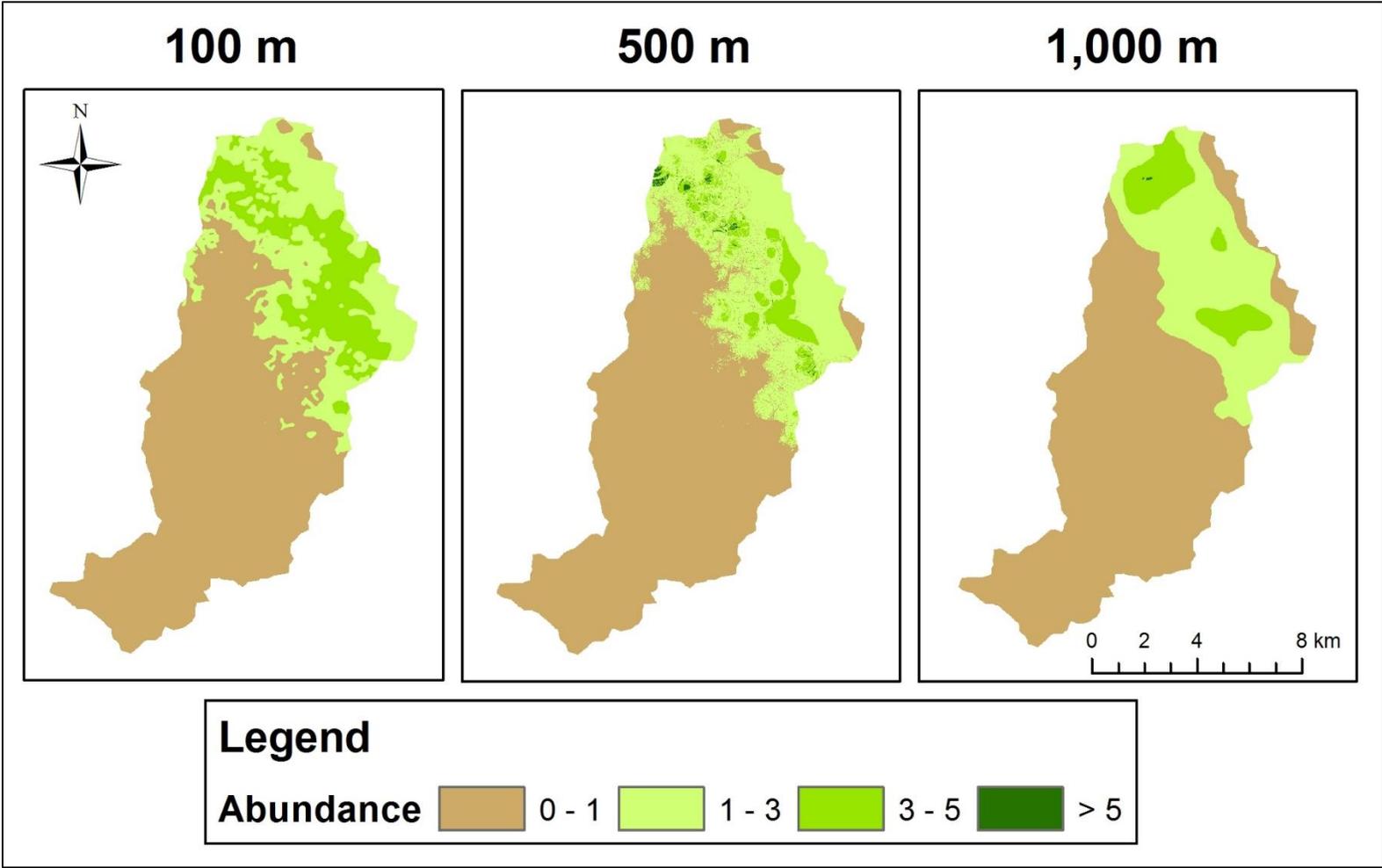
Black-faced Solitaire

Red-billed Pigeon

| 100 m | 500 m | 1,000 m |

Legend

Abundance   0 - 1   1 - 3   3 - 5   > 5
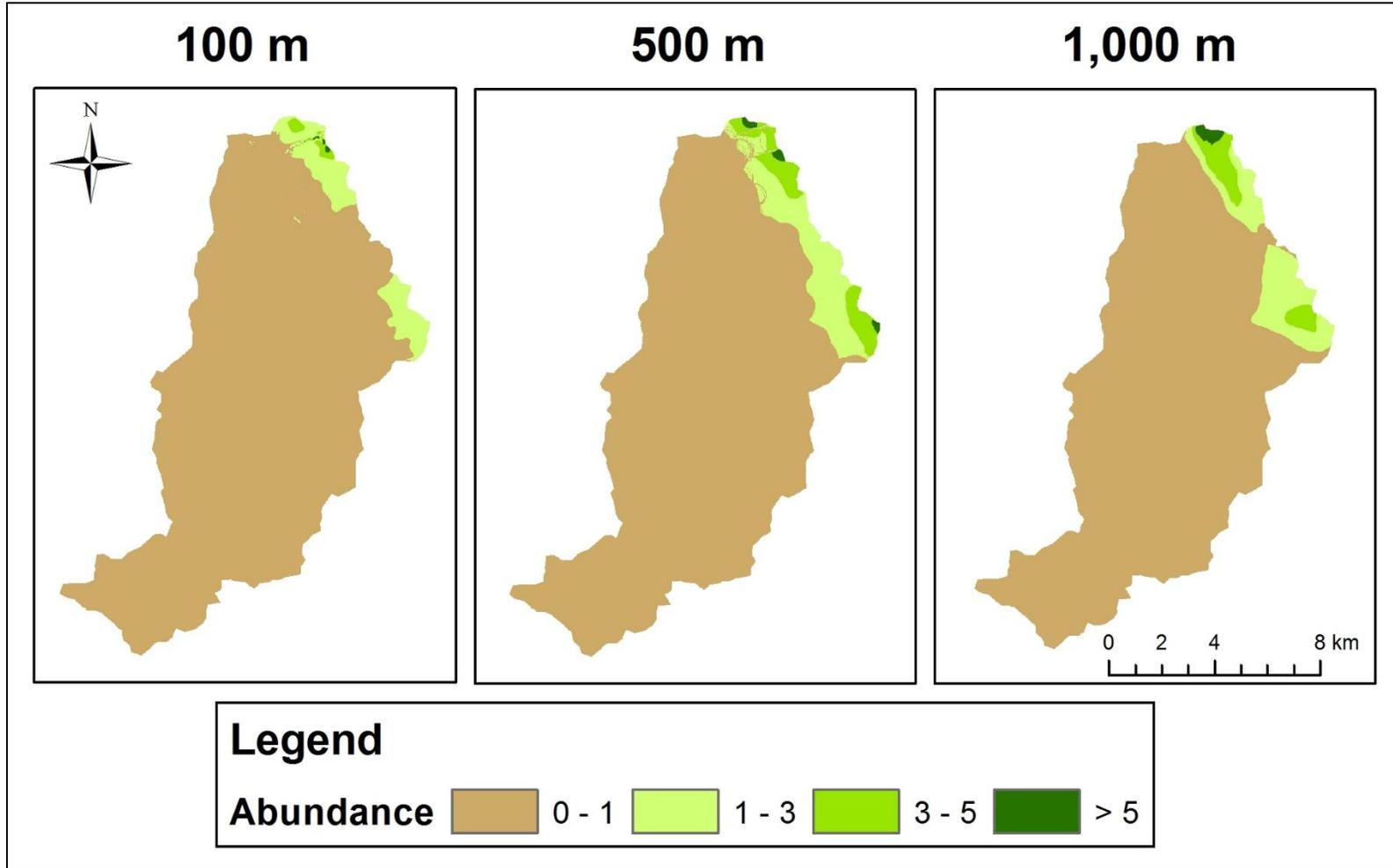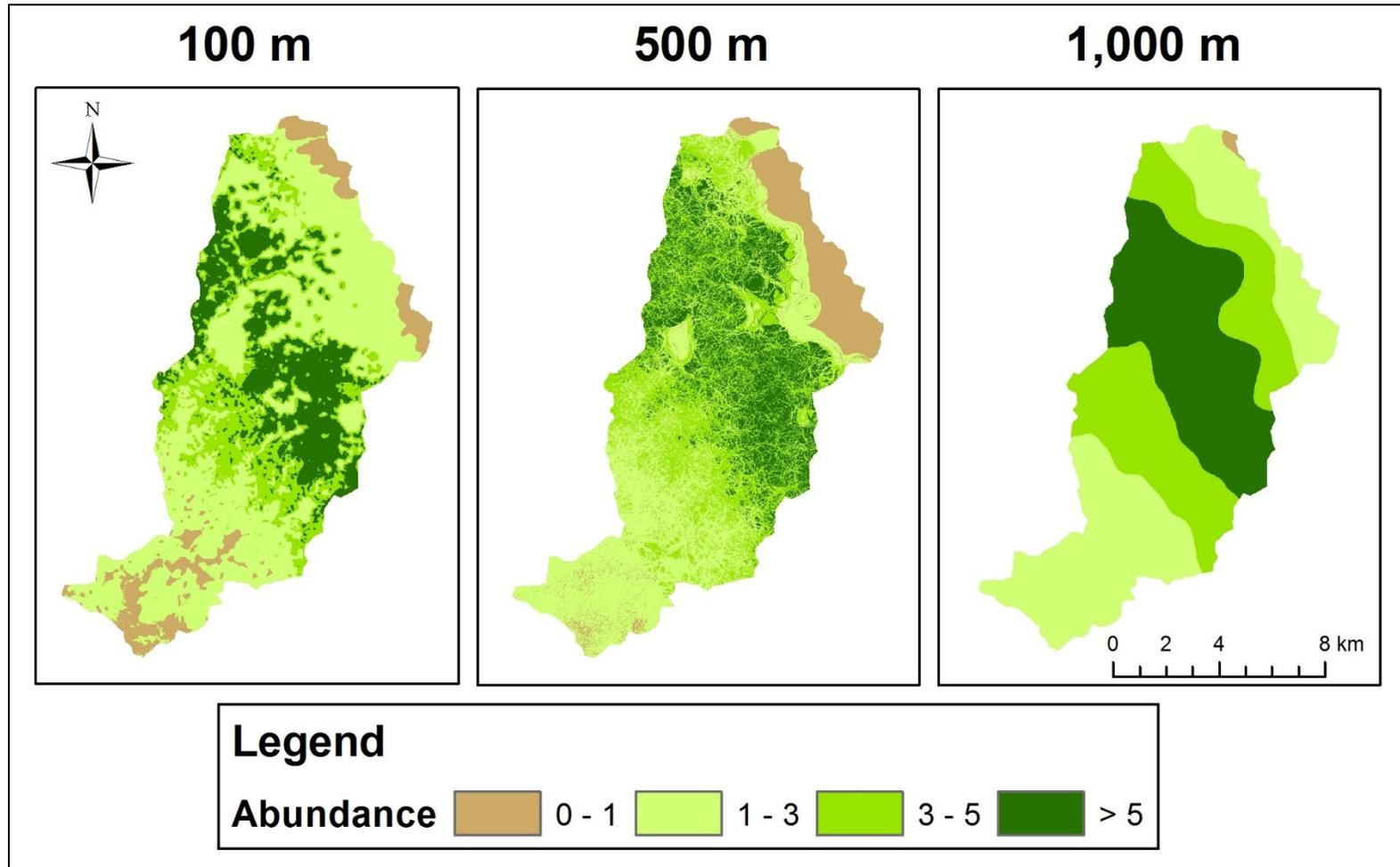
APPENDIX G

AIC RANKINGS OF MULTI-SCALE ABUNDANCE MODELS FOR FOCAL SPECIES

ΔAIC = difference in AIC relative to the top-ranked model, w = AIC weight, K = number of

model parameters.

Long-tailed Manakin

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ patchDens100+distStrm1k	0	1.50E-01	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ patchDens100+ed500+ed500²+distStrm1k	0.47	1.20E-01	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ patchDens100+distStrm1k	0.49	1.20E-01	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+patchDens100+ed500+ed500²+ distStrm1k	1.68	6.50E-02	24
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+patchDens100+distStrm1k	2.7	3.90E-02	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+ed500+ed500²+distStrm1k	3.17	3.10E-02	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+patchDens100+ed500+ed500²+distStrm1k	3.17	3.10E-02	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+distStrm1k+mnPARiFor100	3.31	2.90E-02	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+patchDens100+distStrm1k	3.33	2.90E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ patchDens100+ ed500+ed500²+distStrm1k	3.36	2.80E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+distStrm1k	3.7	2.40E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ patchDens100+distStrm1k	3.76	2.30E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ed500+ ed500²+distStrm1k	3.83	2.20E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+distStrm1k	3.86	2.20E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ ed500+ed500²+distStrm1k	4.53	1.60E-02	21

elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ distStrm1k	4.84	1.30E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+patchDens100+ed500+ed500²+distStrm1k	4.87	1.30E-02	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ed500+ ed500²+distStrm1k+mnPARiFor100	4.99	1.30E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+distStrm1k+ mnPARiFor100	5.1	1.20E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+patchDens100	5.18	1.10E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+ed500+ed500²+distStrm1k	5.33	1.10E-02	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+patchDens100+ed500+ed500²	5.37	1.00E-02	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+patchDens100	5.84	8.20E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ patchDens100	5.97	7.60E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ distStrm1k+mnPARiFor100	5.99	7.60E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed500+ed500²+distStrm1k	6.2	6.80E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed500+ ed500²+distStrm1k	6.33	6.40E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed500+ ed500²+mnPARiFor100	6.33	6.40E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+patchDens100+distStrm1k	6.37	6.30E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+ed500+ed500²+distStrm1k	6.41	6.10E-03	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+ed500+ed500²+distStrm1k+ mnPARiFor100	6.47	6.00E-03	24
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+distStrm1k	6.76	5.20E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm1k	6.84	5.00E-03	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+patchDens100	6.9	4.80E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+distStrm1k	6.95	4.70E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ patchDens100+ed500+ed500²	7.16	4.20E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+distStrm1k	7.28	4.00E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ patchDens100+ed500+ed500²	7.33	3.90E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm1k	7.37	3.80E-03	18

elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+distStrm1k+ mnPARiFor100	7.37	3.80E-03	18
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+ed500+ed500^2+ distStrm1k+mnPARiFor100	7.37	3.80E-03	20
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+ed500+ ed500^2+distStrm1k+mnPARiFor100	7.51	3.60E-03	21
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ proxFor500+ed500+ed500^2+distStrm1k+mnPARiFor100	7.6	3.40E-03	23
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+ed500+ed500^2+distStrm1k	7.8	3.10E-03	22
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+patchDens100	7.86	3.00E-03	18
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+patchDens100+ed500+ed500^2	7.96	2.80E-03	22
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ proxFor500+patchDens100+ed500+ed500^2	8.01	2.80E-03	22
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ proxFor500+ed500+ed500^2+mnPARiFor100	8.03	2.70E-03	23
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+patchDens100	8.07	2.70E-03	17
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+proxFor500+distStrm1k+mnPARiFor100	8.09	2.60E-03	22
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+distStrm1k+ mnPARiFor100	8.1	2.60E-03	18
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+patchDens100	8.15	2.60E-03	20
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ ed500+ed500^2+distStrm1k+mnPARiFor100	8.31	2.40E-03	21
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+ patchDens100+ed500+ed500^2	8.45	2.20E-03	20
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+ed500+ed500^2+distStrm1k+mnPARiFor100	8.99	1.70E-03	23
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+proxFor500+ed500+ed500^2	9.02	1.70E-03	22
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+patchDens100+ed500+ ed500^2	9.08	1.60E-03	19
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+proxFor500	9.23	1.50E-03	20
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ ed500+ed500^2+distStrm1k	9.36	1.40E-03	21
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor1k+coreFor1k+ coreFor1k^2+distStrm1k	9.76	1.20E-03	20
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+proxFor500	9.81	1.10E-03	17
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ patchDens100	9.98	1.00E-03	19
elevMn1k+elevMn1k^2+pfor1k+pfor1k^2+coreFor1k+coreFor1k^2+ distStrm1k	10.28	8.90E-04	19

elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+ed500+ed500²+mnPARiFor100	10.37	8.50E-04	23
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500	10.4	8.40E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500	10.53	7.80E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ed500+ed500²	10.62	7.50E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+proxFor500+mnPARiFor100	10.67	7.30E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ ed500+ed500²	10.73	7.10E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+ed500+ed500²	10.86	6.70E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+ed500+ed500²	10.99	6.20E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+distStrm1k+mnPARiFor100	11.12	5.80E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ mnPARiFor100	11.12	5.80E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+ed500+ed500²	11.34	5.20E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²	11.49	4.90E-04	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed500+ed500²	11.49	4.80E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ distStrm1k+mnPARiFor100	11.61	4.60E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²	11.63	4.50E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ mnPARiFor100	11.64	4.50E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	11.69	4.40E-04	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed500+ed500²	11.88	4.00E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor500+mnPARiFor100	11.99	3.80E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor500+ed500+ ed500²+mnPARiFor100	12.02	3.70E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+proxFor500+ ed500+ed500²+mnPARiFor100	12.11	3.60E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+ed500+ed500²+mnPARiFor100	12.37	3.10E-04	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100	12.8	2.50E-04	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+mnPARiFor100	12.97	2.30E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+coreFor1k+ coreFor1k²+mnPARiFor100	13.08	2.20E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	13.13	2.10E-04	18

Model			
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor100	13.26	2.00E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ ed500+ed500²	13.65	1.60E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ mnPARiFor100	14.55	1.10E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ ed500+ed500²+mnPARiFor100	15	8.40E-05	21
elevMn1k+elevMn1k²	38.74	5.90E-10	14
null	90.73	3.00E-21	12

Lesson's Motmot

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+patchDens100	0	1.00E-01	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+patchDens100	0.17	9.50E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+patchDens100	0.39	8.50E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ patchDens100	0.58	7.70E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500	1.13	5.90E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500	1.54	4.80E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+proxFor500+patchDens100	1.93	3.90E-02	22
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+patchDens100+distStrm1k	1.97	3.80E-02	22
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+proxFor500+patchDens100	2.01	3.80E-02	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k	2.04	3.70E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+proxFor500+patchDens100	2.11	3.60E-02	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor500+patchDens100	2.13	3.60E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+patchDens100+distStrm1k	2.39	3.10E-02	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²	2.53	2.90E-02	18
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ patchDens100+distStrm1k	2.56	2.90E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+proxFor500	3.11	2.20E-02	21

elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+distStrm1k	3.12	2.20E-02	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+distStrm1k	3.44	1.90E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+proxFor500	3.44	1.90E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+proxFor500	3.84	1.50E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+proxFor500+patchDens100+ distStrm1k	3.91	1.50E-02	23
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+distStrm1k	4	1.40E-02	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+proxFor500+patchDens100+distStrm1k	4	1.40E-02	22
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor500+patchDens100+distStrm1k	4.1	1.30E-02	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+proxFor500+patchDens100+distStrm1k	4.11	1.30E-02	22
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor500	4.15	1.30E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ distStrm1k	4.36	1.20E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+mnPARiFor500+proxFor500+distStrm1k	5.1	8.10E-03	22
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ mnPARiFor500+proxFor500+distStrm1k	5.32	7.20E-03	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor1k+proxFor500+distStrm1k	5.79	5.70E-03	21
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ proxFor500+distStrm1k	5.95	5.30E-03	20
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+ed500²+ coreFor1k+coreFor1k²+distStrm1k	7.88	2.00E-03	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+patchDens100	13.39	1.30E-04	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+patchDens100	14.04	9.20E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ patchDens100	14.12	8.90E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500	15.1	5.40E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+patchDens100+distStrm1k	15.24	5.10E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+patchDens100	15.27	5.00E-05	20

elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+proxFor500+patchDens100	15.33	4.90E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+patchDens100	15.57	4.30E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ patchDens100	15.67	4.10E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ proxFor500+patchDens100	15.82	3.80E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+proxFor500+ patchDens100	15.92	3.60E-05	22
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k	16.03	3.40E-05	17
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+	16.03	3.40E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+patchDens100+ distStrm1k	16.03	3.40E-05	22
elevMn100+elevMn100²+pfor1k+pfor1k²+patchDens100	16.04	3.40E-05	17
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ patchDens100+distStrm1k	16.05	3.40E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+patchDens100	16.49	2.70E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+distStrm1k	17.08	2.00E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+proxFor500+patchDens100	17.1	2.00E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+proxFor500	17.1	2.00E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+proxFor500+patchDens100	17.14	2.00E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+proxFor500+patchDens100+distStrm1k	17.2	1.90E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²	17.29	1.80E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500	17.39	1.70E-05	17
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²	17.5	1.60E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ proxFor500+patchDens100	17.56	1.60E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ patchDens100+distStrm1k	17.64	1.50E-05	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor500+ patchDens100	17.67	1.50E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ proxFor500+patchDens100+distStrm1k	17.77	1.40E-05	20

elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+proxFor500	17.89	1.30E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+proxFor500+ patchDens100+distStrm1k	17.92	1.30E-05	23
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+proxFor500+patchDens100	17.97	1.30E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²	17.98	1.30E-05	16
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+proxFor500	18.02	1.30E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+distStrm1k	18.02	1.30E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+coreFor100+coreFor100²+distStrm1k	18.02	1.30E-05	21
elevMn100+elevMn100²+pfor1k+pfor1k²+patchDens100+ distStrm1k	18.03	1.30E-05	18
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+patchDens100+distStrm1k	18.47	1.00E-05	20
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+coreFor100²	18.51	9.90E-06	18
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+proxFor500+patchDens100+ distStrm1k	19.07	7.50E-06	22
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ mnPARiFor500+proxFor500+distStrm1k	19.08	7.40E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+proxFor500+patchDens100+ distStrm1k	19.14	7.20E-06	22
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+distStrm1k	19.22	6.90E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+proxFor500	19.25	6.80E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+proxFor500	19.31	6.60E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ proxFor500	19.36	6.50E-06	18
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ distStrm1k	19.39	6.40E-06	18
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+distStrm1k	19.49	6.10E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ proxFor500+patchDens100+distStrm1k	19.54	5.90E-06	20
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor500+ patchDens100+distStrm1k	19.67	5.50E-06	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor500	19.76	5.30E-06	17
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ proxFor500+distStrm1k	19.89	4.90E-06	19

Model	ΔAIC	w	K
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+proxFor500+patchDens100+distStrm1k	19.92	4.90E-06	21
elevMn100+elevMn100²+pfor1k+pfor1k²+distStrm1k	19.96	4.80E-06	17

elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+
    mnPARiFor500+coreFor100+coreFor100²+proxFor500+
    distStrm1k
	20.01	4.70E-06	22

elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+proxFor500	20.22	4.20E-06	19
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+distStrm1k	20.43	3.80E-06	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ coreFor100+coreFor100²+proxFor500+distStrm1k	21.16	2.60E-06	21
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor1k+ coreFor100+coreFor100²+proxFor500+distStrm1k	21.29	2.50E-06	21
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ proxFor500+distStrm1k	21.35	2.40E-06	19
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor500+distStrm1k	21.73	2.00E-06	18
elevMn100+elevMn100²+pfor1k+pfor1k²+coreFor100+ coreFor100²+proxFor500+distStrm1k	22.1	1.60E-06	20
pfor1k+pfor1k²	40.86	1.40E-10	14
null	70.33	5.50E-17	12

White-eared Ground Sparrow

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100	0	1.30E-01	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+distStrm500	0.31	1.10E-01	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100	0.4	1.00E-01	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+ed100+distStrm500	1.19	6.90E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+ed100	1.23	6.80E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+distStrm500	1.32	6.50E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+ed100	1.87	4.90E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+proxFor1k	1.96	4.70E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+proxFor1k+distStrm500	2.29	4.00E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+proxFor1k	2.38	3.80E-02	20

elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+ed100+distStrm500	2.63	3.40E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²	2.85	3.00E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+proxFor1k+ed100+distStrm500	3.18	2.60E-02	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+ coreFor100²+mnPARiFor100+proxFor1k+ed100	3.23	2.50E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+proxFor1k+distStrm500	3.31	2.40E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ distStrm500	3.37	2.30E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+proxFor1k+ed100	3.87	1.80E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ ed100	4.3	1.50E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ ed100+distStrm500	4.55	1.30E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ patchDens100+proxFor1k+ed100+distStrm500	4.62	1.20E-02	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ proxFor1k	4.8	1.10E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ proxFor1k+distStrm500	5.35	8.60E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ proxFor1k+ed100	6.29	5.40E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor100+coreFor100²+ proxFor1k+ed100+distStrm500	6.54	4.80E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed100+ distStrm500	6.85	4.10E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed100	7.08	3.60E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed100	7.39	3.10E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed100+ distStrm500	7.91	2.40E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed100+ ed500+ed500²+distStrm500	7.95	2.40E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ distStrm500	8.37	1.90E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100	8.83	1.50E-03	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed100+distStrm500	8.85	1.50E-03	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100	8.97	1.40E-03	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed100	9.07	1.30E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed100+ ed500+ed500²	9.17	1.30E-03	20

elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+distStrm500	9.25	1.20E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed100	9.39	1.10E-03	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed100+ ed500+ed500²+distStrm500	9.67	1.00E-03	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed100+ed500+ed500²+distStrm500	9.81	9.30E-04	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed100+ ed500+ed500²	9.86	9.10E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed100+distStrm500	9.9	8.90E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+distStrm500	10.3	7.30E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+proxFor1k	10.7	6.00E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+proxFor1k	10.87	5.50E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed100+distStrm500	10.95	5.30E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed100+ed500+ed500²	11.12	4.80E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+distStrm500	11.2	4.70E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed500+ ed500²+distStrm500	11.22	4.60E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed100+ed500+ed500²+distStrm500	11.5	4.00E-04	22
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed100	11.71	3.60E-04	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed100+ed500+ed500²	11.78	3.50E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed500+ ed500²	11.93	3.20E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed500+ ed500²	12.46	2.50E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed500+ ed500²+distStrm500	12.61	2.30E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed100+ distStrm500	12.93	2.00E-04	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed100+ed500+ed500²+ distStrm500	13.12	1.80E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed500+ed500²+distStrm500	13.21	1.70E-04	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed100	13.71	1.30E-04	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed500+ed500²	13.89	1.20E-04	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+distStrm500	14.26	1.00E-04	17

elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed500+ed500²	14.43	9.30E-05	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed500+ed500²+distStrm500	14.6	8.50E-05	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed100+ed500+ed500²	14.67	8.20E-05	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed100+ ed500+ed500²+distStrm500	14.9	7.30E-05	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²	15.11	6.60E-05	16
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+distStrm500	16.16	3.90E-05	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed100+ed500+ ed500²	16.6	3.10E-05	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	16.93	2.60E-05	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed500+ed500²+distStrm500	17.24	2.30E-05	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed500+ ed500²+distStrm500	19.21	8.50E-06	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed500+ed500²	19.95	5.80E-06	19
elevMn1k+elevMn1k²	26.73	2.00E-07	14
null	96.82	1.20E-22	12

Orange-billed Nightingale-Thrush

Model	ΔAIC	*w*	*K*
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+proxFor1k	0	1.80E-01	18
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed100+ ed100²+proxFor1k	0.89	1.10E-01	20
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k	1.04	1.10E-01	17
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ proxFor1k	1.22	9.60E-02	19
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ coreFor100+coreFor100²+ed100+ed100²+proxFor1k	1.55	8.20E-02	22
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed100+ ed100²	2.06	6.30E-02	19
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k	2.35	5.50E-02	18
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ ed100+ed100²+proxFor1k	2.45	5.20E-02	21
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ coreFor100+coreFor100²+ed100+ed100²	2.51	5.00E-02	21
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ coreFor100+coreFor100²+ed100+ed100²+proxFor1k	2.71	4.60E-02	23
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ coreFor100+coreFor100²+proxFor1k	3.09	3.80E-02	20
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ed100	3.47	3.10E-02	20
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ coreFor100+coreFor100²	3.83	2.60E-02	19

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ coreFor100+coreFor100²+ed100+ed100²	3.84	2.60E-02	22
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ coreFor100+coreFor100²+proxFor1k	4.5	1.90E-02	21
elevMn1k+elevMn1k²+pfor500+pfor500²+distStrm1k+ed1k+ coreFor100+coreFor100²	5.33	1.20E-02	20
elevMn1k+elevMn1k²	9.43	1.60E-03	14
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+ed100+ed100²	10.32	1.00E-03	19
elevMn1k+elevMn1k²+pfor500+pfor500²+ed100+ed100²	10.69	8.40E-04	18
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k	10.77	8.10E-04	17
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+proxFor1k	10.89	7.60E-04	18
elevMn1k+elevMn1k²+pfor500+pfor500²+ed100+ed100²+ proxFor1k	11.04	7.10E-04	19
elevMn1k+elevMn1k²+pfor500+pfor500²	11.63	5.30E-04	16
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+coreFor100+ coreFor100²+ed100+ed100²	11.79	4.90E-04	21
elevMn1k+elevMn1k²+pfor500+pfor500²+proxFor1k	11.85	4.70E-04	17
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+coreFor100+ coreFor100²+ed100+ed100²+proxFor1k	11.87	4.70E-04	22
elevMn1k+elevMn1k²+pfor500+pfor500²+coreFor100+ coreFor100²+ed100+ed100²	12.92	2.80E-04	20
elevMn1k+elevMn1k²+pfor500+pfor500²+coreFor100+ coreFor100²+ed100+ed100²+proxFor1k	13.17	2.40E-04	21
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+coreFor100+ coreFor100²	14.14	1.50E-04	19
elevMn1k+elevMn1k²+pfor500+pfor500²+ed1k+coreFor100+ coreFor100²+proxFor1k	14.31	1.40E-04	20
elevMn1k+elevMn1k²+pfor500+pfor500²+coreFor100+coreFor100²	15.18	9.00E-05	18
elevMn1k+elevMn1k²+pfor500+pfor500²+coreFor100+ coreFor100²+proxFor1k	15.48	7.70E-05	19
null	60.07	1.60E-14	12

Slaty-backed Nightingale-Thrush

Model	ΔAIC	w	K
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500	0	2.60E-01	19
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²	1.12	1.50E-01	18
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500+mnPARiFor100	1.97	9.70E-02	20
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500+patchDens100	2	9.50E-02	20

Model			
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500+ed100+ed100²	2.58	7.10E-02	21
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor100	3.09	5.50E-02	19
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+patchDens100	3.11	5.50E-02	19
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+ed100+ed100²	3.3	5.00E-02	20
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500+patchDens100+ed100+ed100²	4.54	2.70E-02	22
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor500+mnPARiFor100+ed100+ed100²	4.57	2.60E-02	22
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+mnPARiFor100+ed100+ed100²	5.27	1.90E-02	21
elevMn500+elevMn500²+pfor500+pfor500²+coreFor1k+ coreFor1k²+patchDens100+ed100+ed100²	5.3	1.80E-02	21
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500	5.87	1.40E-02	17
elevMn500+elevMn500²+pfor500+pfor500²	6.82	8.50E-03	16
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500+ ed100+ed100²	7.61	5.70E-03	19
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500+ mnPARiFor100	7.64	5.70E-03	18
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+mnPARiFor500	7.68	5.60E-03	18
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500+ patchDens100	7.74	5.40E-03	18
elevMn500+elevMn500²+pfor500+pfor500²+ed100+ed100²	7.77	5.30E-03	18
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor100	8.68	3.40E-03	17
elevMn500+elevMn500²+pfor500+pfor500²+ed1k	8.79	3.20E-03	17
elevMn500+elevMn500²+pfor500+pfor500²+patchDens100	8.81	3.20E-03	17
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor100+ ed100+ed100²	9.43	2.30E-03	19
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500+ mnPARiFor100+ed100+ed100²	9.46	2.30E-03	20
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor500+ed100+ed100²	9.49	2.20E-03	20
elevMn500+elevMn500²+pfor500+pfor500²+mnPARiFor500+ patchDens100+ed100+ed100²	9.55	2.20E-03	20
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor500+mnPARiFor100	9.57	2.20E-03	19
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ed100+ed100²	9.58	2.20E-03	19
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor500+patchDens100	9.68	2.00E-03	19
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+mnPARiFor100	10.71	1.20E-03	18
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+patchDens100	10.78	1.20E-03	18

elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor100+ed100+ed100²	11.21	9.50E-04	20
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor500+mnPARiFor100+ed100+ed100²	11.33	9.00E-04	21
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+ mnPARiFor500+patchDens100+ed100+ed100²	11.48	8.30E-04	21
elevMn500+elevMn500²+pfor500+pfor500²+ed1k+patchDens100+ ed100+ed100²	11.58	7.90E-04	20
elevMn500+elevMn500²	24.19	1.40E-06	14
null	112.27	1.10E-25	12

Gray-breasted Wood-Wren

Model	ΔAIC	w	K
elevMn1k+pfor500+coreFor1k+coreFor1k²	0	5.50E-01	16
elevMn1k+pfor500	1.39	2.80E-01	14
elevMn1k+pfor500+ed100+ed100²+coreFor1k+coreFor1k²	3.42	9.90E-02	18
elevMn1k+pfor500+ed100+ed100²	4.01	7.40E-02	16
pfor500	17.98	6.90E-05	13
null	228.8	1.10E-50	12

Rufous-and-white Wren

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ mnPARiFor100+ed100	0	1.00E-01	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ed100	0.41	8.30E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ mnPARiFor100	0.64	7.40E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100	0.84	6.70E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k+ed100	1.37	5.10E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+ed100	1.39	5.10E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ mnPARiFor100+proxFor1k+ed100	1.48	4.80E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ed100	1.96	3.80E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+mnPARiFor100+ proxFor1k	2.02	3.70E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ mnPARiFor100+proxFor1k	2.27	3.30E-02	20
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100	2.32	3.20E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100	2.57	2.80E-02	17

elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100	2.73	2.60E-02	17
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100	2.77	2.50E-02	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+proxFor1k+ed100	2.88	2.40E-02	21
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+ proxFor1k+ed100	2.93	2.30E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+patchDens100+proxFor1k	3.82	1.50E-02	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ ed100	3.82	1.50E-02	19
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ patchDens100+proxFor1k	3.99	1.40E-02	20
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+ed100	4.25	1.20E-02	18
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+ed100	4.3	1.20E-02	18
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+patchDens500	4.35	1.20E-02	18
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+ patchDens500	4.47	1.10E-02	18
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+proxFor1k	4.7	9.70E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+ed100	4.71	9.60E-03	17
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+proxFor1k	4.72	9.60E-03	18
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100	4.73	9.50E-03	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²	5.06	8.10E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor1k+ed100	5.24	7.40E-03	20
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ ed100	5.33	7.10E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k+ed100	5.4	6.80E-03	18
elevMn1k+elevMn1k²+pfor1k+pfor1k²	5.62	6.10E-03	16
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100	5.67	6.00E-03	17
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+ patchDens500+ed100	5.78	5.60E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+ patchDens500+ed100	5.94	5.20E-03	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ ed100	6.01	5.00E-03	18
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+proxFor1k+ ed100	6.21	4.60E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+ patchDens500+proxFor1k	6.22	4.50E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+proxFor1k+ ed100	6.25	4.50E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+ patchDens500+proxFor1k	6.32	4.30E-03	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ patchDens500	6.51	3.90E-03	18

elevMn1k+elevMn1k²+pfor1k+pfor1k²+proxFor1k	6.64	3.70E-03	17
elevMn1k+elevMn1k²+pfor1k+pfor1k²+coreFor1k+coreFor1k²+ proxFor1k	6.67	3.60E-03	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ proxFor1k	6.71	3.50E-03	18
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ patchDens500+ed100	7.13	2.90E-03	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ patchDens500	7.23	2.70E-03	18
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ proxFor1k+ed100	7.33	2.60E-03	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ patchDens500+ed100	7.6	2.30E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens100+ patchDens500+proxFor1k+ed100	7.61	2.30E-03	20
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ proxFor1k	7.62	2.30E-03	18
elevMn1k+elevMn1k²+ed1k+ed1k²+mnPARiFor100+ patchDens500+proxFor1k+ed100	7.74	2.10E-03	20
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ proxFor1k+ed100	7.99	1.90E-03	19
elevMn1k+elevMn1k²+mnPARiFor100	8.34	1.60E-03	15
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ patchDens500+proxFor1k	8.51	1.40E-03	19
elevMn1k+elevMn1k²+patchDens100	8.99	1.10E-03	15
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+mnPARiFor100+ patchDens500+proxFor1k+ed100	9.13	1.10E-03	20
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ patchDens500+proxFor1k	9.23	1.00E-03	19
elevMn1k+elevMn1k²+ed1k+ed1k²	9.37	9.40E-04	16
elevMn1k+elevMn1k²+mnPARiFor100+ed100	9.52	8.70E-04	16
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens100+ patchDens500+proxFor1k+ed100	9.6	8.40E-04	20
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens500	9.72	7.90E-04	17
elevMn1k+elevMn1k²+mnPARiFor100+proxFor1k	9.78	7.70E-04	16
elevMn1k+elevMn1k²+patchDens100+ed100	9.97	7.00E-04	16
elevMn1k+elevMn1k²+mnPARiFor100+patchDens500	10.24	6.10E-04	16
elevMn1k+elevMn1k²+patchDens100+proxFor1k	10.42	5.60E-04	16
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²	10.59	5.10E-04	16
elevMn1k+elevMn1k²+patchDens100+patchDens500	10.68	4.90E-04	16
elevMn1k+elevMn1k²+mnPARiFor100+proxFor1k+ed100	10.95	4.30E-04	17
elevMn1k+elevMn1k²+ed1k+ed1k²+ed100	11.03	4.10E-04	17
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+ed100	11.14	3.90E-04	17
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens500+ed100	11.14	3.90E-04	18

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+ed1k+ed1k²+proxFor1k	11.37	3.50E-04	17
elevMn1k+elevMn1k²+patchDens100+proxFor1k+ed100	11.4	3.40E-04	17
elevMn1k+elevMn1k²+mnPARiFor100+patchDens500+ed100	11.45	3.30E-04	17
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens500	11.48	3.30E-04	17
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens500+proxFor1k	11.58	3.10E-04	18
elevMn1k+elevMn1k²+patchDens100+patchDens500+ed100	11.72	2.90E-04	17
elevMn1k+elevMn1k²+mnPARiFor100+patchDens500+proxFor1k	11.72	2.90E-04	17
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens500+ ed100	12.02	2.50E-04	18
elevMn1k+elevMn1k²+patchDens100+patchDens500+proxFor1k	12.18	2.30E-04	17
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+proxFor1k	12.39	2.10E-04	17
elevMn1k+elevMn1k²+mnPARiFor100+patchDens500+ proxFor1k+ed100	12.92	1.60E-04	18
elevMn1k+elevMn1k²+ed1k+ed1k²+patchDens500+proxFor1k+ ed100	12.95	1.60E-04	19
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+proxFor1k+ed100	12.99	1.50E-04	18
elevMn1k+elevMn1k²+ed1k+ed1k²+proxFor1k+ed100	13.03	1.50E-04	18
elevMn1k+elevMn1k²+patchDens100+patchDens500+ proxFor1k+ed100	13.21	1.40E-04	18
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens500+ proxFor1k	13.44	1.20E-04	18
elevMn1k+elevMn1k²+coreFor1k+coreFor1k²+patchDens500+ proxFor1k+ed100	14	9.30E-05	19
elevMn1k+elevMn1k²	14.01	9.20E-05	14
elevMn1k+elevMn1k²+patchDens500	14.77	6.30E-05	15
elevMn1k+elevMn1k²+ed100	15.12	5.30E-05	15
elevMn1k+elevMn1k²+proxFor1k	15.33	4.80E-05	15
elevMn1k+elevMn1k²+patchDens500+ed100	15.94	3.50E-05	16
elevMn1k+elevMn1k²+patchDens500+proxFor1k	16.25	3.00E-05	16
elevMn1k+elevMn1k²+proxFor1k+ed100	16.41	2.80E-05	16
elevMn1k+elevMn1k²+patchDens500+proxFor1k+ed100	17.4	1.70E-05	17
null	99.44	2.60E-23	12

Social Flycatcher

Model	ΔAIC	w	K
ed500+ed500²+ed100+patchDens500+patchDens500²+ elevMn100+elevMn100²+patchDens1k+patchDens1k²+ distStrm1k	0	1.20E-01	22
ed500+ed500²+patchDens500+patchDens500²+elevMn100+ elevMn100²+patchDens1k+patchDens1k²+distStrm1k	0.049	1.20E-01	21

Model			
ed500+ed500²+ed100+patchDens500+patchDens500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k+patchDens100+patchDens100²	0.141	1.10E-01	24
ed500+ed500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k	0.412	1.00E-01	19
ed500+ed500²+ed100+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k	0.774	8.40E-02	20
ed500+ed500²+ed100+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k+patchDens100+patchDens100²	1.329	6.30E-02	22
ed500+ed500²+patchDens500+patchDens500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k+patchDens100+patchDens100²	1.499	5.80E-02	23
ed500+ed500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²+distStrm1k+patchDens100+patchDens100²	2.125	4.30E-02	21
ed500+ed500²+ed100+elevMn100+elevMn100²+distStrm1k	2.508	3.50E-02	18
ed500+ed500²+elevMn100+elevMn100²+distStrm1k	2.799	3.00E-02	17
ed500+ed500²+ed100+patchDens500+patchDens500²+elevMn100+elevMn100²+distStrm1k	3.145	2.60E-02	20
ed500+ed500²+patchDens500+patchDens500²+elevMn100+elevMn100²+distStrm1k	3.716	1.90E-02	19
ed500+ed500²+ed100+patchDens500+patchDens500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²	3.941	1.70E-02	21
ed500+ed500²+ed100+elevMn100+elevMn100²+distStrm1k+patchDens100+patchDens100²	4.18	1.50E-02	20
ed500+ed500²+ed100+patchDens500+patchDens500²+elevMn100+elevMn100²+distStrm1k+patchDens100+patchDens100²	4.276	1.50E-02	22
ed500+ed500²+ed100+patchDens500+patchDens500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²+patchDens100+patchDens100²	4.331	1.40E-02	23
ed500+ed500²+patchDens500+patchDens500²+elevMn100+elevMn100²+patchDens1k+patchDens1k²	5.042	9.90E-03	20
ed500+ed500²+ed100+patchDens500+patchDens500²+patchDens1k+patchDens1k²+distStrm1k+patchDens100+patchDens100²	5.109	9.60E-03	22
ed500+ed500²+ed100+patchDens500+patchDens500²+patchDens1k+patchDens1k²+patchDens100+patchDens100²	5.341	8.50E-03	21
ed500+ed500²+ed100+patchDens500+patchDens500²+patchDens1k+patchDens1k²+distStrm1k	5.352	8.50E-03	20
ed500+ed500²+ed100+patchDens500+patchDens500²+patchDens1k+patchDens1k²	5.461	8.00E-03	19
ed500+ed500²+elevMn100+elevMn100²+distStrm1k+patchDens100+patchDens100²	5.615	7.40E-03	19
ed500+ed500²+patchDens500+patchDens500²+patchDens1k+patchDens1k²+distStrm1k	6.134	5.70E-03	19

ed500+ed500²+patchDens500+patchDens500²+elevMn100+ elevMn100²+distStrm1k+patchDens100+patchDens100²	6.247	5.40E-03	21
ed500+ed500²+ed100+patchDens500+patchDens500²+distStrm1k	6.326	5.20E-03	18
ed500+ed500²+patchDens500+patchDens500²+patchDens1k+ patchDens1k²	6.806	4.10E-03	18
ed500+ed500²+ed100+patchDens500+patchDens500²+ distStrm1k+patchDens100+patchDens100²	6.837	4.00E-03	20

ed500+ed500²+patchDens500+patchDens500²+elevMn100+
    elevMn100²+patchDens1k+patchDens1k²+patchDens100+
    patchDens100²
	7.068	3.60E-03	22

ed500+ed500²+ed100+elevMn100+elevMn100²+patchDens1k+ patchDens1k²	7.155	3.40E-03	19
ed500+ed500²+patchDens500+patchDens500²+distStrm1k	7.194	3.40E-03	17
ed500+ed500²+ed100+patchDens500+patchDens500²	7.216	3.30E-03	17
ed500+ed500²+patchDens500+patchDens500²+patchDens1k+ patchDens1k²+distStrm1k+patchDens100+patchDens100²	7.742	2.60E-03	21
ed500+ed500²+ed100+patchDens500+patchDens500²+ elevMn100+elevMn100²	7.854	2.40E-03	19
ed500+ed500²+ed100+patchDens500+patchDens500²+ patchDens100+patchDens100²	7.935	2.30E-03	19
ed500+ed500²+elevMn100+elevMn100²+patchDens1k+ patchDens1k²	8.096	2.20E-03	18
ed500+ed500²+ed100+elevMn100+elevMn100²+patchDens1k+ patchDens1k²+patchDens100+patchDens100²	8.18	2.10E-03	21
ed500+ed500²+ed100+distStrm1k	8.378	1.90E-03	16
ed500+ed500²+distStrm1k	8.454	1.80E-03	15
ed500+ed500²+patchDens500+patchDens500²+patchDens1k+ patchDens1k²+patchDens100+patchDens100²	8.687	1.60E-03	20
ed500+ed500²+patchDens500+patchDens500²	8.797	1.50E-03	16
ed500+ed500²+ed100+patchDens500+patchDens500²+ elevMn100+elevMn100²+patchDens100+patchDens100²	9.138	1.30E-03	21
ed500+ed500²+patchDens1k+patchDens1k²+distStrm1k	9.444	1.10E-03	17
ed500+ed500²+patchDens500+patchDens500²+distStrm1k+ patchDens100+patchDens100²	9.52	1.10E-03	19
ed500+ed500²+patchDens500+patchDens500²+elevMn100+ elevMn100²	9.542	1.00E-03	18
ed500+ed500²+ed100+distStrm1k+patchDens100+patchDens100²	9.604	1.00E-03	18
ed500+ed500²+ed100+patchDens1k+patchDens1k²+distStrm1k	9.662	9.80E-04	18
ed500+ed500²+ed100+patchDens1k+patchDens1k²+distStrm1k+ patchDens100+patchDens100²	10.102	7.90E-04	20
ed500+ed500²+elevMn100+elevMn100²+patchDens1k+ patchDens1k²+patchDens100+patchDens100²	10.611	6.10E-04	20
ed500+ed500²+ed100+patchDens1k+patchDens1k²	10.878	5.40E-04	17
ed500+ed500²+ed100+elevMn100+elevMn100²	11.041	4.90E-04	17

Model	ΔAIC	w	K
ed500+ed500²+distStrm1k+patchDens100+patchDens100²	11.16	4.70E-04	17
ed500+ed500²+ed100	11.387	4.20E-04	15
ed500+ed500²+patchDens1k+patchDens1k²	11.421	4.10E-04	16
ed500+ed500²+ed100+patchDens1k+patchDens1k²+ patchDens100+patchDens100²	11.452	4.00E-04	19
ed500+ed500²+patchDens500+patchDens500²+patchDens100+ patchDens100²	11.454	4.00E-04	18
ed500+ed500²+patchDens1k+patchDens1k²+distStrm1k+ patchDens100+patchDens100²	11.492	3.90E-04	19
ed500+ed500²+patchDens500+patchDens500²+elevMn100+ elevMn100²+patchDens100+patchDens100²	12.477	2.40E-04	20
ed500+ed500²+elevMn100+elevMn100²	12.613	2.30E-04	16
ed500+ed500²+ed100+patchDens100+patchDens100²	13.234	1.60E-04	17
ed500+ed500²+ed100+elevMn100+elevMn100²+patchDens100+ patchDens100²	13.458	1.50E-04	19
ed500+ed500²+patchDens1k+patchDens1k²+patchDens100+ patchDens100²	13.804	1.20E-04	18
ed500+ed500²+patchDens100+patchDens100²	15.653	4.90E-05	16
ed500+ed500²+elevMn100+elevMn100²+patchDens100+ patchDens100²	16.075	4.00E-05	18
ed500+ed500²	23.28	1.10E-06	13
null	64.455	1.20E-15	12

Keel-billed Toucan

Model	ΔAIC	w	K
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ed100+ mnPARiFor100+distStrm100	0	2.30E-01	20
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ed100+ distStrm100	1.71	9.60E-02	19
elevMn1k+elevMn1k²+coreFor100+ed100+mnPARiFor100+ distStrm100	1.89	8.80E-02	18
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ed100+ mnPARiFor100	2.35	7.00E-02	19
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ mnPARiFor100+distStrm100	2.81	5.60E-02	19
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+distStrm100	3.12	4.70E-02	18
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ patchDens100+patchDens100²+distStrm100	3.41	4.10E-02	20
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ mnPARiFor100	3.71	3.50E-02	18
elevMn1k+elevMn1k²+coreFor100+ed100+mnPARiFor100	3.75	3.50E-02	17
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ed100+ patchDens100+patchDens100²+distStrm100	3.88	3.20E-02	21

Model	ΔAIC	w_i	K
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ed100	4.24	2.70E-02	18
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²+ mnPARiFor100+distStrm100	4.4	2.50E-02	20
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²	4.43	2.50E-02	17
elevMn1k+elevMn1k²+coreFor100+ed100+distStrm100	4.75	2.10E-02	17
elevMn1k+elevMn1k²+coreFor100+patchDens100+ patchDens100²+distStrm100	4.81	2.00E-02	18
elevMn1k+elevMn1k²+coreFor100+pfor1k+pfor1k²+ patchDens100+patchDens100²	4.84	2.00E-02	19
elevMn1k+elevMn1k²+coreFor100+ed100+patchDens100+ patchDens100²+distStrm100	5.34	1.60E-02	19
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²+ mnPARiFor100	5.65	1.30E-02	19
elevMn1k+elevMn1k²+elevMn1k+coreFor100+pfor1k+pfor1k²+ ed100+patchDens100+patchDens100²	6.06	1.10E-02	20
elevMn1k+elevMn1k²+coreFor100+patchDens100+patchDens100²	6.14	1.10E-02	17
elevMn1k+elevMn1k²+coreFor100+mnPARiFor100+distStrm100	6.5	8.80E-03	17
elevMn1k+elevMn1k²+coreFor100+mnPARiFor100	6.61	8.30E-03	16
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²+ distStrm100	6.66	8.10E-03	19
elevMn1k+elevMn1k²+coreFor100+distStrm100	7.1	6.50E-03	16
elevMn1k+elevMn1k²+coreFor100+ed100	7.14	6.40E-03	16
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²+ patchDens100+patchDens100²+distStrm100	7.2	6.20E-03	20
elevMn1k+elevMn1k²+coreFor100+ed100+patchDens100+ patchDens100²	7.38	5.60E-03	18
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²+ patchDens100+patchDens100²	7.54	5.20E-03	19
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²	7.67	4.90E-03	18
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²+ patchDens100+patchDens100²+distStrm100	7.71	4.80E-03	21
elevMn1k+elevMn1k²+coreFor100	7.93	4.30E-03	15
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²+ mnPARiFor100	8.26	3.60E-03	18
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²+ mnPARiFor100+distStrm100	8.44	3.30E-03	19
elevMn1k+elevMn1k²+coreFor100+ed100+pfor500+pfor500²+ patchDens100+patchDens100²	8.65	3.00E-03	20
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²	9.1	2.40E-03	17
elevMn1k+elevMn1k²+coreFor100+pfor500+pfor500²+ distStrm100	9.2	2.30E-03	18
elevMn1k+elevMn1k²	30.99	4.20E-08	14
null	64.44	2.30E-15	12

Northern Emerald-Toucanet

Model	ΔAIC	*w*	*K*
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ distStrm1k+proxFor500	0	5.20E-01	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ ed500+distStrm1k+proxFor500	1.48	2.50E-01	20
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ distStrm1k	3.97	7.20E-02	18
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ ed500+distStrm1k	5.32	3.60E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ proxFor500	6.03	2.60E-02	18
elevMn100+elevMn100²+pfor1k+pfor1k²+distStrm1k+proxFor500	6.53	2.00E-02	18
elevMn100+elevMn100²+pfor1k+pfor1k²+distStrm1k	7.07	1.50E-02	17
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+distStrm1k+ proxFor500	7.33	1.30E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500	7.55	1.20E-02	17
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ ed500+proxFor500	7.62	1.20E-02	19
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+distStrm1k	7.94	9.80E-03	18
elevMn100+elevMn100²+pfor1k+pfor1k²+mnPARiFor500+ed500	9.06	5.60E-03	18
elevMn100+elevMn100²	10.46	2.80E-03	14
elevMn100+elevMn100²+pfor1k+pfor1k²	10.87	2.30E-03	16
elevMn100+elevMn100²+pfor1k+pfor1k²+proxFor500	11.49	1.70E-03	17
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500	11.87	1.40E-03	17
elevMn100+elevMn100²+pfor1k+pfor1k²+ed500+proxFor500	12.43	1.00E-03	18
null	99.63	1.20E-22	12

APPENDIX H

PARAMETER ESTIMATES WITH STANDARD ERRORS FOR COVARIATES IN TOP-

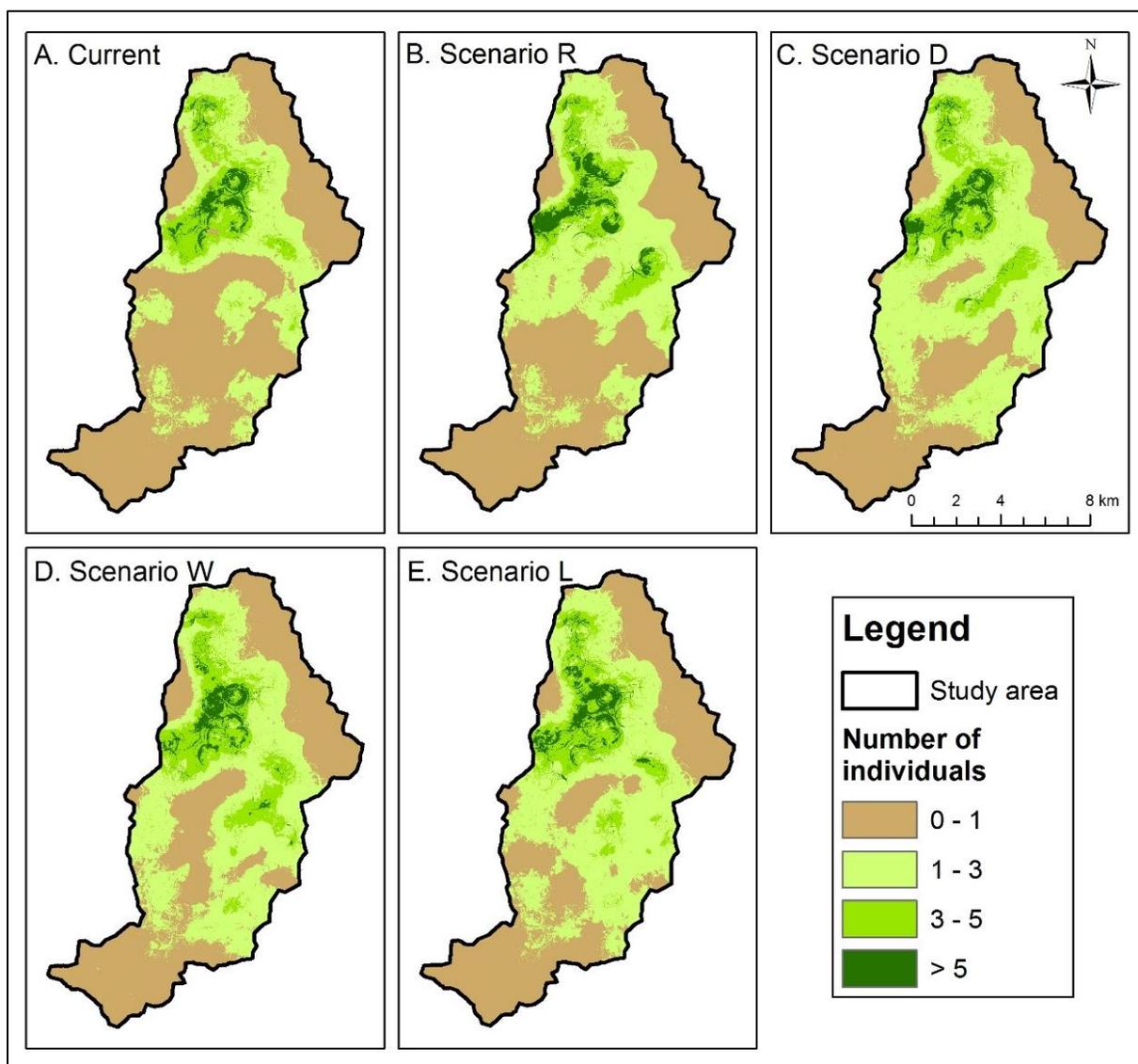RANKED MULTI-SCALE ABUNDANCE MODELS FOR FOCAL SPECIES

Variable	Long-tailed Manakin	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren	Social Flycatcher	Keel-billed Toucan	Northern Emerald-Toucanet
Intercept	1.17±0.348	2.630±1.685	1.716±0.632	-0.316±0.479	-4.052±1.651	1.902±0.3827	4.196±1.150	0.583±0.515	1.218±0.4572	0.289±0.9941
elevMn100		0.710±0.171						-0.446±0.212		2.205±0.6690
elevMn100²		-0.127±0.164						-0.602±0.206		-1.363±0.4164
elevMn500					8.203±2.383					
elevMn500²					-3.148±1.093					
elevMn1k	-0.161±0.179		1.452±0.434	1.533±0.852		0.318±0.1882	1.659±0.464		0.303±0.1633	
elevMn1k²	-0.913±0.161		-1.149±0.357	-2.792±0.803		-0.896±0.1603			-0.479±0.1340	
distStrm100									0.180±0.0853	
distStrm500										
distStrm1k	-0.388±0.145			-0.972±0.280				-0.491±0.209		-0.431±0.1585
pfor100										
pfor100²										
pfor500				0.567±0.285	0.432±0.588		1.943±1.114			
pfor500²				-0.362±0.316	0.816±0.499					
pfor1k	0.269±0.166	-0.557±0.205	-0.222±0.228			-0.156±0.1793			-0.337±0.1666	0.227±0.2150
pfor1k²	-0.468±0.185	-0.863±0.223	-0.788±0.251			-0.535±0.1850			-0.283±0.1320	-0.149±0.2237
coreFor100			0.885±0.288						-0.304±0.1803	
coreFor100²			-0.881±0.252							
coreFor500										

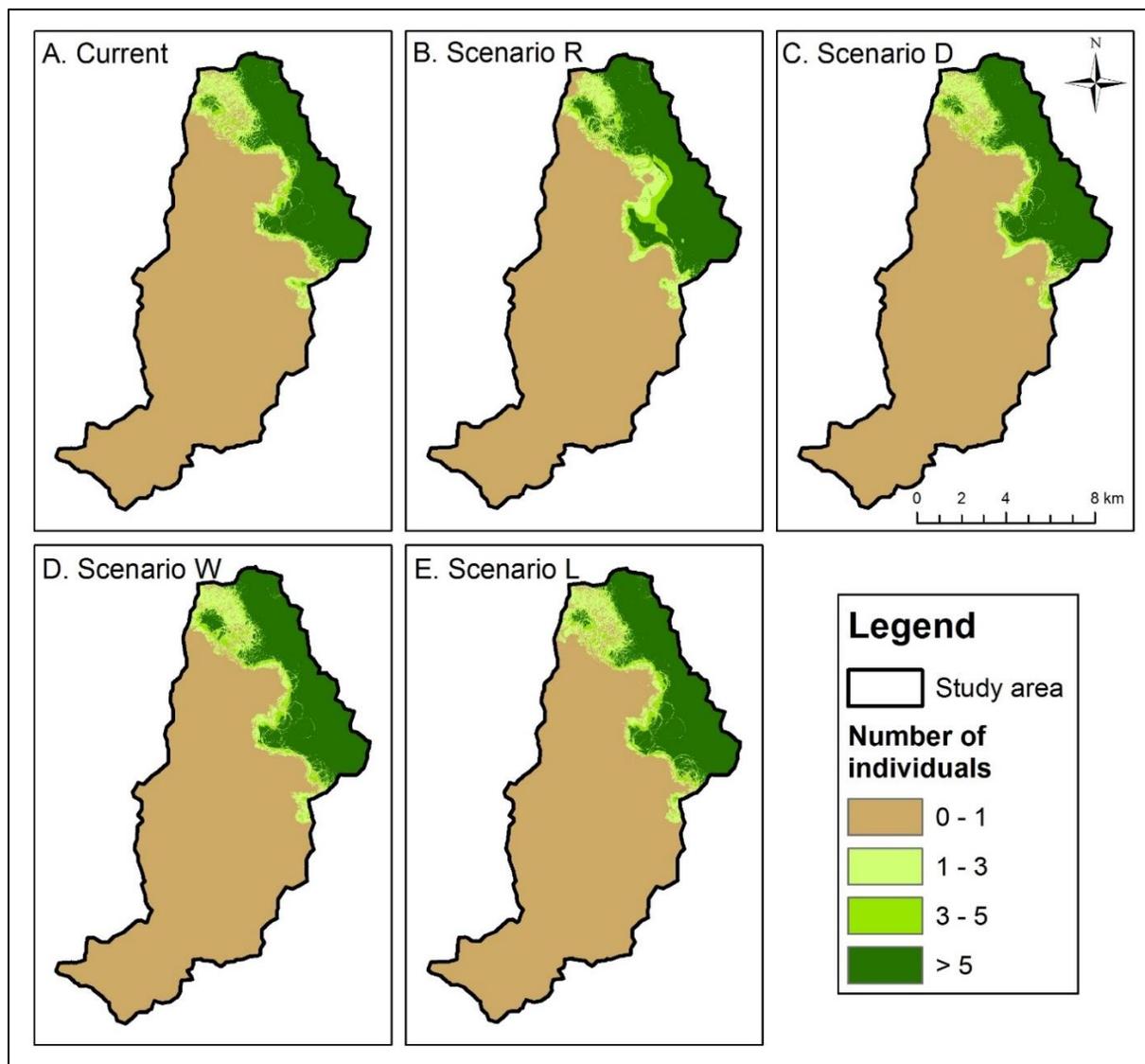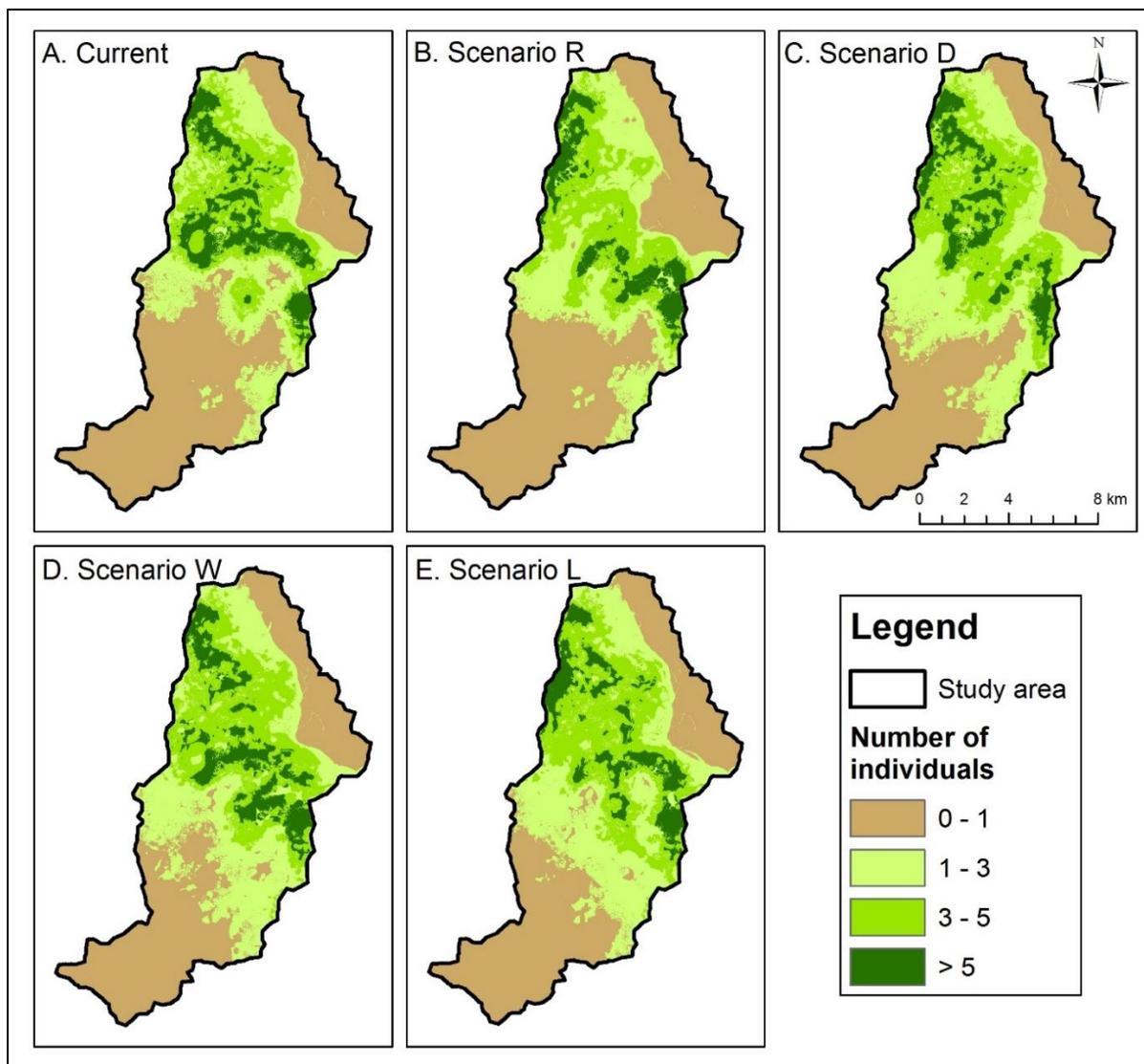| Variable	Long-tailed Manakin	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren	Social Flycatcher	Keel-billed Toucan	Northern Emerald-Toucanet
coreFor500²										
coreFor1k					0.813±0.615	0.512±0.3346	1.354±0.599			
coreFor1k²					-0.423±0.201	-0.314±0.1569	-0.374±0.179			
ed100						-0.143±0.0899		0.167±0.116	0.185±0.0829	
ed100²										
ed500		-0.229±0.168						1.088±0.296		
ed500²		-0.537±0.161						-0.515±0.190		
ed1k										
ed1k²										
patchDens100	-0.408±0.202									
patchDens100²										
patchDens500		-0.236±0.150						0.407±0.217		
patchDens500²								-0.274±0.143		
patchDens1k								-0.540±0.220		
patchDens1k²								0.110±0.147		
mnPARiFor100			0.381±0.189			0.252±0.1122			-0.162±0.0828	
mnPARiFor500		-0.172±0.111			0.522±0.320					0.413±0.1503
mnPARiFor1k				-0.290±0.174						
proxFor100										
proxFor500	0.178±0.072									0.231±0.0903
proxFor1k		0.152±0.103								

Variable	Long-tailed Manakin	Lesson's Motmot	White-eared Ground-Sparrow	Orange-billed Nightingale-Thrush	Slaty-backed Nightingale-Thrush	Rufous-and-white Wren	Gray-breasted Wood-Wren	Social Flycatcher	Keel-billed Toucan	Northern Emerald-Toucanet
Temp.	-0.8467± 0.45	-3.017± 1.726	-1.703± 0.715	-0.5918± 0.555	-3.5485± 0.790	-1.502± 0.375	-0.606± 1.070	-1.3728± 0.584	-1.486± 0.571	-1.927± 1.122
Day	-0.0699± 0.189	-0.219± 0.163	0.345± 0.204	-0.1648± 0.339	0.1257± 0.224	-0.526± 0.178	-0.417± 0.324	-0.2406± 0.210	-0.259± 0.167	0.327± 0.188
Year	0.0338± 0.157	0.131± 0.135	0.916± 0.260	0.1126± 0.287	0.3040± 0.218	0.401± 0.149	-0.696± 0.408	-0.2275± 0.198	-0.507± 0.166	0.548± 0.178
Time	-0.1404± 0.137	-0.664± 0.157	-0.498± 0.189	-0.0656± 0.256	0.0584± 0.165	-0.325± 0.121	-0.279± 0.188	0.0743± 0.170	-0.281± 0.121	0.157± 0.128
Wind	-0.334± 0.177	-0.456± 0.195	-0.030± 0.173	0.0477± 0.410	0.1846± 0.169	-0.481± 0.223	-0.601± 0.278	-0.1826± 0.206	-0.536± 0.211	-0.061± 0.156
Obs. A	1.078± 0.304	1.5857± 0.380	1.144± 0.421	1.289± 0.533	1.183± 0.610	2.483± 0.431	1.167± 0.472	1.071± 0.417	2.120± 0.445	2.46±± 0.618
Obs. B	0.17± 1.066	8.9624± 83.390	-13.225± 182.861	-18.056± 3290.283	-13.020± 1106.257	10.721± 449.032	5.931± 26.763	-0.960± 1.201	-14.741± 348.318	-10.54± 50.145
Obs. C	-0.754± 0.578	-0.9658± 0.875	-17.61± 3954.480	13.965± 745.840	-0.311± 1.249	-1.224± 1.179	0.388± 0.829	-0.588± 0.700	-4.372± 0.847	5.93± 34.860
Obs. D	-0.701± 0.507	-0.7446± 0.574	0.263± 1.068	12.030± 382.687	-1.396± 1.141	-0.937± 0.653	-0.857± 0.646	0.773± 1.010	-0.717± 0.604	-2.06± 0.816
Obs. E	1.725± 1.023	0.0609± 0.663	-1.964± 0.538	0.772± 1.084	0.283± 0.847	-0.257± 0.639	-0.682± 0.625	0.524± 0.806	-1.036± 1.093	-2.26± 0.676
Obs. F	-1.576± 0.453	-0.4525± 0.671	1.349± 1.040	3.586± 68.814	0.801± 1.105	-1.398± 0.733	-0.346± 0.808	-0.665± 0.558	-1.178± 0.542	-1.20± 0.907

APPENDIX I

MAPS OF PREDICTED ABUNDANCE OF FOCAL SPECIES IN THE CURRENT STUDY

AREA LANDSCAPE AND UNDER EACH REFORESTATION SCENARIO

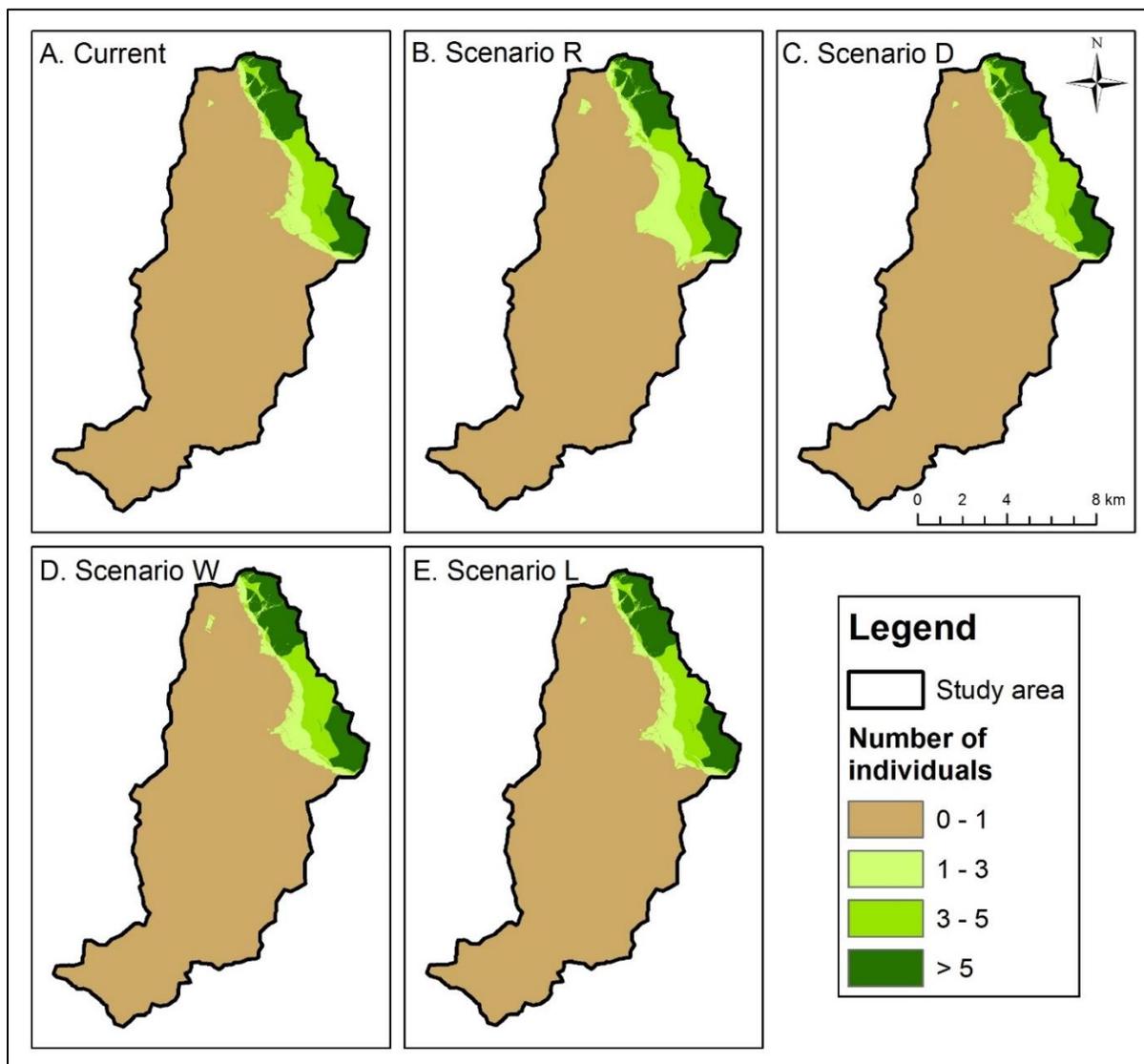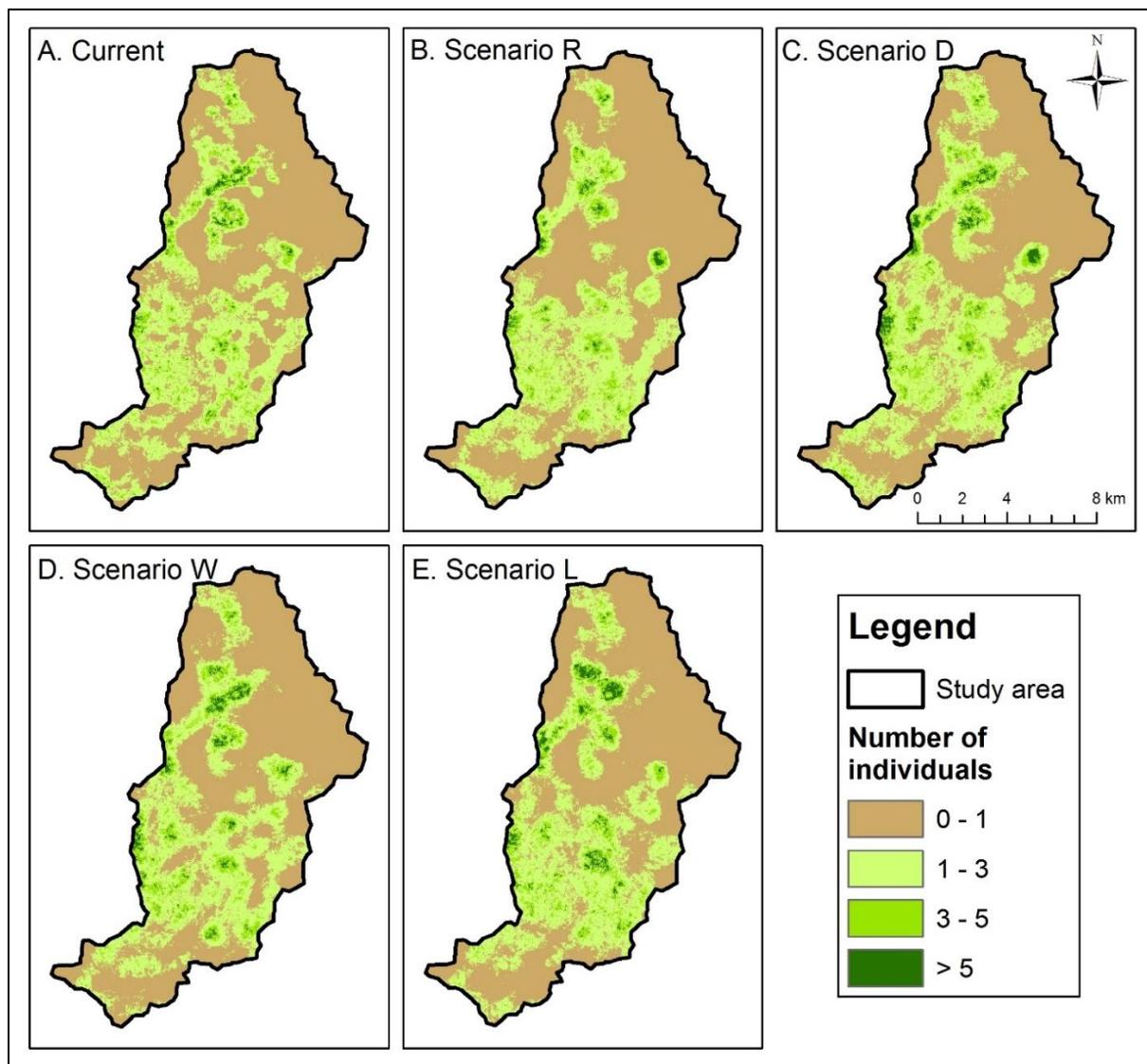**Long-tailed Manakin**

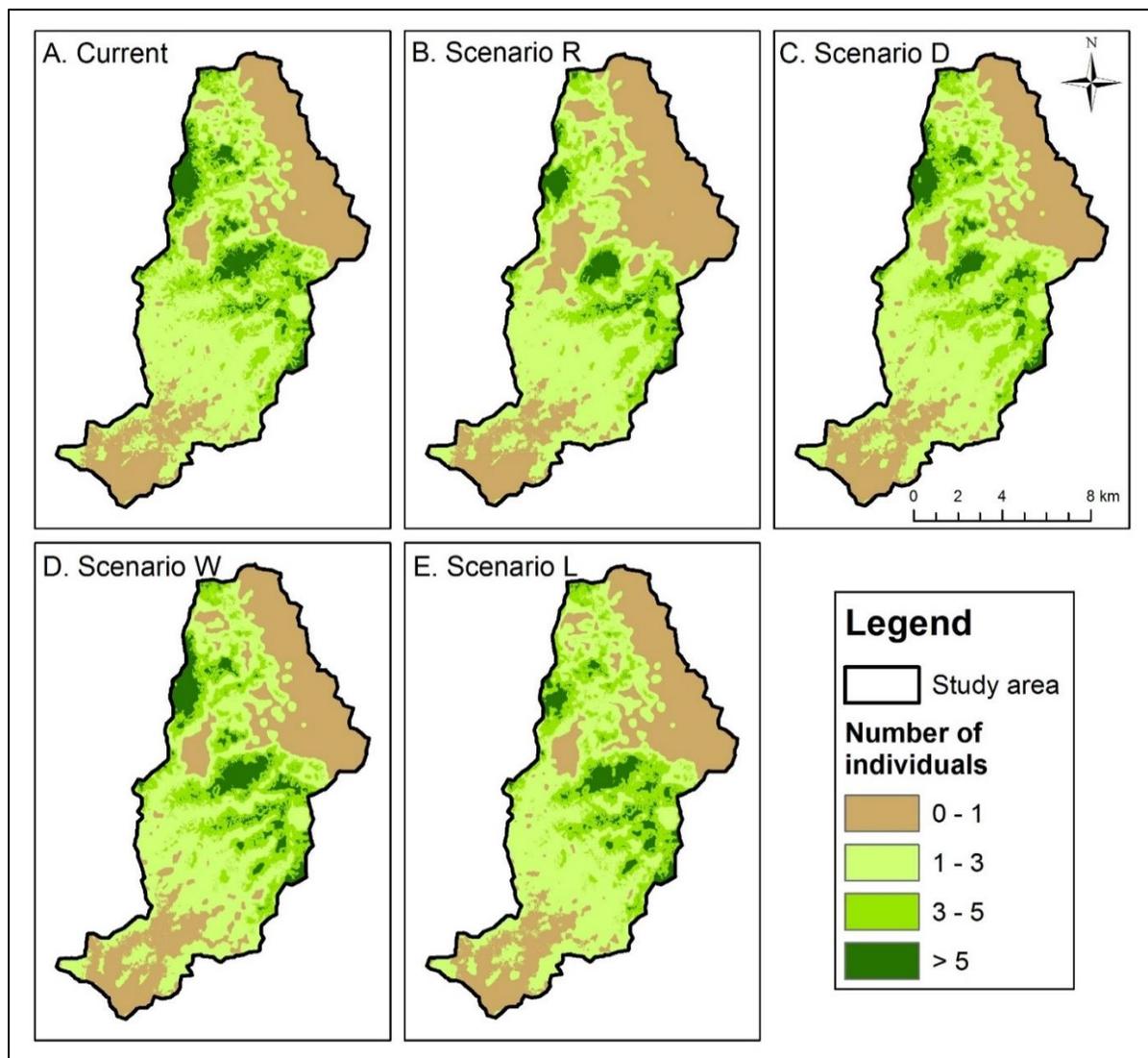**Lesson's Motmot**

White-eared Ground-Sparrow

Orange-billed Nightingale-Thrush

Slaty-backed Nightingale-Thrush

Rufous-and-white Wren

Gray-breasted Wood-Wren

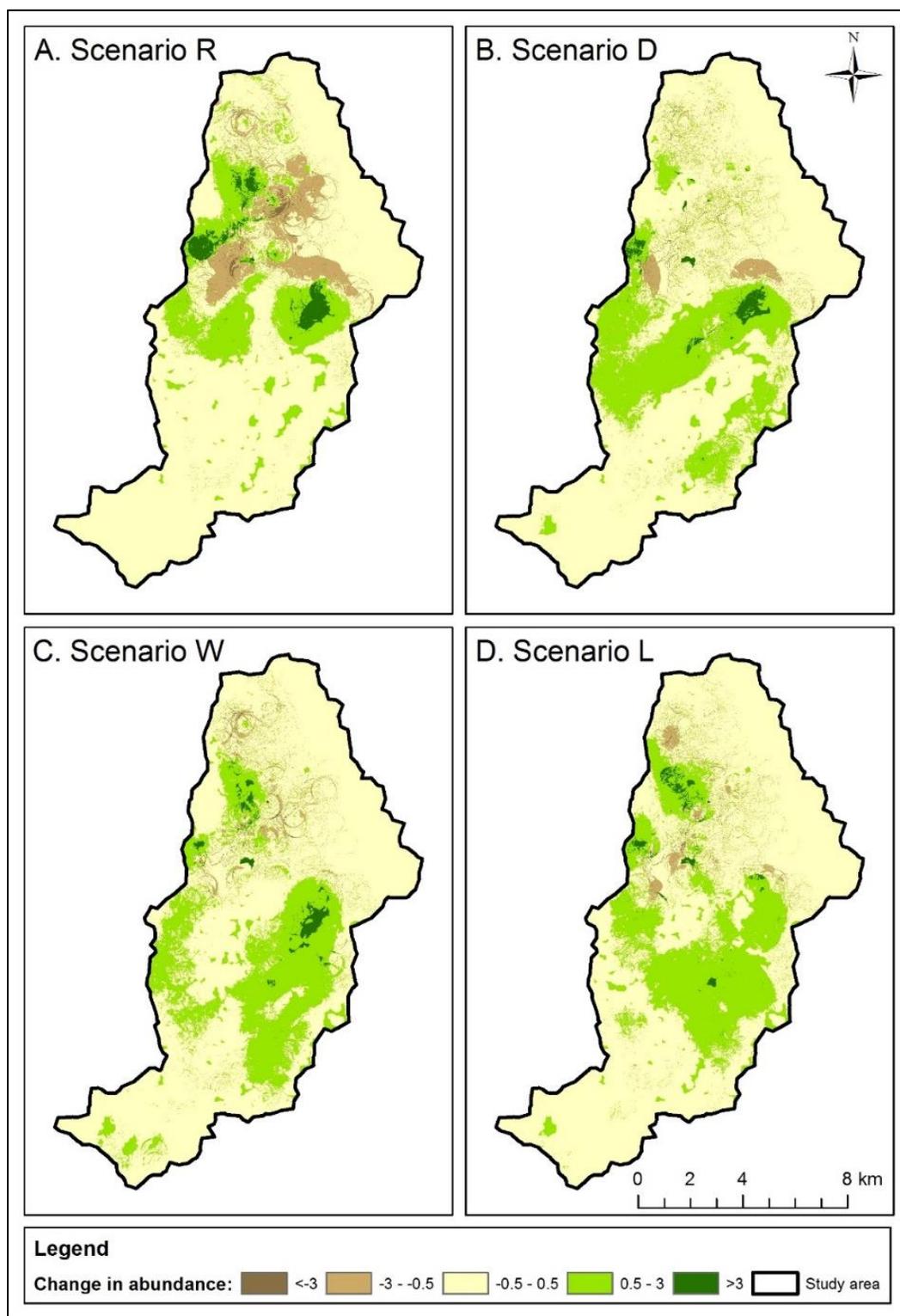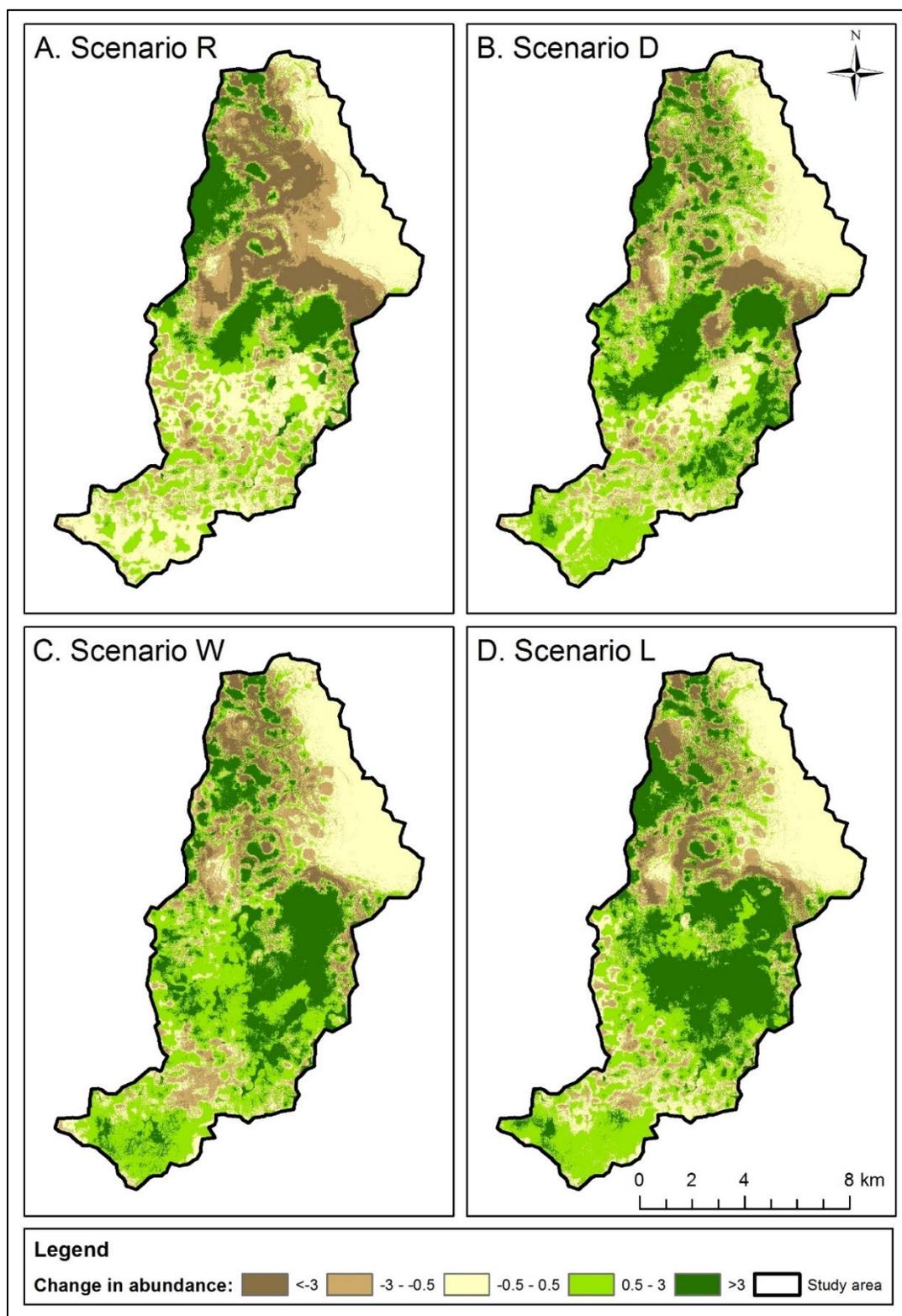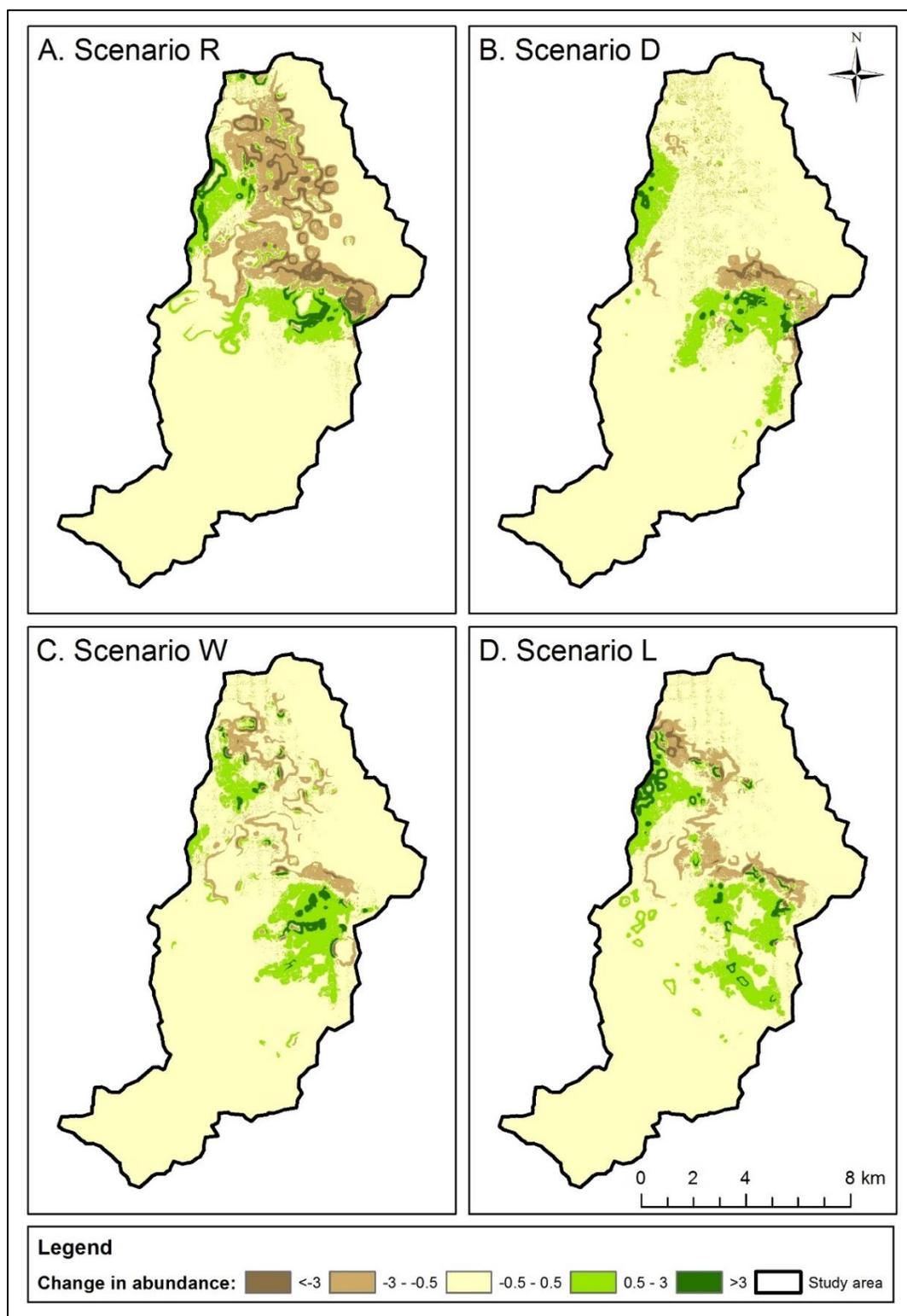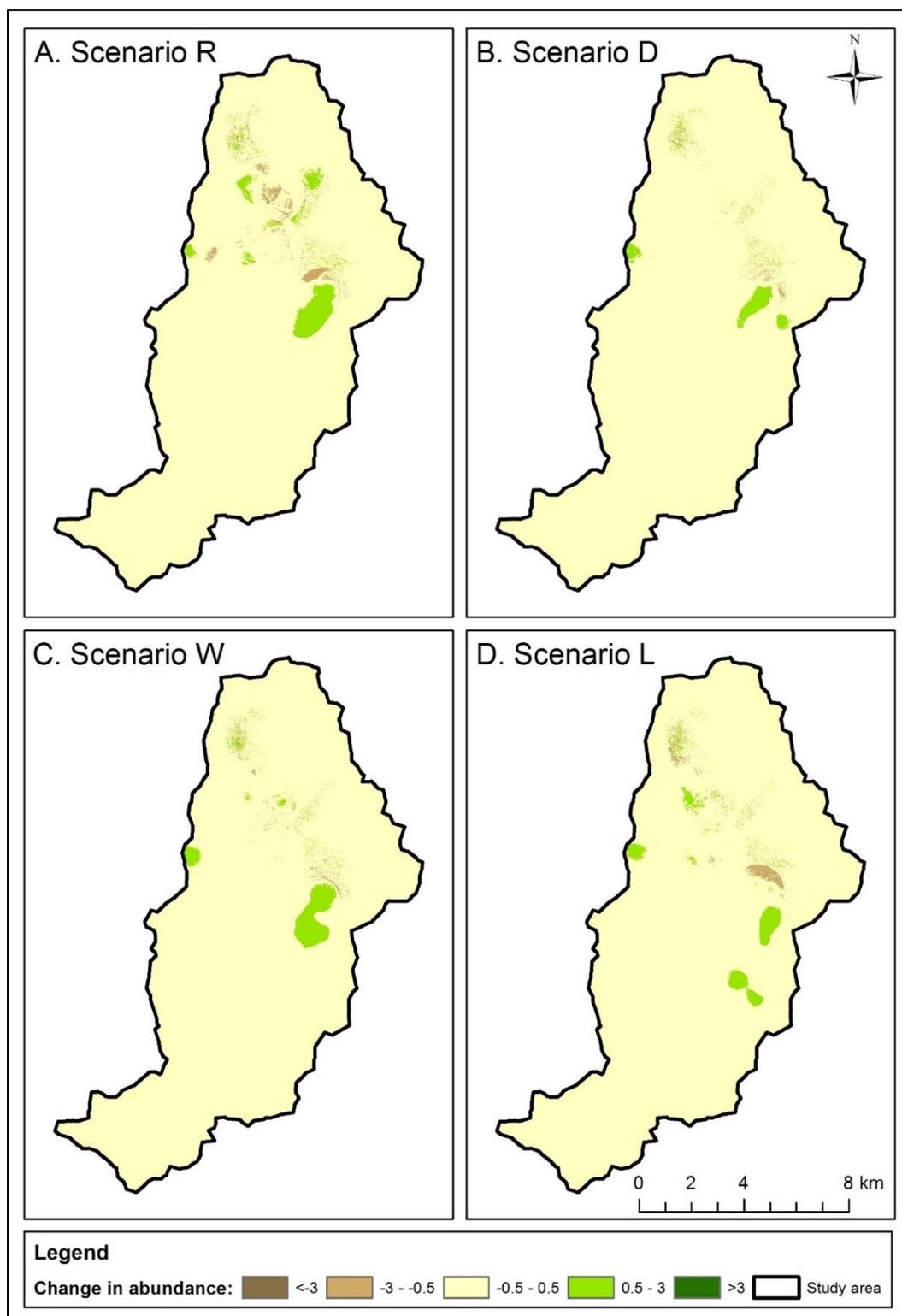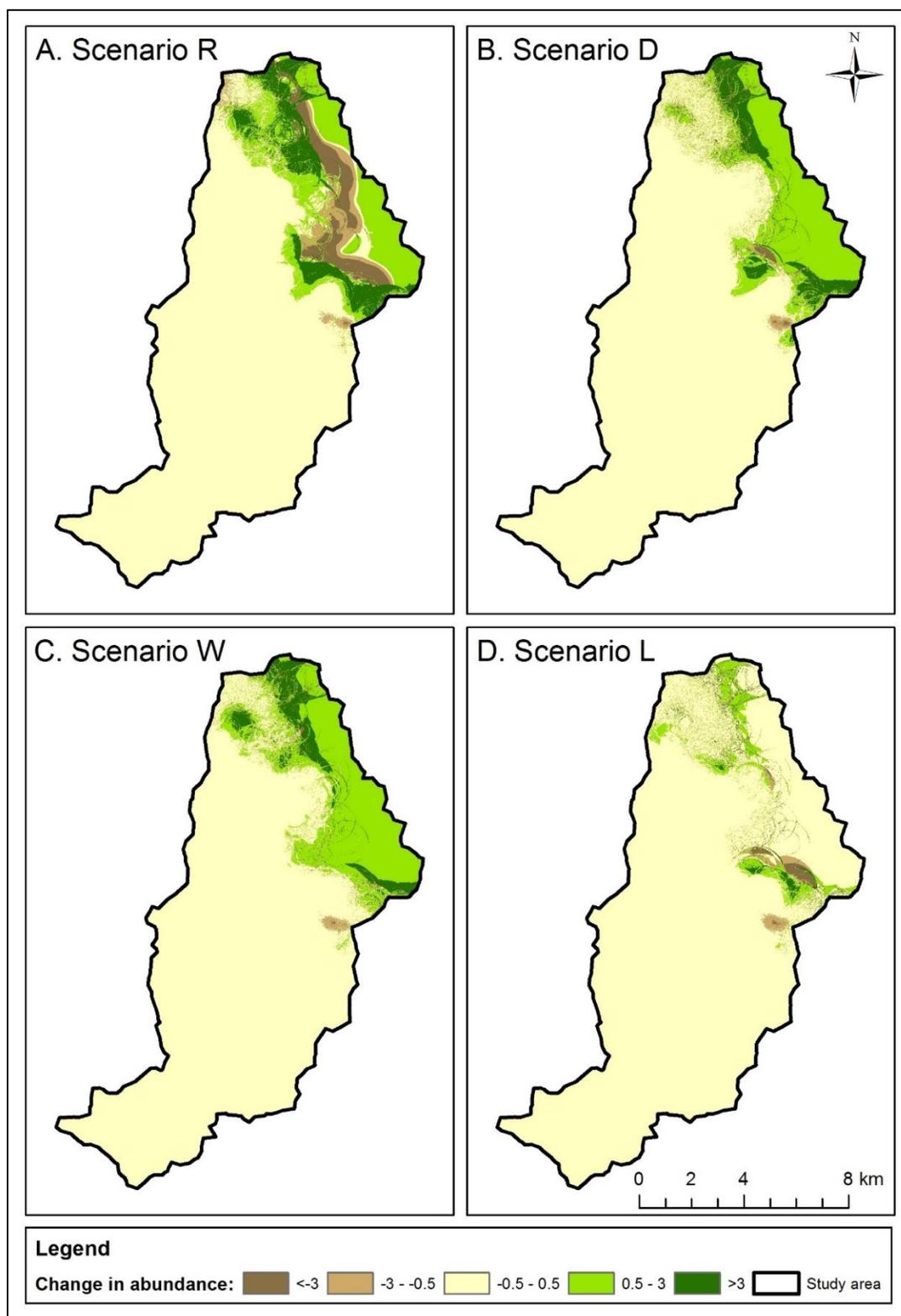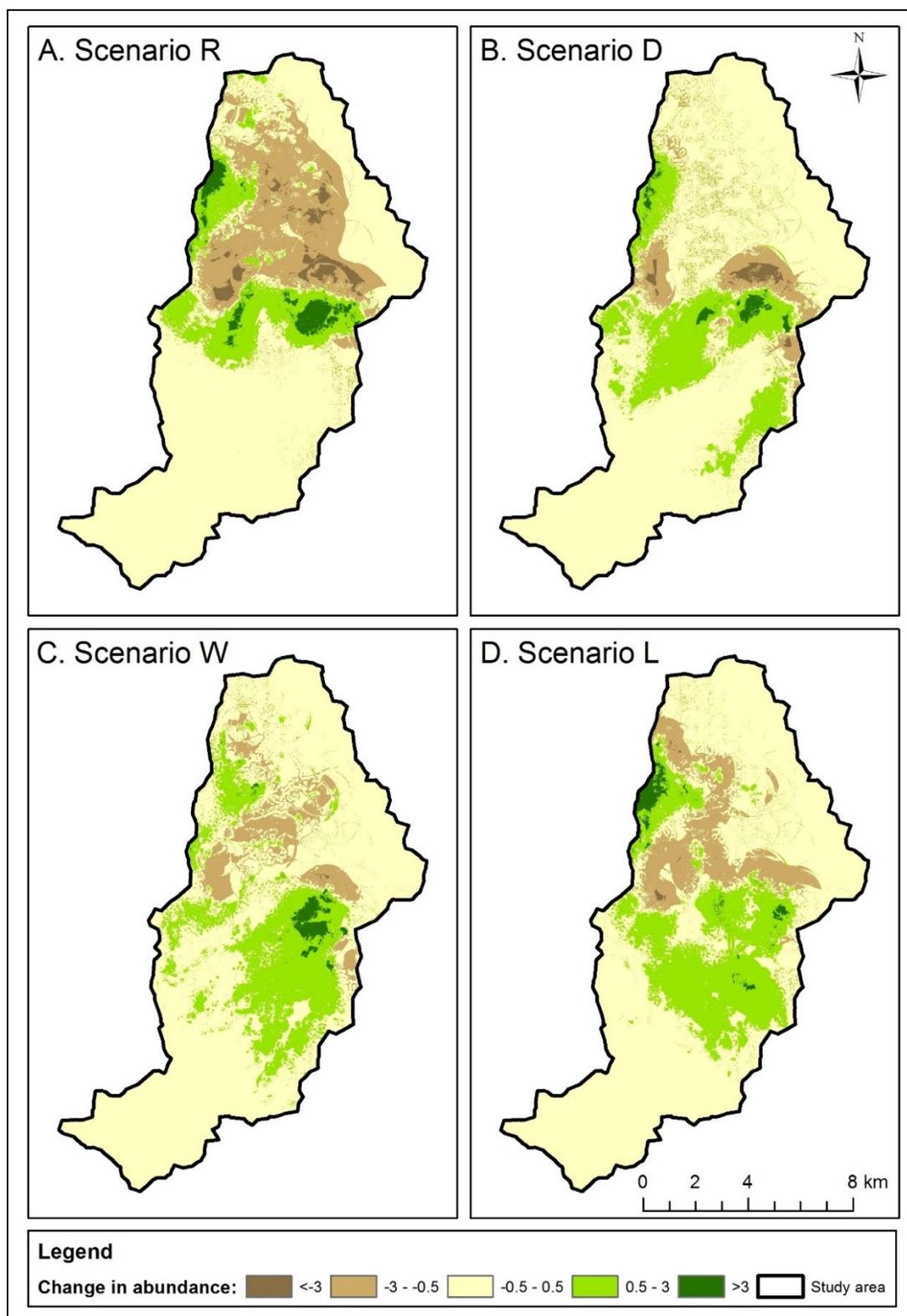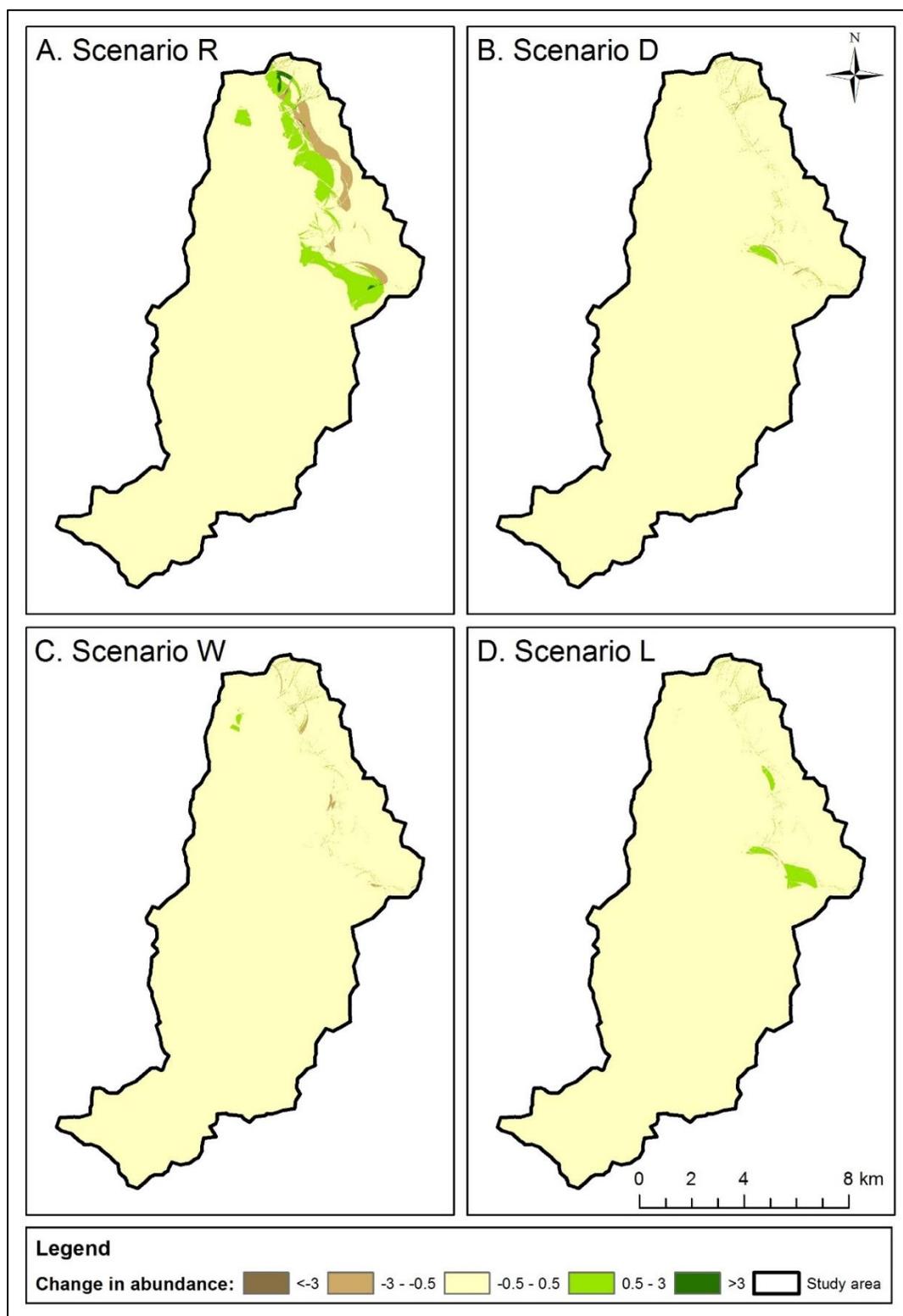**Social Flycatcher**

Keel-billed Toucan

A. Current
B. Scenario R
C. Scenario D
D. Scenario W
E. Scenario L

0   2   4   8 km

Legend

Study area

Number of individuals

0 - 1
1 - 3
3 - 5
> 5
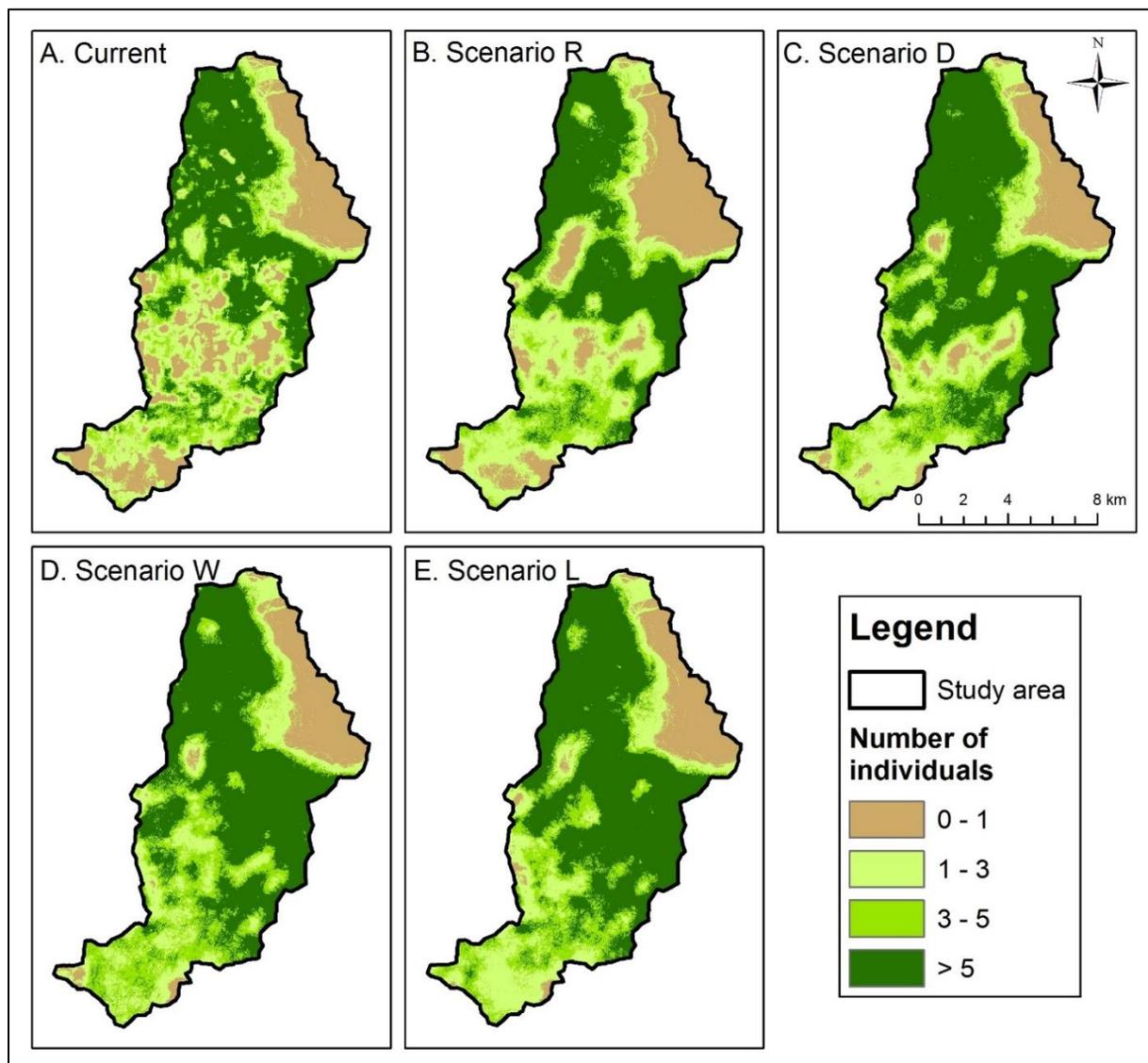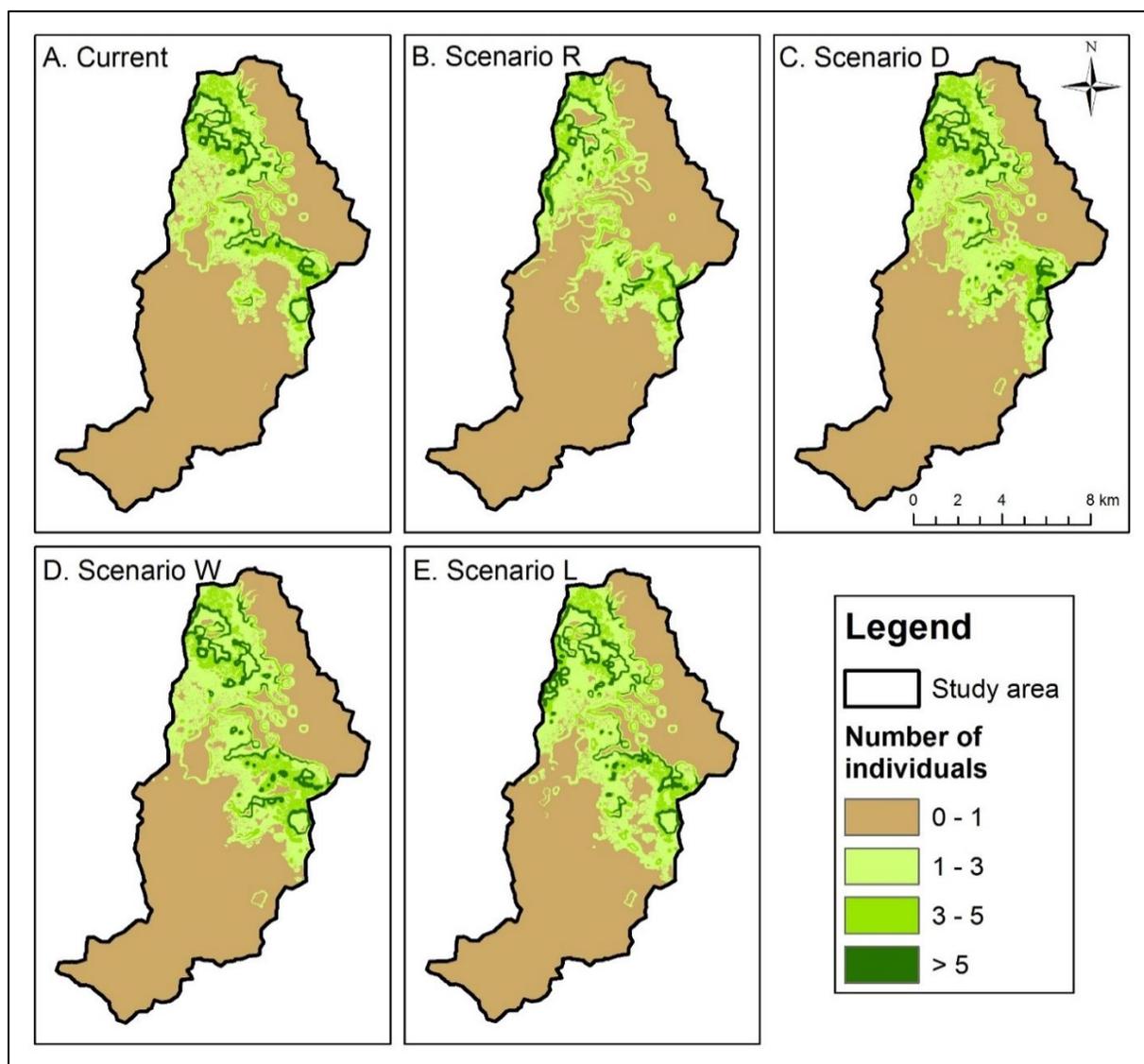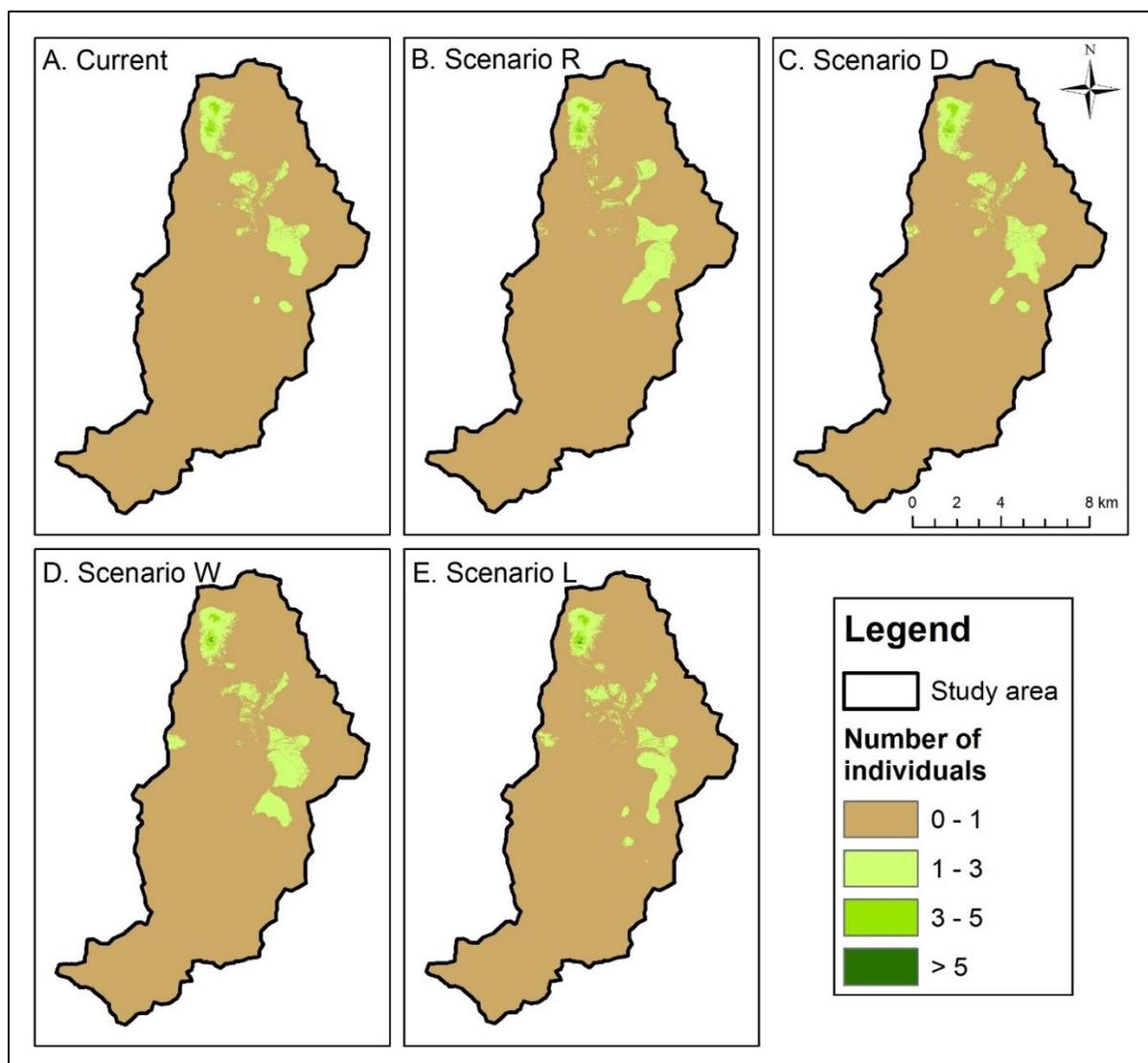
Northern Emerald-Toucanet
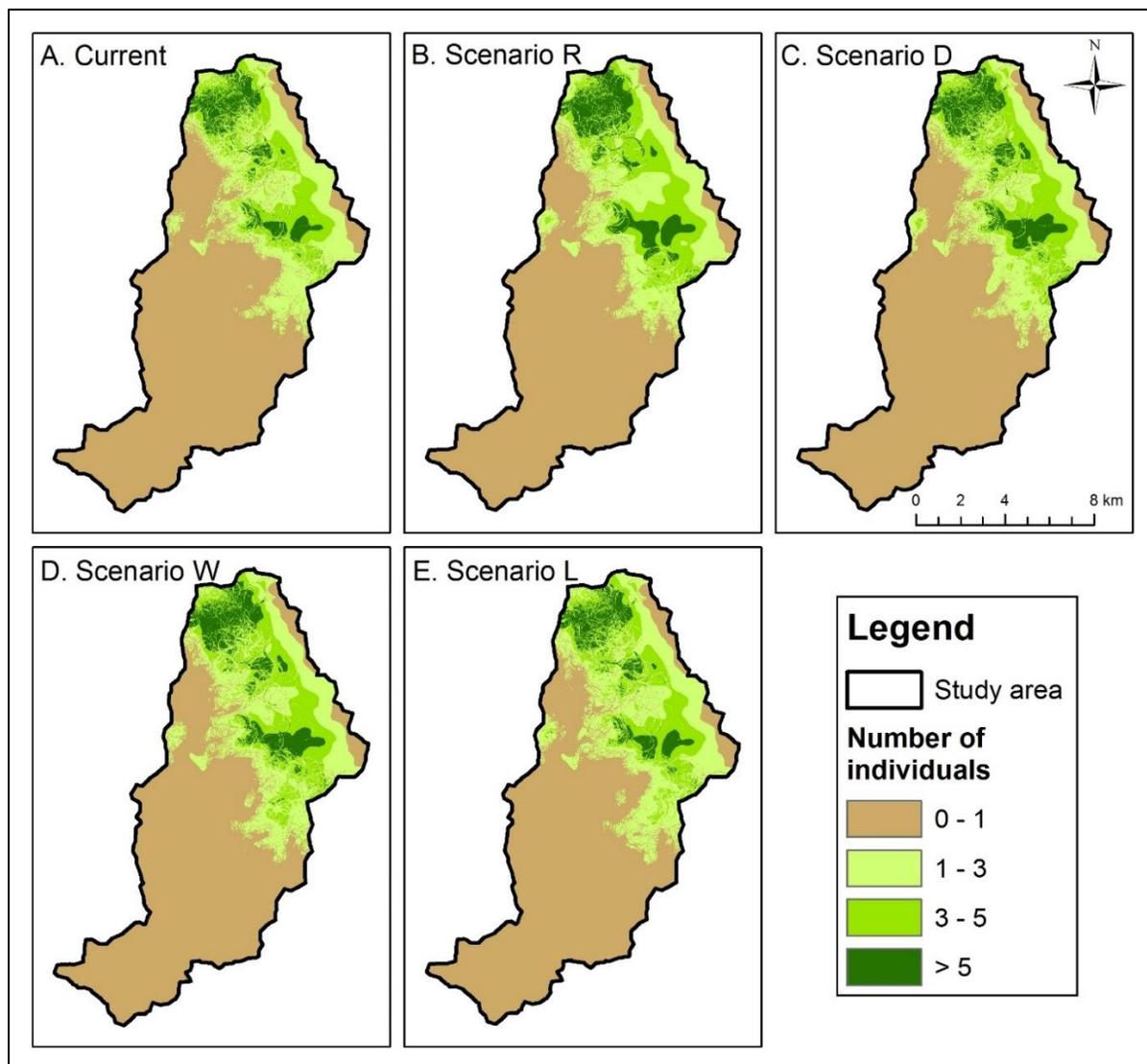
APPENDIX J

MAPS OF PREDICTED CHANGES IN ABUNDANCE OF FOCAL SPECIES UNDER EACH

REFORESTATION SCENARIO

Long-tailed Manakin

Lesson's Motmot

Legend

Change in abundance: ▨ <-3 ▨ -3 - -0.5 ▨ -0.5 - 0.5 ▨ 0.5 - 3 ▨ >3 ▢ Study area

White-eared Ground-Sparrow

Orange-billed Nightingale-Thrush

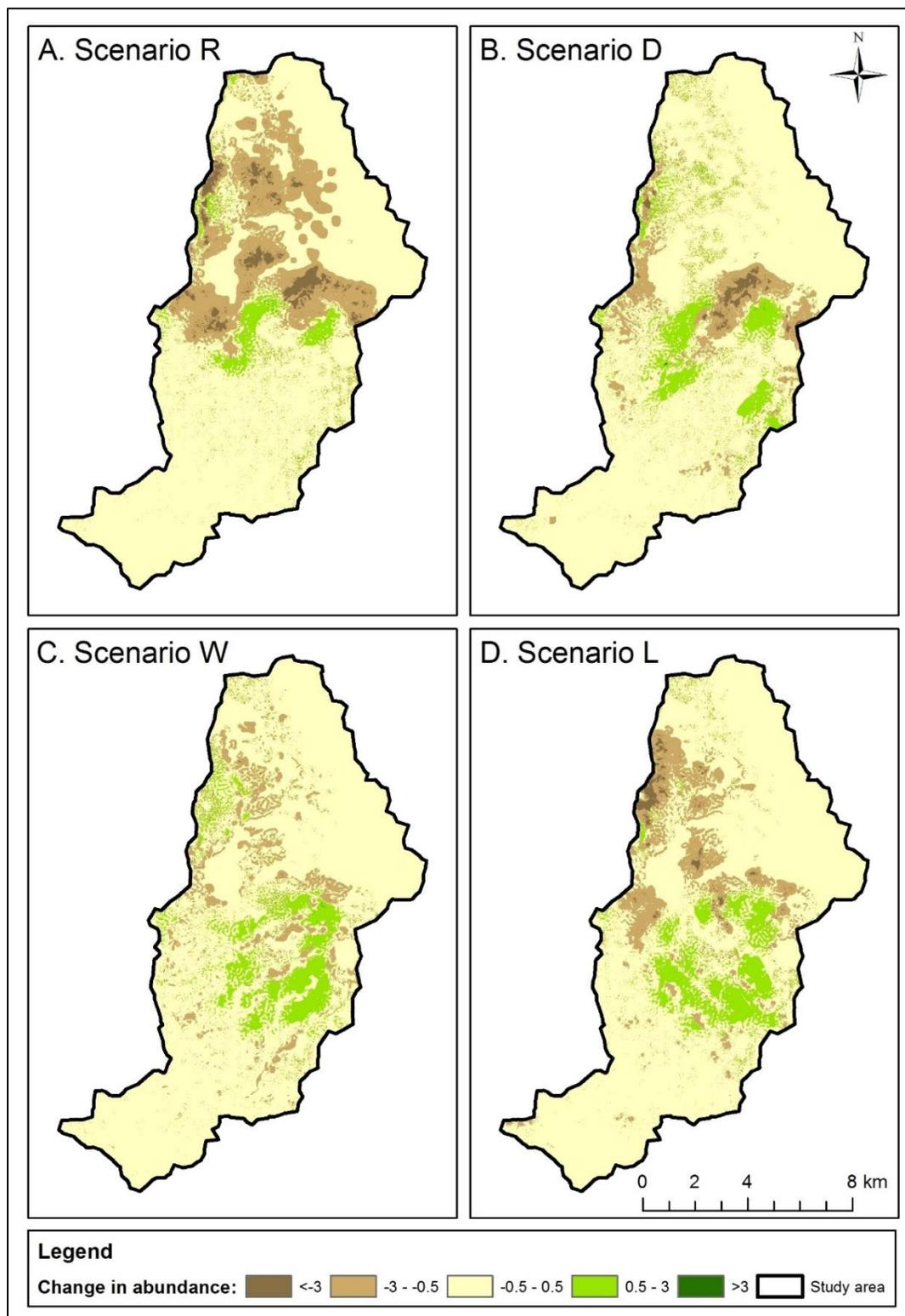**Slaty-backed Nightingale-Thrush**

Rufous-and-white Wren

Gray-breasted Wood-Wren

Social Flycatcher
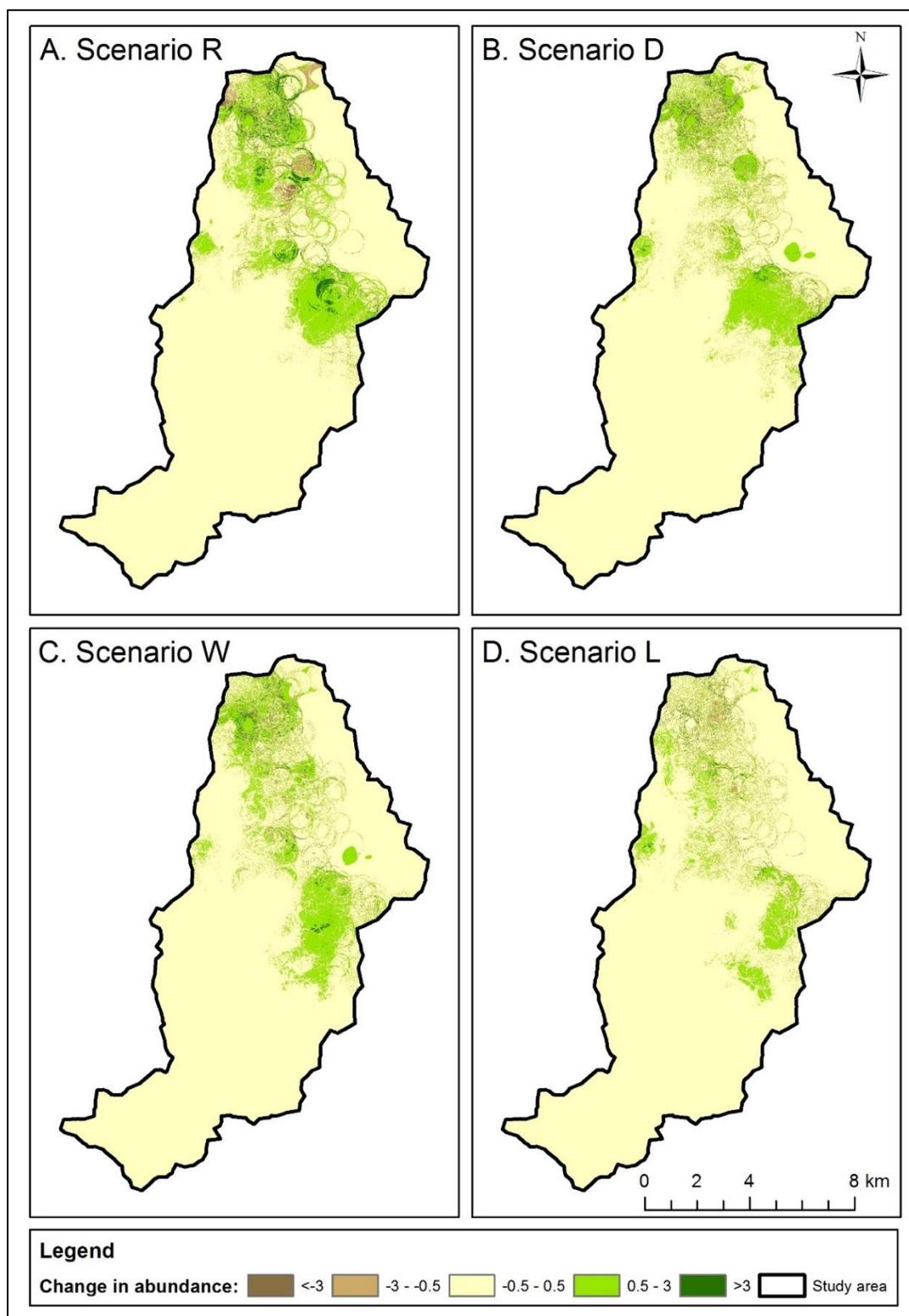
Keel-billed Toucan

A. Scenario R

B. Scenario D

C. Scenario W

D. Scenario L

Legend

Change in abundance: <-3 | -3 - -0.5 | -0.5 - 0.5 | 0.5 - 3 | >3 | Study area
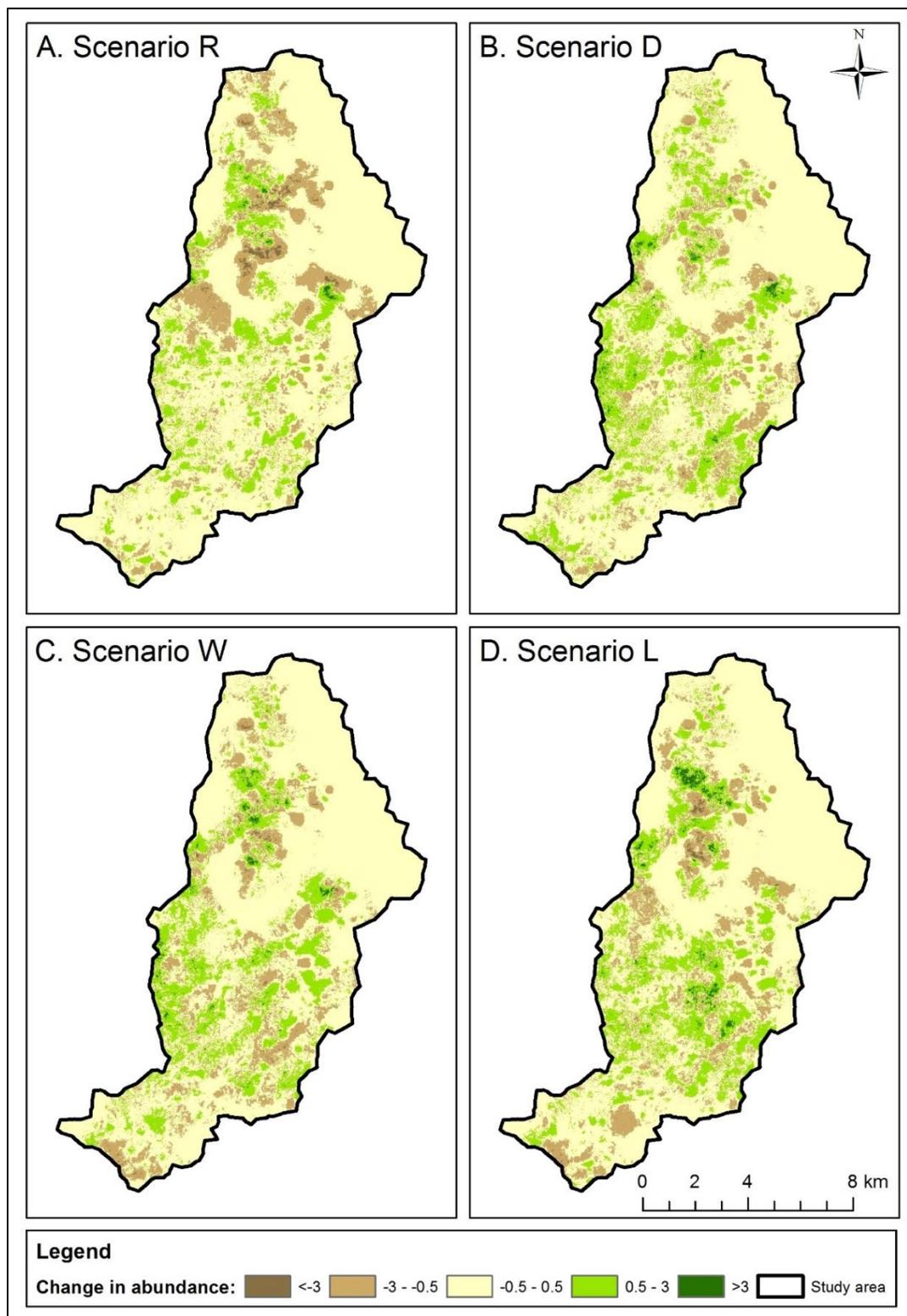
Northern Emerald-Toucanet

APPENDIX K

DESCRIPTION OF FUNDRAISING VIDEO

I developed a four minute video about my research in the spring of 2016 to help raise funds to support my fieldwork. The video included a description of the conservation challenges that I aimed to address with my research as well as footage of me conducting avian fieldwork in Costa Rica. This project taught me several key lessons about strategic development of visual material to raise research funds. First, it is essential to keep the video short to hold the attention of a general public audience. It is also important to provide hooks to capture and hold the attention of the audience. Additionally, crowdfunding for research conducted through the University of Georgia requires official documentation and internal review, so it is important to plan for that process ahead of time and factor the review period into the timeline for launching the fundraising campaign. Finally, timing is key. There is usually a brief window when momentum for such a campaign can be generated through speaking engagements and word of mouth, and it is important to capitalize for maximal fundraising. Screenshots from my fundraising video are included below.

Screenshot 1. The introduction to the video.

Screenshot 2. Talking about my bird research in Costa Rica.
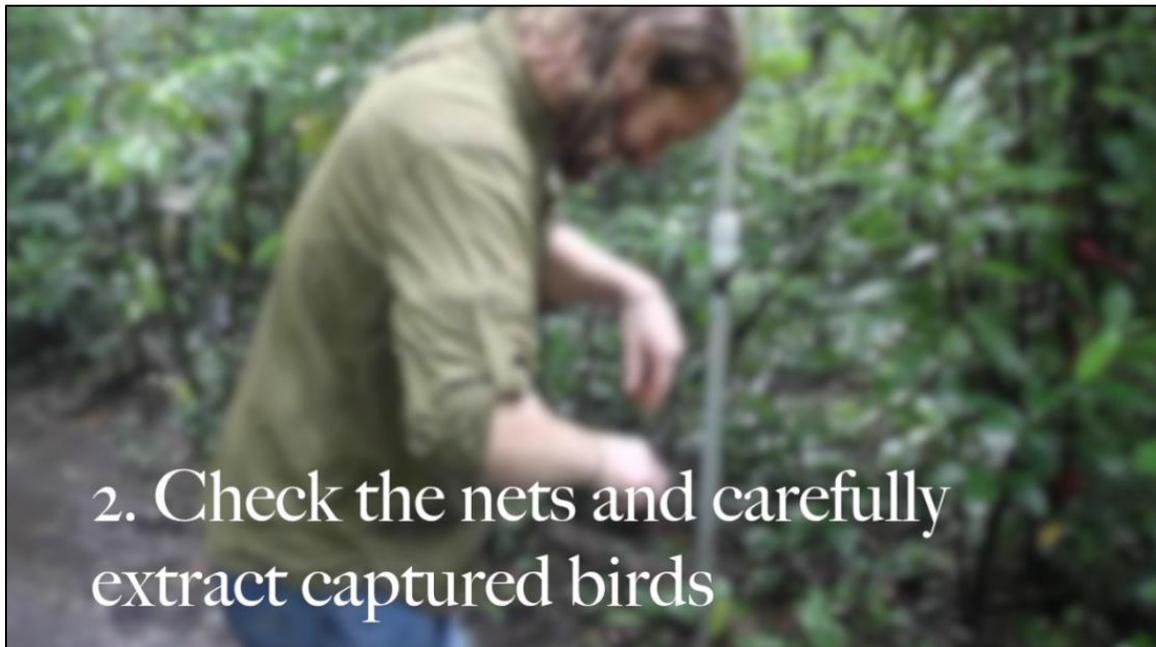
Screenshot 3. Footage of my fieldwork. Including text in the video can help general public viewers follow along and retain key points.

Screenshot 4. Taking measurements of a Lesson's Motmot (*Momotus lessonii*).