Effect of riparian forest network on landscape connectivity for wildlife

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Introduction

One major consequence of deforestation for forest dwelling wildlife is a reduction in the amount of total forest (Fahrig 2003; Fischer and Lindenmayer 2007). Moreover, in contrast with the original landscape, remaining forested landscape is often not continuous but instead is fragmented. Typically, natural patches of forest of several sizes and shapes exist, separated by a matrix of land cover that contrasts in structure and composition with the natural forest (Turner and Gardner 2015; Saura and Rubio 2010). These two processes of landscape change, habitat loss and fragmentation, reduce the ability of species to move to perform vital life needs across the landscape (Fischer and Lindenmayer 2007; Fahrig 2003). Therefore, reduced and impeded movement is a matter of conservation concern (Crooks and Sanjayan 2006).

Landscape connectivity depends on the landscape structure, the spatial relationship among habitat patches and the surrounding matrix (Taylor et al. 1993). Landscape structure is a function of the amount of habitat, number of patches, size of patches, and distance between patches (Taylor et al. 1993), and the relationships between these elements defines the structural connectivity of a given landscape (Goodwin and Fahrig 2002). For instance large amount of habitat, large patch sizes and short distances between patches positively affect structural connectivity. In contrast, reduced amount of habitat, large number of small patches and large distances between them negatively affect structural connectivity. Structural connectivity depends also on the composition and configuration of the matrix; forested corridors in the matrix can help ameliorate the effect of fragmentation by increasing structural connectivity between patches of forest (Rosenberg, Noon, and Meslow 1997; Tewksbury et al. 2002; Haddad et al. 2003). Although structural connectivity broadly indicates habitat availability, it does not measure landscape permeability for most species. To understand how species make use of the structural connectivity, and in particular if corridors facilitate movement, one must look in to functional connectivity.

Functional connectivity measures the degree to which a landscape facilitates the ability of a species to carry out its movement needs (Tischendorf 1997). Functional connectivity considers species movement abilities, needs and sensitivity to modification (i.e. degradation, fragmentation) of their habitat; thus, the amount of connected habitat of a given landscape varies widely between species (Tischendorf and Fahrig 2000). For example members of a species might need to move as juveniles to colonize unoccupied habitats, while other species perform seasonal migrations, or move locally in search for food (Nathan et al. 2008). These varying types of movement needs result in different spatial and temporal movement patterns and distances of travel; for example a given species' dispersal event can cover a relatively large distance when compared to movement pattern in search for food (Nathan et al. 2008). In this proposal I will focus primarily on the effect of landscape structure on species within year movement pattern, those that they perform to find food, rest and reproduce.

The composition and configuration of the matrix strongly influences species ability to move (Kuefler et al. 2010; Watling et al. 2011; Prugh et al. 2008). In theory, a homogeneous matrix that contrasts strongly with a species' preferred habitat reduces movement between patches of habitat resulting in low functional connectivity; while a heterogeneous matrix with low contrast should permit movement, maintaining functional connectivity (Watling et al. 2011; C. Estades and Temple 1999). In particular, species that affiliate strongly with forests avoid no forested habitat; for these species the presence of structural corridors that provide continuous tree cover greatly facilitates movement of individuals (Cassady St Clair et al. 1998).

Determining the impact of land composition and pattern improves our understanding of the connectivity. However, the wide range of movement needs and species behaviors complicates evaluations of connectivity for multiple species (Haddad et al. 2003; Haddad 2008), and we lack a general understanding of the type of species that depend on corridors to travel thru no forested matrices. A systematic assessment of the definition of functional connectivity for a variety of species that leads to a general understanding of the type of species that depend on corridors is necessary to inform our understanding of how land cover changes may affect species ability to use a landscape.

In this proposal, I will explore the degree to which a landscape facilitates movement with special focus on the role that riparian forests have in maintaining connectivity. Riparian forest due to their linear shape and vast extents in the landscape can forms corridors that connect isolated patches of forest. The connector function of riparian forest likely influences both structural and functional connectivity. In this proposal, I want to improve our knowledge of how much and where the network of riparian forest increases connectivity and explore which species benefit from these corridors for movement to address the broad aim of maintaining wildlife population in fragmented landscapes. To do that I will develop the following objectives:

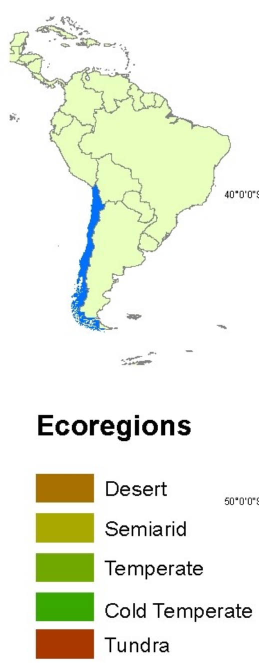
1) Assess the contribution of riparian forests to structural connectivity

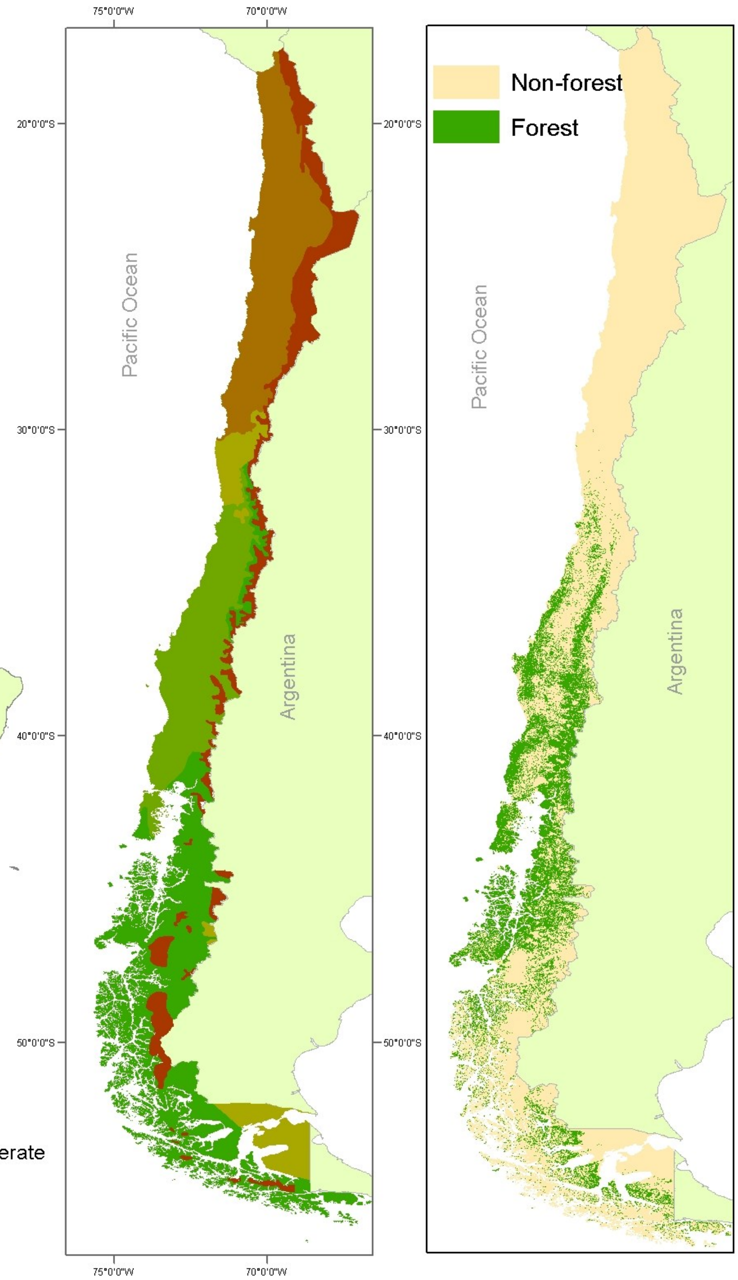
2) Evaluate the potential effect of riparian forest on functional connectivity of forest birds with varying traits

3) Evaluate effect of riparian corridors on movement decision of a forest dwelling bird in response to perceived risk of predation

4) Investigate the effect of forest regulation on the protection of the riparian forest network

Figure 1. The study area of my dissertation covers continental Chile. Chile is located in the Southern cone of America within 17ºS to 56 ºS latitude and 75 ºW to 66 ºW longitude. The topography is characterized by two mountain ranges, Andes and Coastal, parallel one to each other and separated by valleys. The location of the country, with a large latitudinal extension (~4,000 km) along the Pacific Ocean, the extreme topography and the South Pacific Anticyclone are the major factors influencing Chilean climate (Muñoz et al. 2007) and ultimately its biodiversity.





Proposal Significance

Scientific contribution: Landscape connectivity is an integral property of landscape structure (Tylor et al. 1993), and it has important implications for wildlife species in fragmented landscapes (Wiens 2006; Goodwin and Fahrig 2002). Riparian forests can be important elements of landscape connectivity (Vogt et al. 2007; Clerici and Vogt 2013; Saura, Vogt, et al. 2011; Vogt et al. 2009), however we do not know the particular contextual settings, and the particular species traits, for which this natural connectivity matters. My propose work will deepen our understanding of the role of riparian forest in structural and functional connectivity of the landscape by:

In **chapter 1,** I will provide quantitative information on the frequency of corridor occurrence along rivers and how much these corridors improve connectivity in continental Chile.

In **chapter 2**, using a functional understanding of connectivity, I will determine what set of traits are possessed by species that benefit from corridor structures.

In **chapter 3**, I will investigate the effect of perceived predation risk on the corridor use and gap avoidance of a forest dwelling bird.

In **chapter 4**, I will determine the effect of several forest regulations on the protection of riparian network and suggest how existing network of riparian corridor can be used more efficiently for conservation purpose of wildlife species.

My proposal dissertation is designed to explore the effect of riparian forest in landscape connectivity at several extents of analysis, countrywide, watershed, small landscapes and multi patch. The multiscale approach is not trivial because different patterns and properties tend to emerge at different scales (Bissonette 1997; Kotliar and Wiens 1990). Assessments of landscape patterns at large extent is necessarily an analysis of correlative models conducted at a relatively large resolution, useful to identify general patterns. Analysis at smaller areas, on the other hand, allow for analysis at a finer resolution, and hypothesis testing in search for mechanistic explanation of ecological patterns (Bissonette 1997; Turner and Gardner 2015).

Conservation and management contributions:

My analysis of the Chilean landscape will not only improves our ecological understanding of landscapes patterns, but also it will provide insight about country level trends in riparian zone forest amounts. This is important for conservation planning and environmental sustainability at broad scale.

Further, I will conduct a watershed scale analysis of the effect of actual regulation on landscape connectivity. This will provide insight into the degree to which current riparian buffer policy provides for the movement needs of wild species, and the effect of alternative buffer management- this information will be useful to plan future regulations.

At the species habitat level (~100 ha landscapes), the analysis of functional connectivity for groups of species will help identify the traits of species that need corridors for movement.

At the multi-patch scale, a better understanding of the movement decision that species made to survive in an agricultural landscape will provide information useful to plan management at the private property level.

Ultimately, in order to make these results available for an extended group of local actors potentially interested in this information, such as researchers, students, and staff of non-governmental and government agencies, I will prepare digital maps and other educational material. Some of this information may be posted in the web page of the Ministry of Environment.

Chapter 1. The effect of riparian forest on landscape structural connectivity

Introduction

The main goal of this chapter is to assess the contribution of the network of riparian forests to landscape structural connectivity. Landscape connectivity is a measure of the degree to which a landscape facilitates the movement of energy, information, ecological processes and species (Goodwin and Fahrig 2002; Fagan and Calabrese 2006). A network of riparian forest could increase landscape structural connectivity at broad scale if it provides continuously forested habitat through the landscape. However, strong heterogeneity of forest pattern across broad regions raises the question of how riparian forests affect structural connectivity in different settings, and what conditions influences the effect of riparian forests on structural connectivity.

Riparian forests can affect structural connectivity by forming structural corridors. Corridors, here defined as linear strips of forested habitat that connect two patches of forest, are critical for the structural connectivity of fragmented landscapes. However, while it is clear that individual riparian corridors are critical connectors of forest habitats (Gillies and Cassady St. Clair 2010), it is no know to what extent riparian forest form corridors across larger areas, and if these corridors matter for overall connectivity.

The effect of riparian forests on landscape structural connectivity will likely vary among regions. The questions therefore are where and under which conditions riparian forests improve connectivity. For instance, riparian areas form natural forested corridors in dry ecosystems where forests only occur near rivers (Patten 1998). In contrast, in temperate regions forests occur in large areas, which means that riparian forests are part of larger patches of forest and may not form corridors. However, even in temperate regions riparian forest may provide important corridors after other areas have been deforested (Riitters et al. 2002). A thorough assessment of the conditions where riparian forests affect connectivity is necessary, especially to examine plausible explanation to the observe patterns of forest within the riparian area.

My main goal is to examine the effect of riparian forest network on landscape structural connectivity. Specifically I will address the following questions:

a) How do riparian forests affect structural connectivity, in terms of providing corridors?

b) Where do riparian forest corridors matter for connectivity?

c) What conditions influence the effect of riparian forest on landscape structural connectivity?

Methods

Study area and unit of study

My study will cover Chile (756336 km^2) without the oceanic islands. The geography of Chile is dominated by the presence of the Andean range that shapes the physiology into three main zones: coastal cordillera, central depression and principal cordillera (Figure 1). The combination of the latitudinal extension, the extreme topography, and the South Pacific Anticyclone are the major factors influencing Chile's climate (Muñoz et al. 2007) that ultimately determine its distribution of vegetation. Chile territory is dominated by vegetated areas (59%; agricultural land, pastures and shrubs, forests and wetlands) in central and southern Chile, and areas without vegetation (32,8%) (Corporación Nacional Forestal 2011). The wide range of variation in the proportion of forest cover across the study area makes Chile an ideal area to assess landscape forest patterns (Figure2).

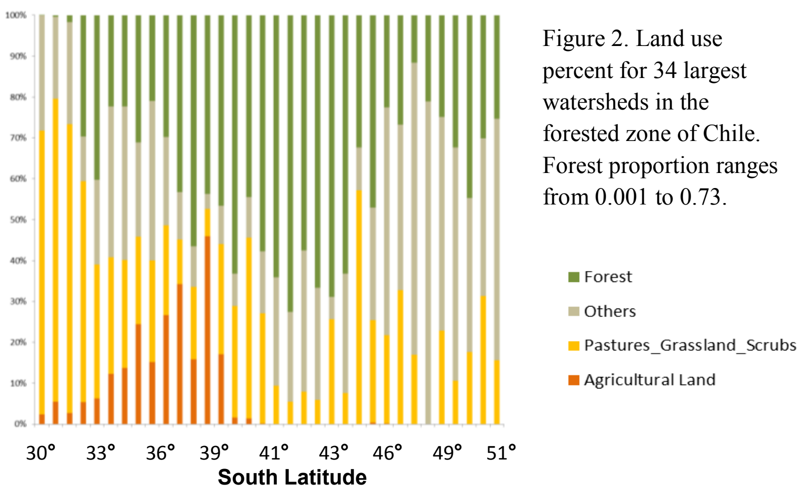


Figure 2. Land use percent for 34 largest watersheds in the forested zone of Chile. Forest proportion ranges from 0.001 to 0.73.

My study unit is the watershed. Watersheds are an ideal study unit because a) watersheds capture the hydrological networks that physically connect the origin of the streams in the mountain to the outlet of the rivers in the coast, and b) watersheds capture the variability that is typical for mountainous regions such as altitudinal gradients and topographical complexity. The hydrological system of the country encompasses 129 watersheds, most of which encompass the main physiographic areas of the valley, and the Andean and Coastal Cordilleras. However, some of the watersheds are small, and contain only coastal range.

To assess the contribution of riparian forest to structural connectivity I will develop two approaches that are based on a classification of a binary forest/non-forest layer into forest pattern classes (Figure 3).

Generation of information layers

Information on Chilean forest will be derived from tree canopy cover data for the year 2000 (Hansen et al. 2013). This dataset represents cells approximately 30 m in size encoded as the percentage of the vegetation taller than 5 m in height per grid cell in a range from 0-100 (Hansen et al. 2013). I reclassified the tree cover layer in to a binary layer of forest and non-forest. Pixels were reclassified as forest if pixels have more than 10% of trees cover in the arid region (above 30 Latitud S), and more than 25 % of trees cover in the humid region (below 30 Latitud S). I based my forest reclassification on the official definition of forest by Chilean Forest Law (Ministry of Agriculture 2008).

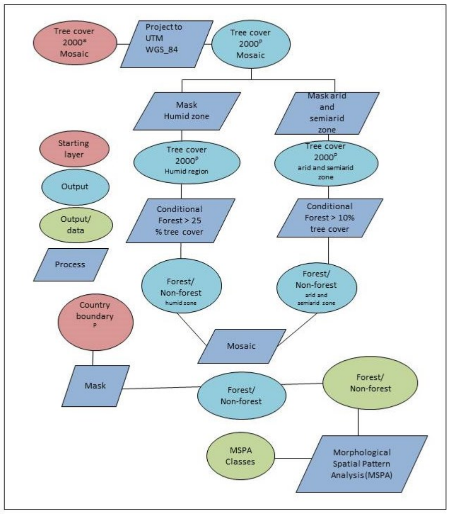


Figure 3. Workflow of the steps of the morphological image analysis that I will conduct to assess structural connectivity.

To determine the landscape elements that are structural connectors I will conduct an image morphological analysis of forest habitats (Soille and Vogt 2009; Vogt et al. 2007). Image morphology, specifically the Morphological Spatial Pattern Analysis (MSPA), classifies a binary forest raster image (forest and non-forest pixels) into seven classes of forest patterns: core, edge, islet, bridges, branch, loop and perforation (Figure 4). MSPA uses a classification algorithm after defining the neighborhood types as either 8- or 4-pixel neighborhood, and specifying edge width, based on the number of pixels. I will use an 8-pixel neighborhood, and a 2 pixels edge size or 60 m. Therefore bridge, islet, branch, and loop categories result from forested areas without core, i.e., areas compose of 4 pixels wide or narrower (< 120 m approximately). I will conduct the MSPA analysis using the software Guidos (Vogt 2015).

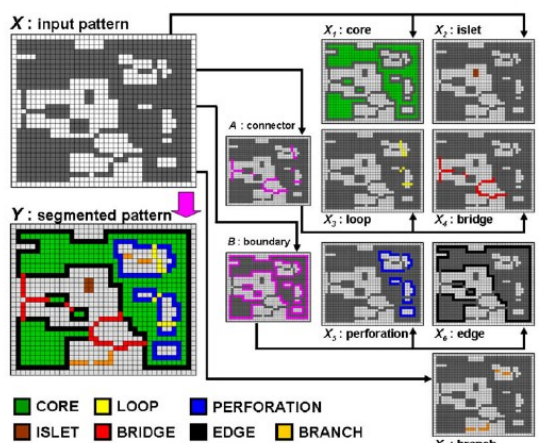


Figure 4. Image morphology analysis detects nine forest classes. From Soille and Vogt 2009

Sensitivity analysis: to assess the effect of variation of the forest threshold and edge size, I will perform a sensitivity analysis.

A sensitivity analysis is necessary to determine the variation in the amount of corridors based on different forest thresholds, and edge of different widths. I will test variation in corridor amount for forest threshold that varies from 10 % to 50 %. I will test the effect of variation on edge size using 1, 2, and 3 pixel edge sizes. These sizes will lead to corridors of a maximum of 60, 120 and 180 meters width.

Analytical methods

The resulting MSPA classification will be used to develop two approaches to measure the contribution of riparian forest to connectivity. First, I will conduct a descriptive analysis comparing the MSPA classes within a riparian area of a fixed buffer width with the rest of the landscape. Second, I will conduct a spatial analysis combining the MSPA analysis and using the integral connectivity index (IIC).

a) How riparian forests affect structural connectivity, i.e., forming corridors?

Descriptive approach

My objective is to quantify how much of the riparian forests provide structural connectivity in a given watershed. As I have mentioned before, structural connectivity depends on the spatial relationship between patches of forest and forested corridors that connects them (Rosenberg et al 1997). An analysis of forest pattern with MSPA provides information on the shape of the patches of forest that compose riparian areas. Furthermore, an evaluation on landscape metric will provide useful information the spatial arrangement of those forest patterns.

I will use the MSPA class ‘bridge’ to quantify the proportion of corridors form in riparian areas. First, to identify the forest close to river I will use a 60 m fixed buffer along the hydrological network of Chile. Fixed buffers are the most widely tool use when no more realistic determination of riparian areas based on topography and soil hydrology is available (Fernández et al. 2012). Second, I will summarize the classes of forest that appear in the riparian buffer by using proportion of forest classes, and specifically I will calculate the proportion of bridges in the riparian buffer to bridges in the watershed as a measure of the contribution of riparian forest to corridors. I will assess my results using maps and a descriptive comparison between study units.

I will conduct the assessment of the forest pattern within the riparian forest of each watershed to identify patches of forest, distance between patches, and the type of matrix that separate them. These landscape metrics are common metric to describe structural connectivity (Taylor et al. 1993). This analysis will provide a fine scale understanding of the effect of environmental conditions and land use on pattern of forest in the riparian area, thus will help explain why riparian forest form corridor more often in one place than another.

b) Where riparian forest matter for connectivity?

My descriptive approach will allow me to measure how many of the riparian forests connect patches of habitat within a given watershed. Further, I will identify those riparian forest corridors that are the most important contributors to connectivity based on their position relative to the patches of forests and the location of other patches and corridors in the network. I will use a procedure developed specifically to identify key structural corridors (Saura, Vogt, et al. 2011) and that combines morphological spatial pattern analysis (Soille and Vogt 2009; Vogt et al. 2007) and indices of landscape network connectivity that measure the change in connectivity after the removal of a patch or corridor (Saura and Pascual-Hortal 2007; Rubio and Saura 2012; Pascual-Hortal and Saura 2006). Specifically, I will use the Integral Index of Connectivity (IIC) that estimates the possibilities of dispersal between all pair of patches. This index uses a binary connection model in which two patches are either connected or not, and then considers the effects of quality, strength, and frequency of use (Saura, Vogt, et al. 2011). The IIC can be divided into three fractions: the 'intra' fraction that accounts for connectivity within a patch, 'flux' that accounts for how well connected a patch is, and 'connector' that accounts for the degree that a link or patch acts as connector (Saura and Rubio 2010; Rubio and Saura 2012). Corridors can only contribute to the connector portion of the IIC; therefore I will focus on this portion of the IIC to estimate the contribution of each individual link.

There are two ways to measure the connector function of structural links using IIC: one that accounts for the ability of a species to move certain distance (IIC-distance) and a second that assume that all bridges are usable for movement (IIC-steps) (Saura, Vogt, et al. 2011). I will use IIC-steps because my goal is to determine the contribution of all bridges, especially those that are riparian forest, independent of species' ability to move. The only constraint is that connectivity is only considered among forested habitat patches.

To construct my network model, I will use the core and bridges forest classes from MSPA to define nodes and links, respectively. I will use area as attribute of each node and the length of the bridge will determine the attribute of links. I will set a large distance threshold of movement in a way that all possible corridors facilitate movement between nodes, as was defined for IIC-steps. Then, I will use Conefore Sensinode (Saura and Torné 2009) to measure dIIC for each corridor. This metric quantifies the decrease in connectivity when the corridor is removed from the landscape.

c) What influences the effect of riparian forest on landscape structural connectivity?

To explore the mechanisms that explain the contribution of riparian forest as provider of structural connectivity, I will relate structural connectivity to different environmental and land composition variables (Table 1). As I mentioned before, environmental variables influence the contribution of riparian forest directly by determining the condition for tree growth, and indirectly by determine patterns of land composition changes. To represent environmental condition, I will use precipitation and ecoregions- arid, semiarid and temperate zones- as proxies for climate and habitat conditions. Land use/cover composition can directly influence the contribution of riparian forest by determining how riparian areas are managed, and indirectly by influencing the dominant land cover. I will relate a measures of contribution of riparian forests to the proportion of each land use type (agriculture, forest, pastures and shrubs, among others), with watersheds being the unit of analysis.

Table 1. Explanatory variables used to determine mechanism for the contribution of riparian forest to structural connectivity

Variable	Description	Source of information
Ecoregion	Arid, semiarid and temperate zone defined based on climatic conditions of precipitation and temperatures	WWF
Elevation	Elevation category low (≤300 masl) and high (> 300 masl). 7.5 arc-second spatial resolution (~30,7 m)	Global Multi-resolution Terrain Elevation Data 2010
Land use/cover	Land use classification: Urban and industrial areas, Agriculture, Shrubs and pastures, Forest, Wetlands, Snow and Glaciers, Water bodies, Areas with no vegetation, and others. Forest land use has 4 subcategories that include native forest and plantation.	Coorporación Nacional Forestal 1997-2011

To relate my environmental and land composition variables with the two measures of the contribution of riparian forest to connectivity, I will use generalized linear models that account for possible deviation from normality. Furthermore, because of the variation in the amount of forest across space, I plan to use a geoadditive model that account for the effect of non-linear relationships between the amount of corridors and continuous covariates that vary in space (Kammann and Wand 2003). I conducted an exploratory analysis using forest and latitude as predictive variables and the proportion of corridors on riparian areas as response variable. Then, to detect any possible relationship between unexplained variance and other explanatory landscape metrics, I plotted the residuals of this model to proportion of agriculture and pasture_shrubs_grassland, and ecoregions. In this preliminary analysis I used latitude as a surrogate of environmental gradient. In future analysis I will replace spatial location by precipitation and temperature to better understand the conditions where riparian forest contributes to corridors.

In a separated analysis I will explore the effect of elevation on amount of corridors. To do this, I will overlay broad categories of elevation (e.g., lower than 300 masl and higher than 300 masl) and the forest class (output from MSPA) at the pixel level. I will summarize result of this classification using descriptive measures (e.g., mean and range per class).

Expected and preliminary results/deliverables

a) How do riparian forests affect structural connectivity?

My descriptive analysis of the contribution of riparian forest to structural connectivity will provide a countrywide assessment of the proportion of riparian forests that are structural corridors. These results will be presented in a map showing the variability among watersheds and highlights those with higher proportion of riparian corridors. I have already conducted a preliminary analysis of 34 largest watersheds that in total cover an area approximately 90% of the forested areas of Chile. I found that riparian forest contribute only 6% of the corridors on average across watersheds (Figure 5).

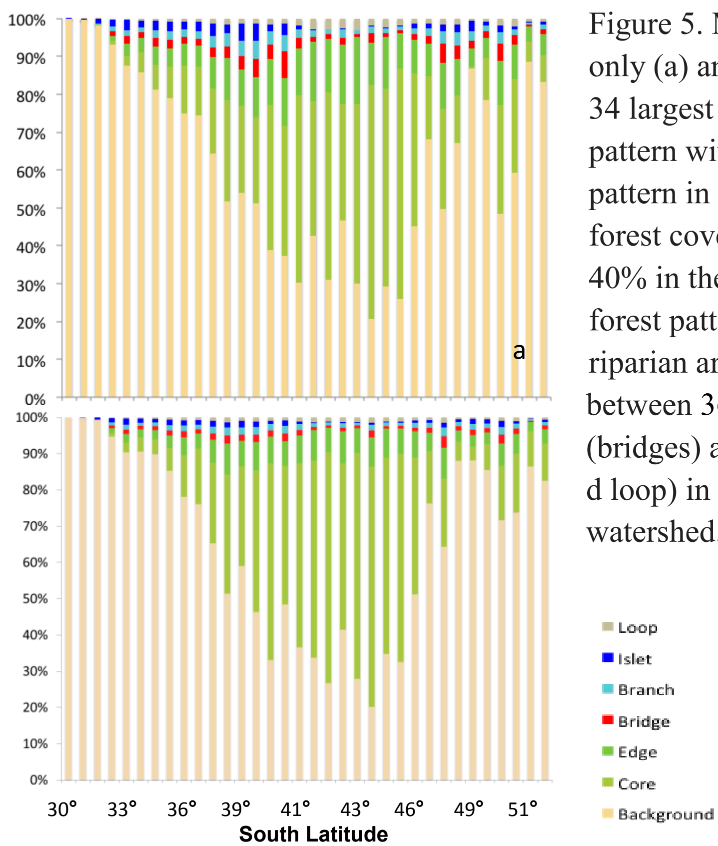


Figure 5. MSPA classes within the riparian area only (a) and within the entire watershed (b) for the 34 largest watersheds of Chile. Overall, forest pattern within the riparian areas coincide the forest pattern in their corresponding watershed, i.e., if forest cover 40% of a watershed, forest also cover 40% in the riparian area. However, the specific forest pattern varies between watershed and riparian areas. Some watersheds, e.g., those between 36°and 41°**,** seems to have more corridors (bridges) and other connector forests (branch, islet d loop) in the riparian areas than in the whole watershed.

b) Where *do riparian forests contribute to maintain structural connectivity?*

I will represent the average of link contribution for each study unit in a map of the country. The link contribution of a corridor strongly depends on the spatial arrangement of forest within the study area. Therefore, I expect that the map will represent the effect of land use and land cover in the contribution of riparian forest to structural connectivity. Furthermore, I will present a set of critical individual corridors in a table that describes their location, structural and compositional characteristics and the land composition surround them.

Finally, results from this analysis will be summary in two ways. First, in order to identify the general pattern at the country level of the corridor function, I will average the link contribution in each watershed and map these results. Second, I will select corridors that have a link contribution above the average. For each of this selected corridor I will describe the context and condition where they occur.

c) *What are the characteristics of landscapes where riparian forest matter for connectivity?*

My exploratory analysis showed that latitude and amount of forest explained most of the variation on the proportion of riparian corridors, and that proportion of forest has a negative effect on the contribution of riparian forest to corridors (Figure 6). This is an expected result. Areas with small amounts of forests have only few patches of forest to be connected, and there are only few corridors in these areas. Large patches of forest, not corridors, help maintain connectivity in areas with high proportion of forests. Then plots of the residual of this model to the other explanatory variable do not show further plausible relationships.

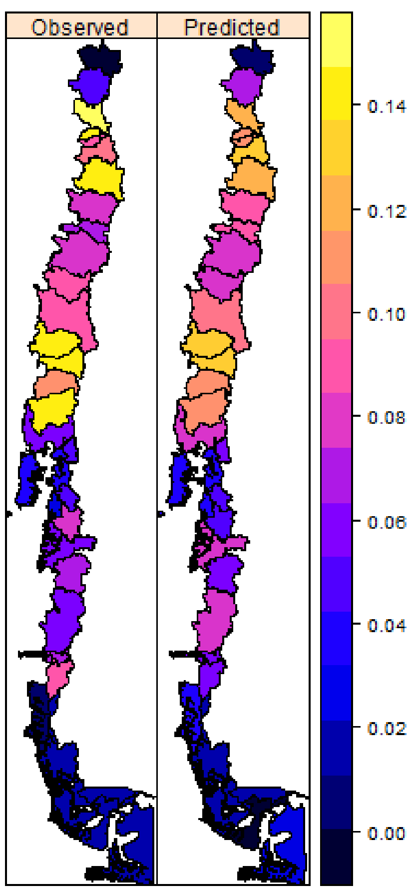


Figure 6. Observed and predicted proportion of corridors in the riparian forest using a geoadditive model with forest and latitude as smooth terms. Estimated Smooth (forest) = -0.096, p-value=0.0363, Smooth (Y)= 8.444, p-value < 0.001, Deviance explained= 85,5% , R-sq (adj) = 0.797

Significance

In landscape and conservation planning, it is assumed that riparian forest provide physical connection between patches of forest (Fremier et al. 2015; Clerici and Vogt 2013). My country-level assessment of the riparian forests pattern will provide empirical evidence of how often riparian forest actually contribute to connectivity, and will allow me to explain why riparian forest contribute to connectivity in some place more than others. My results will be relevant to the understanding of landscape ecology of Chile and other regions of the world with heterogeneous biogeographical conditions.

Results from this chapter will provide insight about the conditions where connectivity could be maintained through riparian corridors in order to mitigate the effect of forest deforestation. My preliminary analysis at the broad landscape scale shows that few riparian areas form physical corridors. Riparian forest form more often small isolated patches of forest. Further analysis of these results will provide information on the effect of the spatial arrangement of riparian forest and the conditions where they contribute the most to structural connectivity.

Chapter 2: The effect of landscape corridors on birds with varying traits

Introduction

Understanding the effect of landscape structure on species persistence is a key topic in conservation biology (Crooks and Sanjayan 2006). Special attention has been giving to corridors, because they can ameliorate the impact of fragmentation on species persistence on human dominated landscape (Beier and Noss 1998; Chetkiewicz, St. Clair, and Boyce 2006).

Functional connectivity quantifies how much a landscape facilitates movement for a given species, and is determined by the amount of suitable habitat, the spatial arrangement of those patches, and the ability of a species to reach them through the matrix (Goodwin and Fahrig 2002). In recent years, there has been an increased recognition of the effect of the matrix composition and configuration on species richness and abundances. Indeed, matrix structure can be more important than the spatial arrangement of the patches of habitat (Estades and Temple 1999; Franklin and Lindenmayer 2009; Watling et al. 2011). Heterogeneous matrix, one composed by several types of vegetation (shrubs, threes, crops), and/or with low contrast with species habitat should facilitate movement of species. In contrast, a homogeneous matrix with contrasting habitat can be a barrier for movement for forest specialist species. However, despite the great attention to the matrix composition, we still lack an understanding on the effect of corridors within the matrix. Studies that effectible represent corridor within the matrix are necessary to predict the effects of corridors on landscape functional connectivity at broad scale.

Empirical studies have shown that forested corridors can greatly benefit forest birds (Cassady St Clair et al. 1998; Castellón and Sieving 2006; Gillies, Beyer, and St. Clair 2011). However, there is a range of responses of birds to landscape corridors. Landscape models studies have shown that birds that are specialist are more sensitive to changes of their habitat (to landscape composition) than generalist species, and respond negatively to forest loss (Fahrig 2003; Carrara et al. 2015). Similarly, translocation studies have shown that specialist bird benefit from corridors structures for movement (Gillies and Cassady St Clair 2008). There are several life-history traits that determine which species are more specialized on forest, and that variability has not been explored in depth (Table 2). Previous studies have shown that understory specialist birds are very susceptible to connectivity and depend on forested corridors and vegetation structure such as shrubs (Sieving, Willson, and De Santo 2000; Castellón and Sieving 2007; Castellón and Sieving 2006). However, there is a lack of understanding on the effect of the matrix on movement of bird with other traits such as large tree user, and how they may be benefit from corridors (Castellón and Sieving 2012). Despite the

Table 2. Life-history traits and their function on species movement abilities and habitat specialization. Adapted from Ibarra and Martin (2015a).

Function	Life-history trait	Categories
Movement	Body size	Mass (gr)
Movement	Home range size	Area (ha)
Movement	Migratory status	Resident, local migrant or long distance migrant
Habitat Specialization	Habitat use	Large tree user, understory user, vertical profile generalist or shrub user
Habitat Specialization	Foraging substrate	Foliage, bark, ground or aerial

fact that large tree users may show better flying abilities than understory users, there is increasing evidence that these species are sensitive to fragmentation (Dias et al. 2015; Anjos, Zanette, and Lopes 2004; Martensen, Pimentel, and Metzger 2008). Therefore, understanding the variability among specialists and between the guilds of specialist versus generalist species in terms of their responses to landscape structure should deepen our understanding on the mechanism that determines species use of corridors.

Species movement capabilities also play a role in determining species responses to landscape corridors (Gillies, Beyer, and St. Clair 2011; Castellón and Sieving 2006). However, the characteristics of species movement capabilities has not been included in recent analyses of the effect of landscape structure on birds abundance (Carrara et al. 2015; Dias et al. 2015). Adding information on movement capabilities could help to account for the variability not represent by the categorization of species on habitat specialization.

I propose to investigate the effect of landscape composition and configuration on several life-history traits to a) examine the effect of corridors on birds' abundance and b) determine avian traits that benefit from corridor structures.

Methods

Study area and species

My study area is located in the Toltén watershed in south-central Chile (Figure 7). This is an ideal landscape to test the effect of corridors on birds' abundance because remnants of natural forest form corridors next to rivers or very small (< 1ha) scattered patches of forest within the agriculture matrix (Miranda et al. 2015). This area is part of the temperate region of South America that was dominated by deciduous and evergreen forest 200 years ago (Otero 2006). Deforestation had left an heterogeneous landscape where natural forest covers only 50 %, primarily in steep high altitude areas, and lands-use changes occur primarily in bottom lands where large extensions of crops (wheat, oats, barley, rye and potato), orchards (Blueberry), pastures for livestock grazing, and monocultures of exotic forest plantations occur (Miranda et al. 2015).

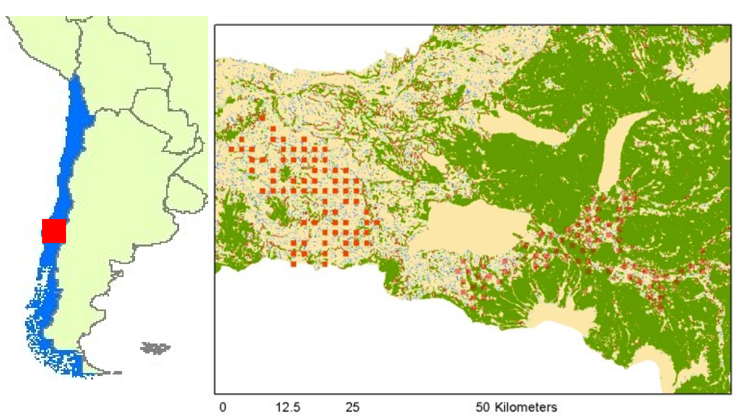


Figure 7. Study area, Toltén Watershed in Araucania region Chile. 80 sites (red squares) are part of long-term monitoring of wildlife biodiversity of the temperate forest of South America, a biodiversity hotspot.

Life-history traits and bird

My study will focus on birds. Despite the fact that most bird have the ability to fly large distances, many bird species are highly sensitive to fragmentation and respond to variation on landscape structure at small scale (100 ha) (Dias et al. 2015; Carrara et al. 2015). Moreover, birds that occur in the temperate region have a range of life-history traits that relate to species habitat specialization and movement capability (Ibarra and Martin 2015a; APPENDIX 2).

Site selection

I will monitor a subset of site from 80 sites that were selected randomly for a previous study (N. Galvez, pers comm; Ibarra and Martin 2015b), and are a good representation of the variability on landscape composition and configuration of the region (Figure 7). Sites will be selected to represent a range of total amount of forest, and matrix composition and configuration. Total amount of forest frequently explain much of the richness and abundance of birds species (Fahrig 2003; Carrara et al. 2015), then I anticipate accounting for amount forest in the model before response variable with other connectivity metrics.

Bird Counts

Each site will be surveyed once between October and December using point-transect surveys. I will locate five point separated by 125 m on each site. I will record all species heard and seen for 6 minutes. Individual will be recorded at two distances from center of point count (0-25 and 25-50) to account for detectability (Buckland et al. 2005). This point count method was developed for and applied in the region recently (Ibarra and Martin 2015a) and is part of a long-term monitoring of bird diversity. Using this method will help to make my result comparable to other landscapes close to my study area, while supporting the long-term monitoring of birds in this region.

Stand and landscape variables

To quantify the effect of landscape composition and configuration on bird density I will measure a set of stand and landscape variable. Landscape variables will be measured using a fixed buffer that forms approximately 100 ha. This landscape size is known to influence birds richness (Carrara et al. 2015).

Previous studies of birds' density in temperate forest of Chile have used multiple variables to represent stand, patch and landscape characteristics (Table 3). From this list I anticipate using variables such as understory density, tree DBH and height and forest canopy cover at each point count that are known to influence bird presence and abundance in the study area (Vergara and Armesto 2009; Ibarra and Martin 2015b). At the landscape level I will use amount of forest and average minimum distance between patches of forest. I will select other potential variables using information from model outputs from these previous studies to choose those that consistently had an effect on species abundances.

Measures of matrix connectivity, and specifically, measure of corridors abundance and position in the matrix, are much less frequent than common measures at the stand, patch, or landscape level on bird density studies. I will measure matrix composition (e.g., percent of vegetation cover) and matrix configuration, including number of corridors and stepping-stones. To measure number of corridors and other forest pattern in the matrix, I will use the result from the image morphology analysis (Chapter 1. Structural connectivity). Further, I will try develop a methodology to represent corridors in the matrix that not only account for the addition of connected area, but also for the dual function of a corridor as habitat and as movement conduits.

Table 3. Stand and landscape level variables used by previous studies to explain bird density.

Variable	**Description**	**Example**	**References**
Stand level			
Patch size	Patch area	Area (ha)	Estades and Temple 1999; Vergara and Armesto 2009
Patch nearest neighbor	Distance to closest patch of same habitat	Any distance measure	Estades and Temple 1999
Forest composition	Composition of plant species	Tree composition	Estades and Temple 1999
		Understory composition	Ibarra and Martin 2015b; Vergara and Armesto 2009
Forest structure	Variables that represent forest structure	Mean diameter at breast height (DBH)	Estades and Temple 1999; Vergara and Armesto 2009; Ibarra and Martin 2015b
		Canopy height (m)	
		Tree density (ind/area)	
		Total understory cover (%)	
		Total canopy cover (%)	
Landscape level (e.g., 100 ha)			
Habitat variables	Amount of habitat	Total amount of forest (area)	Carrara et al. 2015; Vergara and Armesto 2009
		Proportion of forest	
		Proportion of forest of different ages (old growth, secondary, forest)	
Matrix configuration	Shape and/or position of linear forested element in the matrix	Area added by structural links	Martensen, Pimentel, and Metzger 2008
Connectivity variables	Additional habitat area provide by fragment at a certain distance threshold	e.g., 10, 20, 100, 200 m	Dias et al. 2015 Martensen, Pimentel, and Metzger 2008
Matrix composition	Abundance of the cover types of the areas outside the habitat	Proportion of shrubs, pastures, crop, among others	Estades and Temple 1999; Carrara et al. 2015

Statistical analysis. I will assess the effect of stand and landscape level variables on individual bird density using models that account for detectability and that account for possible deviation from normality of the data, i.e., generalized linear models.

Expected Results

I expect that overall corridor will improve connectivity for most traits but that some traits will have a stronger response to the presence of corridors (Figure 8). For example, within the habitat-use guild, large tree users should increase connectivity when corridors are more abundant. While, connectivity of vertical profile generalist, those species that use any part of the forest profile, understory and shrub users should vary less because they are more willing to use vegetation with varies heights, such us shrubs.

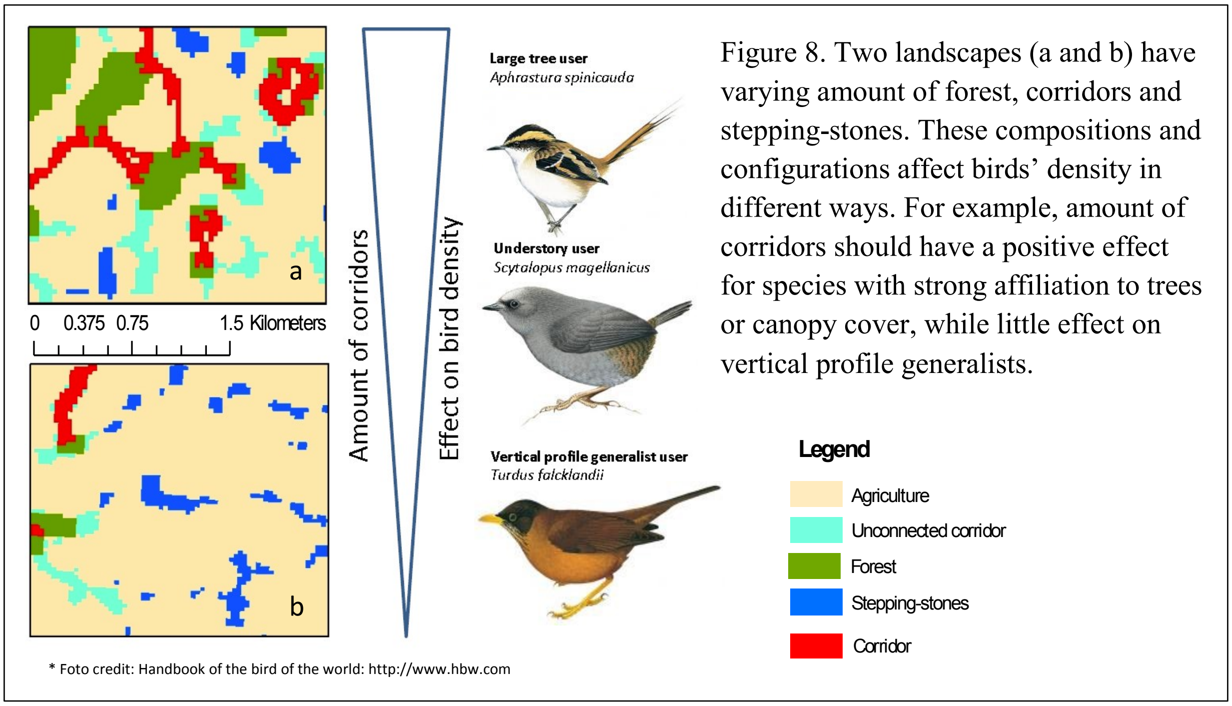


Figure 8. Two landscapes (a and b) have varying amount of forest, corridors and stepping-stones. These compositions and configurations affect birds' density in different ways. For example, amount of corridors should have a positive effect for species with strong affiliation to trees or canopy cover, while little effect on vertical profile generalists.

Moreover, I expect that home-range size will explain the effect of corridors on functional connectivity. Species with large home ranges move frequently to find food, shelter, or nest areas, or that perform seasonal migration, which I expect that they will rely more on corridors than species with small home ranges (Lees & Peres 2008).

Significance

This work will provide a synthesis of our understanding of the type of species that rely more on corridors for movement and the fragmentation condition where species needs more corridor structures to move. The classification of species based on life history traits will allow testing the dependency of these groups to corridors and extrapolating this result to a wider set of species that share similar traits, making this chapter relevant for conservation planning and management in Chile and elsewhere.

Chapter 3: the effect of perceived predation risk on the corridor use and gap avoidance of a forest dwelling bird

Introduction

Movement decisions that individuals make to survive in a particular landscape have significant impact on species persistence in fragmented landscape (Fahrig 2007). To survive and reproduce, animals move to find food and to escape from predators, competitors or other potential risk factors (Fahrig 2007; Nathan et al. 2008). Movement pattern reflects individuals optimal behavior that relate their motivation to move and their susceptibility to competition and predation and their level of conspecific attraction (Bélisle 2008; Zeigler et al. 2011; Knowlton and Graham 2010).

Individuals movement patterns depend on species responses to the landscape structure (Fahrig 2007; Bowler and Benton 2005). Landscape heterogeneity resulted from forest deforestation can greatly influence species movement behavior of bird that are forest specialist (Bélisle, Desrochers, and Fortin 2001; Turcotte and Desrochers 2003). Because resources are usually scattered in several small habitat patches of forest, individual must use multiple patches to supplement or complement their daily feeding needs (Dunning, Danielson, and Pulliam 1992).

Among forest specialist birds of the neotropics, leaf-foraging insectivorous birds are the most sensitive to fragmentation (patch size and isolation)(Martensen, Pimentel, and Metzger 2008). Forest specialist birds avoid gap crossings and/or the time spent in non-forest habitat (Desrochers and Hannon 1997; Cassady St Clair et al. 1998; Turcotte and Desrochers 2003). Empirical and theoretical studies suggest that increase perceive risk of predation in open areas may drives forest bird gap avoidance (Zanette et al. 2011; Zollner and Lima 2005). In a study of food availability for a passerine bird, Turcotte and Desrochers (2003) proved that where food is a limiting factor, individuals move outside of forests to increase their energy intake. The authors suggested that the specie was welling to fly into open habitat despite a higher predation risk (Turcotte and Desrochers 2003). However, their study did not include a formal test of increase of perceive predation risk or actual increase on predation risk. Their results may also reflect the optimal foraging behavior of a forest specialist, in that individuals prefer to forage in the forest unless food becomes a limited resource; in that case the individual is force to find food in the open habitat or a nearby patch of forest (Caraco, Martindale, and Whittam 1980). Studies that can further explore the effect of perception to predation risk on species movement pattern would increase our understanding of the drivers that determine species persistence in fragmented landscape.

Here, I will investigate the effect of increase perceived predation risk on the movement decision of a passerine bird. Specifically, I would like to test if an increase perception to predation risk drives gap avoidance of a forest dwelling bird. Further, I will test if corridors are perceived as areas with lower risk, then facilitating movement of this specie.

Methods

Study area and species

The thorn-tailed rayadito is a furnariid bird endemic to the temperate forest of South America (Rozzi et al. 1995). Rayadito is a specialist of forested habitats with high canopy cover and high density of large trees, where it finds food and nesting sites (Vergara and Armesto 2009). It is insectivore that forages primarily in the foliage of trees, but occasionally on seeds (Ippi and Trejo 2003; C. F. Estades 2001). In the pre-Andean range, rayadito eats primarily Lepidoptera and Arachnids (de la Maza 2013). Rayaditos are secondary cavity nesters, using cavities built by other birds, such as woodpeckers (J. Moreno et al. 2005). During the breeding season, rayaditos are territorial and spend most of their time in the vicinity of the nest (typically, birds will visit the nest 10-12 times/hour when chicks are 3 days old; Moreno et al. 2005). During the non-breeding season, rayaditos' territorial behavior diminishes and the species ranges more widely, in single- or mixed- species flocks with other forest specialist birds (e.g., tree runner) (Ippi and Trejo 2003; Rozzi et al. 1995). The species is well known for the noisy alarm call that individuals emit in the presence of predators or threats, named *mobbing call*. During winter, a mobbing call by rayaditos typically attracts several conspecific and heterospecific birds and, together, they mob the predator with the apparent proximate goal of driving the predator away, ultimately to decrease predator attacks (Ippi and Trejo 2003). The most frequent predator of adults is the Austral Pygmy owl or "Chuncho" (*Glacidium nanum*, King 1828).

I will study rayaditos that inhabit the central valley of the Araucania District in south-central Chile (Figure 6); same landscape studied in chapter 2. Although thorn-tail rayaditos can cross gaps of forest, the species appears to be sensitive to habitat connectivity on its northern distribution (Vergara et al. 2013).

Rayaditos are a good model species for this study because they exhibit a clear mobbing response to predators. This makes it relatively easy to keep track of the location of wild individuals, and thus to determine whether they are willing to cross specific distances in different habitat conditions. Among forest specialist birds of the neotropics, leaf-foraging insectivorous birds are the most sensitive to fragmentation (patch size and isolation)(Martensen, Pimentel, and Metzger 2008). Although rayaditos may occur at lower abundance in fragmented landscapes, they can still persist here, allowing us to study the behavior of this forest specialist bird in a fragmented landscape. Also, the species perform clear responses to stimulus in their environment (e.g., mobbing behavior when predator is present), making it possible to study the effect of this interaction on the species' movement behavior. Rayaditos are among the most abundant species in the temperate forest (Rozzi et al. 1995). Therefore, there is a high chance of encountering individuals of the species in the field. Rayaditos are noisy and perform constant calls making their detection an easy task (Ippi and Trejo 2003). Finally, because the species is a forest specialist, the results of this study could potentially be used to propose possible responses of other specialist bird species that are harder to detect in their habitats.

Field experiments

In order to determine the effect of perceived predation risk and several landscape elements on rayadito's movement behavior, I will use a playback trial, which is a test of the response of a bird lured by a call that has been previously recorded. Playback trial has been used before to study the Chickadee's movement behavior in fragmented landscape during winter (Desrochers and Hannon 1997; Cassady St Clair et al. 1998). Calls of a bird are useful because they direct bird movements and can attract several species of passerine birds (Desrochers and Hannon 1997; Cassady St Clair et al. 1998), and help standardized movement motivations and identify the destination in replicated landscape sections (Bélisle, Desrochers, and Fortin 2001).

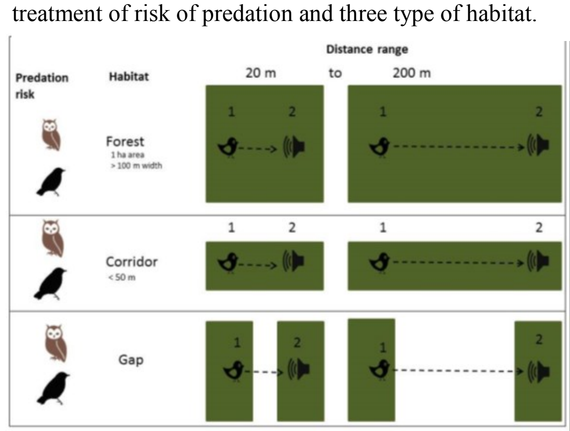
I will conduct playback trials during non-breeding season (June, July, and August), when rayaditos move more (Ippi and Trejo 2003). I will create two treatments, high and low perceived risk to predation:

High perceived predation risk calls: I will try two ways to represent high risk. One is to use a *mobbing call* and is used by rayaditos in the presence of a predator or threat (Ippi et al. 2013). A second call is the call of the predator. In both tests I will use a model of a predator in the predation risk trials, so experiment will have both an auditory and physical attractor. In addition to the playback treatment, I will try increase perception risk by treating the site area previously with the predator call (like day(s) in advance to the treatment).

Low perceived predation risk calls: I will use a *loud trill call*. Rayaditos use this call during non-breeding season to communicate between conspecifics. The exact function of this call is not clear, but there is a high chance that individuals use it to communicate food availability and attract individuals to form flocks (Ippi et al. 2013; Ippi 2009). Ippi (2009) suggests that this call does not represent threats or risk of predation. As an alternative loud trill call I will play the call of another bird that does not interact with rayaditos, such as the Austral Thrush (*Turdus falcklandii*), and exhibit a model of the species as well.

In order to determine the effect of land cover and pattern on rayadito's perceived risk of predation, I will conduct playback experiments under a simulated condition of high and low risk perceived risk to predation and three habitat conditions: gaps of forest (open agricultural fields), corridors (linear forest patches), and forest patches (Figure 8). Previous work on corridor function for understory bird in this region showed that species were infrequent in corridors < 10 m wide and always presents in corridors between 25 and 50 m wide (Sieving, Willson, and De Santo 2000). Here, I will use the same width categories (< 10 m, 25-50 m). This will allow me to check if the canopy specialist rayaditos have similar responses as the understory birds. In summary, I will test three habitat conditions (forest, gap, and corridors). Within each habitat condition,

Figure 8. Experimental trial of playback call under two treatment of risk of predation and three type of habitat.



playback trials will be performed at distances that vary between 0 to 200 meters.

Each experiment will be performed using the following procedure. First, one individual bird (or flock) will be located visually. Then, I will play the call of rayadito two times with a space of 1 minute in between. Third, I will wait 5 minutes for the individual or flock to respond to the call. I will conduct some preliminary testing of this procedure and adjust the specific times accordingly. My criteria for a positive response is if the bird(s) is attracted to the location of the speaker, specifically, if a bird moves to within 5 m of the speaker. My criteria for a negative response is if bird(s) do not move toward the speaker. I will rate a playback as inconclusive if bird(s) move in a way that is not clearly directed toward or fails to result in presence within 5 m of the speaker. I will record the response of all birds that I have visual contact with, after playing the call. As a complementary response variable I will measure the speed of the response of the individual/flock on each trial. Each trail will last approximately 15 minutes.

I conducted a power analysis to estimate sample size (APPENDIX III). I estimated that n should be larger than 200 to have a power of 40%, and 500 to have a power of 50%. This give very little power to this study design despite having observed very distinct responses between forest and gaps (Figure 9; Desrochers and Hannon 1997).

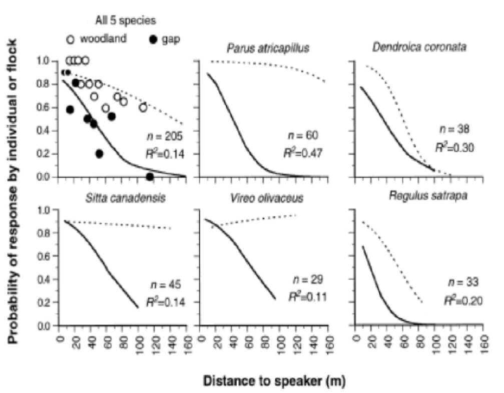


Figure 9. Example of probability of response curve for bird of the boreal forest in Canada. From Desrochers and Hannon 1997

Statistical analysis for trials

After completion of all trials, I will use logistic regression models to determine the probability of occurrence of the responses of rayadito to the playback across distances for each type of habitat. I will use the General Linear Model to test for differences in the playback response between the five type of habitat studied. In addition, because there is a high chance that other species will respond to the trials, I will fit a regression for each species individually and for all species together.

Expected Results

I conducted a brief exploratory field work during breading season 2015. I visited one potential study site compose of a small patch of forest (~2 ha). Here I conducted one playback trial inside the forest patch. I played the alert call (mobbing call) that last 1 minute. Two rayaditos approached within 3 minutes. They set in a tree less than 2 meter from me. I moved within the forest while observing the individuals. I played the call again 40 meters apart from starting point, and one of the individual approached me within a minute. Then I move out of the forest patch to an open area and played the call from a tree located 20 meters from the edge of the forest. Here, the individual did not follow that call. Finally, I played the call from another edge of the forest, one that limit with an area of shrubs and scattered trees. I step 15 meters from the edge. Here, I had a positive response within 4 minutes. The individual approached me less than a meter. These responses are expected during the reproductive season due to the territorial behavior of the species. I think it was the same individual or the couple that responded in all trials to defend their breading territories. It was clear that no other rayaditos were around that territory.

During winter I expect similar responses, but that differences will rise with the high perceived risk treatments. On high perceived predation risk, I expect individuals to move approaching the calls in forest habitat, but that they will not cross a gap unless some corridor structure provides support for movement across trees.

This work will provide information on the willingness of species to move in different habitat. I expect to find that both the habitat type and the distance traveled affect the willingness of species to move and that these two variables interact. I anticipate that the species may be equally willing to use big forest patches or linear riparian stripe that are wide at all distances tried in the trial but they may have a lower probability to cross large gaps or to traverse large distances in narrower corridors.

Significance

Wild habitats in agricultural landscape around the world frequently occur next to rivers. Therefore, understanding how forest specialist faunas make use of these remaining habitats can help us to find alternative habitat and/or corridors for species survival. My work will increase our understanding of connectivity of agricultural landscapes by providing empirical test of a mechanism that may explain species movement patterns beyond landscape structure. I will provide information on the effect of perceived risk of predation on gap crossing and determine how forested features and open-field gaps modulate this biotic interaction.

Chapter 4. Assessment of forest regulation to protect the network of riparian forest

Introduction

The aim of this chapter is to evaluate if current forest regulation in Chile do protect the connector function of the network of riparian forest. Globally the most common tool to protect freshwater ecosystems from human activities in forested regions is the use of buffers of trees along river (Richardson, Naiman, and Bisson 2012). Riparian buffers allow the maintenance of water quality by up taking nutrients, intercepting sediments and improving bank stability (Sweeney and Newbold 2014). Buffer can also ameliorate the impacts of the human activities on terrestrial wildlife (Machtans, Villard, and Hannon 1996; Marczak et al. 2010; Lees and Peres 2008). Riparian buffer become refugee for wildlife species in areas where forestry production alter habitat availability in upland areas after a clear cut (Shirley and Smith 2005). In agricultural lands riparian buffers provides habitat and help connect other small forest patches otherwise isolated (Dias et al. 2015; Gillies and Cassady St Clair 2008; Smith-Ramírez et al. 2010).

A buffer guideline usually defines a width and the management allowed within the riparian area, and specific guideline can vary widely between regions (Lee, Smyth, and Boutin 2004). However, for the most part buffer maintenance is enforce only where land is used for forestry, and not in land dedicated to agriculture or urban areas (Lee, Smyth, and Boutin 2004).. The lack of protection of buffer on agriculture and urban areas may create large gap of forest in the network of riparian forest, and reduce the potential for a riparian connectivity network (Fremier et al. 2015).

In Chile the protection of tree corridors along waterbodies dates back to 1900. The first notion to protect riparian areas appear in 1931 in the Forest Legislation by including the riparian areas of any kind (forested or not) as land suitable for forestry (Ministerio de Tierras y Colonización 1931). Riparian areas susceptible to flooding events could not be converted to agriculture. Moreover, this early legislation prohibited the clearing of any vegetation next to springs around a 400 m buffer in steep slopes and 200 m buffer in flat areas. The guideline for buffer maintenance in the 1931 Forest Law were active until 2008 (Ministerio de Agricultura 2008), when the new Regulation on soils, water and wetland was approved. This new regulation employs variable buffer guidelines depending on the distance to the shoreline, size of the river and the conditions of the terrain. However, similar to regulation in other region of the world (e.g., USA; Lovell and Sullivan 2006), Chile's regulation focuses on forestry land and does not enforce buffer maintenance in riparian areas in land suitable for agriculture or urban areas. My study will be the first to evaluate the extent to which the regulation was enforced, and the impact of the regulation on connectivity.

The goal of this chapter is to evaluate the effect that the riparian buffer regulation and alternative buffer regulation have on the landscape connectivity for wildlife species in Chile. My objectives are to identify the largest gaps in the riparian network protection and determine the importance of forest connection between larger patches of forest that occur along the hydrological network. Finally, I will examine possible alternatives to protect and restore riparian areas that lay out of the actual forest protection.

Methods

Study area: my study area is the county Araucania. Land use in the Araucania region, located in the temperate region of South America, is dominated by agriculture and forestry of native forest and plantation of non-native trees (Figure 10; Corporación Nacional Forestal 2011). The heterogeneity of the land use and land cover of this county makes it a good study area to test the effect of forest regulation on riparian forest network protection, because the regulation varies by land use type. I have chosen to focus on one country that has accurate land use information because forest regulation seems to be determined by specifics of land use type and topographic conditions. Therefore, accurate information on land use is necessary to accurately model forest protection scenarios.

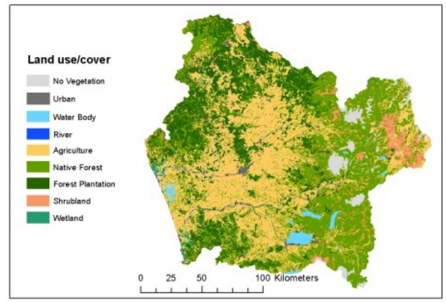


Figure 10. Land use composition of the county of Araucania. Agriculture land use is composing of pasture for livestock and crops field.

As an alternative, I will extent the methods applied to county Araucania to all counties in Chile. A country wide assessment would be ideal to assess forest protection along rivers. This study extent would give a broader insight of the effect of protection in a range of environmental conditions and would allow an assessment of connectivity for large distance movement (e.g., migration or distribution range shift due to climate). However, information on land use of Chile across counties is heterogeneous, increasing the large error common of a broad scale analysis.

Assessment of regulation and translation to forest patterns

Forest policy in Chile has several instruments and regulation that may exert influence on forest associated to rivers (Table 4). Therefore, I will start this chapter by analyzing the potential effect of the actual regulation on forest pattern, and construct a conceptual model of the forest patterns that would result if all regulations were enforced. I will use this conceptual model to build three landscapes scenarios:

1. *Contemporary landscape*: represent the actual regulation, as it was enforced.

2. *Restored landscape*: represent an ideal scenario where native forest is restored in riparian areas where conditions allow forest establishment.

3. *Buffer Landscape*: represent a minimum maintenance scenario where tree buffers are enforce in agricultural and forestry land.

I will compare these three scenarios and discuss the implication for connectivity.

Table 4. Summary of forest law and regulations that protect forest associated to rivers.

Policy/Name	Forest Definition	Guidelines	Type of water course	Type of land use
Forest law 1925 (Ministerio de Tierras y Colonización 1931)	Native forest protection	Native forest 400 m each side	Springs	Any
Forest law 2008 (Ministerio de Agricultura 2008)	Native forest for preservation	Forest that contain a tree species in a conservation category	Any	Any
	Native forest for protection and conservation	Native forest 200 m each side from water course	Natural water course	Any
Regulation of soils, waters and wetlands 2011 (Ministerio de Agricultura 2011)	Protection buffer	5 m buffer of no intervention	Water course larger than 0.2 m^2 and smaller than 0.5m^2	Forestry
	Protection buffer	10 m buffer of no intervention 10 m buffer of light intensity management (slope >30 and < 45%) 20 m buffer of light intensity management (slope > 45%)	Water course larger than 0.5 m^2	Forestry

Data source

Information on land cover will be extracted from the national land use/cover classification (Corporación Nacional Forestal 2011). This product was recently updated for 2013, and has a Kappa accuracy index of 94% for land use, and 84% for land cover type (Universidad Austral and Universidad de La Frontera 2014). The classification contains nine use/cover classes: Urban/industry, Agriculture, Shrubs and Pastures, Forest, wetlands, non-vegetated areas, glacier and snow, water body, and non-classified (Figure 10). This land use/cover product provides information on sub-uses; divide forest on three types (plantations, native forest, mixed forest) and agriculture in two types (agriculture and crop-pastures rotations).

Land capability classifies soils in eight classes that represent their limitation and erosion risk, and assigns sustainable uses of the land. This classification is used to determine soils with aptitude for cultivation or forestry, and provides a guideline to enforce forest regulation (Mauricio Nuñez, personal communication). Information on land capability is available from the same source as the national land use/cover classification (Corporación Nacional Forestal 2011).

Habitat connectivity analysis

To determine the potential connectivity resulting from enforcing forest regulations, I will combine graph network and resistance surface analysis (Nowakowski et al. 2015). I will use a graph network model to assess the spatial relationship between nodes and links, and resistance surface analysis to determine the strength of each link between patches of habitat. I will determine nodes as habitat patches compose of native forest and dissected by the hydrological network. The strength of the link between the selected patches of habitat will be derived using resistance surfaces. I will use the resistance surfaces developed in Chapter 2 for forest specialist birds, based on species estimates of habitat suitability. Specifically, I will use the resistance surface of the species that is most sensitive to modifications of the forest. I will analyze resistance surface of the matrix that separate two patches of habitat located along the river. I will define the matrix using a 200 m buffer along the river. The strength of the link will be calculated as the average value of the resistance surface of that buffered area. I will analyze the graph network using a several distance threshold to represent species with different abilities to travel (100, 1000, and 5000 m).

Analysis

For my analysis, I will apply similar method than those I use for chapter 1, and which are based on graph theory analysis and designed to determine connectivity at broad landscapes. To determine the gaps in the riparian network and their importance to connectivity, I will assess their overall connectivity, i.e. how much habitat is effectible connected for a given distance threshold, using the Equivalent Connectivity (Saura, Estreguil, et al. 2011). I will also use specific connectivity measures, i.e., the integral index of connectivity (IIC) that determine the contribution of each node and link to the overall connectivity (Pascual-Hortal and Saura 2007). The Integral Index of Connectivity estimates the possibilities of dispersal between all pair of patches. This index uses a binary connection model in which two patches are either connected or not; effect of quality, strength or frequency of use are considered (Saura, Vogt, et al. 2011). As I described above, the strength of the link between nodes will be qualified using resistance values of the matrix between patches of forest.

Expected Results/Deliverable

Identification of large gaps in the riparian forest protection

To identify the largest gap in protection of the actual regulation I will assess the number of networks and the Equivalent Connectivity (Saura, Estreguil, et al. 2011) for all the modeled Landscape: Regulation Enforced Landscape, Restoration landscape and Buffer Landscape. To compare the effect of each regulation I will construct a graph with the distance threshold on the x-axis and Equivalent Connectivity on the y-axis, and another one with the number of network that compose the whole riparian area. This graph will show the differences in total connectivity between landscapes. I anticipate that the Regulation Enforced Landscape will have many networks components and less total Equivalent Connectivity index because the lack of buffer regulation in agricultural land will create gap of forest.

Effect of link strength in the riparian network for overall connectivity

I will provide a summary table of the average contribution of link to connectivity for each scenario landscape. The table will contain the result for each distance threshold. I expect that links in the Restoration Landscape will contribute more to connectivity that links in the Buffer landscape because the Restoration Landscape involves wider forest protection next to the river which means that the resistance surface analysis will result in stronger links between patches of habitat compare to the Buffer Landscape.

Significance

Environmental regulation that span large geographic areas can have strong impact on biodiversity conservation, i.e., policies that regulate the protection of rivers that impacts large extension of riparian network (Fremier et al. 2015; Clerici and Vogt 2013). In this chapter, I will use a scenario approach to compare different riparian regulations in terms of their impact on landscape connectivity for birds. This approach will allow me to test if the forest regulation placed in Chile since 1931 has had any effect on maintaining landscape connectivity, and to propose modification to the regulation to improve protection of the riparian network. Overall, the ability to project, visualized and evaluates the potential impact of this kind of regulation on biodiversity can greatly improve the design of new regulation and stimulate discussions before regulation are put into place (Martinuzzi et al. 2015). Furthermore, this chapter will generate a methodology that later can be used to test the effect of forest regulations in landscape connectivity elsewhere.

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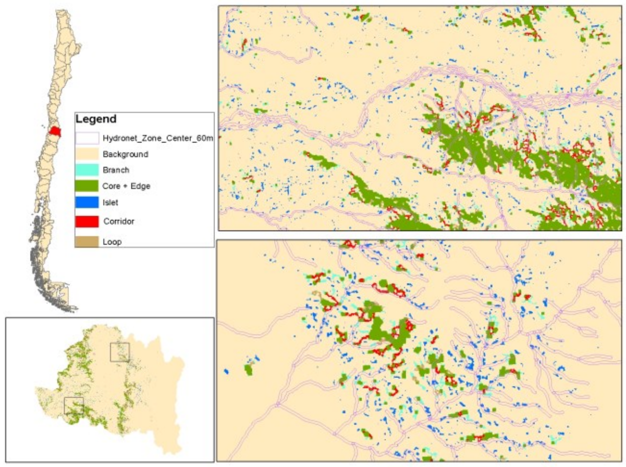
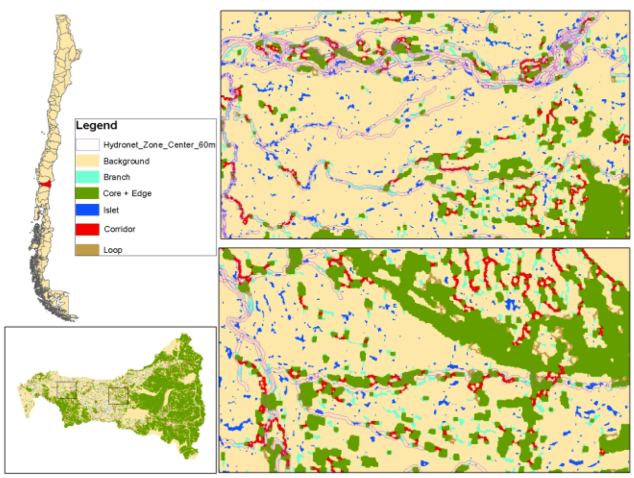
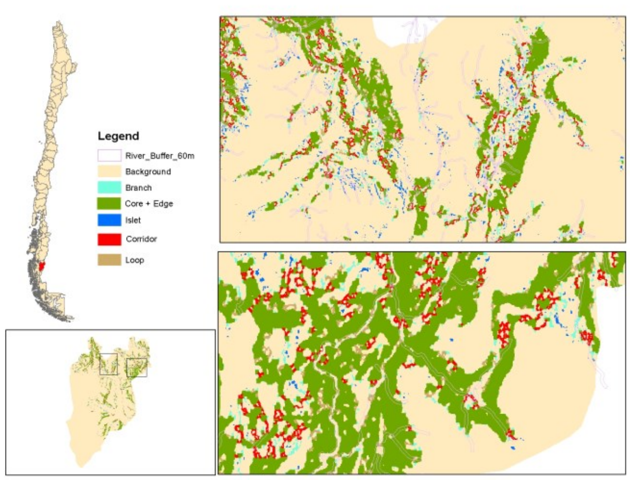
APPENDIX I. Morphological image analysis for three watersheds under different environmental conditions



1. Mapocho watershed has a contribution of riparian forest to corridors of 11%, proportion of forest is 22% and agriculture is 14%.



2. Tolten watershed has a contribution of riparian forest to corridors of 14%, proportion of forest is 50% and agriculture is 20%



3. Aysen watershed has a contribution of riparian forest to corridors of 8 %, proportion of forest is 12 % and agriculture is 0%

APPENDIX II. List of birds inhabit temperate rain forest and their traits (Ibarra and Martin 2015a)

	Habitat-use guild [a]	Nest guild [b]	Foraging guild [c]	Foraging substrate [d]	Migratory status [e]	Average clutch size [f]	Average body mass (g) [g]	Species specialization index (SSI) [h]
Chilean pigeon (*Patagioenas araucana*)	VPG	NCN	F(G)	G	P	1.5	200	0.12 (G)
Austral parakeet (*Enicognathus ferrugineus*)	LTU	SCN	F(G)	F(G)	P	7.5	200	2.68 (S)
Green-backed firecrown (*Sephanoides sephaniodes*)	VPG	NCN	N(I)	F(A)	M	2	5.98	0.23 (G)
Striped woodpecker (*Veniliornis lignarius*)	LTU	PCN	I	T(G)	R	3.5	39.97	1.21 (S)
Chilean flicker (*Colaptes pitius*)	LTU	PCN	I	T(G)	R	4	125	0.37 (I)
Magellanic woodpecker (*Campephilus magellanicus*)	LTU	PCN	I	T(G)	R	1.5	260	1.96 (S)
Thorn-tailed rayadito (*Aphrastura spinicauda*)	LTU	SCN	I(F)	T(F)	P	5	11.74	0.41 (I)
Des Murs`s wire-tail (*Sylviorthorhynchus desmursii*)	UU	NCN	I	F	R	3	10.5	0.72 (S)
White-throated treerunner (*Pygarrhichas albogularis*)	LTU	PCN	I	T	R	3	25.6	0.38 (I)
Black-throated huet-huet (*Pteroptochos tarnii*)	UU	SCN	I(G)	G	R	2	144.33	0.96 (S)
Chucao tapaculo (*Scelorchilus rubecola*)	UU	SCN	I(G)	G	R	2	40.35	0.78 (S)
Magellanic	UU	SCN	I(G)	G(F)	R	2.5	11.67	0.57 (I)

tapaculo (*Scytalopus magellanicus*)								
White-crested elaenia (*Elaenia albiceps*)	VPG	NCN	I(F)	F(A)	M	2.5	15.62	0.16 (G)
Tufted tit-tyrant (*Anairetes parulus*)	SU	NCN	I(F)	F	R	3	7.2	0.32 (I)
Fire-eyed diucon (*Xolmis pyrope*)	SU	NCN	I(F)	A	P	2.5	30.45	0.11 (G)
Chilean swallow (*Tachycineta meyeni*)	LTU	SCN	I	A	M	4	16	0.23 (G)
Southern house wren (*Troglodytes aedon*)	SU	SCN	I	F	M	5	10.37	0.24 (G)
Austral thrush (*Turdus falcklandii*)	VPG	NCN	F(I)	G(F)	R	3	78.75	0.03 (G)
Patagonian sierra-finch (*Phrygilus patagonicus*)	VPG	NCN	G(H)	G	M	3.5	21.3	0.60 (I)
Austral black bird (*Curaeus curaeus*)	VPG	NCN	I(H)	G	R	4.5	90	0.25 (G)
Black-chinned siskin	SU	NCN	G(H)	G	M	4.5	15.83	0.09 (G)

APPENDIX III. Power analysis_Chapter 3_Movement decision of a forest dwelling bird

To determine sample size for my experiment, I conducted a power analysis. A power analysis is useful to determine the probability to reject a false hypothesis for a range of sample sizes.

I based my power analysis on data from a previous study gap-crossing experiment on Chickadee (Figure 1; Desrochers and Hannon 1997). Chickadees are forest specialist, with similar life-history traits to rayaditos. The objective of this study was to detect differences on movement patterns between forests and gaps. They use logistic regression to detect this difference.

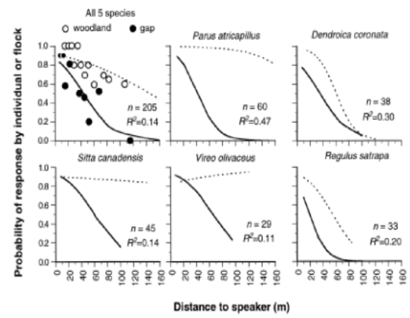


Figure 2. To develop response function for two type of habitat I extracted coefficients from *Parus atricapillus*

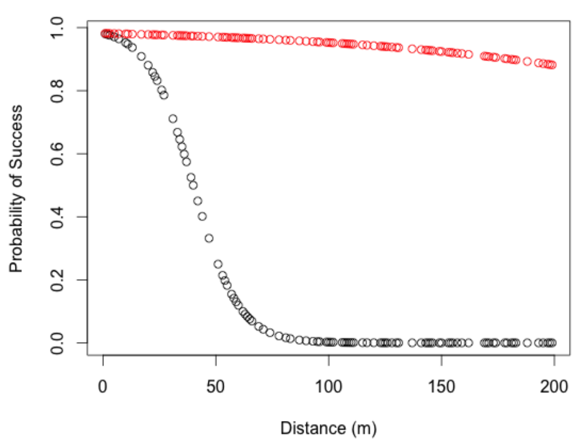


Figure 3. Hypothetical responses of the bird two forest habitat and gap.

Based on their estimated probability function I calculated coefficient b_0 and b_1 for forest (b_0=4; b_1=-0.01) and gap (b_0=4; b_1=-0.1), the two most contrasting treatment. This information I used to create a probability function curve for a starting sample size of 100, and distance sampled randomly from 0 to 200 m (Figure 2).

Curves of forest and gap habitat seem very different. To test for significance between forest and gap and the interaction with distance on the success probability, I use a general linear model, on family binomial as the data is describe as a Bernoulli distribution.

```
Summary of General Linear Model success ~ dist * habitat

                Estimate Std. Error  z value Pr(>|z|)
(Intercept)     25.63937 6098.01531   0.004    0.997
dist             0.02702   50.94409   0.001    1.000
habitat        -23.60272 6098.01515  -0.004    0.997
dist:habitat    -0.01351   50.94408   0.000    1.000

Null deviance: 276.939  on 199  degrees of freedom
Residual deviance:  31.371  on 196  degrees of freedom
AIC: 39.371
Number of Fisher Scoring iterations: 20
```

The summary above shows no significant differences between forest and gap (habitat coefficient), and did not detect an interactive effect of distance on habitats (dist:habitat coefficient). This means that the null hypothesis is not rejected with an n =100 and with given coefficient values, forest (b_0=4; b_1=-0.01) and gap (b_0=4; b_1=-0.1), despite observed clear difference between habitats.

Now, this example is just one realization of the pattern. To measure power I created a loop to run 1000 realization at a time and collect the p-value for habitat coefficient and dist:habitat. I counted those that resulted on significant p-value at alpha 5% and measure power as the proportion of significant p-value over 1000 iterations.

Using this loop structure I calculated power at several sample size and for different b_0 and b_1 coefficients and a set distance range of 10:200 m (Table 1).

	Power	
Sample size	Habitat	Habitat*Distance
20	0	0
100	0.252	0.005
200	0.409	0.008
300	0.413	0.025
400	0.442	0.016
500	0.455	0.016

Table 1. results from power analysis for different sample sizes.

Results from this exercise shows that there is very little power to reject a false hypothesis and that there is a high probability of committing type II error.

Logistic regression analysis spends a good amount of data in defining the behavior of the curve in the origin, middle and end of the curve. The curve for each habitat start at same intercept and at the end the curves are very distinct. While the middle of the curve is actually what I want to focus on. Therefore I shrunk the distance range to cover the middle areas, and repeated the iteration process. I found an important increase in power especially in habitat coefficient when distance ranges between 20:100. In this range, power increases to 75% for detecting differences between habitats. This suggests that I could modify my design to test difference at only few distances that are relevant (20m and 100 m) and use a different statistical analysis to detect the differences between habitats.