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DISTRIBUTION OF SLENDER-BILLED PARAKEETS (*ENICOGNATHUS LEPTORHYNCHUS*) IN A FRAGMENTED AGRICULTURAL LANDSCAPE OF SOUTHERN CHILE

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Resumen. – Distribución de los choroyes (*Enicognathus leptorhynchus*) en un paisaje agrícola fragmentado del sur de Chile. – Comprender la base de la selección de hábitats tiene importantes implicaciones en la formulación de políticas de conservación y manejo. Los objetivos del trabajo fueron: 1) determinar cómo los choroyes (*Enicognathus leptorhynchus*) utilizaron un paisaje agrícola fragmentado en el sur de Chile en términos de coberturas de uso del suelo y árboles aislados, 2) examinar variaciones estacionales, y 3) proporcionar recomendaciones para tomadores de decisión y agricultores interesados en la conservación de la especie y de los hábitats que utiliza. Para esto, se estimaron abundancias del choroy y componentes del paisaje en 30 sitios de 36 km² en una extensión de 50 por 80 km, centrada en la ciudad de Osorno. Los componentes del paisaje fueron analizados con en una regresión linear múltiple para detectar asociaciones entre estos elementos y las abundancias del choroy. Los resultados obtenidos revelaron la capacidad del choroy de utilizar el paisaje en forma de mosaico de manera distinta entre estaciones. No se encontró asociación alguna entre la abundancia del choroy y los elementos del paisaje para la estación noreproductiva. Sin embargo, una mayor cantidad de árboles aislados fue detectada como importante para mantener mayores abundancias de choroyes en la estación reproductiva. Los árboles maduros, solamente disponibles en el paisaje en la forma de árboles aislados, benefician a los choroyes como sitios para nidificación y alimentación - dos variables determinantes de su presencia. Estos árboles también pueden facilitar el movimiento a través de los paisajes agrícolas. La persistencia del choroy en este paisaje es intrínsecamente depende de la conservación y perpetuación de cualquier porción de bosque maduro, especialmente de los árboles maduros aislados. Muchas alternativas e implicaciones de este estudio pueden tener aplicabilidad en paisajes similares en otras partes del mundo.

Abstract. – Understanding the basis of habitat choices has important implications in the formulation of practical conservation or management policies. Our objectives were: 1) to determine how Slender-billed Parakeets (*Enicognathus leptorhynchus*) used a fragmented agricultural landscape of southern Chile in terms of landscape cover and scattered tree elements, 2) to examine seasonal variations, and 3) to provide conservation recommendations to landowners and managers interested in conserving the species and the habitats it uses. We estimated parakeet abundances and landscape components by sampling 30 36-km^2 sites across a 50 by 80 km region, centered at Osorno. Landscape components were used in a multiple linear regression to detect associations between these elements and Slender-billed Parakeet abundances. The results obtained revealed the ability of the vulnerable Slender-billed Parakeet to utilize a mosaic landscape. Parakeets used the landscape differently according to seasons. Associations between parakeet abundances and landscape elements during the non-breeding season were not detected. However, large numbers of scattered trees appeared to be important to support larger parakeet abundances during the breeding season. Mature trees, available in the landscape only as scattered trees, benefit Slender-billed Parakeets as nesting and feeding places - the two most important determinants of their presence. Scattered trees can also benefit the species by facilitating movement across agricultural landscapes. The persistence of the Slender-billed Parakeet in this landscape is intrinsically linked to the conservation and perpetuation of any remaining portion of original old-growth forest, especially the scattered mature trees. Many alternatives and recommendations from this study may have applicability to similar landscapes throughout the world. *Accepted 26 May 2012.*

Key words: *Enicognathus leptorhynchus,* Slender-billed Parakeet, agricultural landscape, Chile, forest fragmentation, Psittacidae, scattered trees.

INTRODUCTION

Landscape composition, structure, and dynamics are key components of conservation and management plans to preserve biodiversity (Virkkala *et al.* 2004, Vergara & Armesto 2009). Habitat loss, fragmentation, and conversion to agriculture and development are among the most important factors affecting animal populations worldwide (Petit *et al.* 1999, Virkkala *et al.* 2004, Evans *et al.* 2005, Lampila *et al.* 2005). Psittacines are among the world's most threatened group of birds, with at least 28% of species facing some risk of extinction (Collar 1997, 2000; Snyder *et al.* 2000). Habitat loss and the chick trade are considered to be the main causes of psittacine population declines in the Neotropics (Guix *et al.* 1999, Wright *et al.* 2001, Pain *et al.* 2006).

Data on species-habitat associations have been widely used in the formulation of practical conservation or management policies (Marsden & Fielding 1999, Carter *et al.* 2006). This is because understanding the basis of habitat choices has important implications for explaining the distribution of organisms in the wild (Chalfoun & Martin 2007). Animals use habitats in response to a combination of factors including resource availability, life-history traits, behavior, and dispersal abilities; with food availability and nesting sites being the primary determinants of psittacine presence or absence (Collar 1997, 2000).

Birds living in fragmented habitats are more susceptible to extinction risks than those in continuous environments because fragmentation usually leads to reduced habitat availability and may affect dispersal ability (Watson *et al.* 2005, Fahrig 2007, Nathan *et al.* 2008, Boscolo & Metzger 2009). Moreover, animal movements tend to vary according to the configuration of the landscape and matrix characteristics (Watson *et al.* 2005, Fahrig 2007, Nunes & Galetti 2007). Even for highly mobile species that use the "whole landscape", increased travel distances through unfamiliar terrain may present serious obstacles (Dale *et al.* 2006). Because such species may travel considerable distances, their studies require a landscape approach, including population censuses and habitat descriptions that take into account all habitat types across the landscape mosaic (Virkkala *et al.* 2004).

The Slender-billed Parakeet (*Enicognathus leptorhynchus*) is an endemic secondary cavity nesting psittacine of the south-temperate forests of Chile for which available natural history information is scant and anecdotal. There is also one anecdotal sighting of the species in Argentina (Matarasso & Webster 2006). Early reports indicate that the species was widely distributed throughout the lowland *Nothofagus* forests of southern Chile (Philippi 1864, Hellmayr 1932, Goodall *et al.* 1957), which have been largely fragmented and degraded by humans for agriculture and livestock grazing (Echeverría *et al.* 2006, 2007). Currently, the structure and composition of the original forest has been changed into a mosaic landscape composed of an agricultural matrix with scattered mature trees (relict from the original forest), exotic plantations of *Pinus radiata* and small fragments of second-growth forest composed of small trees of native species. The only available source of cavities with suitable sizes for Slender-billed Parakeets to nest is the old trees scattered in the agricultural matrix. Under this current landscape scenario, the ability to use a mosaic of different habitats may affect the Slender-billed Parakeet's future survival.

Although the Slender-billed Parakeet is categorized as a vulnerable species for southern Chile (SAG 1998), its habitat requirements are still unknown. The primary objectives of this research were: 1) to determine how Slender-billed Parakeets used a fragmented agricultural landscape of southern Chile in terms of landscape cover and scattered tree elements, 2) to examine associations between landscape elements and the abundance of Slender-billed Parakeets for the non-breeding and the breeding seasons, and 3) to provide conservation recommendations to landowners and land managers interested in conserving the species and the habitats it uses. Many alternatives and recommendations from this study may have applicability to similar landscapes throughout the world. As no previous quantitative studies addressed the effects of landscape composition on Slender-billed Parakeet abundances, it was hypothesized, that during the non-breeding season parakeets should not be restricted to a specific location and would search for areas associated with more foraging opportunities and roost sites. Conversely, during the breeding season, as Slender-billed Parakeets depend on mature trees with hollows to use as nest sites and the latter are only available as scattered trees in the agricultural matrix, the species should be selecting landscapes based on the abundance of scattered mature trees.

METHODS

Study area. Our study was located in a human-dominated lowland area comprising part of both the Lakes and Rivers Regions between the Andean and Coastal Range slopes in the central valley of southern Chile. To define the study area in a north-south orientation we selected the city of Osorno (40°42'S, 73°10'W) as the central point of an extension of 50 km (Fig. 1). The east-west orientation comprised approximately 80 km (the extension of the central valley excluding the most continuous forests from the Andean and Coastal slopes, Fig. 1). The regional climate is wet-temperate, with a yearly average precipitation of 1383 mm and an average temperature of 11.4°C (Luebert & Pliscoff 2006). Rainfall is distributed throughout the year, with a slight reduction during the Austral summer (December–March).

The central valley original vegetation was composed of a continuous deciduous lowland forest dominated by *Nothofagus obliqua*, *Laurelia sempervirens*, and *Persea lingue* trees (Donoso 1993, Luebert & Pliscoff 2006). Forest loss and fragmentation in the region has occurred for at least 100-150 years (Castellón & Sieving 2006), changing the structure and composition of the original forest into a mosaic landscape with scattered, small fragments of second-growth forest surrounded by prairies with extensive areas of farmland and pastures,

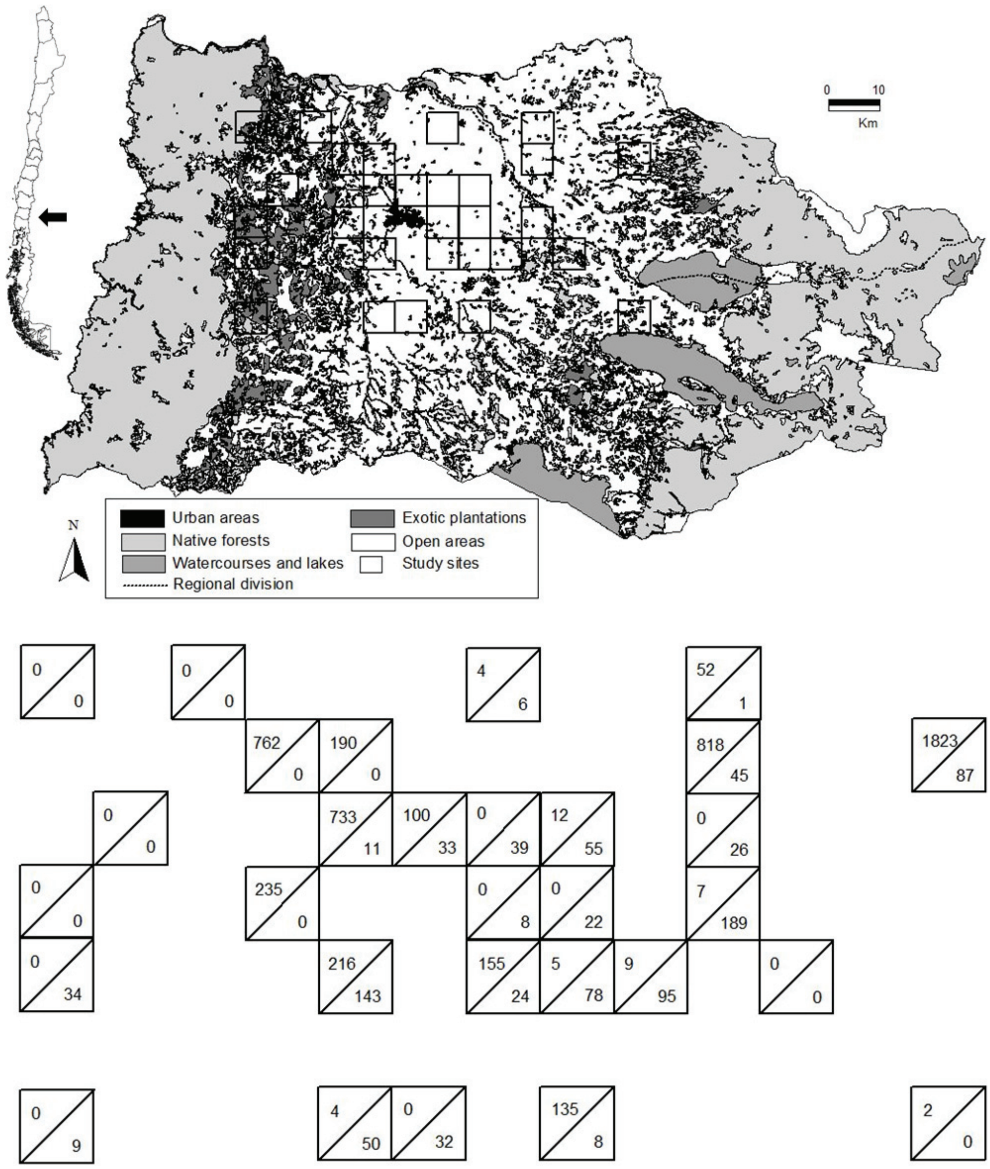

FIG. 1: Location of the study area in Chile (left side) and land cover classes. Study sites are represented with their location in the map and also enlarged (below) with the Slender-billed Parakeet abundances during non-breeding (above) and breeding seasons (below).

and exotic plantations of *Pinus radiata*. In the agricultural and livestock grazing matrix, numerous scattered mature trees of native species still persist (Fig. 2), and Slender-billed Parakeets use this element to nest. The small second-growth forest patches are composed only of small trees that do not provide suitable nesting sites.

FIG. 2: Example of scattered mature *Nothofagus obliqua* trees in an agricultural landscape near Osorno, Chile. Note lack of understory regeneration due to intensive livestock grazing.

Study design. Slender-billed Parakeets were monitored during the non-breeding and breeding seasons of 2009 in 30 study sites of 36 km² (6 x 6 km) each. Sites were randomly chosen from a grid laid across the study area irrespective of ease of access or distances from roads. To survey the selected sites, permission was obtained from landowners. When access to a site could not be gained or GIS information was not available, an adjacent area was selected. This approach ensured a broad and systematic selection of sites encompassing the inherent landscape variability (Virkkala *et al.* 2004, Manning *et al.* 2006).

The area of each individual study site (i.e., 36 km^2) was decided based on observations of the juvenile movement abilities. Prior information based on radio-telemetry of fledglings (n = 12; Carneiro 2010) suggested that 36 km² was an appropriate size to measure landscape associations. However, the 36 km² plots could be an underestimation of the optimal area to study Slender-billed Parakeet habitat associations during the non-breeding period; given the larger spatial ranges used by the birds at that time.

A grid-based sampling approach was used to associate parakeet abundances based on field counts to landscape components. This sampling approach permits the identification of the most important landscape components related to the abundance of the Slender-billed Parakeet.

Landscape variables. Landscape components in each study site were selected and measured according to 1) Human presence (HP): all variables directly associated with human presence (i.e., urban areas, primary and secondary roads, and dispersed buildings in rural areas) that could negatively affect parakeet abundances were grouped as one single variable, 2) Foraging and nesting habitats: native forest (NF), composed principally of *Nothofagus* second-growth forest, was used as a variable indicative of foraging habitats, and scattered trees (ST) was utilized to represent foraging and nesting sites, and 3) Roosting sites: watercourses (WC) were selected because of their association with riparian vegetation (most riparian fragments were not represented in the native forest category because of their small size) and the relation of these elements with the presence of roosting sites (Carneiro 2010). Although agricultural crops are numerous in the study area and Slender-billed Parakeets are commonly observed feeding on them, they could not be used in the analysis because individual agricultural plots are smaller than the resolution of the GIS database available (CONAF-CONAMA-UACH 2008). All variables except the number of scattered trees were expressed as proportions of the total area of each 36 km^2 site.

Urban areas, native forests, and watercourses were measured using an existing GIS database (CONAF-CONAMA-UACH 2008) derived from recent aerial photographs and LANDSAT images (taken in 2005), which mapped patches larger than 6.25 ha. Scattered trees and areas corresponding to buildings and roads were digitized as points and polygons, respectively, from georeferenced QuickBird® satellite images available from Google Earth Pro. Several points and polygons from the resulting map were ground truthed in the field using a global positioning system (GPS). All analyses using spatial digital data were performed in ArcGIS 9 (ESRI 2008).

Slender-billed Parakeet surveys. Parakeets were counted during two different periods representing their non-breeding and breeding seasons of 2009. Surveys for the non-breeding period occurred from April to June and for the breeding period, from October to December. All bird surveys were conducted by the same person (APBC) to avoid any among-observer variation.

A transect line of 4 km was established preferentially through the center of each plot to search into the area. Casagrande & Beissinger (1997) recommended the use of line transect surveys rather than point transects for estimating parakeet abundances. Surveys took place during the two to three hours before dusk when parakeets were most active. All flocks and single birds within each study site were recorded during the survey period, which lasted 1.5 to 2 h. A flock was defined as a group of two or more birds moving together. The size of the flocks was estimated through field counts using binoculars, and when not possible through posterior counts of images taken with a digital camera. Particular efforts were made to avoid double-counting by carefully observing parakeets, common sense, and by recording the direction of the movement of the flying birds. For individuals detected behind the observer the only birds that were recorded were the ones believed to be present when the observer passed by but were not detected.

Abundances for each study site that included every single bird or flock (represented by the total number of birds) were used in the regression analyses as the response variable. Abundances were used as the response variable rather than the number of flocks because the Slender-billed Parakeet is a highly social flocking bird. However, separate regression analyses were conducted for birds perched and birds in flight to elucidate the influence of some elements, such as scattered trees. Flying birds may use scattered trees as important landscape connectors that facilitate movements (Gibbons *et al.* 2008, Manning & Lindenmayer 2009), while perched birds may use these elements as specific attractions, such as feeding, nesting, or roosting sites.

Detectability was assumed to be near unity during the non-breeding season given the conspicuousness and noisiness of parakeets, coupled with the open and level terrain and the fact that most trees had no leaves. However, for the breeding season detectability could have been reduced because females were not always available to be counted and parakeets tended to be in smaller groups (Pizo & Simão 1997), making detection more difficult and possibly influencing total counts.

Statistical analyses. A multiple linear regression was used to quantify the relationships among the landscape components and Slender-billed Parakeet abundances. All landscape cover variables sum up to 36 km² in each plot, and therefore the proportions of these variables were not independent of each other. Collinearity between explanatory variables and spatial autocorrelation can hamper the detection of key environmental factors underlying bird-environmental relationships (Mac Nally & Horrocks 2000, Heikkinen *et al.* 2004, Sarasola *et al.* 2008). To solve potential problems related to the inter-correlations between the explanatory variables, a principal component analyses (PCA) for the explanatory variables was first run, and then the scores of the orthogonal principal components were used in a subsequent multiple linear regression (Quinn & Keough 2002, Graham 2003). Normality of regression residuals was assessed by inspection of normal probability plots. STATISTICA 7 (Statsoft 2004) software was used to perform all analyses.

RESULTS

On average, for all study sites only 11.6% (± 2.5) of the land was covered by native forest (Fig. 1). Open areas composed principally of agricultural and livestock grazing fields were dominant (79.4% ± 4.0). Scattered mature trees (2379.4 ± 239.0 trees per study site or 66.1 trees per km²) were part of this landscape. Watercourses and variables related with human presence represented 0.7 (± 0.2) and 1.5% (± 0.2) of the land cover for all study sites, respectively. The other 6.8% were represented by scrublands and exotic plantations, and were not used in the present study because very few study sites contained this element.

Slender-billed Parakeet surveys. Overall 120 km of line transects were surveyed once during each season (i.e., non-breeding and breeding seasons). A total of 5262 parakeets in 18 (60%) sites (mean of 175.4 ± 71.0 parakeets per site) during the non-breeding period, and 995 parakeets in 21 (70%) sites (mean of 33.2 ± 8.3 parakeets per site) during the breeding period were observed (Fig. 1). From these abundance totals, 3801 (72%) were represented by flying birds and 1461 (28%) by perched birds in the non-breeding season; while for the breeding season, 385 (39%) were flying birds and 610 (61%) were perched birds.

Principal Component Analyses (PCA). The first two principal components explained more than 95.0% of the cumulative variance in the data (Table 1). The first principal component (81.0% of the variance explained) was positively related to number of scattered trees (factor loading = 0.97). The second principal component (15.5% of the variance explained) was positively related to the amount of native forest. Third and fourth principal components explained 2.2 and 1.3% of the total data variance, respectively, and presented eigenvalues smaller than one, being excluded from the subsequent analyses.

Landscape associations during non-breeding and breeding seasons. No significant associations

TABLE 1. Principal component analyses (PCA) on the landscape cover categories and number of scattered trees per study site. Factor loadings, percentage of total and cumulative variance explained are presented. *ß* and P values from the regression analysis are also shown.

	Principal component 1	Principal component 2
% total variation explained	81.0	15.5
% cumulative variation	81.0	96.5
Native forest	–0.79	0.61
Watercourses (i.e., riparian vegetation)	0.20	0.46
Human presence	0.34	–0.49
Scattered trees	0.97	0.23
ß non-breeding season in flight (*P*-value)	0.225 (0.240)	–0.026 (0.891)
ß non-breeding season perched (*P*-value)	0.244 (0.203)	–0.031 (0.870)
ß breeding season in flight (*P*-value)	0.569 (0.001)	0.075 (0.637)
ß breeding season perched (*P*-value)	0.564 (0.001)	0.087 (0.588)

between Slender-billed Parakeet abundances and landscape elements were detected during the non-breeding season when the response variable was the number of birds in flight ($F_{2\text{-}27}$ = 0.731, r^2 = 0.051, P = 0.491) nor when it was number of birds perched ($F_{2\text{-}27}$ = 0.865, r^2 = 0.060, P = 0.432). In contrast, during the breeding season associations were identified by multiple regression analyses for both groups: flying ($F_{2\text{-}27}$ = 6.626, r^2 = 0.329, P = 0.005) and perched ($F_{2\text{-}27}$ = 6.532, r^2 = 0.326, P = 0.005). Best models suggested that Slender-billed Parakeet abundances both when flying and when perched were positively related to the number of scattered trees as represented by the first principal component (*ß* = 0.569, P = 0.001 and *ß* = 0.564, P = 0.001, respectively; Table 1).

DISCUSSION

Slender-billed Parakeet surveys. Slender-billed Parakeet populations were distributed widely in the central valley and occurred heterogeneously at varying abundances (Fig. 1). This pattern has also been documented for the Superb Parrot (*Polytelis swainsonii*) in Australia (Manning *et al.* 2006). Lower abundances seem to occur in the coastal areas, where large extensions of exotic plantations were found. Unfortunately, we could not statistically assess this relationship because few study sites contained this element, and a large number of zeroes in the land cover proportions could preclude pattern detection and thus compromise the analysis (Aebischer *et al.* 1993).

Landscape associations during non-breeding and breeding seasons. The spatial distribution of animals within a population is commonly thought to reflect the distribution of one or several limiting resources in the landscape (Mitchell & Powell 2004, 2007). Our inability to identify associations between landscape elements and parakeets' abundances during the non-breeding season were probably explained by the lack of an important landscape element in the dataset: agricultural crops. Slender-billed Parakeets were commonly observed to feed on wheat, barley, and corn during the winter. Agricultural crops are numerous in the study area and are generally smaller than 6.25 ha; consequently they were not represented in the GIS database (CONAF-CONAMA-UACH 2008) and were not used in the analyses. Furthermore, the location and composition of specific crops in the landscape changes from year to year, which also would have led to biased interpretations if using remote sensed data from previous years.

Another problem could be related to an underestimation of the optimal size of the study sites (36 km^2) for the non-breeding period. The Slender-billed Parakeet is a highly mobile species and during this period engages in long distance movements in search of productive areas with food sources and roosting sites. Agricultural crops were scattered and the temporal availability and dynamics of the crops differed among study sites. According to Mitchell & Powell (2007) in heterogeneous, patchy habitats, movements among patches could vary according to food availability on a daily and seasonal basis. These factors highlight the challenges to studying a highly-mobile species that responds quickly to resource variations and can use the "whole landscape."

Although significant associations between habitats and roosting sites were not detected by regression analyses, we know from field observations that parakeets were using native riparian vegetation as concentration centers. Therefore, the importance of such forests for the Slender-billed Parakeets as roosting sites should not be underestimated. Specific studies about roost site selection should be developed to understand the potential importance of riparian vegetation for Slender-billed Parakeets during the non-breeding season. Apart from the potential plot size underestimation, the hours during which censuses were conducted could have contributed to a lack of significance, because censuses were carried out before birds began to arrive to their roost sites.

Multiple regression results for the breeding season detected a positive association between parakeet abundances and the number of scattered trees in the landscape both for flying and for perched birds. However, models explained no more than 33% of the variation in abundance. Much of the remaining variation could likely be explained with finer spatial scale data (Nunes & Galetti 2007). In fact, in a parallel study of the Slender-billed Parakeet nest site selection, the characteristics of the individual tree used for nesting and its immediate surrounding (radius of 50 m centered at the nest tree) appeared to be more important than landscape characteristics (radius of 3500 m surrounding the nest tree) in nest site selection (Carneiro 2010). However, in that study only the breeding population was examined, whereas the present study considered all members of the population. Nevertheless, in both studies the importance of conservation of any portion of original old forest, represented essentially by scattered mature trees, was highlighted.

Because of past land-clearing practices in the study area, mature trees with hollows suitable as nest sites were only available as scattered mature trees within the agricultural matrix (Fig. 2). The small native forest fragments were largely second-growth and composed mainly of small trees. Although the Slender-billed Parakeet is a highly mobile species that can travel considerable distances, a tendency to remain near their nesting sites during the breeding season could be an advantage (i.e., central place foraging theory, Manning *et al.* 2006). According to Forshaw (1989) throughout the nesting period one parent always remains in close proximity of the nest. If so, having large numbers of mature scattered trees would be an advantage not only in terms of more possibilities for finding suitable nest cavities, but also as potential foraging sites. Slender-billed Parakeets feed commonly on flowers, seeds, fungi species, buds, fruits and seeds of native trees and also on introduced fruiting trees (e.g., cherry and apple trees). All these food resources were found dispersed throughout the agricultural landscape. Although non-breeding birds would be present during the surveys, and are theoretically not subject to remaining close to nesting trees, the Slender-billed Parakeet is nevertheless a flocking bird and non-breeding birds may also freely associate with the breeding population (Manning *et al.* 2006). Marsden & Pilgrim (2003) argued that the availability of food in human-altered landscapes allows non-breeding parakeets to survive in these modified ecosystems.

In summary, scattered mature trees favored Slender-billed Parakeets during the breeding season as nesting and feeding sites, the two most vital determinants of their presence (Collar 1997, 2000) as indicated by the analysis of perched birds. Moreover, scattered trees can also facilitate movement across agricultural landscapes by providing resting and feeding sites for flying birds. Such trees may also serve as shelter from predators and roosting sites. In fact, it was observed that during this period, breeding adults roosted in the scattered mature trees. All these potentialities of use have been reported for other birds, especially for secondary cavity nesters (Fischer & Lindenmayer 2002, Gibbons & Boak 2002, Fischer *et al.* 2005, Haslem & Bennett 2008, Manning & Lindenmayer 2009).

Management considerations. Our findings revealed the ability of the vulnerable Slender-billed Parakeet to utilize a mosaic landscape containing only 11.6% of native forest. However, we should be cautious about any conclusions regarding Slender-billed Parakeet abundances and their associations with landscapes elements because 1) we do not know if this population is stable or in decline, 2) our multiple regression models for the breeding season data presented a large amount of unexplained variation, and 3) models for the non-breeding season were not significant.

Scattered mature trees are common elements in agricultural landscapes worldwide. The increasing number of studies of these elements during the last decade highlights the importance of maintaining these trees. Representing the only traces of the original forests, such trees provide critical habitat for native biota and also provide important ecosystems services (see Gibbons & Boak 2002, Gibbons *et al.* 2008, Haslem & Bennett 2008, Manning & Lindenmayer 2009). Throughout the study area, scattered trees consist mainly of *N. obliqua* (preferred as a nest site) and *L. sempervirens.* Despite their ecological importance, scattered mature trees are rapidly declining in southern Chile, and the lack of sufficient recruitment due to intensive grazing by livestock (Fig. 2) and cultivation may leave few future options for Slender-billed Parakeets in these landscapes. This challenge illustrates the need for action at both the farm and the landscape scale for conserving and perpetuating scattered trees to preserve the native fauna.

The conservation of scattered mature trees in agricultural landscapes is essential for the maintenance of the Slender-billed Parakeet; however, it should be supplemented by also protecting the few remaining native forest fragments, as they can be potential future sources of nesting cavities. Although this study did not detect significant relationships with native secondary forests, we observed that parakeets were using native forest fragments as roosting sites during the non-breeding season. However, more studies should be conducted to clarify the relative importance of additional landscape elements for Slender-billed Parakeets during the non-breeding season.

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