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# Multi-level analysis of bird abundance and damage to crop fields

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ABSTRACT

Bird damage to agricultural crops is an important cause of economic loss for farmers worldwide. Predictive habitat models relating bird abundance and damage to characteristics of the agricultural environment at multiple scales are a key tool for designing management programs to reduce impacts of birds on agricultural production. In this study, we explored habitat features influencing abundance and damage of monk parakeets (*Myiopsitta monachus*) to corn (*Zea mays*) and sunflower (*Helianthus annuus*) fields, as a basis for the design and evaluation of management strategies for preventing damage in the future. Using a multi-level approach, we evaluated within-field, field, and landscape variables at three spatial scales potentially related to monk parakeet abundance and damage in crop fields. Monk parakeet abundance and damage was greater in sunflower than in corn fields. Landscape variables, such as distance to nearest site with trees, percentage of landscape with trees, and availability of foraging sites for monk parakeets around the crop fields were more important than local variables in explaining monk parakeet damage to crop fields. However, local variables, such as field area, plant density and percentage of field border with trees, also were related to damage. Relationships varied depending on the crop under consideration and spatial scale of analysis. Based on this study, managers should consider both local and landscape factors when planning management measures to prevent bird damage to crops.


## 1. Introduction

Resolution of human–wildlife conflicts is a significant challenge because these conflicts are widespread, have large economic impacts, and often require solutions that take into account the landscape context of the problem. Bird damage to agricultural crops, which is an important cause of economic loss for farmers worldwide (Conover, 2002; De Grazio, 1978), is one source of such conflict that may be tied closely to patterns and processes on the landscape (Clergeau, 1995). Because most birds that cause agricultural damage move over large areas, bird abundance, spatial distribution of foraging, and consequently crop damage may be related to the way birds perceive and are affected by elements of the landscape that occur at multiple scales, such as quality of food within foraging patches, size and shape of crop fields, and habitat composition surrounding the fields (Amano et al., 2004, 2008; Clergeau, 1995; Hagy et al., 2008; Otis and Kilburn, 1988; Tourenq et al., 2001).

The scales at which bird pests respond to the landscape have profound implications for management (Clergeau, 1995; Zaccagnini et al., 1995). For example, if local factors such as plant density or field shape are the most important factors influencing bird damage to crops, individual landowners potentially can manipulate these factors to decrease the problem. However, if crop damage is strongly influenced by landscape-level factors (e.g., distribution of crop fields across the landscape, availability of other habitats for nesting, etc.), land use decisions at multiple scales may influence crop damage sustained by individual farmers, and design of effective management programs will require more complex programs or policies that integrate multiple landholdings. The correct spatial scale for management thus depends on how birds perceive and use the landscape.

Predictive habitat models that relate bird abundance and damage to characteristics of the agricultural environment are a key

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tool for designing programs to reduce impacts of birds on agricultural production (Amano et al., 2008). Detection of useful predictor variables for the effects of landscape structure on the occurrence of birds is dependent upon selection of the right scale for analysis (Boscolo and Metzger, 2009; Lawler and Edwards, 2002). Likewise, the spatial scale at which landscape variables are measured is likely to affect detection of relationships between bird damage to crops and landscape structure and composition. Although some studies of bird pests have evaluated both local and landscape factors in the same study (Amano et al., 2004, 2008; Hagy et al., 2008; Otis and Kilburn, 1988; Tourenq et al., 2001; Zaccagnini et al., 1995), none of these studies analyzed multiple spatial scales at the landscape level nor explicitly evaluated the scale at which landscape variables best explain bird abundance and damage to crop fields.

The objectives of this study were to: (1) examine the association of environmental variables with abundance and crop damage of monk parakeets (*Myiopsitta monachus*) across three levels of organization (within-field or plot level, field or patch level, and landscape level), and (2) compare performance of landscape-level measures at three spatial scales where landscapes are defined as mosaics of spatially heterogeneous land cover within a specified radius of crop fields where bird abundance and damage were measured. Monk parakeets are among the most important bird pests causing damage to grain crops in South America, particularly in Argentina and Uruguay (Bruggers et al., 1998; Bruggers and Zaccagnini, 1994; Spreyer and Bucher, 1998). Although high quality foods for monk parakeets in agricultural landscapes are maturing grain crops (e.g., sunflower and corn, Aramburú, 1997; Aramburú and Bucher, 1999; Spreyer and Bucher, 1998), parakeets also forage on wild seeds, fruit of native trees, and other grain and fruit crops (Spreyer and Bucher, 1998). This species constructs stick nests on tall natural and artificial structures, including native savanna trees (e.g., *Prosopis* spp. and *Acacia* spp.), introduced *Eucalyptus* trees, and utility poles (Spreyer and Bucher, 1998), and uses nests all year around for breeding and roosting. Monk parakeets forage out from the nest and then return to that site, thus functioning as central-place foragers (Stephens and Krebs, 1986). Daily movement from the nest site to foraging areas generally is between 3 and 5 km, although possibly longer (up to 24 km) during the non-breeding season (Spreyer and Bucher, 1998). Considering the large daily movement of monk parakeets, their nesting habits, and generalist foraging behavior (Bucher et al., 1991; Hyman and Pruett-Jones, 1995), we expected characteristics of the landscape around a crop field, as well as field-level factors, to influence abundance and damage of parakeets in that particular field.

## 2. Methods

### 2.1. Study area

The study was conducted in a 525,000-ha area comprising the Department of Paraná (Entre Ríos Province, Argentina, Fig. 1). The area is characterized by diverse production activities, with a predominance of crops, beef cattle and milk production (Engler and Vicente, 2009). Crop fields, pastures, and remnant woodlands are interspersed across the study area.

#### 2.2.1. Sampling scheme

The study was conducted in the 2006–2007 and 2007–2008 austral summer seasons (December to February). Damage to grain crops by monk parakeets occurs principally to ripening sunflower and corn, which were the focus of this study, and also occasionally to sorghum, wheat and rice (Spreyer and Bucher, 1998). We used a geographic information system (ArcGIS v.9.2) to place a grid with a cell size of 10 × 10-km over Paraná Department and selected 25 non-contiguous grid cells in 2006 and 31 cells in 2007 using systematic sampling with the first cell selected at random and every other cell selected thereafter. This sampling scheme allowed us to cover the study area within the time-limits imposed by crop maturation and represents the number of fields we could evaluate before harvest.

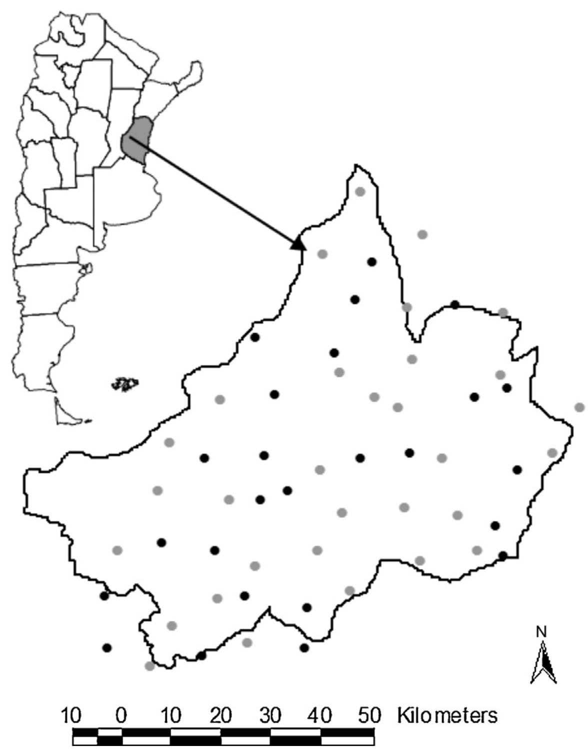


**Fig. 1.** Map showing the location of Department of Paraná (Entre Ríos Province, Argentina) and the crop fields sampled in 2007 and 2008. Black dots indicate corn fields ($n = 25$) and grey dots indicate sunflower fields ($n = 31$).

We identified the nearest corn or sunflower field to geographic coordinates for the central point of each cell. Based on the type of crop we sampled in the first cell, when possible we choose a different type in the next cell in order to have both types of crop fields with a relatively even distribution throughout the study area (Fig. 1). A crop field (or patch) was defined as a contiguous area covered by corn or sunflower that differed from its surroundings. Based on a first visit to each crop field, we planned the date for sampling bird abundance and damage to coincide with the ripening crop in each field, which is when damage by monk parakeets was expected. Study sites included 13 corn and 11 sunflower fields in the 2006–2007 summer season (hereafter 2007 season) and 9 corn and 16 sunflower fields in the 2007–2008 summer season (hereafter 2008 season). The mean size (SE) of corn fields was 22.52 ha (3.46), and the mean size of sunflower fields was 24.25 ha (2.99).

### 2.3. Bird abundance surveys

Monk parakeets were surveyed using field-edge (180°) unlimited distance point counts in the direction of the crop (Bibby et al., 2000; Freemark and Rogers, 1995). The observation period at each point was 5 min. Points were located on the border of crop fields in proportion to their size (range = 4–11 points per field) with a minimum distance of 200 m between consecutive points to decrease the possibility of double counting birds (Freemark and Rogers, 1995). Surveys were conducted between sunrise and mid-morning (10:00 h), with one field sampled per morning. All parakeets observed in the field, as well as entering or leaving the field, were recorded. Relative abundance of monk parakeets was estimated for each crop field as the average number of birds observed per point per field.

### 2.4. Estimation of crop damage

Each crop field was sampled for monk parakeet damage in a fixed number of sampling stations ($n$ = 36 stations/field in 2007, $n$ = 80 stations/field in 2008) along 2–4 transects systematically distributed over the field in line with crop rows (Zaccagnini, 1998). Sampling stations were systematically placed with a random start on a row for each of three strata: field edge (plants in the first line), border (25 m from the edge of the field), and center of field. The number of sampling stations per stratum per field was as follows: 2007—field edge – 8, border – 16, center – 12; 2008—field edge – 12, border – 36, and center – 32.

Each sampling station comprised five consecutive plants perpendicular to the direction of the sampling row. At each station, we registered the number of damaged and non-damaged plants (infestation or frequency of damage). Frequency of damage by monk parakeets in each field was estimated as the proportion of damaged plants over total number of plants using a stratum weighted proportional estimator (Cochran, 1977; Zaccagnini et al., 1985). With this estimator, the proportion of damaged plants in each stratum (edge, border, and center) is weighted by the estimated number of plants in the stratum to account for differences in size, and consequently number of plants, in the strata (Cochran, 1977, pg. 90). We estimated the number of plants by stratum based on plant density (see below) and the surface of each stratum in square meters, calculated using Patch Analyst extension in ArcGIS 9.2 (Rempel, 2010).

### 2.5. Factors hypothesized to influence abundance of monk parakeets and damage to crops

Within-fields the structure of crop plants, characterized by plant height, row spacing, and plant density, is directly related to accessibility of the plants by birds and rewards for foraging on them (e.g., seeds obtained from sunflower heads). Phenological stage of the plants influences nutritional content of seeds and possibilities of handling and consumption by the birds. Both crop structure and phenology have been shown to be related to bird damage to crops (Bridgeland and Caslick, 1983; Clark et al., 1982; Hagy et al., 2008). Because weeds serve as alternative foods for birds and, in some cases, attract birds to crop fields before the crop is mature enough to be eaten, weed density within fields also may influence bird abundance and damage to crop fields (Otis and Kilburn, 1988; Hagy et al., 2008).

At the field level, we expected the size of crop field, as well as the field perimeter and its complexity (regularity), to be related to bird abundance and damage on the crop fields, because these factors affect the amount and accessibility of food (Clark et al., 1982; Tourenq et al., 2001). Additionally, we expected an abundance of trees on the border of the crop field would have a positive effect on bird abundance and damage in the field, because of their attractiveness to birds as loafing sites (Otis and Kilburn, 1988). Finally, control measures for parakeets, if applied, were expected to reduce the abundance of monk parakeets and their damage to the crop field.

At the landscape level, the need for multiple resources (e.g., foraging and nesting sites) likely constrains the choice of crop fields by parakeets, and thus their abundance and damage at a particular site. Because the distance between roosting and foraging sites affects energy expenditure, we expected availability of areas for perching and nesting close to the crop fields, measured by distance to the nearest site with man-made structures and trees (which are used as roosting or nesting sites) and the percentage of

**Table 1**
Environmental factors hypothesized to influence abundance of monk parakeets and damage by these parakeets to crops at three levels of organization[a] and variables used as potential explanatory predictors in statistical models (*). See Sections 2.6 and 2.7 for more details.

| Spatial level | Environmental factors | Variables |
|---|---|---|
| Within-field | Characteristics of the crop plants that make foraging easier or more profitable for the birds | Plant height |
| | | Row spacing |
| | | Plant density (PLTDEN)* |
| | | Phenological stage (PHENST)* |
| | Abundance of alternative food sources within a crop field | Weed cover (WDCOV) * |
| Field | Accessibility and amount of high quality food | Field area (AREA) * |
| | Accessibility of high quality food | Field Shape Index (SHAPE)*, based on field perimeter and complexity |
| | Accessibility of perch sites at the field | Abundance of trees on border (TREES) * |
| | Application of a control measure to prevent monk parakeets from using the crop field | Presence of bird control measures |
| Landscape | Abundance and availability of areas for perching and nesting close to the crop fields | Distance to the nearest site with man-made structures and trees (DISTCO)* |
| | | Percentage of landscape with tree patches (TRPLAND)* |
| | | Aggregation (measured with a Clumpiness Index) of tree patches |
| | | Mean nearest-neighbor distance among tree patches |
| | | Patch shape complexity (measured with a Shape Index) of tree patches |
| | Abundance and availability of high quality food in the landscape | Percentage of landscape with crops susceptible to damage (corn and sunflower, CRPLAN)* |
| | | Aggregation (measured with a Clumpiness Index) of crop patches susceptible to damage (CRCLUMP)* |
| | | Mean nearest-neighbor distance among all susceptible crop fields |
| | | Patch shape complexity (measured with a Shape Index) of susceptible crop |
| | Abundance of alternative food sources in the landscape | Percentage of landscape with pastures and other agricultural uses, including weedy and fallow fields (PSTPLAND)* |

[a] Factors were hypothesized based on Amano et al. (2008),Bridgeland and Caslick (1983), Clark et al. (1982), Hagy et al. (2008), Otis and Kilburn (1988), Tourenq et al. (2001), Wiens and Dyer (1975), or our field observations.

landscape with tree patches around the crop field, to positively influence use of particular fields by monk parakeets (Amano et al., 2008; Bridgeland and Caslick, 1983; Hagy et al., 2008; Otis and Kilburn 1988; Tourenq et al., 2001; Wiens and Dyer, 1975). Similarly because reduced travel time between forage patches provides a means of optimizing energy intake per unit of energy expenditure in the search for food, we also expected abundance of corn and sunflower fields and aggregation of these fields in the surrounding landscape to be positively related to use of particular fields by monk parakeets. In contrast, we could not predict a prior the influence of alternative food sources near a crop field. Alternative food patches could increase the use of a particular crop field by birds by attracting the birds to the area, or reduce the use of a crop field by providing an alternative food source (Otis and Kilburn, 1988; Clark et al., 1982; Hagy et al., 2008, Table 1).

### 2.6. Within-field and field-level variables

Variables within each field were measured on the sampling plots used for damage evaluation as follows: (1) plant height and (2) phenological stage of one plant in the center of each plot and two plants on opposite edges; (3) plant density, estimated as the number of rooted plants on a meter of row divided by the area corresponding to this meter of row (1 m $\times$ distance between rows in m); and (4) weed coverage, estimated as the proportional coverage by weed plants a 1 $\times$ 1-m quadrat in each sampling plot (Colbach et al., 2000; Otis and Kilburn, 1988). Measurements for crop structure variables in each plot were then averaged over all sampling plots in a field to obtain one value per field for each variable. Because plant density and plant height were substantially correlated ($r \geq 0.60$), with more dense crops having shorter plants, we used plant density for model construction, based on its widespread agronomical use for characterizing crop structure.

The following variables characterized the field: (1) percentage of the field border with trees, recorded in the field on a 3-point scale (1 = 0–5%, 2 = 5–50% or 3 = >50%), and estimates of (2) field area, (3) field perimeter, and (4) shape complexity, calculated with the Patch Analyst extension for ArcGIS (Rempel, 2010). Because field area and perimeter were substantially correlated ($r \geq 0.60$), we used field area for model construction based on relationships documented in other studies between bird damage and field area (e.g., negative for red-winged blackbirds (Clark et al., 1982), positive for greater flamingos (Tourenq et al., 2001)). We did not include variables related to bird control measures on the crop fields because, based on field observations and interviews with each landowner, we determined that no control measures were taken against monk parakeets on any of the crop fields evaluated in this study.

### 2.7. Landscape-level variables

We examined composition and configuration of the landscape within circular buffers of 3 different radii from the center of each crop field (1000, 3000 and 5000 m). These landscape extents were chosen based on the expected daily movement range of monk parakeets from the nest site to foraging areas while breeding (range: 3.5–8 km, Spreyer and Bucher, 1998). We set an upper buffer limit of 5000 m to avoid overlapping buffers and reduce potential spatial autocorrelation of the landscapes around each crop field (Boscolo and Metzger, 2009; Koper and Schmiegelow, 2006; Renfrew and Ribic, 2008). We did not use buffers smaller than 1000 m because of problems with artificial borders in estimation of landscape indices (McGarigal et al., 2002).

Buffers for crop fields sampled in 2007 and 2008 were obtained from Landsat TM images (226–82 21-January-2007 and 24-January-2008) classified by Noelia Calamari (INTA, EEA Paraná) using supervised classification. The 2007 Landsat image was classified using ECHO (Extraction and Classification of Homogeneous Objects) in MultiSpect Application v3.1 (2007) and the 2008 Landsat image was classified using ImageSVM (Support Vector Machine, van der Linden et al., 2007) in ERDAS imagine 9.1 (2006). Ten land cover types were identified, and classification was validated with 100 points per land cover type randomly selected using Quickbird images (available in GoogleEarth$^{TM}$, http://earth.google.com) and ground sampling. Overall classification accuracy was 82% and 84% for 2007 and 2008 satellite images, respectively. Our analysis focused on availability of three land cover classes: (1) crops that could be susceptible to damage by monk parakeets at the time of the study (corn and sunflower), (2) tree patches, potentially used as sites for perching, nesting or daily loafing, and (3) pastures, fallow and weedy fields, that can include food items for monk parakeets such as flowers and seeds.

We calculated landscape metrics representing landscape composition and configuration within the buffers surrounding each field using FRAGSTATS 3.3 software (McGarigal et al., 2002). Composition metrics included percentage of landscape with each of the three land cover classes. Configuration metrics included aggregation of susceptible crop fields and aggregation of tree patches (measured with a Clumpiness Index), mean nearest-neighbor distance among all susceptible crop fields and among all tree patches within the buffer, and patch shape complexity (measured with a Shape Index) of susceptible crop fields and tree patches. Additionally using Google Earth, we measured distance from the crop field to the nearest site with man-made structures, such as houses and barns, which commonly have adjacent trees used by monk parakeets as nesting or resting sites (Burger and Gochfeld, 2005; Spreyer and Bucher, 1998). Substantial correlations ($r \geq 0.60$) occurred among some landscape metrics, particularly at higher extents (3000 and 5000 m) and only uncorrelated metrics ($r < 0.60$) were included in the same model. Because of the importance of land cover in explaining bird abundance (Fahrig, 2001; Hagy et al., 2008; Renfrew and Ribic, 2008), we sought to include configuration metrics uncorrelated with percentage of landscape for the two primary cover classes (crops susceptible to damage and tree patches). In the case of susceptible crops, this was possible with the Clumpiness Index. However, in the case of tree patches, all configuration metrics were correlated with percentage of this cover type on the landscape, and no configuration metrics were included in models. Finally, because percentage of landscape with crops susceptible to damage was negatively correlated with percentage of landscape with trees at higher buffer extents (3000 and 5000 m), we included only one of these variables at a time for model construction at those buffer extents.

### 2.8. Statistical analyses

We modeled relative abundance of monk parakeets and monk parakeet damage in each crop field as a function of within-field, field and landscape variables at each buffer extent (1000, 3000 and 5000 m) separately to identify important variables at each level, corresponding to environmental factors hypothesized to influence abundance and damage (Table 1). Then, we constructed a set of multi-level models combining important variables at within-field, field and landscape level for each buffer extent. Because both response variables and transformations of these variables (square root for abundance and cosine for proportion of crop damaged) were not normally distributed, a generalized linear model framework (GLM) was used with a negative binomial error structure for relative abundance of monk parakeet and a binomial error structure for proportion of crop damaged (SAS v. 8.0, SAS Institute Inc. 2006). Each model included only one to three explanatory variables because final sample sizes for model construction were relatively small for each crop (corn, $n = 22$; sunflower, $n = 27$). We first constructed models for each single variable, and then models with sets of two and three variables within each level (within-field, field and landscape, Appendix A, Supplementary material). We used this exploratory approach, rather than a more restricted set of a prior models (Fletcher and Koford, 2002), because we had no prior information on the explanatory power of our variables in combination. We also ran a null model for each set of models to examine the degree to which variability of dependent variables was explained by random effects (Appendix A, Supplementary material). For parakeet damage, we constructed a set of performance-based models (post-hoc models) that contained the strongest predictors from each of the three levels. We used the within-field variable with the minimum AICc value as the base model and added the variable with the best performance at field and landscape levels in multi-level models (Fletcher and Koford, 2002; Renfrew and Ribic, 2008). Multi-level models were not run for parakeet abundance because we were not able to clearly identify predictors within each level.

We developed models for corn and sunflower separately because within-field variables such as plant height, plant density, and weed density differed greatly between these crops, and we expected use, and potentially damage, of crop fields by monk parakeets to differ based on differential preferences for these crops (Aramburú and Bucher, 1999). All models were evaluated using SAS PROC GENMOD and maximum likelihood estimation. We used Akaike information criteria adjusted for small sample size (AICc) for comparing model performance within each level and for comparing single-level and multi-level models. We considered models with $\Delta$ AICc scores $\leq 2$ to be competitive (Burham and Anderson, 2002). For evaluating individual variable performance at each level, we used model averaging and the sum of competitive models in which a variable was present ($\Sigma\omega_i$, Burham and Anderson, 2002). We tested for normality and spatial autocorrelation of GLM regression model residuals with Shapiro–Wilk normality tests (McCullagh and Nelder, 1989) and semivariogram plots (Isaaks and Srivastava, 1989), respectively. No violations of normality or spatial autocorrelation were observed.

## 3. Results

### 3.1. Monk parakeet abundance and damage in crop fields

We found that monk parakeets (birds/point/field) were significantly more abundant (Wilcoxon test = 549.50, $P = 0.007$) in sunflower fields ($x = 9.29$, SE = 1.52) than in corn fields ($x = 5.27$, SE = 1.61). Bird abundance did not differ between years within sunflower fields (Wilcoxon test = 205.50, $P = 0.22$) or corn fields (Wilcoxon test = 171.00, $P = 0.110$). Similarly, monk parakeet damage was significantly higher (Wilcoxon test = 455.00, $P < 0.0001$) in sunflower fields ($x = 4.29\%$ damaged plants, $SE$ = 0.88) than in corn fields ($x = 0.90\%$, $SE = 0.46$), and no statistically significant differences occurred in damage within crop type between years (Wilcoxon test = 166.50, $P = 0.17$ for corn; Wilcoxon test = 175.00, $P = 0.97$ for sunflower). Both monk parakeets and damage by monk parakeets were observed in most sunflower fields (25 of 27), but only in half of the corn fields (11 of 22 fields). Monk parakeet abundance was strongly correlated with damage in corn fields ($r = 0.75$, $P < 0.001$), but not in sunflower fields ($r = 0.49$, $P = 0.01$).

### 3.2. Monk parakeet abundance and damage in crop fields in relation to within-field, field and landscape variables

We did not detect any association of abundance of monk parakeets in corn and sunflower fields with within-field, field or landscape characteristics. The top performing model was the null model, followed by models that included only one variable at all levels (Appendix B, Supplementary material). All variables produced models with similar AICc values ($\Delta$ AICc $\leq 2$ between the minimum and the maximum value for all univariate models, Appendix B, Supplementary material). Additionally, all 95% confident intervals for coefficients of predictor variables included zero, indicating these factors did not explain monk parakeet abundance in corn or sunflower fields. Given the lack of explanatory power of all variables, we did not explore multi-level models with abundance data.

In contrast to abundance, parakeet damage to crop fields was associated with within-field, field, and landscape characteristics. Most variables representing within-field and field characteristics were included in the top performing models at each level for either corn or sunflower (Table 2). Similarly, most landscape variables were included in the top performing models at each buffer extent (1, 3 and 5-km, Table 2). Null models performed poorly at all levels, with model weights ranging between 0.00 and 0.02 (Table 2).

#### 3.2.1. Within-field and field level variables

Monk parakeet damage to corn and sunflower fields increased as weed coverage increased, and damage decreased as plant density increased (Table 2). Also, monk parakeet damage to corn fields decreased as phenological stage of corn advanced (Table 2). Based on the sum of Akaike model weights ($\Sigma\omega_i$) and the 95% confidence intervals for coefficients, phenological stage and plant density were the most important within-field variables for explaining monk parakeet damage to corn and sunflower fields, respectively, while weed coverage was less important for both crop types (Table 3).

At the field level, monk parakeet damage to corn fields decreased as the field shape became more irregular or different from a regular square (i.e., Shape Index increased, Table 2). Monk parakeet damage to sunflower fields increased as field area declined and tree abundance on the field perimeter increased (Table 2). Field shape was the most important variable explaining monk parakeet damage to corn fields, and field area and tree abundance were the most important variables explaining monk parakeet damage to sunflower fields (Table 3).

#### 3.4.1. Landscape-level variables

At all buffer extents, monk parakeet damage to corn fields was related positively to the percentage of landscape with trees; percentage of landscape with pastures, weedy and fallow fields around the crop field; and aggregation of crops susceptible to damage (Table 2). In sunflower fields, parakeet damage increased within the 1-km buffer as the percentage of landscape with trees increased and distance to the nearest site including man-made structures declined (Table 2). At larger buffer extents, damage in sunflower fields increased as the percentage of the landscape with tree patches and percentage of landscape with pasture and weedy and fallow fields increased around the crop field. Percentage of the landscape with tree patches around the crop field was consistently a very important variable explaining monk parakeet damage to both corn and sunflower fields at all buffer extents (Table 3).

The relationship between monk parakeet damage to sunflower and aggregation of crops susceptible to damage was less clear than for corn with this factor only occurring in two of the five competitive models at the landscape level (Table 2). The best landscape-level models for explaining parakeet damage were at the 1-km buffer extent for corn and the 3-km buffer extent for sunflower (Table 2). For both crop types, damage of monk parakeets to crop fields was better explained by landscape-level

**Table 2**
Minimum AICc models for monk parakeet damage to corn and sunflower fields in Entre Rios (Argentina) during 2007 and 2008 summer seasons. Models are ordered based on model performance within each level with lower AICc values indicating better model performance. Parentheses indicate a negative relationship with damage. Variables are defined as in Table 1.[a]

| | Corn | | | Sunflower | | |
|---|---|---|---|---|---|---|
| Spatial level | Model | AICc | Akaike weight ($\omega_i$) | Model | AICc | Akaike weight ($\omega_i$) |
| Within-field | (−PHENST) | 63.90 | 0.24 | (−PLTDEN) + WDCOV | 306.40 | 0.46 |
| | (-PHENST) + WDCOV | 64.17 | 0.21 | (− PLTDEN) | 307.10 | 0.32 |
| | (-PHENST) + (− PLTDEN) | 64.26 | 0.20 | | | |
| | (-PHENST) + (− PLTDEN)+ WDCOV | 64.71 | 0.16 | | | |
| | (−PLTDEN) + WDCOV | 65.85 | 0.09 | | | |
| | (− PLTDEN) | 65.88 | 0.09 | | | |
| | Null model | 69.25 | 0.02 | Null model | 331.92 | 0.00 |
| – | | | | | | |
| Field | (−SHAPE) | 63.37 | 0.62 | (−AREA) | 315.59 | 0.63 |
| | | | | TREES | 317.14 | 0.29 |
| | Null model | 69.25 | 0.03 | Null model | 331.92 | 0.00 |
| – | | | | | | |
| Landscape – 1 km[a] | 1TRPLAND + 1PSTPLAND +1CRCLUMP | 22.70 | 0.91 | (−DISTCO) + 1TRPLAND | 281.48 | 0.44 |
| | | | | (−DISTCO) + 1TRPLAND + 1CRCLUMP | 282.84 | 0.22 |
| | Null model | 69.25 | 0.00 | Null model | 331.92 | 0.00 |
| Landscape – 3 km | 3TRPLAND + 3PSTPLAND + 3CRCLUMP | 35.40 | 0.41 | 3TRPLAND + 3PSTPLAND | 276.68 | 0.77 |
| | 3TRPLAND + 3CRCLUMP | 35.95 | 0.31 | | | |
| | 3TRPLAND + 3PSTPLAND | 36.47 | 0.24 | | | |
| | Null model | 69.25 | 0.00 | Null model | 331.92 | 0.00 |
| Landscape – 5 km | 5TRPLAND + 5PSTPLAND + 5CRCLUMP | 42.49 | 0.60 | 5TRPLAND + 5PSTPLAND | 287.12 | 0.62 |
| | 5TRPLAND + 5PSTPLAND | 43.79 | 0.31 | 5TRPLAND + 5PSTPLAND + (−5CRCLUMP) | 288.13 | 0.38 |
| | Null model | 69.25 | 0.00 | Null model | 331.9 | 0.00 |
| – | | | | | | |
| Multi-level | (−PHENST) + (−SHAPE) + 1TRPLAND | 38.93 | 0.96 | (−PLTDEN) + (−AREA) + 1TRPLAND | 249.34 | 0.99 |
| | Null model | 69.25 | 0.00 | Null model | 331.92 | 0.00 |

[a] In landscape models, numbers preceding the variable code indicate buffer sizes (in kilometers).

models at all buffer extents than by models describing only the field characteristics or conditions within the field.

The relative performance of single-level models versus multi-level models in explaining parakeet damage to crop fields differed between corn and sunflower. For corn fields, landscape-level models with variables within the 1-km and 3-km buffers performed better than the multi-level model (Table 2). However, for sunflower fields, the multi-level model, which included a landscape variable in addition to within-field and field variables, outperformed all of the single-level models (Table 2).

## 4. Discussion

Crop damage by monk parakeets was explained by variables measured at within-field, field, and landscape levels. In contrast, monk parakeet abundance in crop fields was not explained by environmental variables at any level of analysis or spatial extent. We may have obtained this result because abundance of monk parakeets in fields is not affected by the variables that we measured (i.e., key variables were not measured), or perhaps more likely, a single count per field did not capture differences between fields in the use by parakeets (i.e., abundance was not well evaluated in order to capture differences among fields). Because bird damage is cumulative and bird abundance is not, damage may have provided a better overall indication of field use by parakeets than our measure of abundance.

Landscape variables were more important than local variables in explaining monk parakeet damage to corn and sunflower fields. Landscape variables can contribute to explaining patch-level use by birds because landscape characteristics influence the ability of a species to move between patches and energetic costs of movement or supply clues about the quality of patches during the process of patch selection, or because the landscape provides other key resources that do not occur in the focal patch (Bruun and Smith, 2003; Surmacki, 2005). For monk parakeets, distance to the nearest sites with man-made structures and adjacent trees, percentage of the landscape with tree patches around the crop fields, and availability of pasture and weedy and fallow fields contributed to explaining monk parakeet damage to corn and sunflower fields. These results may indicate the importance of landscape processes, such as landscape complementation or supplementation, for the monk parakeet.

Landscape complementation refers to the occurrence of habitat patches containing non-substitutable resources for a species in close proximity (i.e., food and nesting sites, Dunning et al., 1992). Because monk parakeets use nests all year around for breeding and roosting (Spreyer and Bucher, 1998), the abundance and/or proximity of tree patches that harbor potential nesting sites to crop fields may influence spatial distribution of parakeets on the landscape. Energetic costs for movements between nesting and foraging sites also could influence population size of parakeets and, consequently, the amount of damage on the landscape. Similar to our study, proximity of roosts and loafing areas to sunflower fields has been documented as an important variable explaining difference in damage among fields by red-winged blackbirds (*Agelaius phoeniceus* L., Hagy et al., 2008).

Landscape supplementation occurs when patches with substitutable resources occur in proximity in the landscape and, therefore, sustain a larger population than does a landscape in which these habitats are far apart (Dunning et al., 1992). Because monk parakeets are generalist foragers (Bucher et al., 1991; Hyman and Pruett-Jones, 1995), multiple food sources (e.g., seeds from pastures and weedy fields in addition to crops) may support higher parakeet populations than crops alone, and result in more damage to crops where both sources are available, as we observed. However, studies of other bird pest species have found that availability of alternative foraging sites around crop fields can be related negatively to bird use or damage on those fields prompting

**Table 3**
Regression results for factors considered in predicting monk parakeet damage to crop fields in Entre Ríos (Argentina) in 2007 and 2008 summer seasons. Coefficients and associated 95% confidence intervals (CI) for each predictor variable were derived from multi-model inferences using all parameter subsets and Akaike weights ($\omega_i$) at each level. $\Sigma\omega_i$ for each predictor variable shows the sum of Akaike weights for all possible models in which the predictor variable was incorporated at each level.

| | | Corn | | | | Sunflower | | | |
|---|---|---|---|---|---|---|---|---|---|
| Spatial level | Variable | AICc | Coefficient | CI (±) | $\Sigma\omega_i$ | AICc | Coefficient | CI (±) | $\Sigma\omega_i$ |
| Within-field | PLTDEN | 65.88 | −0.17 | 0.18 | 0.54 | 307.10 | −0.27 | 0.10[a] | 1.00 |
| | PHENST | 63.90 | −0.51 | 0.40[a] | 0.81 | 333.23 | 0.005 | 0.03 | 0.22 |
| | WDCOV | 69.52 | 0.27 | 0.31 | 0.47 | 331.50 | 0.17 | 0.19 | 0.44 |
| Field | AREA | 71.63 | <0.001 | <0.001 | 0.05 | 320.72 | −0.01 | 0.008[a] | 1.00 |
| | SHAPE | 63.37 | −3.14 | 2.70[a] | 0.83 | 328.79 | 0.11 | 0.20 | 0.32 |
| | TREES | 71.63 | −0.008 | 0.09 | 0.18 | 329.86 | 0.17 | 0.12[a] | 0.93 |
| Landscape1 km | DISTCO | 70.40 | <0.001 | <0.001 | 0.01 | 326.83 | (−) <0.001 | <0.001[a] | 0.66 |
| | 1CRPLAN | 69.97 | <0.001 | <0.001 | 0.00 | 324.64 | <0.001 | <0.001 | 0.00 |
| | 1CRCLUMP | 55.10 | 13.77 | 11.58[a] | 0.97 | 325.50 | 0.27 | 0.51 | 0.31 |
| | 1TRPLAND | 33.79 | 0.06 | 0.03[a] | 1.00 | 283.58 | 0.02 | 0.006[a] | 1.00 |
| | 1PSTPLAND | 69.66 | 0.06 | 0.04[a] | 0.93 | 325.90 | −0.002 | 0.002 | 0.17 |
| Landscape3 km | 3CRPLAN | 48.54 | −0.001 | <0.001[a] | 0.01 | 308.59 | (−) <0.001[a] | <0.001 | 0.00 |
| | 3CRCLUMP | 56.13 | 9.73 | 9.89 | 0.73 | 304.19 | −0.18 | 0.64 | 0.22 |
| | 3TRPLAND | 40.72 | 0.05 | 0.02[a] | 0.99 | 334.17 | 0.02 | 0.006[a] | 1.00 |
| | 3PSTPLAND | 71.66 | 0.06 | 0.06 | 0.65 | 323.65 | 0.04 | 0.01[a] | 1.00 |
| Landscape −5 km | 5CRPLAN | 52.31 | −0.02 | 0.01[a] | 0.07 | 319.06 | (−) <0.001 | <0.001[a] | 0.00 |
| | 5CRCLUMP | 70.83 | 12.61 | 15.58 | 0.64 | 332.13 | −0.63 | 0.92 | 0.38 |
| | 5TRPLAND | 51.24 | 0.06 | 0.02[a] | 0.93 | 317.25 | 0.02 | 0.006[a] | 1.00 |
| | 5PSTPLAND | 71.59 | 0.14 | 0.08[a] | 0.98 | 320.16 | 0.05 | 0.02[a] | 1.00 |

[a] Confidence intervals that do not include zero, indicating that these factors probably were related to monk parakeet damage to corn or sunflower fields.

the recommendation of alternative food plots as a way to decrease damage to crops (Avery 2002; Amano et al., 2004, 2008; Hagy et al., 2008). The high preference of monk parakeet for sunflower and, at lesser extent, corn compared to other seeds (Aramburú and Bucher, 1999; Canavelli, unpublished) may explain damage in these fields, even though alternative seeds were available in the landscape.

Although landscape characteristics around the crop fields were key for predicting monk parakeet damage to crop fields, local variables (within-field and field levels) also were important. These results could be related, in part, to foraging preferences of monk parakeets in relation to crop condition, which are poorly known. Greater monk parakeet damage occurred in immature corn and regularly shaped corn fields. Small sunflower fields with low plant density and high percentage of the field border with trees were more prone to monk parakeet damage than other fields. In earlier studies, damage by monk parakeet was observed to be negatively related to field area and plant density in corn fields (Bucher, 1984), but these relationships were clearly detected in only sunflower fields in this study.

Focal patch studies employing multiple buffers have shown that birds may respond strongly to landscape variables measured in buffers equal or greater than 1 km (e.g., Cooper and Walters, 2002; Renfrew and Ribic, 2008; Sallabanks et al., 2006). In this study, models at the buffer width of 1 km for corn fields and 1 and 3 km for sunflower fields had better performance for predicting monk parakeet damage than models at the buffer width of 5 km. We sampled most crop fields at the end of the reproductive season (January). Assuming these buffer extents reflect the scale of the foraging process under study, the results are consistent with reduced mobility and small home range of monk parakeets during nesting season and may indicate that daily distances of travel between nest and foraging sites are shorter during nesting than originally proposed (between 3 and 8 km, Spreyer and Bucher, 1998). The importance of variables within 1–3 km buffers around fields also may be related to the generalist feeding characteristics of parakeets, as they could easily shift among food items within a relatively small area (Boscolo and Metzger, 2009), particularly in a season where natural food items are easily available, such as spring or summer. Because the daily distance traveled by monk parakeets is greater in the non-reproductive seasons than in the reproductive season (Spreyer and Bucher, 1998), the best landscape scale for predicting damage by parakeets to crop fields also could change with season.

Results from this study support the need to consider both landscape and local factors for predicting and managing monk parakeet damage to crop fields. Because farmers that plant sunflower are likely to suffer greater losses than farmers planting corn, they will benefit most by planning management alternatives to decrease monk parakeet damage. In order to prevent monk parakeet damage, sunflower farmers may consider increasing plant density, but within the recommended range of plant density, in order to avoid other problems such as smaller plants and/or yields. Other cultural practices include synchronizing planting time of sunflowers within the region and moving the harvest date forward to decrease exposure of sunflower to foraging birds (Canavelli et al., 2012; Linz et al., 2011). Additionally, farmers could consider planting non-preferred crops on the border of the fields, as buffering crops around sunflowers and corn, to dissuade monk parakeets from using the fields (Canavelli et al., 2012). Our observation of increasing crop damage in the presence of alternative food sources (e.g., pastures and fallow fields) suggests that alternative feeding areas or lure crops may not be successful in decreasing damage by monk parakeets in particular crop fields. However, this management alternative needs more evaluation, particularly with very attractive food sources, such as sunflower (Linz et al., 2011). The use of feeding stations (alternative food close to perching sites) to attract birds away from the crop of interest (e.g., sunflower) has been shown to be costly (in time, effort, and resources) and ineffective, with very few birds being attracted compared to the birds using the crop fields (Linz et al., 2011).

Other cultural practices that could be proposed based on results from this study, such as increasing field size and eliminating trees close to the crop field (≤1 km), could have direct implications for conservation of biodiversity in farmlands and for the sustainability of the crops themselves. Both measures decrease availability of non-crop habitats, such as arborous or weedy edges, resulting in a simplified landscape. This process may have negative consequences for biodiversity, such as loss or decrease of native species, as well as decrease crop yields because of lower regulation of soil water and other crop pests, or less availability of pollinators, among other reasons (Batáry et al., 2011; Bianchi et al., 2006; Power, 2010; Steffan-Dewenter, 2002). Cultural practices to decrease monk parakeet damage to crops potentially could be more detrimental to crop yields than the parakeet damage, especially when damage is usually low as in this study area and is considered slight to moderate by farmers (Canavelli et al., 2013).

In summary, when the magnitude of damage by monk parakeets justifies applying management measures, the alternatives should be considered with caution in the context of an integrated management strategy (Bruggers et al., 1998; Zaccagnini and Canavelli, 1998). Also, they should be evaluated not only in relation to efficacy to decrease monk parakeet damage, but also in relation to the potential environmental impacts derived from these methods which, in some cases, could be more detrimental to the crop yields than the bird damage itself. This implies the development of more sophisticated approaches to pest management than those used in the past and constitutes a continuous challenge for biologists, agronomists, and other stakeholders involved in the management of bird damage to crops (Fall and Jackson 2000).

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2014.07.024.

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