The Wilson Journal of Ornithology 128(2):300–307, 2016

ROLE OF LANDSCAPE ELEMENTS ON RECENT DISTRIBUTIONAL EXPANSION OF EUROPEAN STARLINGS (*STURNUS VULGARIS*) IN AGROECOSYSTEMS OF THE PAMPAS, ARGENTINA

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ABSTRACT.—Previous studies of European Starlings in Argentina have focused on identifying biological aspects correlated with establishment of new populations in urban and suburban areas. Starlings have recently invaded rural areas in the Pampas. To understand the factors involved in the recent expansion of European Starlings into these rural habitats, we investigated how expansion patterns were associated with season, proportion of crop fields, distance to woodlots, and distance to small and big urban centers in agroecoystems of the Pampas. We surveyed 392 fields during 2011–2013 to collect data on presence of starlings and landscape features. We found that the range of European Starlings has expanded by a total area of ~65,000 km^2 since 2005, at a linear range expansion rate of 22.2 km per year. Generalized linear mixed model analysis revealed that presence of European Starlings was significantly related with reduced distances to nearest small urban area. Our findings indicate that range expansion of European Starlings into rural areas of Argentina may follow a neighborhood diffusion pattern, by which well-established populations act as sources of individuals that disperse short distances into nearby favorable areas. In absence of human control, this species is expected to continue its spread and population increase. *Received 22 April 2015. Accepted 22 November 2015.*

Key words: agriculture, biogeography, biological invasions, Neotropics, Sturnidae.

Landscapes in South America and elsewhere have been heavily modified for agricultural production (Bruggers et al. 1998, Bomford and Sinclair 2002, Codesido et al. 2015). The Pampas of central Argentina is one of the largest agricultural regions of the world (Soriano et al. 1992). The pre-European Pampas was homogeneous grassland; however, native vegetation has been increasingly replaced by crops through the twentieth century (Baldi and Paruelo 2008). Even though originally the Pampas had no treed vegetation, woodlands with both native and exotic tree species have become established along riparian habitat and roadsides and were intentionally planted around railway stations, near rural buildings, on ranches as shading woodlots for cattle, and in urban areas (Ghersa et al. 2002, Zalba and Villamil 2002).

The introduction of trees to the Pampas was followed by the expansion of opportunistic birds that nest on them, such as doves, pigeons, and parakeets (Daguerre 1936, Murton et al. 1974, Bucher and Aramburú 2014, Codesido et al. 2015). These birds are now among the most abundant species in the bird assemblage of the Pampas and are widely regarded as avian crop pests (Bruggers et al. 1998, Codesido et al. 2012). Pest birds rely heavily on herbaceous plants, bushes, and trees for feeding, nesting, and shelter (Warburton and Perrin 2006, MacLeod et al. 2011, Bucher and Aramburú 2014). Most previous studies have focused on how increases in avian crop pest populations are associated with landscape characteristics, such as crop types and the presence of rangelands, woodlots, urbanization, roads and railway networks, since these modified environments provide important resources for these pest species (Bucher and Aramburú 2014, Codesido et al. 2015). Less research effort has focused on how avian crop pests are expanding their ranges or how non-native birds are invading these agricultural landscapes and presenting new agricultural threats (Bruggers et al. 1998, Bucher and Aramburú 2014).

One of the most widespread invasive birds throughout the world is the European Starling (*Sturnus vulgaris*), which has many traits associated with introduction success (Duncan et al. 2003) and has been listed as one of the world's 100 worst invasive species (Lowe et al. 2004). Originally native to Europe and Asia, it has expanded its range over the past hundred years and has established viable populations on Australia (introduced in

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1856), New Zealand (1862), North America (1890), South Africa (1899), and in Pacific and Caribbean Islands (Flux and Flux 1981, Feare 1984). More recently, European Starlings were accidentally released in Argentina, and were first recorded in wooded urban areas of Buenos Aires city in 1987 (Pérez 1988). As of 2005, the range of European Starlings bordered the Pampas and ran along the Atlantic coast up to 30 km inland (Peris et al. 2005). Although its early dispersal history was strongly associated with urban areas (Peris et al. 2005, Rebolo Ifran and Fiorini 2010, Girini et al. 2014), starlings have recently begun spreading into suburban and rural environments (Jensen 2008), and have recently been recorded in rural Pampas (EZ, pers. obs.).

The expansion of starlings into rural areas is of particular concern, because starlings are avian crop pests and large populations can cause significant economic losses in agriculture (Campbell et al. 2015). Starlings eat a wide range of seeds, grains, and fruits from both native and cultivated species (Feare et al. 1992, Bomford and Sinclair 2002, Pimentel et al. 2005), and also feed on a variety of invertebrates such as leatherjackets (Diptera), earthworms (Lumbricidae), caterpillars (Orthoptera), pillbugs (Isopoda), and Lepidoptera (Westerterp et al. 1982, Moore 1986). Starlings use holes for nesting but are not primary excavators (Feare 1984). In Argentina, starlings use a wide array of facilities as nest sites, although most nests are in holes excavated by woodpeckers (*Colaptes* spp.), mostly in exotic species of old trees, such as elms (*Ulmus* spp.), poplars (*Populus* spp.), eucalyptus (*Eucalyptus* spp.), and oaks (*Quercus* spp.), which tend to be planted in both urban and rural areas (Peris et al. 2005). Given the invasive characteristics of European Starlings, it is likely that they will become abundant in the future and may significantly impact agricultural production and native ecosystems. Characterizing the pattern of spread of invasive species constitutes a necessary step in managing biological invasions (Hulme 2006).

The goal of this work was to document the recent invasion of European Starlings into agroecosystems in the Argentinean Pampas and understand the landscape factors involved with range expansion into more rural areas. Specifically, our aims were to (1) estimate the size and rate of rural range expansion of European Starlings in the Pampas agroecosystems and (2) examine associations between presence of European Starlings and landscape features such as land-use, distance to woodlots, and distance to small and big urban centers.

MATERIAL AND METHODS

Study Area.—Our study area in the Pampas region of central Argentina extends over about 225,000 km^2 (500 km from north to south, 450 km from east to west; 33–39°S, 57–63° W; Fig. 1). The region is almost flat, with only a few hills and rocky outcrops at isolated sites. Mean annual temperature is ~15°C, with warm summers and cool winters (Jan mean temperature ranges 21.5–23.5°C, Jul mean temperature ranges 7.5–9.5°C); mean annual precipitation ranges 800–1000 mm (Soriano et al. 1992).

The natural vegetation is a gramineous steppe dominated by grasses such as *Nasella*, *Piptochaetium*, *Aristida*, *Melica*, *Briza*, *Bromus*, *Eragrostis* and *Poa*, intermingled with prairies, marshes and other edaphic communities (Soriano et al. 1992). More recently, the Pampas region has been used for intensive crop production not managed by tilling or cattle grazing (Bilenca et al. 2012). Planted stands of tall trees are new to the Pampas and have added structural complexity to the grasslands (Zalba and Villamil 2002).

Surveys of European Starlings.—From December 2011 to June 2014, we recorded European Starlings through both systematic and opportunistic surveys. We conducted systematic surveys at 25 sites distributed evenly throughout our study area (Fig. 1). Sites were at least 40 km apart and had varying proportions of land under crop production and livestock use. In each of these sites, we selected four independent fields, two crop stubbles, and two livestock paddocks. We did four surveys in each site: two during spring-summer (2011–12 and 2012–13) and two during autumn (2012 and 2013). Thus, each site was surveyed twice each season throughout 2 years, but each sampling was carried out in different fields, so that, we avoided dependence among data. We surveyed pastures and natural or semi-natural grasslands in livestock paddocks, and surveyed winter crop stubble (wheat *Triticum aestivun*, barley *Hordeum vulgare*, rye *Secale cereale*) during spring–summer and summer crop stubble (soybean *Glycine max*, corn *Zea maiz*, sunflower *Helianthus annus*, and sorghum *Sorghum sp.*) during fall. In total, we surveyed 392 fields (196 of each land use type; at least 1000 m apart), since

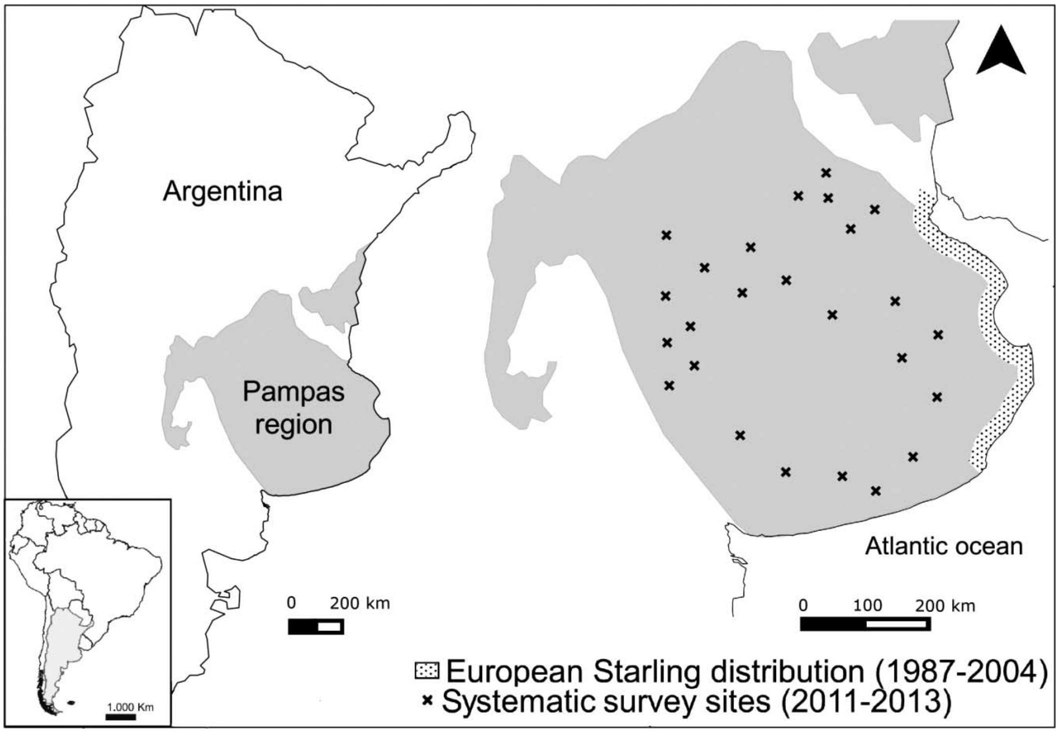

FIG. 1. Study area and locations of sampling sites in agroecosystems of the Pampas, Argentina. Detail of distribution of European Starlings in Argentina by Peris et al. (2005).

during December 2011 we could not survey in two sampling sites because of logistical problems. Bird surveys were carried out 4 hrs after dawn. Within each field and avoiding boundaries, we randomly established a transect 700 m long by 100 m wide (Bibby et al. 2000), and walked the transect for 15 mins while recording the numbers of European Starlings by transect. We also conducted opportunistic surveys during extensive traveling by the authors covering the study area, where we recorded presence of starlings while driving slowly along primary and secondary roads.

Surveys of Landscape Attributes on Systematic Samplings.—For each transect at each field we recorded: a) the proportion of crop fields surrounding the transect (including the field where the transect was set and the adjacent fields to that field), b) distance in meters from the center of the transect to the nearest woodlot (patches with presence of exotic trees >0.2 ha), c) distance from the center of the transect to the nearest big urban area (i.e., with more than 10,000 people), and d) distance from the center of the transect to the nearest small urban area (i.e., with less than 10,000 people, train stations, or farmhouses). Distance variables were measured using Google Earth® images, expressed in meters.

Statistical Analyses.—To estimate the range expansion of European Starlings, we compared our bird distribution data (systematic and opportunistic records) with baseline data reported by Peris et al. (2005) who compiled data from 1987 to 2004 on the basis of personal observations, published sources, and field reports provided by experienced birdwatchers. The linear range expansion for European Starlings was estimated as the average linear distance between the initial and final distribution borders between both databases.

To examine the associations between landscape attributes and presence of European Starlings at its recent expansion area (northeast and east of province, this study; $n = 10$ sites; 160 transects), we compared certain landscape attributes at the 27 transects where European Starlings were recorded with another 27 transects without the species which we randomly choose from the total of 133 sampled transects where the species was absent. We used generalized lineal mixed models

(Zuur et al. 2009) in order to analyze the association between farmland landscape attributes and presence of European Starlings by field (the response variable). The explanatory variables were as follows: season (with two levels, spring-summer and autumn) was included as categorical variable, and proportion of crop fields surrounding the transect, distance to woodlot, distance to large urban area, and distance to small urban area as continuous variables. All these variables were specified as fixed effects, whereas site was treated as a random effect. The presence of European Starlings fitted binomial data distribution (presence/absence) and 'logit' link function (Crawley 2007). We employed a backward selection procedure removing non-significant terms from the model one by one, in decreasing order of probability. The stepwise procedure from the saturated model (i.e., with all explanatory variables) through a series of simplifications to the minimal adequate model was made on the basis of deletion chi-squared tests that assessed the significance of the increase in deviance that results when a given term is removed from the current model (Crawley 2007). We checked the model fit by means of graphical validation tools for the binomial data distribution (Zuur et al. 2009). Statistical analyses were carried out using R software, version 3.1.0 (R Core Team 2014).

RESULTS

Range Expansion.—From December 2011 to June 2014, starlings were present in 84 surveys (27 systematic and 57 opportunistic surveys) throughout the agroecosystems of the Pampas. We recorded a total of 1141 individuals (composed of individual records and flocks of up to 110 individuals), 56% in spring-summer (mean = 11,9 individuals, ES = 2,2, *n* = 54) and 44% in autumn (mean = 16,6 individuals, ES = 5,1, *n* = 30). The estimated average linear distance between the initial and current distribution for European Starlings was 221.8 km, with an average progression from 2005–2014 of 22.2 km per year (Fig. 2).

Associations between Landscape Elements and Presence of European Starlings.—Our generalized linear mixed model showed that presence of European Starlings was attributed to the distance to the nearest small urban area (mean = 6,627, ES =864 m, *n* = 54; Table 1 and 2). The presence of the species was not significantly associated with season, or with distance to nearest big urban area (mean = 14,329 m, ES =1,534 m, *n* = 54), or with distance to nearest woodlot (mean = 332, ES = 30 m, *n* = 54), or with crop landscape (mean = 53%, SD = 32%, *n* = 54). Closeness to small urban areas increased the likelihood that starlings were present. The average distance to the nearest small urban area in fields with presence of European Starlings (mean = 4,359, ES = 90 m, *n* = 27) was almost 51% less than the average distance in fields without European Starlings (mean = 8,895 m, ES = 300 m, *n* = 27).

DISCUSSION

The spread of European Starlings seems to be still far from finished 28 years after its introduction in Argentina. Instead, the range expansion is increasing both in size and rate. Expansion of European Starlings into the Pampas covers an area close to 65,000 km^2,more than the area already reported by Peris et al. (2005), with an average range expansion of 22.2 km per year. This expansion rate is 296% greater than the average expansion previously quantified (Peris et al. 2005; 7.5 km per year), although slow if compared with the 43 km per year of European Starlings in North America over the twentieth century (Wing 1943). Importantly, this rate might underestimate the real expansion rate, since European Starlings were not detected in intensive surveys made during 2006–2008 (Codesido et al. 2012, 2013; Fig. 2), thus the recent expansion of the species within the Pampas agroecosystems of Argentina most likely occurred very recently (i.e., since 2009). Our results are in agreement with recent records of European Starlings that have also been reported opportunistically by several birders in the Pampas since 2010 (eBird 2015).

Our study revealed that some landscape elements influenced the process of range expansion by starlings in the Pampean agroecosystems of Argentina. European Starlings colonized sites that were close to small urban areas (small towns, train stations, or farmhouses). Most of these human settlements had treed vegetation around houses, providing suitable nesting sites and roosting, as well as peridomestic fruit orchards (mulberries, figs, date palms, etc.) which provide feeding sites. In addition, urban areas usually act as centers of well-established populations (Kessel 1953), so that dispersal of starlings may follow a neighborhood diffusion pattern, by which well-established populations act as sources of individuals that

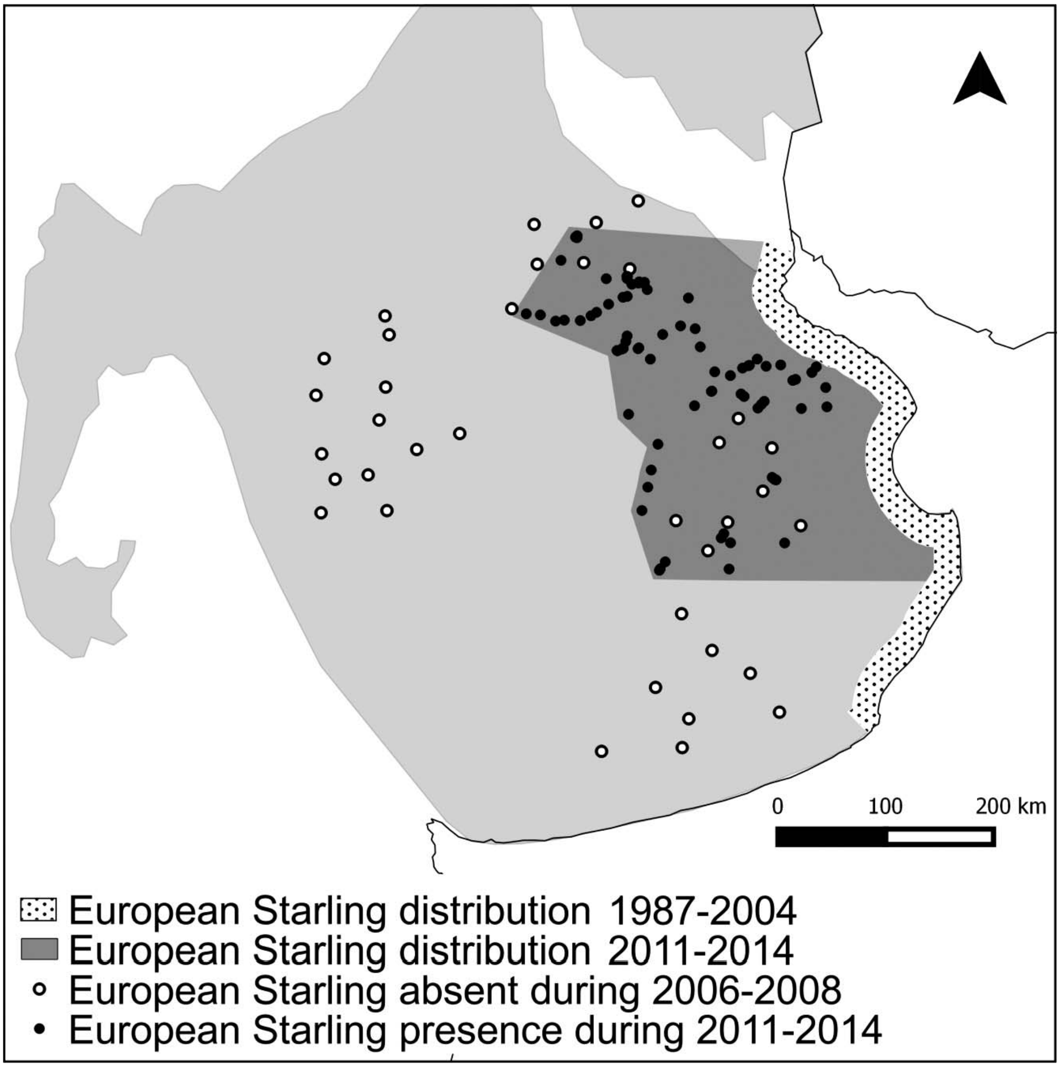

FIG. 2. Expansion of European Starlings (detail of systematic and opportunistic records) in agroecosystems of the Pampas, Argentina.

travel short distances into nearby favorable areas (Bucher and Aramburú 2014). This pattern is consistent with the pattern of diffusion from the east to the west reported for USA (Wing 1943, Kessel 1953). Patterns of invasion and range expansion in the USA have been attributed to the movement of first-year and non-breeding second-year starlings during migration or more general wandering dispersal patterns (Kessel 1953). These irregular movements, and the apparent random selection of breeding areas by younger birds, would be sufficient to account not only for extensions of the breeding range but also for many of the winter extensions.

TABLE 1. Generalized linear model of the probability of presence of European Starlings in agroecosystems of the Pampas, Argentina. $N = 54$ transects (27 presences and 27 absences).

Explanatory variables	Coefficients ± *E.S.*	*Z*	*P*
Intercept	1.211 ± 0.6012	2.01	0.044
Distance to nearest small urban area	−0.0002 ± 0.00009	2.28	0.029

Besides the proximity to small urban areas, we found no evidence that other landscape elements may have influenced the expansion of European

TABLE 2. Summary of analyses of backward selection procedure of some landscape attributes on presence of European Starlings. Significant explanatory variables are in bold. $N = 54$ transects (27 presences and 27 absences).

Explanatory variables	*g.l.*	X^2	*P*
Season	1	0.36	0.551
Distance to nearest big urban center	1	0.59	0.442
Distance to nearest woodlot	1	1.71	0.192
Proportion of crop fields surrounding the transect	1	2.96	0.086
Distance to nearest small urban area	**1**	**8.09**	**0.004**

Starlings in the rural Pampas region. Climatic factors may be excluded (at least in terms of the starlings' physiological tolerance), because the climate of the Pampas is within the same boundary value ranges of the surrounding areas, where European Starlings were introduced originally.

Even though initial expansion of European Starlings occurred slowly, the rate of expansion is currently accelerating, which could indicate that European Starlings have overcome the lag phase of the invasion process. Population lag phases have been defined as a period of slow population growth followed by a marked increase in the rate of growth and are common in the establishment and spread of many invasive species (Crooks 2005, Aikio et al. 2010). The occurrence of lag phases within exotic bird populations makes it possible for currently rare exotic species to later explode in numbers and geographic extent (Aagaard and Lockwood 2014). The current range expansion pattern indicates that European Starlings have left the lag phase of their invasion in Argentina and may be entering a period of explosive growth.

Management Implications.—Once introduced species are established, their control or eradication is difficult and likely to be highly costly (Kolar and Lodge 2001, Campbell et al. 2015). European Starlings are already successfully established in the Pampas. In the absence of human control, this species is expected to continue its spread and population increase, because of its adaptability to urban and suburban habitats (Lovell 1941, Feare 1984), its nearly omnivorous diet (Moore 1986, Feare et al. 1992), and its large reproductive output (Feare 1984). This potential for further expansion, together with its agricultural pest status in its exotic range (Bomford and Sinclair 2002, Lowe et al. 2004), should be taken into account when considering the potential damage it may cause particularly in western areas of Argentina like the provinces of Mendoza, San Juan, La Rioja, Catamarca and Salta, where vineyards and olive groves (which have been heavily damaged by starlings elsewhere; Bomford and Sinclair 2002) are among the main agricultural productions. Moreover, although in Argentina European Starlings build nests in areas environmentally disturbed (Peris et al. 2005), they may also represent a novel competitor with native species for nest sites, although the impact on native biota is much more difficult to predict (Ingold 1998, Massaro et al. 2013). Considering all the above and the fact that the earlier intervention is carried out, the better the economic return on control investment (Campbell et al. 2015), there is an urgent need to start a control program of starlings efficiently and effectively in the Pampas.

ACKNOWLEDGMENTS

Special thanks to the workers and owners of all the agricultural establishments that allowed access to work on their property (particularly to Alan Goodall, INTA Pergamino, CEPT N°5 Miranda, Bomberos de Udaquiola, Tatay, El Haras, Hermanos Laplace, Hinojales, Pelerí, La Torcacita, Don Remigio, Santa Elena de Inchauspe, Monte Unión, La Providencia, Manantiales). We appreciate the review and the improvements in English usage made by Elizabeth Hobson through the Association of Field Ornithologists' program of editorial assistance. Financial support was provided by Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET PIP 2010-2012 GI 11220090100231), Agencia Nacional de Promoción Científica y Tecnológica (BID PICT2010-1412), Universidad Nacional de La Plata (PPID/N004), and Universidad de Buenos Aires (UBACyT X282; X406, GC 20020090100070).

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