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ARTÍCULO ORIGINAL

Urban birds in the Sonoran Desert: estimating population density from point counts

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Abstract

We conducted bird surveys in Hermosillo, Sonora using distance sampling to characterize detection functions at point-transects for native and non-native urban birds in a desert environment. From March to August 2013 we sampled 240 plots in the city and its surroundings; each plot was visited three times. Our purpose was to provide information for a rapid assessment of bird density in this region by using point counts. We identified 72 species, including six non-native species. Sixteen species had sufficient detections to accurately estimate the parameters of the detection functions. To illustrate the estimation of density from bird count data using our inferred detection functions, we estimated the density of the Eurasian Collared-Dove (*Streptopelia decaocto*) under two different levels of urbanization: highly urbanized (90-100% of urban impact) and moderately urbanized zones (39-50% of urban impact). Density of *S. decaocto* in the highly-urbanized and moderately-urbanized zones was 3.97±0.52 and 2.92±0.52 individuals/ha, respectively. By using our detection functions, avian ecologists can efficiently relocate time and effort that is regularly used for the estimation of detection distances, to increase the number of sites surveyed and to collect other relevant ecological information.

Keywords: Eurasian Collared-Dove, *Streptopelia decaocto*, detection function, distance sampling, point count, Hermosillo, Sonora.

Aves urbanas en el Desierto Sonorense: estimando densidades poblacionales a partir de conteos de puntos

Resumen

Realizamos conteos de aves en Hermosillo, Sonora, usando muestreos de distancias para caracterizar las funciones de detección en trayectos por punto para las aves urbanas, nativas y no nativas, en un ecosistema desértico. De marzo a agosto de 2013 muestreamos 240 puntos en la ciudad y sus alrededores; visitamos cada punto tres veces. Nuestro propósito fue proveer información para agilizar la evaluación de la densidad de aves de la región utilizando puntos de conteo. De las 72 especies que identificamos, seis no son nativas. En 16 especies obtuvimos suficientes registros para estimar, de forma adecuada, los parámetros de las funciones de detección. Para ilustrar la estimación de la densidad por medio de puntos de conteo utilizamos las funciones de detección inferidas y estimamos la densidad de la tórtola turca (*Streptopelia decaocto)* en dos distintos niveles de urbanización: alto (90-100% de impacto urbano) y moderado (39-50% de impacto urbano). La densidad de *S. decaocto* en las zonas altamente urbanizadas y en las moderadas fue de 3.97±0.52 y 2.92±0.52 individuos/ha, respectivamente. Si los ecólogos utilizan nuestras funciones de detección podrán administrar su tiempo y esfuerzo, por lo regular dedicado a estimar las distancias de detección, para incrementar el número de sitios muestreados y colectar otra información ecológicamente relevante.

Palabras clave: tórtola turca, *Streptopelia decaocto*, función de detección, muestreo de distancias, puntos de conteo, Hermosillo, Sonora.

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Introduction

According to the Secretaría del Medio Ambiente y Recursos Naturales (Semarnat), from 1993 to 2002, 2.8 million hectares changed from natural ecosystems to urban and rural areas (Semarnat 2011). Urban areas are in constant expansion, causing a massive and unpredictable environmental change (McDonnell and Pickett 1990, Chance and Walsh 2004, McKinney 2008, Fuller *et al*. 2009). For some animals, urbanization may imply new food sources or nesting sites, but for others, urbanization may imply new predators or competitors, and depleted resources (Marzluff 2001, Blair 2001, Shochat 2004). Ecologists are interested on how the urban expansion

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affects native wildlife populations, particularly the avifauna (Marzluff *et al*. 2001a, Pennington and Blair 2012).

Birds are particularly adaptable to urban environments. In fact, some native and non-native species have developed dense and stable populations within urban areas (Blair 2001, Pennington and Blair 2012). Some native species, such as the American Crow (*Corvus brachyrhynchos*), the Black-billed Magpie (*Pica pica*), and the Greater Roadrunner (*Geococcyx californianus)* have become even more abundant inside cities than in their natural ecosystems (Marzluff *et al*. 2001b, Jerzak 2001, Schoech and Bowman 2001, DeStefano and Webster 2012). Some non-native species such as the House Sparrow (*Passer domesticus*), the Rock Pigeon (*Columba livia*), the European Starling (*Sturnus vulgaris*), and the recently introduced Eurasian Collared-Dove (*Streptopelia decaocto*) have expanded their distribution along with urbanization (Mennechez and Clergeau 2001, Blair 2001, McKinney 2006, Olden 2006, Fuller *et al*. 2009). Both native and non-native populations should continuously be monitored to detect population trends. Therefore, estimating abundance is a critical step towards their management and conservation. Increasing our knowledge of urban birds is also relevant to promote the awareness of citizens on the natural heritage of their surroundings.

It is important to rely on sampling methods that effectively estimate density (individuals per unit of area). Bird counts (number of birds detected in a given area) do not account for imperfect detection, this is, when individuals are overlooked during sampling. Therefore, counts can only obtain indices of relative abundance (Conroy and Carroll 2009). A popular count technique in ornithology is point counts (Ralph *et al*. 1995), where an observer records all birds seen and heard for a defined period of time at a point with a fixed radius. Distance sampling is a widely used method employed to estimate bird density (Bibby *et al*. 1998, Gregory *et al*. 2004, Buckland *et al*. 2001, Conroy and Carroll 2009) accounting for imperfect detection. In contrast to counts, distance sampling consists on counting individuals and measuring their distance from the observer, under the assumption that all birds at a zero distance are detected. Distance sampling has two forms: line-transect sampling and point-transect sampling. Line-transect sampling consists of counting organisms and measuring their distance while walking along a line. Line-transect sampling is not usually suitable for urban areas since the random allocation of sampling units is difficult given the frequent occurrence of obstacles such as building or streets. Point-transect sampling consists on measuring distances from every detected bird to a fixed observer during a defined period of time within a given radius. Therefore, point-transect sampling is more appropriate for urban areas (Buckland *et al*. 2001).

Detection distances are used to infer the detection function $g(x)$, i.e., the probability to detect a bird at a given distance (x) from the observer (Buckland *et al*. 2001). The characterization of the detection function is the key to estimate density accounting for imperfect detection. Once a detection function is obtained from the distance data, the detection function can be used to estimate density in future point counts (i.e., without measuring distances). However, no one seems to take advantage of using detection functions from previous studies (e.g., Norvell *et al*. 2003, Somershoe *et al*. 2006, Kark *et al*. 2007, Newson *et al*. 2008, Fuller *et al*. 2008, Fuller *et al*. 2009, Loss *et al*. 2009, Walker and Shochat 2010). Researchers usually calculate their own detection functions when they need to estimate densities, instead of devoting their time and effort in other relevant aspects of their studies.

The objective of this study was to characterize detection functions of several native and non-native species present in the city of Hermosillo, Sonora, through an exhaustive bird sampling. By providing these detection functions, researchers interested in studying urban bird communities in similar habitats will be able to estimate population density (Thomas *et al*. 2010) from simple point counts without spending time and effort on recording detection distances. In addition, we exemplify the use of detection functions to estimate density from point count data. We do this in the context of a relevant aspect to be studied in urban environments: the increasing abundance of several exotic bird species which possibly compete and displace native species. In this regard, the recent invasion of the Eurasian Collared-Dove may require population monitoring since several native dove species could suffer from resource competition from this exotic species (Romagosa 2012). Therefore, we use records from our study to illustrate our suggestion of future uses of our detection functions.

Methods

Study area

Hermosillo, Sonora (29º08'N, 110º96'W; 211 m altitude) is a medium-size city (population 784,342; INEGI 2012) within the Mexican portion of the Sonoran Desert. The city has a hot desert climate (BWh in the Köppen climate classification), with 200 mm of mean annual rainfall. Hermosillo reaches high temperatures in summer (>40 ºC) and winter can bring

temperatures as low as 0 ºC (annual average temperature of 25 ºC).

Survey method

The study was conducted during the breeding season of 2013 (March to August). We divided this breeding season in three sampling periods: March-April, May-June and July-August. We visited the same sampling points each time. We used a grid of 440 quadrants of 1 km^2 defined by the UTM grid that covers the entire urban area of Hermosillo and its surroundings. Following the urban-rural gradient categorization proposed by McDonnell and Pickett (1990) and recommended by other authors (e.g., Marzluff *et al*. 2001a; Pennington y Blair, 2012), we gave each quadrant one of four levels of urbanization (0-29%, 30-59%, 89-60% and 90-100% of urban impact) corresponding to its percent cover of buildings and streets. The levels of urbanization were estimated using satellite images from Google Earth (2013) and from the Inventario Nacional de Viviendas (updated to 2012, INEGI 2013) at each quadrant. From the total of 440 quadrants, 60 quadrants were randomly selected to sample, 15 quadrants of each level of urbanization. We randomly positioned four plots within each square. A total of 240 plots distributed within the city's boundaries were visited each period. We sampled each plot for 8 minutes using 200 m fixed-radius point transects (Buckland *et al*. 2001) between 05:40 h and 09:30 h, just after sunrise and before the temperature reached more than 30 ºC. Sampling was performed by a two-person team, the observer was the same during the entire sampling period. Birds disturbed during the observer's arrival were recorded at their initial location. We recorded individuals and groups of individuals (clusters hereafter) detected, as well as their species, cluster size and detection distance from the observer. We measured each detection distance (in meters) using a Nikon Prostaff Laser 440 Rangefinder®. We recorded all birds seen and heard, while birds flying through the sampling point were neither recorded nor considered for the analysis.

Data analysis

We estimated parameters of detection functions for species with >75 detections (Buckland *et al*. 2001), using program *DISTANCE* (V 6.0 release 2, Thomas *et al*. 2010). We adjusted three key functions (half-normal, hazard-rate and uniform), each with three expansion adjustments (cosine, simple polynomial and hermit polynomial) with up to four terms. We chose the model with lowest value of the Akaike's Information Criterion (AIC) as the most plausible (best) model. We used detection distances below the 90th percentile to reduce the impact of outliers and improve the model fit.

To illustrate the use of our detection function (built with all detection distances in our three sampling periods) using count data to estimate density, we used our records on *S. decaocto* from two levels of urbanization, highly-urbanized zones (90-100% of urban impact) and moderately-urban zones (30-59% of urban impact) during the third sampling period (when the species was more abundant within the breeding season). The highly-urbanized zones differed from the moderately-urbanized zones because of the heavy vehicular traffic, tall and dense buildings and poor vegetation structure. Moderately-urbanized had lower vehicular traffic, sparser and smaller buildings (mostly houses), few unpaved streets and a medium vegetation structure with several native plants. We used data that can be easily obtained from bird counts: clusters detected (n) and the number of plots surveyed (k). For the highly-urbanized level of urbanization we used the records obtained in 60 plots and for the moderately-urbanized level of urbanization we used the records obtained in 55 plots.

Among all species identified we used count data from *S. decaocto* given that the specie is one of the most common species in Hermosillo and it is important to monitor this species continentally. *Streptopelia decaocto* is a recently-introduced (1980) avian species to the American continent that has been able to expand its distribution along most of America quite rapidly. Recent studies have encountered *S. decaocto* from southern Canada, all over the United States and Mexico, down to Central America (Romagosa 2012). The rapid and increasing distribution of *S. decaocto* is occasionally attributed to the continuous urban expansion (Crooks y Soule 1999). Several studies have identified that *S. decaocto* inhabits areas that present some degree of urban impact (Johnston, 2001; Bonter *et al*. 2010).

The estimator of density ($\hat{D}$) is given by the expression (Buckland *et al*. 2001):

$$\hat{D} = \frac{n\hat{h}(0)\bar{s}}{2\pi k}$$

where $\hat{h}(0)$ is the estimator of the derivative of the probability density function of detection distances evaluated at zero distance, direct output of program *DISTANCE*, and $\bar{s}$ is the average number of individuals per detection. The standard error of density SE($\hat{D}$), assuming a Poisson distribution of counts, can

be approximated using the delta method as follows (Buckland *et al*. 2001):

$$SE(\hat{D}) = \hat{D}\sqrt{\frac{1}{n} + \frac{\left(SE\left(\hat{h}(0)\right)\right)^2}{\left(\hat{h}(0)\right)^2} + \frac{Var(\bar{s})}{\bar{s}^2}}$$

where $SE\left(\hat{h}(0)\right)$ is also a direct output of program *DISTANCE* and Var($\bar{s}$) is the sampling variance of the average number of individuals per detection. Finally, we used our estimates of density and their standard errors to test statistical differences in density of *S. decaocto* between highly-urbanized and moderately-urbanized zones using a Wald test (McCulloch *et al*. 2008).

Results

We recorded a total of 11,024 individuals from 72 species (Table 1) during the breeding season of 2013 in 240 point transects with three replicates. According to each species' account in The Birds of North America (BNA), this 72 species include 39 resident breeders, 12 summer breeders, and 21 migrants (Poole 2013). Ten species comprised 80% of the individuals detected (Figure 1). We found six non-native species inhabiting the city of Hermosillo, with *Paser domesticus* being the most abundant, followed by *Streptopelia decaocto, Columba livia*, *Sturnus vulgaris*, and the parrots *Myiopsitta monachus* and *Amazona albifrons*. Order Columbiformes is the most abundant taxa, represented by *S. decaoc*to, *C. livia*, *Zenaida asiática*, *Z. macroura*, and *Columbina inca*; Columbiformes comprises 40% of the individuals detected. Native species of high relative importance in the urban bird community included (in decreasing order) *Zenaida asiatica*, *Z. macroura*, *Columbina inca*, *Haemorhous mexicanus*, *Auriparus flavipens*, *Quiscalus mexicanus*, and *Melanerpes uropygialis* (Figure 1). Two identified species are included in the Red List of Threatened Species (IUCN 2013), *Vireo bellii* as near threatened and *Toxostoma bendirei* as vulnerable.

We had 16 species with sufficient detections to carry out the analysis and model a best fitting detection function (Table 2). Uniform key functions with cosine adjustments and hazard-rate key functions were superior for modeling detection functions in our bird community compared to models with half-normal and hermit and polynomial adjustments.

The best detection function for *S. decaocto* was the uniform key with a 4th order cosine adjustment, $\hat{h}(0)$ = 11.086 ha^{-1} (Table 2, Figure 2).

We will now illustrate the use of the inferred detection functions to transform counts into density estimates. In the highly urbanized zones we had n = 122 detections of *S. decaocto* in k = 60 plots, and an average cluster size per detection of $\bar{s}$ = 1.111 individuals. With the estimate $\hat{h}(0)$ = 11.09 ha^{-1} (Table 2) we estimated a density ($\hat{D}$) = 3.97 individuals/ha. With a Var($\bar{s}$) = 0.001, and $SE\left(\hat{h}(0)\right)$ = 0.97 ha^{-1} (Table 2), we obtained and SE($\hat{D}$) = 0.52 individuals/ha and a 95% CI(D) = (2.96, 4.98).

In the moderately-urbanized zones we had n = 63 detections of *S. decaocto* in k = 55 plots, with an average cluster size per detection of $\bar{s}$ = 1.44 individuals. With the estimate $\hat{h}(0)$ = 11.09 ha^{-1} we estimated a density ($\hat{D}$) = 2.92 individuals/ha. With a Var($\bar{s}$) = 0.007, and having $SE\left(\hat{h}(0)\right)$= 0.97/ha, we obtained SE($\hat{D}$) = 0.52 individuals/ha and a 95% CI(D) = (2.92, 3.94).

The Wald test did not show enough evidence of statistical differences in density between these two zones (z = 1.43, P = 0.15).

Discussion

The bird community of the city of Hermosillo shares some dominant components with other urban bird communities in the Sonoran Desert and the world. For instance, *Paser domesticus* (exotic) is also the most abundant species in urban Tucson (Emlen 1974) and Phoenix (Green and Baker 2003) in Arizona, USA; native and exotic columbids (pigeons and doves) also attain high relative abundances. Large body mass and granivorous diets, attained by these dominant species, are traits that have related to success in urban areas (Lancaster and Rees 1979, Beissinger and Osborne 1982, Ikin *et al*. 2002, Kark *et al*. 2007, Johnston-López 2014). Furthermore, reduced bird diversity in urban environments, as revealed in this work by the existence of few species comprising the majority of the bird abundance (Figure 1), is a widespread pattern (Emlen 1974, Beissinger and Osborne 1982, Mills *et al*. 1989, Green and Baker 2003). More predictable food sources and reduction in predation risk by top predators in urban areas compared to the surrounding arid environments are thought to change trophic relationships that ultimately lead to the dominance of fewer urban specialists (Faeth *et al*. 2005) with important exotic component such as *Paser domesticus*, *Columba livia* and, more recently, *Streptopelia decaocto*. Urbanization also reduces the insectivorous component of the native bird community in the surrounding desert (Walker and Shochat 2010), such as *Campylorhynchus brunneicapillus* and *Polioptila melanura*, which inhabit the less urbanized areas in Hermosillo (Johnston-López 2014).

Table 1. Species identified during the breeding season in Hermosillo, Sonora. Migratory strategies were retrieved from each species account in The Birds of North America online (Pool 2013).

Taxa	Common Name	Migratory strategy	Individuals	Detections
GALLIFORMES				
Odontophoridae				
Callipepla gambelii	Gambel's Quail	RBr	43	27
ACCIPITRIFORMES				
Cathartidae				
Coragyps atratus	Black Vulture	RBr	37	9
Cathartes aura	Turkey Vulture	RBr	125	98
Accipitridae				
Elanus leucurus	White-tailed Kite	RBr	1	1
Circus cyaneus	Northern Harrier	Mt	1	1
Accipiter cooperii	Cooper's Hawk	Mt	1	1
Buteo swainsoni	Swainson's Hawk	SBr	6	6
Buteo jamaicensis	Red-tailed Hawk	RBr	1	1
COLUMBIFORMES				
Columbidae				
*Columba livia**	Rock Pigeon	RBr	863	404**
*Streptopelia decaocto**	Eurasian Collared-Dove	RBr	898	757**
Zenaida asiatica	White-winged Dove	RBr	973	882**
Zenaida macroura	Mourning Dove	RBr	899	687**
Columbina inca	Inca Dove	RBr	750	595**
CUCULIFORMES				
Cuculidae				
Geococcyx californianus	Greater Roadrunner	RBr	1	1
Crotophaga sulcirostris	Groove-billed Ani	SBr	1	1
STRIGIFORMES				
Strigidae				
Athene cunicularia	Burrowing Owl	RBr	36	31
CAPRIMULGIFORMES				
Caprimulgidae				
Chordeiles acutipennis	Lesser Nighthawk	SBr	23	21
APODIFORMES				
Trochilidae				
Selasphorus sp	-	Mt	1	1
Cynanthus latirostris	Broad-billed Hummingbird	SBr	197	183**
PICIFORMES				
Picidae				
Melanerpes uropygialis	Gila Woodpecker	RBr	290	274**
Picoides scalaris	Ladder-backed Woodpecker	RBr	19	18
Colaptes chrysoides	Gilded Flicker	RBr	5	5
FALCONIFORMES				
Falconidae				
Falco sparverius	American Kestrel	RBr	8	7
Falco columbarius	Merlin	Mt	1	1
Falco peregrinus	Peregrine Falcon	Mt	1	1
PSITTACIFORMES				
Psittacidae				
*Myiopsitta monachus**	Monk Parakeet	RBr	34	19
*Amazona albifrons**	White-fronted Amazon	RBr	2	2

Taxa	Common Name	Migratory strategy	Individuals	Detections
PASERIFORMES				
Tyrannidae				
Tyrannus verticalis	Western Kingbird	SBr	127	117**
Empidonax sp	-	Mt	4	3
Pyrocephalus rubinus	Vermilion Flycatcher	RBr	1	1
Myiarchus cinerascens	Ash-throated Flycatcher	RBr	12	11
Myiarchus tyrannulus	Brown-crested Flycatcher	SBr	1	1
Vireonidae				
Vireo bellii	Bell's Vireo	RBr	44	42
Laniidae				
Lanius ludovicianus	Loggerhead Shrike	RBr	10	9
Corvidae				
Corvus corax	Common Raven	RBr	4	3
Hirundinidae				
Stelgidopteryx serripennis	Northern Rough-winged Swallow	SBr	33	30
Petrochelidon pyrrhonota	Cliff Swallow	SBr	1	1
Remizidae				
Auriparus flaviceps	Verdin	RBr	438	411**
Troglodytidae				
Campylorhynchus brunneicapillus	Cactus Wren	RBr	113	111**
Silvidae				
Polioptila melanura	Black-tailed Gnatcatcher	RBr	139	126**
Mimidae				
Toxostoma curvirostre	Curve-billed Thrasher	RBr	60	58
Toxostoma bendirei	Bendire's Thrasher	RBr	3	3
Mimus polyglottos	Northern Mockingbird	RBr	61	55
Sturnidae				
*Sturnus vulgaris**	European Starling	RBr	19	9
Ptilogonatidae				
Phainopepla nitens	Phainopepla	SBr	40	39
Parulidae				
Oreothlypis celata	Orange-crowned Warbler	Mt	1	1
Oreothlypis luciae	Lucy's Warbler	Mt	2	2
Setophaga petechia	Yellow Warbler	Mt	2	2
Setophaga coronata	Yellow-rumped Warbler (Audubon's)	Mt	12	9
Setophaga townsendi	Townsend's Warbler	Mt	3	3
Cardellina pusilla	Wilson's Warbler	Mt	10	10
Icteria virens	Yellow-breasted Chat	SBr	1	1
Emberizidae				
Melozone fusca	Canyon Towhee	RBr	41	39
Peucaea carpalis	Rufous-winged Sparrow	RBr	73	57
Spizella breweri	Brewer's Sparrow	Mt	26	15
Chondestes grammacus	Lark Sparrow	Mt	156	90**
Zonotrichia leucophrys	White-crowned Sparrow	Mt	3	3
Thraupidae				
Piranga ludoviciana	Western Tanager	Mt	2	2
Cardinalidae				
Cardinalis cardinalis	Northern Cardinal	RBr	7	7
Cardinalis sinuatus	Pyrrhuloxia	RBr	74	72**
Pheucticus melanocephalus	Black-headed Grosbeak	Mt	3	3

Taxa	Common Name	Migratory strategy	Individuals	Detections
Passerina versicolor	Varied Bunting	SBr	5	5
Icteridae				
Agelaius phoeniceus	Red-winged Blackbird	Mt	5	3
Xanthocephalus xanthocephalus	Yellow-headed Blackbird	Mt	43	9
Euphagus cyanocephalus	Brewer's Blackbird	Mt	241	44
Quiscalus mexicanus	Great-tailed Grackle	RBr	418	323**
Molothrus aeneus	Bronzed Cowbird	RBr	40	24
Molothrus ater	Brown-headed Cowbird	RBr	191	65
Icterus cucullatus	Hooded Oriole	SBr	9	7
Icterus bullockii	Bullock's Oriole	Mt	3	3
Fringillidae				
Haemorhous mexicanus	House Finch	RBr	571	383**
Passeridae				
*Passer domesticus**	House Sparrow	RBr	2755	1792**

* Non-native species

** Species with over 75 detections were used in the analysis, except *Cathartes aura* due to its nomadic behavior. *Cardinalis sinuatus* was also modeled since its number of detections fell just under the recommended minimum.

RBr = Resident Breeder, SBr = Summer Breeder, Mt = Migrant

The study of urban bird community dynamics requires reliable estimation of bird abundance to make reliable inferences in the ecological processes that shape structure and composition of those communities. Point counts are one of the most popular methods for estimating abundance of birds (Ralph *et al*. 1998, Rosenstock *et al*. 2002). Studies that conduct point counts can cover larger land extensions and can be conducted by a larger group of people, since only identification training is needed. Some coordinated survey efforts organize annual bird point counts, such as The North American Breeding Bird Survey, and encourage citizen participation. These bird counts collect important information about population trends and promote avian conservation, but they do not account for imperfect detection, and the information cannot be used to correctly estimate densities.

Studies that estimate densities by distance sampling usually rely on visual estimation of distances to save time when collecting the survey data. However, the use of visually-estimated distances (e.g., Norvell *et al*. 2003, Fuller *et al*. 2009, Loss *et al*. 2009, Walker and Shochat 2010) is questionable. Distance sampling analyses assume that all distances are estimated accurately (Buckland *et al*. 2001). Distances are also frequently measured in ranges (e.g., Somershoe *et al*. 2006, Kark *et al*. 2007, Fuller *et al*. 2008, Newson *et al*. 2008). Accurately measuring distances will always be preferred to visually estimating densities, even obtaining them by pacing distances. The use of detection functions inferred from previous distance data could help avoid having to rely on uncertain distances to estimate densities. By using these detection functions to estimate densities, ecologists could relocate their time and effort employed in estimating distances and readjusting their estimating capacity to obtain other important details from their studies, such as environmental information or additional counts. For the city of Hermosillo and other cities in the Sonoran Desert, we recommend that

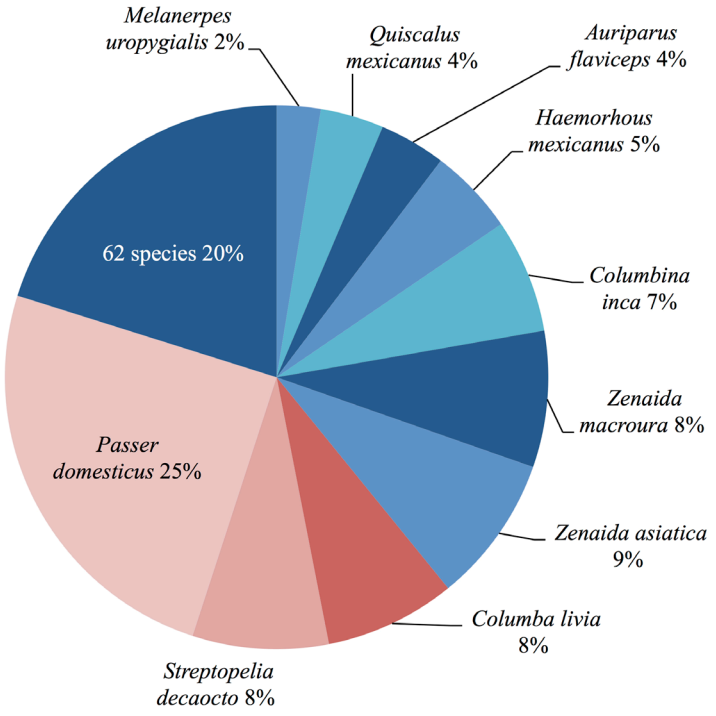


Figure 1. Proportion of individuals detected by species during the breeding season of 2013 in 240 point counts with three replicates in the city of Hermosillo, Sonora.

Table 2. Features of the detection functions for the bird species analysied. For each detection function obtained we show its corresponding key function, expansion and term.

Scientific Name	Key Function	Expansion	Order	$\hat{h}(0)$*	$SE(\hat{h}(0))$
Columba livia	Hazard-rate	Cosine	2	4.915	0.547
Tyrannus verticalis	Uniform	Cosine	2	5.465	0.577
Cardinalis sinuatus	Hazard-rate	None	-	5.508	1.418
Quiscalus mexicanus	Uniform	Cosine	2	6.124	0.484
Zenaida macroura	Uniform	Cosine	2	6.974	0.385
Melanerpes uropygialis	Hazard-rate	None	-	10.404	1.168
Zenaida asiatica	Uniform	Cosine	3	10.688	0.770
Campylorhynchus brunneicapillus	Uniform	Cosine	2	10.794	0.979
Streptopelia decaocto	Uniform	Cosine	4	11.086	0.972
Chondestes grammacus	Uniform	Cosine	1	13.886	1.179
Haemorhous mexicanus	Hazard-rate	Cosine	2	24.832	2.737
Passer domesticus	Uniform	Cosine	3	25.675	1.117
Columbina inca	Uniform	Cosine	4	27.718	2.209
Auriparus flaviceps	Uniform	Cosine	3	28.077	2.533
Polioptila melanura	Uniform	Cosine	2	35.118	5.216
Cynanthus latirostris	Hazard-rate	None	-	57.787	8.734

*Units of $\hat{h}(0)$ and $SE(\hat{h}(0))$ are in ha^{-1}.

research on urban avifaunas use point counts, considering all birds seen and heard (except for those just flying by) within a radial distance of 200 m from the observer and then use our estimates of $\hat{h}(0)$ to convert those counts into density. All bird surveys were conducted by a single observer (KJL) during the breeding season of 2013. Therefore, we did not have the need of accounting for differences between observers and seasons when estimating detection functions. Although our detection functions are representative of trained surveyors, further evaluations of variability due to observers is needed.

Variation of our detection functions among species are evidently due to variation in species detectability, which is quantified by the estimates of $h(0)$. The parameter $h(0)$ is inversely proportional to the effective area (v), that is $h(0) = 2\pi/v$. In our case, v is the inner circle within the 200 m-radius plot, such that the number of birds detected outside it (but within the 200 m-radius plot) equals the number of birds undetected within it (Buckland *et al.* 2001). Relatively large v then represents a better coverage of the 200 m-radius sampling plot by the surveyor. Species such as *Columba livia*, *Tyrannus verticalis, Quiscalus mexicanus* and *Zenaida macroura* that tend to perch high on buildings, electric poles and cables in large groups, and *Cardinalis sinuatus* that sings loud while perched on high branches, are all easily detectable at distances over 60 m (some are easily detected over 150 m) and attain the lowest $h(0)$ estimates among all species (Table 2) and therefore, have relatively large effective areas. Species such *as Zenaida asiatica and Streptopelia decaocto* also tend to perch high on electric poles and cables but individually or in small groups; *Melanerpes uropygialis* and *Campylorhynchus brunneicapillus* tend to sing loud when approached; and *Chondestes grammacus* are all easily detected over 30 m (some are easily detected even at 100 m); these species attain relatively low estimates of $h(0)$ (Table 2) and therefore also have fairly large effective areas. On the other hand, species such as *Haemorhous mexicanus, Passer domesticus, Columbina inca*, and *Auriparus flaviceps* that are relatively abundant and some even sing quite loud, are not easily detectable at relatively large distances because of

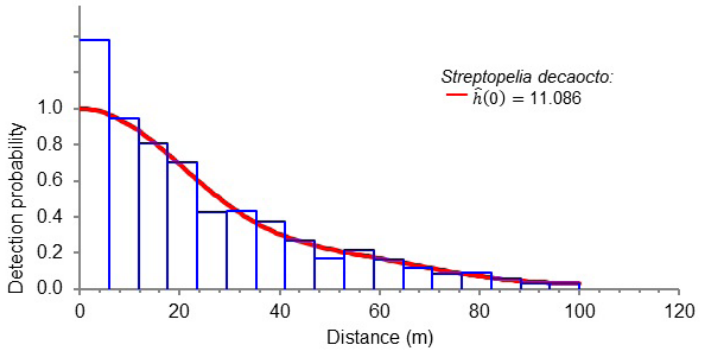


Figure 2. The best detection function for Streptopelia decaocto. The histogram shows how the detection probability decreases with distance.

their small body size. These species are mostly detected under 60 m and attain intermediate $h(0)$ estimates among the species we analyzed (Table 2) and therefore, have small-medium effective areas. Finally, species such as *Polioptila melanura* and *Cynanthus latirostris* are frequently hard to detect because of their tiny body size and their constant "hopping-flying around" behavior. These species are mostly detected under 40 m and therefore attain large $h(0)$ estimates (Table 2) and small effective areas.

Using our detection function results from point counts readily produce relevant management information in terms of population density. In particular, density estimates for *Streptopelia decaocto* using the detection function suggests that the species attains similar abundances in highly-urbanized zones and moderately-urbanized zones. This species has been recorded in both urban and agricultural areas (Johnston 2001, Fuller *et al*. 2009) and rarely in natural lands. Fuller *et al*. 2009 studied the urban birds within the boundaries of the city of Sheffield (England), a 160 km^2 city with temperate climate. Their population estimate for the entire city was 13,271 (95%CI = (11,312, 15,568)) individuals of *S. decaocto* during the summer (May-July). Our population estimate for the species in the city of Hermosillo (Mexico), a 193 km^2 city with arid climate was 57,384 (95% CI = (51,484, 63,284)) individuals during the summer (March-August). We are not aware of any estimate of the species' density by levels of any urban impact classification anywhere else for comparison to our estimates. Fujisaki *et al*. (2010) mention that the range expansion of this species tends to follow human altered landscapes such as road and agricultural areas, but the authors do not have enough data to conclude whether *S. decaocto* was more abundant in urban or suburban areas. Several studies have reported this species in urban areas of several Mexican states (Pineda-López and Malagamba 2011, Chablé-Santos *et al*. 2012, Pineda-López *et al*. 2013), but none of these studies documents the changes in the distribution of this species along an urban-rural gradient.

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