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OCCUPANCY AND DENSITY OF THE MOUNTAIN PLOVER (*Charadrius montanus*) IN NORTHEASTERN MEXICO DURING THE BREEDING AND WINTERING SEASONS

POR

JULIO MERAYO GARCÍA

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DEDICATION

This study is dedicated to my family, who was supporting me from the distance all the time I was living in México.

To all the conservationists who fight to preserve the amazing Mexican wildlife, and specially, to those who focus in the lonely and arid grasslands of the Mexican plateau.

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SYMBOLS AND ABBREVIATIONS

AIC… Akaike Information Criterion

GPCA… Grassland Priority Conservation Areas (APCP, Área Prioritaria para la Conservación de Pastizales)

IC95%… 95% Confidence Intervals

SE… Standard Error

Ψ…Occupancy probability

β … Parameters of the occupancy probability model

ABSTRACT

The Mountain Plover (*Charadrius montanus*) is a migratory short-grassland bird of North America that has suffered a population decline across its range and has been assessed as threatened. In Mexico, the knowledge of the Mountain Plovers' breeding population is restricted to sporadic records of individuals, two nests, and a density estimate based on a limited survey effort; while its wintering population has been studied intermittently and locally. The objective of this research was to determine the occupancy, density, and habitat factors associated with the breeding and wintering populations of Mountain Plover in the Mexican prairie dog towns of the GPCA El Tokio and unexplored dry lake beds from San Luis Potosi and Zacatecas. To achieve this, between April and July of 2018, 2019, and 2020 (breeding seasons), and January and March of 2019 and 2020 (wintering seasons), we surveyed between 77 and 137 randomly selected plots in 37 sites, where we registered the number of plovers, detection distances, and measurements of habitat variables. For analyzing data, we used Presence 2.12 and Distance 7.3. Mountain Plovers were mostly recorded in plots in Mexican prairie dog towns, where the mean occupancy (Ψ) during the breeding seasons was 0.22, 0.20, and 0.08 in 2018, 2019, and 2020, respectively; while mean densities were 0.97, 1.72, and 0.6 birds/km^2. During the winter, mean occupancy was less variable with 0.09 and 0.08; while mean density was 4.57 and 6.93 birds/km^2 in 2019 and 2020, respectively. In both seasons, the plovers used sites with less grass and barer ground than the available. These results provide novel data on the only breeding population in Mexico, and the southernmost for the species, which will serve as a baseline when designing and implementing strategies of conservation and management for the Mountain Plover and the short grasslands in the region.

RESUMEN

El Chorlo Llanero (*Charadrius montanus*) es un ave de pastizal migratoria y endémica de Norteamérica que ha sufrido un declive poblacional en Norteamérica. En México, el conocimiento sobre la población reproductiva del Chorlo Llanero está limitado a registros esporádicos, dos nidos y una estimación de densidad basada en un esfuerzo de muestreo limitado; sus poblaciones invernales han sido estudiadas de manera intermitente y local. El objetivo de este estudio fue determinar la distribución, abundancia y los factores de hábitat asociados a la población invernal y reproductora de Chorlo Llanero en las colonias de Perrito Llanero Mexicano del GPCA El Tokio y de lagunas temporales en San Luis Potosí y Zacatecas. Para esto, entre abril y julio de 2018, 2019 y 2020 (temporadas reproductivas), y entre enero y marzo de 2019 y 2020 (temporadas invernales), muestreamos entre 77 y 137 parcelas seleccionadas aleatoriamente en 37 localidades, registrando no. de inds., distancias de detección y variables de hábitat. Para analizar los datos, empleamos Presence 2.12 y Distance 7.3. La mayoría de registros se obtuvieron en colonias de perrito llanero mexicano, donde la ocupación (Ψ) media durante las temporadas reproductoras fue de 0.22, 0.20 y 0.08, en 2018, 2019 y 2020, respectivamente; mientras que las densidades medias se estimaron en 0.97, 1.72 y 0.6 aves/km^2. En invierno, la ocupación media fue menos variable, 0.09 y 0.08, para 2019 y 2020; mientras que las densidades medias fueron 4.57 y 6.93 aves/km^2. En ambas temporadas, los chorlos usaron sitios con menos cobertura de pastos y más suelo desnudo que el disponible en el área. Estos resultados proporcionan datos nuevos de la única población reproductora de Chorlo Llanero en México, y la más sureña de la especie, los cuales sirven como línea base para el diseño y la implementación de estrategias de conservación y manejo para la especie y los pastizales cortos en la región.

INTRODUCTION

The Mountain Plover (*Charadrius montanus*) is a migratory shorebird associated with North America short-grasslands, especially those grazed by native herbivores such as prairie dogs (*Cynomys* spp.), bison (*Bison bison*), and pronghorns (*Antilocapra americana*) (Knopf & Miller, 2014). During the breeding season is distributed mainly across the western Great Plains, with lesser populations in Mexico and Canada (Knopf & Wunder, 2006). After breeding, the populations migrate southward, with a stopover in eastern Colorado and southeastern Kansas (Pierce, 2017), to finally overwinter in a broad area between California, Texas, and northern Mexico. Its population suffered an annual loss rate of 2% between 1966 – 2015 (Sauer *et al.*, 2017) which has led to being considered as Near Threatened (NT) by the Red List of Endangered Species (BirdLife International, 2017) and Threatened by the Mexican government (Semarnat, 2010).

In Mexico, the species has been poorly studied, with wintering records scattered across eleven of the northern states (Howell & Webb, 1995). Two areas hold the highest number of records and abundances of the species: the GPCA El Tokio in the limits of the states of Nuevo Leon, Coahuila, San Luis Potosi, and Zacatecas, and the GPCA Janos in Chihuahua (Macías-Duarte & Panjabi, 2010). El Llano de La Soledad, within the GPCA El Tokio, is categorized as an International Site of the Western Hemispheric Shorebird Network since 2005, based on the estimation of 1500 wintering Mountain Plovers. In both areas, the Mountain Plover is associated with prairie dogs' short grasslands (*Cynomys* spp.). However, the lack of detailed information about the wintering sites and their fast transformation in croplands are some of the main challenges to its global conservation (Andres & Stone, 2009).

The Mexican breeding population is the southernmost for the species and was discovered 20 years ago in the GPCA El Tokio. For this population, study efforts had been even fewer than for the wintering one, with some reports of birds in breeding plumage and behavior and two nests (Desmond, 2002; González Rojas *et al.*, 2006; Knopf, 1999), and a 10 years-ago population estimation based on a limited sampling effort (Cotera-Correa *et al.*, 2014). The residency status of this population is unknown (Andres & Stone, 2009). The grasslands of this region are seriously endangered due to historic and current land-use changes, with a loss of 77% (~97,078 hectares) of the historical distribution of Mexican prairie dogs in 2011 (González Uribe, 2011; Scott-Morales *et al.*, 2004).

It is, therefore, necessary for its conservation, to determine the population status of the breeding and wintering populations of the species, as well as identify its habitat requirements.

Based on the biogeographical hypothesis that species abundance is higher towards the center of their geographic range (e.g. Andrewartha and Birch 1954) and that this is associated with optimal environmental gradients (Brown 1984), occupancy and density of the Mexican population (the southernmost known) is expected to be less than the estimate for central (core) areas of its distribution in North America.

BACKGROUND

Distributional Range

Breeding

Mountain Plovers are endemic to North America; they breed in southern Alberta and southwestern Saskatchewan in Canada, and across Wyoming, eastern Colorado and Park County, New Mexico, Oklahoma Panhandle, and Nebraska in the US. There are also sporadic breeding reports in Texas, Arizona, and Utah (Day, 1994; Knopf & Rupert, 1999) in the US, and Nuevo León, Coahuila, and San Luis Potosi in Mexico (Desmond & Chavez Ramirez, 2002; Knopf & Wunder, 2006; González Rojas *et al.*, 2006).

In Mexico, the first record in the breeding season was made in 1998, with the observation of several individuals and pairs with nuptial plumage in Nuevo León (Knopf & Rupert, 1999), while nesting was confirmed until 2002 in La India, Coahuila (Desmond & Chavez Ramirez, 2002). The second nest (first successful) was recorded in 2004 in El Llano de la Soledad, Nuevo León (González Rojas *et al.*, 2006). Individuals during the breeding season have also been recorded in El Manantial and El Gallo, in northern San Luis Potosí (Cotera-Correa *et al.*, 2014). All these records occurred in Mexican prairie-dog colonies within the GPCA El Tokio; however, an additional pair with nesting behavior was reported in Laguna El Tapado, an endorreic lake farther south in San Luis Potosí, with patches of halophytic herbs and saltgrass (*Distichlis spicata*) (Luévano *et al.*, 2010).

Wintering

California is considered the stronghold for Mountain Plovers during winter, with high numbers in the valleys of Sacramento, San Joaquín, Panoche, Imperial, and Carrizo

Plain (Wunder & Knopf, 2003). Other states with wintering populations are Arizona, Nevada, and Texas, and it is suspected that, especially in the latter, there could be a high number of plovers (Andres & Stone, 2009).

In Mexico, its wintering frequency was described as higher in prairie dog towns of Nuevo León, Coahuila, and Chihuahua, while is scarcer in the states of Baja California, California Sur, Sonora, Sinaloa, Durango, Zacatecas, San Luis Potosí and Tamaulipas (Howell & Webb, 1995).

Phenology

The breeding populations from the Great Plains migrate annually to wintering grounds on the coast of California, Texas, and the Chihuahuan Desert. These birds leave nesting areas between mid-July and late September, remain 35 to 100 days in a stopover area in eastern Colorado and southwestern Kansas, and arrive at the beginning of November to wintering sites (Pierce *et al.*, 2017). Plovers wintering in California leave wintering grounds during the first half of March (Knopf & Rupert, 1995); however, reported arrivals to breeding grounds vary; birds from eastern Colorado arrive in early March while birds from Montana and Wyoming do it in mid-April (Pierce *et al.*, 2017). These differences are reflected also in the laying, with birds from Colorado and Kansas nesting from late April until mid-June, while northern populations like Wyoming and Montana, start laying in the second half of May until the beginning of July (Bent, 1927). If nesting fails at the early stages of the season, plovers try second attempts (Graul, 1975), so breeding duration increases. Some plovers start to flock in June, immediately after breeding, which most likely are individuals that failed nesting (Graul, 1975).

In Mexico, the earlier reports from the fall are from the second half of October, and counts decrease during the winter, with the lowest numbers in February and March (Gonzalez Rojas *et al.*, 2008). Breeding behavior is observed from April until July (Desmond & Chavez Ramirez, 2002; González Rojas *et al.*, 2006; Knopf & Rupert, 1999; Luévano *et al.*, 2010), with active nests during May-July (Desmond & Chavez Ramirez, 2002; González Rojas *et al.*, 2006; Knopf, 1999), suggesting that breeding season is longer than in northern (US) populations.

Population size and density

Its overall population is estimated at 18,000 individuals (95%CI=12,500 – 28,000; Andres & Stone, 2009); however, it is based on eastern Colorado density estimation with wide confidence intervals (Tipton *et al.*, 2009).

Colorado, Wyoming, and Montana populations harbor ~88% of the breeding Mountain Plovers (Knopf & Miller, 1994). The highest density for the species was reported in short grasslands in South Park, Colorado, with 7.9±0.9 (SE) inds./km^2 (Wunder *et al.*, 2003), while in eastern Colorado rangelands hold densities of 0.23 inds./km^2 (95%CI= 0.17 – 1.76) (Tipton *et al.*, 2009). In Pawnee National Grasslands, known as the epicenter of Mountain Plover breeding (Graul & Webster, 1976), after negative changes in grasslands management for the species, densities dropped to 2.0±0.46 (SE) inds./km^2 (Knopf & Wunder, 2006). The species is common in prairie dog towns in eastern Colorado, with densities of 2.26 inds./km^2 (95%CI=2.15–5.13; Tipton *et al.*, 2009). In Philips County, Montana, prairie dog towns reported densities of 6.8±1.1 (SE) inds./km^2 and 1.28±0.06 (SE) inds./km^2 in the period 1991-1995 (Dinsmore, 2001; Dinsmore *et al.*, 2003), while for a heterogeneous landscape of rangeland and prairie dog towns in Wyoming there are estimates of 4.47±0.55 (SE) inds./km^2 (Plumb, 2005). Croplands were studied in eastern Colorado, where the species is scarce and were reported 0.45 inds./km^2 (95%CI= 0.44–0.53). In Mexico, for 8 prairie dog towns in the GPCA El Tokio, there are breeding density estimates of 5 and 2.7 inds./km^2 in 2003 and 2004, with a total absence of the species in 2005 and 2006 (Cotera-Correa *et al.*, 2014).

Estimations on wintering grounds are roughly 7,000 individuals in California (Knopf, 1996), and 3,000 birds in Texas and Mexico, but these account for only 55% of the estimated breeding population (Andres & Stone, 2009).

In Mexico, for GPCA El Tokio, there is an estimate of 624 plovers in 2003-2005 (Cotera-Correa *et al.*, 2014). Particularly in El Llano de la Soledad, estimates are variable, with 2,110 individuals in 2005 (González-Rojas *et al.*, 2006) and 504 for 2007-2008 (González-Rojas *et al.*, 2008), but it is important to consider that those numbers were obtained using different methodologies. In the GPCA Janos, Chihuahua, there is an estimation of 1,435 wintering individuals in Black-tailed prairie-dog colonies in winter 2005-2006 (Salinas, 2006). Based on this information, the wintering population size of plovers in prairie dog areas of Mexico was estimated at 8,200 individuals (Macías-Duarte & Panjabi, 2010), which would represent 45% of Mountain Plover population; however, due to the scarce number of efforts focused on the species in the country, it should be taken with caution.

Habitat

Historically, the species was associated with plains with prairie dog towns and areas with high disturbance by bison grazing (Knopf, 1994; Askins *et al.*, 2007). Given its preferred habitat, the common name of the Mountain Plover is considered a misnomer (Knopf & Miller, 1994). However, the species has adapted to changes in the landscape and nowadays it breeds in short and mixed grasslands, prairie dog towns, and croplands (Dinsmore, 2003). In Colorado, the species was more distributed in prairie dog towns with an occupancy Ψ=0.5, followed by croplands Ψ=0.13, and being scarce in mixed grasslands Ψ=0.07 (Tipton *et al*., 2008).

During the breeding season it is associated with areas with vegetation height shorter than 8 cm (Graul, 1975), and more than 30% of bare ground (Knopf & Miller, 1994), and with a lot of variation on the dominant grasses; however, the most frequent are Blue grama (*Bouteloa gracilis),* Buffalo grass *(Buchloe dactyloides)* and Needle-and-thread grass (*Stipa comata)* (Graul, 1975; Knopf & Miller, 1994). Nests are usually located aside from conspicuous elements, like cow dung, rocks, or vegetation patches (Graul, 1975).

In Mexico, the species breeds in prairie dog towns (Desmond, 2002; González Rojas *et al.*, 2006). These areas are in plains with gypsum soils, where grasslands are dominated by Hairy muhly (*Muhlenbergia villiflora).* Nesting sites have vegetation heights < 7.2 cm, and > 40% bare ground (Desmond, 2002; González Rojas *et al.*, 2006). In a dry bed lake in San Luis Potosi, the species was recorded in halophytic grassland dominated by Saltgrass (*Distichlis spicata)* (Luévano *et al.*, 2010); while the nest in a Mexican prairie-dog town the most common grasses were Muhly

(*Muhlenbergia* sp.) and Karwinski's grama (*Bouteloa karwinskii*), with a high abundance of Summer bluet (*Hedyotis purpurea*) and McVaugh's bladderpod (*Lesquerella mcvaughiana*; González-Rojas *et al.* 2006).

During winter in Mexico, plovers use mainly prairie-dog towns in Janos and El Tokio (Macías-Duarte & Panjabi, 2010), but in southern USA, it also uses croplands, specially plowed or early growing fields in Texas and California (Pierce *et al.*, 2017; Wunder & Knopf, 2003). Out of these habitats, the species is sporadically reported in open areas with low vegetation and high bare ground cover, like coastal plains and open shrublands with short grasslands (Sullivan *et al.*, 2009). The species has not been reported using croplands in Mexico (Allen-Bobadilla, 2014).

GENERAL OBJECTIVE

Determine the distribution, occupancy and density and associated habitat variables for the breeding and wintering populations of Mountain Plover (*Charadrius montanus*) in northeastern Mexico.

Specific Objectives

- Describe the distribution and estimate occupancy of the breeding and wintering populations of the Mountain Plover *(Charadrius montanus)* in Mexican prairie dog towns and unexplored dry lake beds in northeastern Mexico.
- Estimate density and abundance during breeding and wintering seasons.
- Associate habitat variables with occupancy for breeding and wintering populations.

METHODS

Study area

Our study was implemented in northeastern Mexico, within the Mexican Plateau, and it is divided in two main areas: the GPCA El Tokio and a system of temporary lakes in the physiographic region of the Zacatecan – Potosinan Plateau.

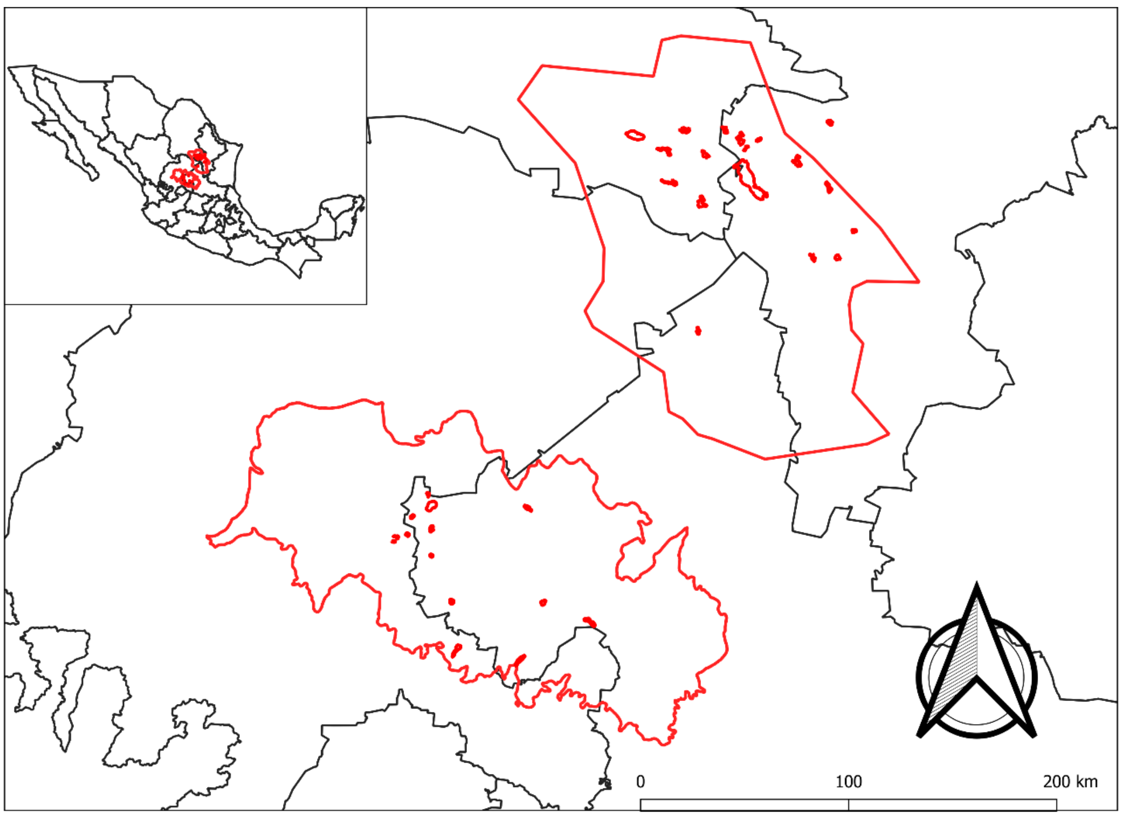

Figure 1.- Study area. The northern polygon is the Grassland Priority Conservation Area (GPCA) El Tokio, which includes all the Mexican prairie dog (*Cynomys mexicanus*) towns; and the southern one is the physiographic province of Llanuras y sierras Potosino - Zacatecanas, which encompasses the temporary lakes.

The GPCA El Tokio is located at the limits of Nuevo León, Coahuila, San Luis Potosí, and Zacatecas. It includes the physiographical subprovinces of Sierras Transversales, Sierras and Llanuras Occidentales, and the Gran Sierra Plegada. It includes most of the remaining colonies of the endemic Mexican Prairie Dog (*C. mexicanus*). These occur in plains with deep gypsum soils, and intermontane valleys with low slopes and shallow soils rich in carbonates (Cotera-Correa, *et al.*, 2010). Uses on these sites include extensive livestock of cows, goats, sheep, and horses, management for biodiversity conservation, and abandonment from agricultural uses (Pronatura, 2017). The surveyed prairie dog towns had an extension of 197.78 km^2

The second study area consists of a system of temporary lakes located in the physiographic subprovince of Plains and mountain ranges of the Zacatecan – Potosinean region. The lakes are located in southwestern San Luis Potosi in the municipalities of Moctezuma, Salinas, Santo Domingo, and Salitral de Carrera; and central Zacatecas in the municipalities of Villa de Cos and General Pánfilo Natera. It is a region with undulated landscapes and calcic soils, poor drainage with endorheic basins hosting temporary and shallow saline lakes. All lakes surveyed are within 100 km of El Tapado lagoon, where Mountain plovers were reported with breeding behavior (Luévano *et al.*, 2010)**.**

El Tokio holds vegetation typical from arid regions, with a high abundance of shrublands dominated by *Yucca carnerosana, Larrea tridentata, Flourensia cernua*, *Opuntia* spp., and *Koeberlinia spinosa*. In saline soils those shrublands are substituted by *Atriplex canescens, Lepidum montano, Lycium berlandieri*, and *Koeberlinia spinosa*. Grasslands are dominated by *Muhlenbergia villiflora var. villiflora, Scleropogon* *brevifolius*, and *Bouteloua gracilis* (Rzedowski, 1994), and forbs like *Frankenia gypsophila*, *Atriplex reptans*, *Calylophus hartwegii*, *Dicranocarpus parvifolius*, *Euphorbia stictospora*, *Nerisyrenia gracilis*, and *Zinnia anomala* (Estrada-Castillón *et al.*, 2010).

In the saline basins of San Luis Potosi and Zacatecas, the most characteristic floristic components are *Suaeda*, *Atriplex*, and *Allenrolfea*, specifically *Atriplex abata*, *A. pringlei*, *Distichlis spicata*, *Geissolepsis suaedifolia*, *Sesuvium portulacastrum*, *Sporobolus nealleyi*, *Suaeda mexicana*, and *S. nigrescens*, with woody plants as *Maytenus phyllanthoides*, *Lycium carolinianum*, *Prosopis laevigata*, among others (Rzedowski, 1957).

The climate characteristic from the Mexican Plateau is Dry (BS), and the climatic type on the GPCA El Tokio is arid temperate BS0kx' (García, 1988; CONABIO, 1998) with temperatures oscillating between 12°C y 18°C, reaching below 0 every winter. The annual rainfall rises 427 mm, and is more accentuated between July and September, with a dry season between October and April, when precipitation drops to 18 mm (CONAGUA).

Sampling design

We located the prairie dog towns and temporary lakes using Google Earth Pro, with satellite images from 2014. For El Tokio, we defined the minimum size for survey sites in 100 ha, based on an exploratory survey where we did not detect plovers in smaller colonies. Using the data from this exploratory survey and following the optimization methods described by Mackenzie (2005) for the occupancy models, we calculated an optimal sample size of 147 plots. These plots were located randomly in the sites using ArcGIS.

The survey was designed to simultaneously obtain data for both occupancy and distance-corrected detection models (Mackenzie & Royle, 2005; Thomas *et al.*, 2010). The surveys were conducted by two observers, which recorded data for occupancy, while the distance sampling was conducted by the most experienced observer with a rangefinder. Plots were visited once per season.

In both seasons, plots were limited by occupancy records, but the distance surveys had variable widths. Within every survey we recorded all plovers detected, but detections by calls or song were only registered when we had the certainty that plovers were situated within the plot.

For the field surveys, we selected periods when northern populations of plovers are not migrating (Pierce, 2017), to avoid the detection of any passing by plover.

Surveys were preferably implemented from sunrise until 11:00 and from 18:30 until sunset. Surveys were not conducted with rain, temperatures >27°C, wind >6m/s, or mist.

In the breeding season, the size of the plots was based on the minimum area of 28 ha for brood rearing estimated by Knopf (1996) and previously used by Tipton *et al.* (2008), adapting the plot size to 30 ha, in a 500x600-m plot.

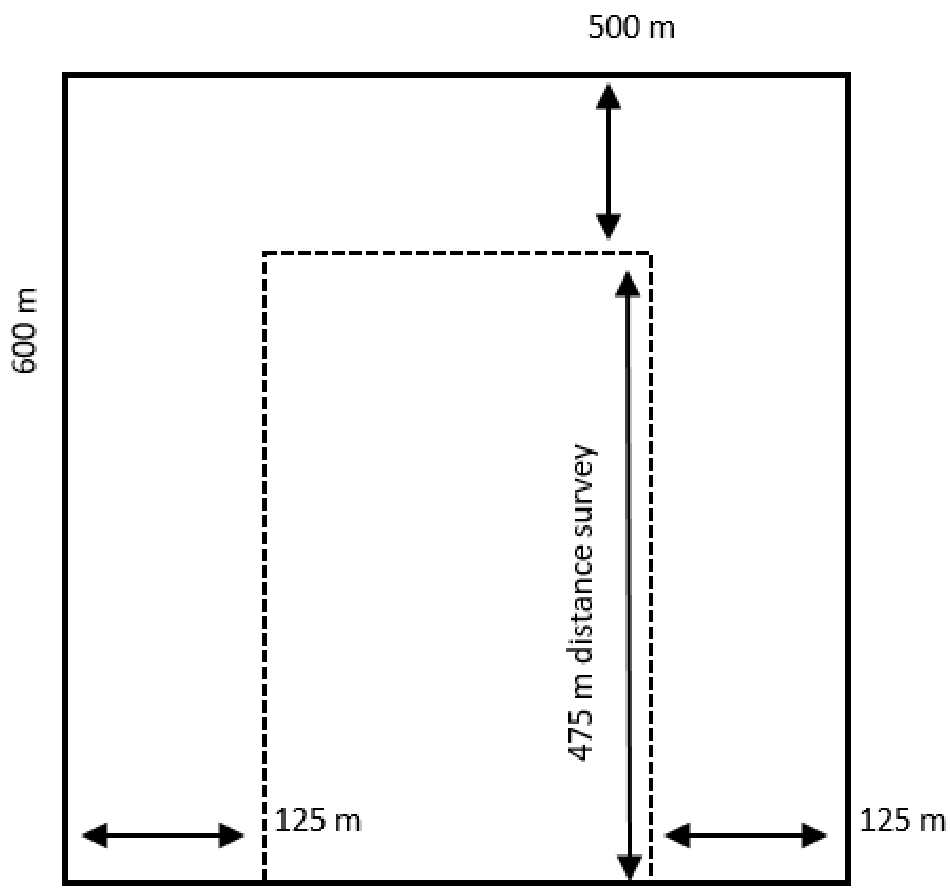

Figure 2.- Diagram of the 600x500m occupancy plot (dotted line shows the observer's path) and the 475-m distance sampling transect sampled during the Mountain Plover (*Charadrius montanus*) breeding season in the (modified from Tipton *et al.*, 2008).

We surveyed between 17 April– 24 July of 2018, 2019, and 2020, with both observers walking simultaneously but recording data independently, and following a predefined transect with a quadrate C shape, at <125m from every point from the plot (Fig. 2). The maximum distance assumed for the optimal detection of the species was 125 meters (Tipton *et al.*, 2008). This data was collected during the first 475 m-linear transect of each plot to avoid the violation of the assumption of individuals being recorded at their initial location (Thomas *et al.*, 2010).

In winter, we surveyed sampling units with the same surface but different shapes, using line transects of 1,000 meters and 300 m of bandwidth. The dates of the survey were between 27 January and 4 March of 2019 and 2020 (Fig. 3).

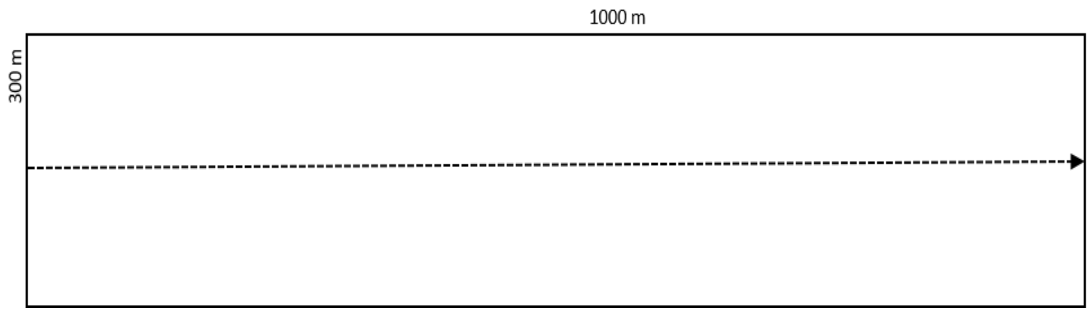

Figure 3.- Diagram of the 1000x300 m occupancy plot (dotted line shows the observer's path) and the 1000 m distance sampling transect sampled during the Mountain Plover (*Charadrius montanus*) wintering season.

For habitat variables, we surveyed 5 plots located systematically within the occupancy plot. We adapted the protocol of Bird Conservancy of the Rockies (Beyer & Panjabi, 2010). Every habitat plot consisted of a circular area of a 5-meter radius where we estimated visually the percentages of shrub, grass, forb, soil disturbed by mammals, bare ground, and debris cover. The height of the vegetation was measured with a rule with 1 cm divisions, averaging the height of several individuals selected randomly within the plot.

Statistical analyses

We analyzed occupancy and density by season for three breeding seasons (2018-2020) and two wintering seasons (2018-2020).

Occupancy

We ran single-species, single-season occupancy models in the software PRESENCE (Hines, 2006) to estimate the probability of detecting occupancy and the proportion of occupied sites using the presence-absence data. Following the approach proposed in this method (MacKenzie, 2006), we calculated the probability of detecting Mountain Plovers during a single survey (p), the single probability of detecting the species presence), and the proportion of plots occupied by the plovers (Ψ). We calculated model parameters using maximum likelihood estimations and assuming closure during each survey season.

Detection was modeled as constant, while occupancy ψ was modeled as constant and as a function of the habitat covariates. Before running the analyses, we made a goodness of fit test using a parametric bootstrap (Bailey *et al.*, 2014). For the analysis of habitat data, we used mean values per sampling unit for all habitat variables. Additionally, we used univariate Student's-t tests to compare the characteristics of plots with detections and non-detections of plovers for each season to reduce problems related to excessive variables, selecting only variables with $p<0.05$ in at least one season. We made correlation tests between the variables to detect redundancy. We considered two variables redundant when they were highly correlated ($R > 0.40$), retaining the variable with the lowest probability in the univariate test.

Density

We estimated density using Distance 7.1 (Thomas *et al.*, 2010), modeling the detection probability as a function of distance. We tested 1) half-normal with cosine adjustment, 2) half-normal with hermit adjustment, 3) hazard-rate with polynomial adjustment, and 4) uniform with cosine adjustments (Buckland *et al.*, 2001). We included historical data from previous surveys made on prairie-dog towns in El Tokio (UANL) to improve the detection probability function for the wintering season.

Model selection

For both analyses, we selected the best models using the lowest Akaike Information Criterion (AIC). In occupancy, in case we obtained models with ΔAIC (the difference in AIC units respect the best-ranked model) lesser or equal to 2 when models differed by one parameter and had similar log-likelihood values, the larger mode was excluded to avoid including uninformative parameters (Mackenzie *et al.*, 2011).

For the distance of detection models, in case we obtained models with ΔAIC lesser or equal to 2, we used the value of probability of the X^2 to choose the model with the best goodness of fit to the detection function (Burnham & Anderson, 2002).

RESULTS

Breeding season

We sampled 77 plots in 15 prairie dog towns in 2018. In 2019 we surveyed 121 plots in 17 prairie dog towns (100 plots) and 12 lakes (21 plots), while in 2020 we surveyed 118 plots in 18 prairie dog towns. The lakes were not surveyed in 2018 and 2020 because they were flooded, while in 2020 we did not visit the area because of restrictions due to the Covid-19 pandemic.

Mountain Plovers were detected in 17/77 plots in 2018, 20/121 in 2019, and 10/118 in 2020. In the prairie dog towns, the species was found in both native and recolonized prairie dog towns, but not in montane valley colonies. Mountain Plovers were not detected within plots in dry lake beds, so this habitat was excluded from the analyses (Fig. 4).

Distribution and occupancy

Mountain Plovers were detected in seven prairie dog towns located in the states of Nuevo Leon (La Casita, La Soledad, La Trinidad, El Potosí, El Salero, and Refugio de los Ibarra) and Coahuila (La India). Grasslands that support Mountain Plovers in the northeastern Mexican Plateau are distributed in a small number of patches separated by unsuitable habitats. with most of the detections in native short-grasslands dedicated to livestock grazing and biodiversity conservancy. We found plovers nesting in agriculture plots without use for ~ 20 years and recolonized by prairie dogs.

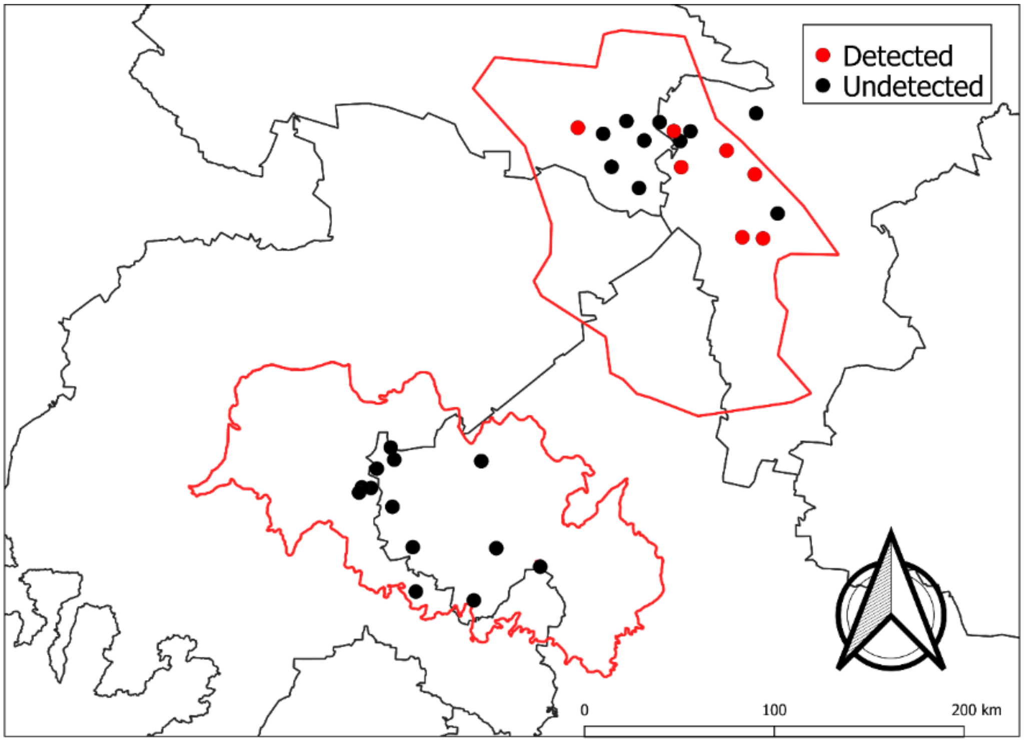

Figure 4.- Location of detections of Mountain Plovers (*Charadrius montanus*) during three breeding season (2018- 2020) in Northeastern Mexico.

Occupancy was Ψ=0.22 (IC95%=0.14 – 0.33) in 2018, Ψ=0.20 (IC95%=0.13 – 0.29) in 2019, and Ψ=0.08 (IC95%=0.04 – 0.16) in 2020 (Fig. 5).

The probability of occupancy was best described by the habitat variable of grass cover, with β from the top model Ψ (grass cover); p (.)= -0.08 (95%CI= (-0.01,-0.15), showing a negative relationship between grass cover and occupancy of Mountain Plover (Fig. 6). Detection probabilities (p) ranged from 0.62 to 0.85.

The plots with detections of Mountain plover had on average less grass cover, with grass height shorter than the available in the prairie dog towns.

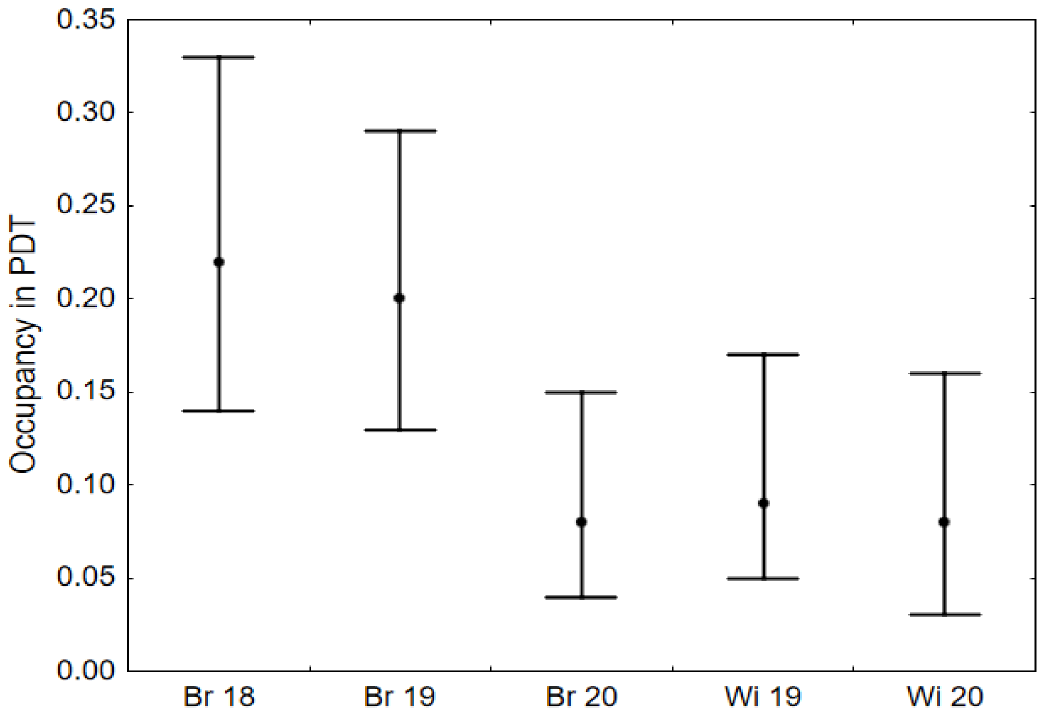

Figure 5.- Mountain Plover (*Chatadrius montanus*) occupancy rate in Mexican prairie dog towns (*Cynomys mexicanus*) during three breeding (2018- 2020) and two wintering seasons (2019- 2020).

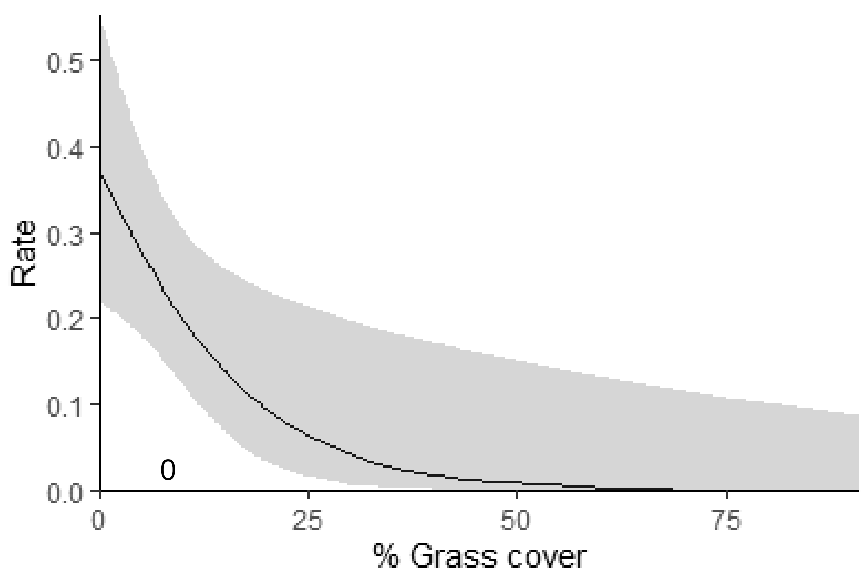

Figure 6.- Relationship between the percentage of grass cover and the occupancy rate of Mountain Plover (*Charadrius montanus*) during the 2019 breeding season.

Table 1.- Comparison of habitat characteristics of plots with and without detections of breeding Mountain Plovers (*Charadrius montanus*) between 2018 and 2020 in Mexican prairie dog (*Cynomys mexicanus*) towns in northeastern Mexico.

Vegetation variables	Plots with detections (n=45)		Plots without detections (n=248)		p^a
	Mean (SE)	Median (range)	Mean (SE)	Median (range)	
Ground cover (%)					
Shrub	0 (0)	0, (0-0)	0.1 (0.1)	0, (0-0)	0.32
Grass	5.1 (0.7)	4.0, (0.8-8.8)	11.9 (1.1)	5.8, (0.7-15.4)	0.0001**
Forb	4.7 (0.7)	3.7, (3.8-6.7)	3.7 (0.4)	1.5, (0.4-4.5)	0.2
Annual	52.7 (6)	52.7, (11.7-100)	50.2 (5.5)	54, (2-95)	0.25
Perennial	40.8 (5.9)	37.8, (0-83)	39.7 (2.5)	32.6, (0-80)	0.54
Bare ground	81.8 (3.5)	88.3, (81.3-93.2)	77.9 (1.6)	86.5, (73.2-95.9)	0.0001**
Mound	2.0 (0.3)	1.2, (0.2-3.4)	1.4 (0.1)	0.4, (0-1.8)	0.07
Others	0.9 (0.5)	0, (0-0.3)	0.3 (0.1)	0.3, (0-0.1)	0.2
Height (cm)					
Shrub	2.9 (1.9)	0.0, (0-0)	55.9 (10.6)	46, (28-51)	0.38
Grass	3.0 (0.3)	3.4, (0.1-4.3)	4.8 (0.2)	4, (3-6)	0.0001**
Forb	4.2 (0.3)	4.2, (3.5-5.4)	5.0 (0.3)	4.3, (3-5.8)	0.61

[a] t- test statistical significance ($p<0.05$)

Density and abundance

We surveyed 76, 100, and 118 distance transects in 2018, 2019, and 2020 with 13, 26, and 11 Mountain plover records, respectively. The data for the breeding season fitted best to the half-normal curve with cosine adjustment. Effective strip width (ESW) was 186 m (95%CI= 141−244), with sightings obtained at distances between 2 and 280 m. The average detection probability was 0.66 (95%CI=0.50-0.87). We estimated densities of 0.97 birds/km^2 (95%CI=0.53–1.76) in 2018, 1.72 birds/km^2 (95%CI=0.97 - 3.03) in 2019, and 0.6 birds/km^2 (95%CI=0.29 – 1.26) in 2020, with abundances for the study area of 187 plovers (95%CI=102 – 340) in 2018, 331 birds (95%CI=187 – 585) in 2019 and 115 individuals (95%CI=55 – 243) in 2020.

Wintering season

Between January and March 2019, we surveyed 137 plots by the double observer in 19 prairie dog towns (113) and 12 temporary lakes (24). Plovers were detected in 10 plots. In 2020 we surveyed 136 plots in 32 sites (19 prairie dog towns and 13 lakes), with plovers detected in 8 plots. Mountain Plovers were in some of the largest and untransformed prairie dog towns of El Tokio (La Soledad, La India, El Manantial), using native grasslands, and in two temporary dry lake beds with saline grasslands overgrazed by cattle in San Luis Potosí.

Distribution and occupancy

Mountain Plovers were detected in La India (Coahuila), Llano de La Soledad, Salinas del Refugio (Nuevo León), El Manantial, and La Mesita lake (San Luis Potosí). Out of the surveys, we observed the species in El Potosi, Nuevo León and the lake of Santa Clara in San Luis Potosí.

The winter occupancy rate was 0.09 (95% CI: 0.05-0.17) in 2019 and 0.08 (95% CI: 0.03-0.16) in 2020. The probability of occupancy was best described by grass cover. The estimated **β** from the top model Ψ (grass cover); p (.), suggested a negative relationship (**β**= -4.09, 95% CI: -0.10 – -8.28) between the cover of grasses and the occupancy of Mountain Plover in the prairie dog towns.

Occupancy was negatively affected by higher grass coverages, with $\Psi < 0.1$ at sites with grass cover greater than 20% (Fig. 8). Detection probabilities (P) ranked from 0.45 to 0.91.

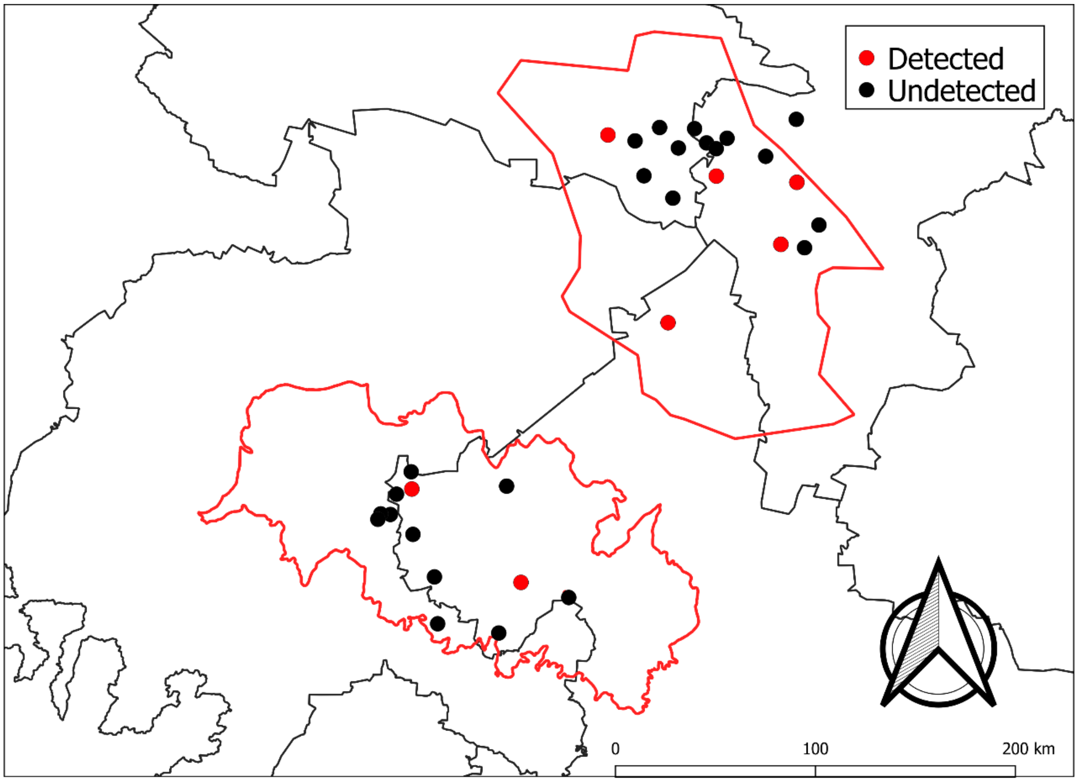

Figure 7.- Location of detections of Mountain Plovers (*Charadrius montanus*) during two wintering seasons (2019- 2020).

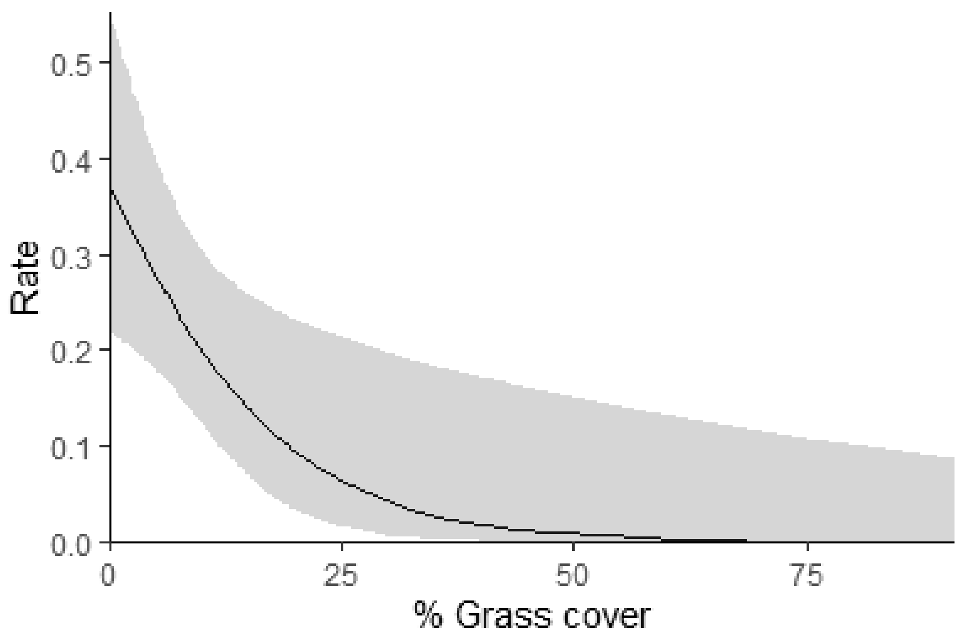

Figure 8.- Relationship between the percentage of grass cover (%) and the occupancy rate of Mountain Plover (*Charadrius montanus*) in the wintering season of 2019.

Table 2.- Comparison of habitat characteristics of plots with and without wintering detections of Mountain Plovers (*Charadrius montanus*) in Mexican prairie dog (*Cynomys mexicanus)* towns in northeastern Mexico.

Vegetation	Detection plots (n=17)		Non-detection plots (n=202)		
	Mean (SE)	Median (range)	Mean (SE)	Median (range)	p^a
Ground cover (%)					
Shrub	0.3(0.2)	0(0-0)	0.2(0.1)	0(0-0)	0.4
Grass	8.2(3.0)	2.7(0.6-10.6)	19.1(1.5)	11.2(2.4-32.4)	0.007*
Forb	6.6(2.5)	3.1(0.9-5.8)	6.9(0.8)	2.3(1.1-6.6)	0.9
Annual	72.7(5.6)	67(56.1-100)	56.9(2.6)	52.5(20.8-100)	0.052
Perennial	13.5(5.6)	0(0-24.8)	27.6(2.3)	16.7(0-50)	0.02*
Bare ground	84.1(5.3)	94.5(79.6-96.3)	73.2(1.7)	81.2(58.6-92.4)	0.09
Mound	1.6(0.3)	1.2(0.1-0.4)	1.8(0.2)	1.2(0.6-2.4)	0.9
Others	0.3(0.6)	0.2(0.1-0.4)	0.5(0.1)	0.1(0-0.5)	0.5
Height (cm)					
Shrub	10.5(6.5)	6.2(2-6.6.4)	35.7(6.2)	23.5(8-46.3)	0.24
Grass	3.4(0.4)	3.5(2.3-4.1)	4.6(0.2)	4.2(3.3-5.3)	0.05*
Forb	2.9(0.3)	2.6(2.2-3.2)	3.9(0.2)	3.5(2.3-5)	0.054

[a] t- test statistical significance (p<0.05)

Density and abundance

We recorded 14 and 17 observations of Mountain Plovers during the winter. For improving the detection curve, we added 44 historical registers of the species obtained in surveys in prairie dog towns from El Tokio and Janos.

Wintering season data fitted best to the uniform curve with cosine adjustment. ESW was 112 meters (95% CI: 82.4−152.7), with sightings obtained at distances between 0 and 315 meters. The average detection probability was 0.36 (95%CI= 0.26−0.48). The average density for the wintering season was estimated at 5.75 birds/km^2, with an estimation for 2019 of 4.57 birds/km^2 (95%CI= 1.38 – 15.16) and 6.93 birds/km^2 (95%CI= 2.2 – 21.8) with abundances for the study area of 385 individuals (95%CI= 170 – 870).

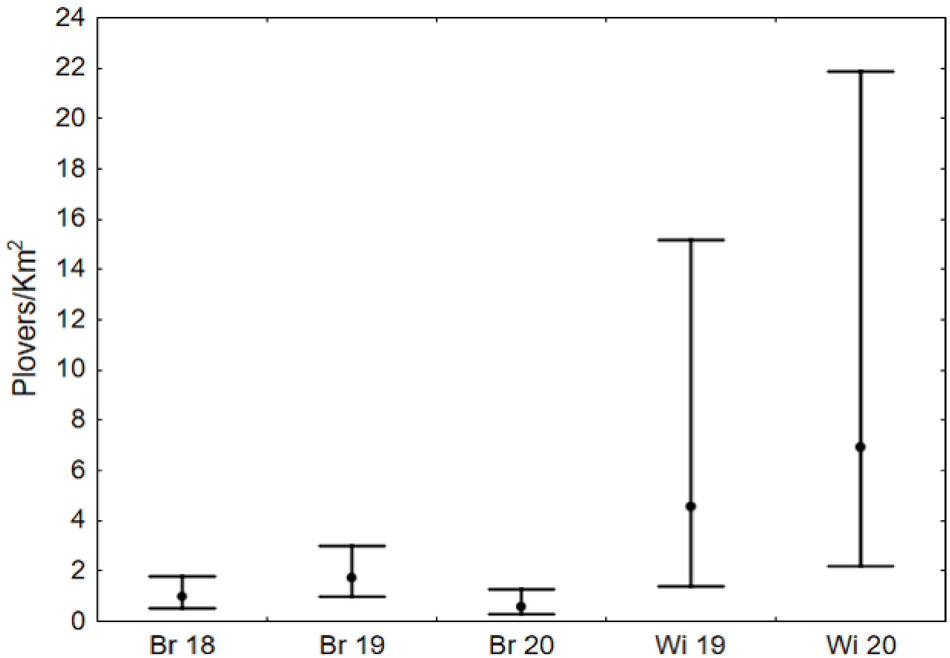

Figure 9.- Mountain Plover (*Chatadrius montanus*) density in Mexican prairie dog towns (*Cynomys mexicanus*) during three breeding (2018- 2020) and two wintering (2019- 2020) seasons.

DISCUSSION

Breeding season

Mountain Plovers are uncommon in the southeastern Chihuahuan Desert, with only seven breeding sites known in Mexico. Our research provides five new breeding locations for the species in Mexico, all within the GPCA El Tokio, adding to the two previous reports within the GPCA (Desmond, 2002; González Rojas *et al.*, 2006). We did not detect plovers breeding in dry lake beds, but due to the intermittent availability of habitat given by the inter-annual variation in their extent and timing when the lakes dry up, that would produce or not suitable habitat, we consider it unlikely that these wetlands would sustain a distinct permanent population of breeding Mountain Plovers.

The closest sites with recent breeding reports of Mountain Plover are more than 1,100 km away, in Black-tailed prairie dog (*C. ludovicianus*) towns in central New Mexico, and due to the high philopatry of the species (Dinsmore, 2003; Graul, 1973; Knopf & Wunder, 2006), the degree of isolation of the Mexican breeding population may be remarkable.

Our study is the first with an extensive sampling effort to reliably estimate the population size and density of Mountain Plovers breeding in Mexico. The area held an average of 229 breeding Mountain Plovers in the period 2018-2020, representing the 1.3% of the current global population (Andres & Stone, 2009). Densities in prairie dog towns were similar in the three years, with a global estimate of 1.52 plovers / km^2 (95%CI=0.98 – 2.36).

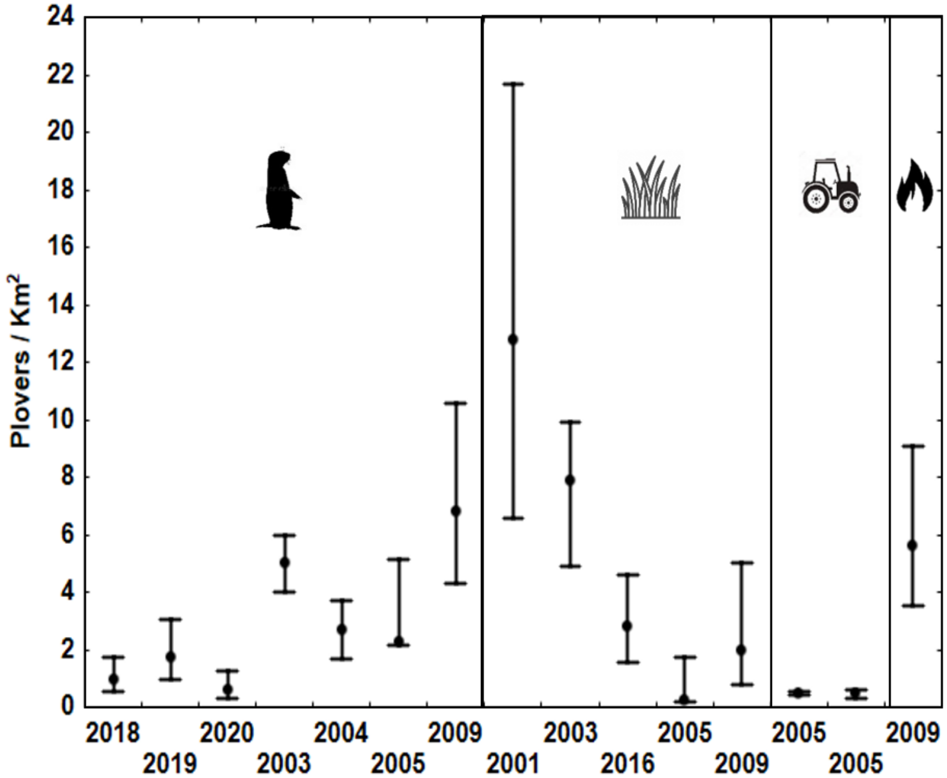

Figura 10.- Densities of breeding Mountain Plovers (*Charadrius montanus*) in this study (2018- 2020) and in other studies across its range.

Our density estimates were lower in 2018 and 2020 than those reported by previous work conducted in El Tokio (2003-2005; Cotera-Correa *et al.*, 2014). Although such difference could be explained by a reduction in the number of plovers in the area, it is most likely the result of a bias in the selection of the sites in the study, where they focused on the largest colonies which may lead to a density overestimation when extrapolated to El Tokio. This data does not give a clear trend for the species in the region, given the high variability among years, with no plovers detected in 2005 and 2006 breeding seasons (Cotera-Correa *et al.*, 2014). We did not find such a great variation in densities, but due to the inconstant monitoring in the region, a long-term program could help to reveal the trend of the breeding Mexican Mountain Plover population. As predicted, our densities were lower than those reported in prairie dog towns in Montana, Wyoming, and Colorado, and more similar to those obtained in rangelands and croplands in these states and Oklahoma (see Fig. 9; Augustine, 2011; Childers & Dinsmore, 2008; Knopf & Wunder, 2006; Plumb *et al.*, 2005; Tipton *et al.*, 2009, McConell *et al.*, 2009). Crops and rangelands are suboptimal habitats for plovers in United States, so this can reflect lower suitability of environmental conditions in the southern edge of the global distribution of the species, as reported by niche modeling for the populations of Mexican prairie dogs in their southernmost localities in San Luis Potosi (González Uribe, 2011). This negative relationship between abundance and ecological distance from the niche centroid of the distribution has been reported in other species (Brown, *et al.*, 1995; Martínez-Meyer *et al.*, 2013).

Wintering season

The winter estimates of density were significantly higher than the breeding estimations, suggesting an increase in the number of birds due to the arrival of northern populations. This is supported by the observation of banded birds, with the relocation in La Soledad and El Manantial of birds previously banded as breeders in South Park, Colorado (Pierce *in prep.*). Re-sighted plovers in La Soledad, La India, and El Potosí are evidence of a non-migratory population of Mountain Plover in Mexico. This was previously suggested (Andres, 2009; Knopf, 1999), but never confirmed.

Our estimates for winter are one of the lowest for the region and suggest a negative trend among the years the species has been monitored. Such trend could be driven by habitat losses or climate change. El Llano de la Soledad, where most of the studies were focused, has not suffered important grassland loss or degradation, keeping large conservation areas with cattle exclusion. This apparent decline could be caused by lower survival, productivity (in resident birds), but also by changes in the use of wintering grounds. Other studies suggest that the species shows plasticity in the use of wintering grounds, with the numbers of plovers in California decreasing in the last decades while more birds are wintering in Texas, something confirmed by birds tagged with geolocators in Montana (Pierce *et al.*, 2017). Previous studies showed the role of climate change in the migratory behavior of birds, with milder winter temperatures leading birds to stay closer to their breeding grounds (Guillemain *et al.*, 2015; Visser, 2008; Visser *et al.*, 2009). This change is stronger in species of dry open areas (Visser *et al.*, 2009). This could reduce the numbers of Mountain Plovers wintering in Mexico, with more individuals saving resources for migration and staying in northern areas such as Texas.

Occupancy and detectability

The overall proportion of occupied plots varied among years, but was lower than occupancy in prairie dog towns (Ψ=0.5) of Colorado; while it was similar to occupancy in croplands (Ψ=0.13) and mixed grasslands (Ψ=0.07; Tipton *et al.*, 2008). Plover occupancy was substantially lower in winter than in breeding, but probably this is due to the formation of flocking that occurs outside of the breeding season (*e.g*. Knopf & Rupert 1995). Given the increased effort required to estimate plover density, occupancy surveys can be a valuable tool for monitoring Mountain Plover populations, especially during the winter season, when the number of detections can be very low, while in breeding season distance sampling is a reliable method for studying its abundance.

CONCLUSIONS

Mountain Plovers have an extremely restricted distribution as a breeding species in Mexico. The species was found breeding in only seven prairie dog towns in Nuevo Leon and Coahuila, but not in dry lake beds in San Luis Potosi and Zacatecas.

The locality with the highest number of records in both seasons, El Llano de la Soledad, remains the biggest prairie dog town in the world, with ~10,000 ha of short grasslands; however, the use of secondary prairie-dog colonies suggests that the conservation of the species in Mexico can be enriched by prairie-dog colonies recovery from agricultural lands.

Due to their patchy distribution and scarcity, we suggest that the combination of distance sampling and occupancy surveys may be a suitable method for monitoring population trends on these low-abundant inland shorebirds. Continued research is needed to identify trends in this population, and the environmental factors that drive habitat selection, survival and breeding success for the Mountain Plovers inhabiting Mexico.

The conservation status of this resident population is critical, with less than 300 breeding individuals in a habitat threatened by shrub encroachment and croplands expansion, so it is urgent to manage, recover, and protect the prairie dog towns of El Tokio.

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Supplementary material

Table 2. Ranking of the bests models from occupancy analyses examining the effects of several variables of habitat in the Mountain Plover presence in Mexican prairie dog colonies in northeastern Mexico in the breeding and wintering season of 2019.

Best ranked models (Breeding 2019)	AIC	deltaAIC	AIC wgt	Likelihood	n° Parameter	=-2*LogLike
psi(Grass_cover),p(.)	122.91	0	0.96	1	2	118.91
psi(Grass_cover+Anual_forbs),p(.)	130.21	7.3	0.025	0.026	4	122.21
psi(Perennial_forbs),p(.)	132.66	9.75	0.0073	0.0076	3	126.66
psi(.),p(.)	133.51	10.6	0.0048	0.005	2	129.51
psi(grass_height),p(.)	134.53	11.62	0.0029	0.003	3	128.53
psi(Anual_forbs_cover),p(.)	142.07	19.16	0.0001	0.0001	3	136.07
psi(bare_ground),p(.)	144.17	21.26	0	0	2	140.17
psi(%Mounts),p(.)	147.61	24.7	0	0	2	143.61
Best ranked models (Winter 2019)	AIC	deltaAIC	AIC wgt	Likelihood	N° parameters	=-2*LogLike
psi(Grass_cover),p(.)	87.69	0.00	0.38	1.00	3.00	81.69
psi(Grass_cover+Perennial_forbs_%),p(.)	88.73	1.04	0.22	0.59	4.00	80.73
psi(Grass_cover+Forbs_cover),p(.)	89.68	1.99	0.14	0.37	4.00	81.68
psi(.),p(.)	90.59	2.90	0.09	0.23	2.00	86.59
psi(Forbs_Height),p(.)	91.45	3.76	0.06	0.15	3.00	85.45
psi(Grass_cover+Grass_height),p(.)	91.76	4.07	0.05	0.13	3.00	85.76
psi(Grass_height),p(.)	92.59	4.90	0.03	0.09	3.00	86.59
psi(Forbs_cover),p(.)	92.59	4.90	0.03	0.09	3.00	86.59
psi(Grass_cover+Forbs_height),p(.)	96.51	8.82	0.00	0.01	3.00	90.51