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Population estimates and land cover use of wintering Mountain Plovers in Texas

Estimaciones poblacionales y uso de la cobertura terrestre de Chorlitos Montañeses invernantes en Texas

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ABSTRACT. Conservation of migratory birds throughout the full annual cycle requires a comprehensive understanding of abundance and distribution in interconnected breeding, migration, and wintering habitats. The Mountain Plover (*Anarhynchus montanus*) is a rare endemic breeder of the Rocky Mountain and Great Plains regions that migrates to wintering grounds in the southwestern USA and northern Mexico. Information regarding its wintering abundance and distribution, particularly in Texas, is limited. This study provides the first population estimate for Mountain Plovers wintering in Texas and examines factors influencing their land cover use. Through distance sampling surveys in six ecoregions of Texas, we estimated an annual wintering population of 3096 (95% CI 1464–6547) Mountain Plovers during 2019–2020, with the greatest abundances in the Southern Texas Plains and Western Gulf Coastal Plain ecoregions. The highest plover densities were in the Southern Texas Plains and Central Great Plains ecoregions. Most plovers were found in cultivated crops, particularly tilled fields and sod farms, and plovers preferentially selected crop fields without residual vegetation or stubble. Grass/hay fields were used less, perhaps because of tall vegetation. Our findings highlight the significance of Texas as a wintering area for Mountain Plovers and emphasize the importance of specific cropland habitats for this species. These results provide crucial insights for conservation and management efforts aimed at protecting Mountain Plovers throughout their annual cycle.

RESUMEN. La conservación de las aves migratorias a través del ciclo anual completo requiere una comprensión integral de la abundancia y distribución en los hábitats interconectados de reproducción, migración e invernada. El Chorlito Montañés (*Anarhynchus montanus*) es un reproductor endémico raro de las regiones de las Montañas Rocallosas y las Grandes Llanuras que migra a áreas de invernada en el suroeste de Estados Unidos y el norte de México. La información acerca de su abundancia y distribución invernal, particularmente en Texas, es limitada. Este estudio proporciona la primera estimación de la población de Chorlitos Montañeses que invernan en Texas y examina factores que influyen en su uso de la cobertura terrestre. A través de estudios de muestreos de distancias en seis ecorregiones de Texas, estimamos una población invernal anual de 3096 (IC 95% 1464–6547) Chorlitos Montañeses durante 2019–2020, con las abundancias más grandes en las ecorregiones de las Llanuras del Sur de Texas y la Llanura Costera del Oeste del Golfo. Las densidades más altas de chorlitos estuvieron en las ecorregiones de las Llanuras del Sur de Texas y las Grandes Llanuras Centrales. La mayoría de los chorlitos fueron encontrados en los cultivos, particularmente en campos cultivados y granjas de césped, y los chorlitos seleccionaron preferentemente campos de cultivo sin vegetación residual ni rastrojo. Los campos de pasto/heno se utilizaron menos, quizás debido a la vegetación alta. Nuestros hallazgos resaltan la importancia de Texas como área de invernada para los Chorlitos Montañeses y destacan la importancia de hábitats de cultivos específicos para esta especie. Estos resultados proporcionan información crucial para los esfuerzos de conservación y gestión destinados a proteger a los Chorlitos Montañeses a través de su ciclo anual.

Key Words: *agriculture; bird density; distance sampling; grassland; non-breeding; shorebirds*

INTRODUCTION

Conservation of migratory birds requires basic knowledge of abundance and distribution across the annual cycle. Considering the full annual cycle is crucial for addressing the interconnectedness of breeding, migratory, and wintering habitats that are vital to population persistence (Hostetler et al. 2015). Conservation efforts focusing solely on breeding grounds may overlook critical threats occurring during the non-breeding seasons, potentially undermining long-term viability (Martin et al. 2007). The Mountain Plover (*Anarhynchus montanus*) is an uncommon, endemic breeding bird of the Rocky Mountains and western Great Plains of North America, where it nests in grasslands, xeric shrublands, and agricultural fields; it winters in similar habitats in the southwestern United States and northern Mexico. The species is one of the rarest endemic shorebirds breeding in North America (Andres et al. 2012). Between 1966 and 2022, the Breeding Bird Survey documented a 2.5% decline per year in the Mountain Plover population (Hostetler et al. 2023). The Mountain Plover is designated as a Species of Greatest Conservation Need in Texas (Texas Parks and Wildlife 2023), a Bird of Conservation Concern in the U.S. (USFWS 2008, 2021), and a threatened species in Mexico (SEMARNAT 2002), where a conservation plan was developed for the species in the Chihuahuan Desert grasslands (de la Maza Benignos et al. 2014).

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Changes in land use, fire regimes, and the grassland herbivore community have altered the abundance, habitat use, and distribution of Mountain Plovers on both breeding and wintering areas (USFWS 1999). There is ample information about abundance and distribution from studies conducted on the breeding grounds (Dinsmore et al. 2003, 2010, Wunder et al. 2003, Dreitz et al. 2005), but contemporary knowledge from the wintering grounds is lacking, which limits our ability to provide informed conservation and management throughout the full annual cycle. Historically, the primary wintering area for Mountain Plovers has been in southern California, which was believed to support over half of the total population (Wunder and Knopf 2003, Hunting and Edson 2008). In recent years however, fewer Mountain Plovers have been found there (Audubon California 2012), and southern California now only accounts for approximately 17% of the current population estimate (Andres et al. 2012). Concurrently, information is accumulating to suggest that Texas and northern Mexico support a much greater wintering population than previously thought (Lockwood and Freeman 2004, de la Maza Benignos et al. 2014, Pierce et. al 2017; C. Shackleford, retired Texas Parks and Wildlife, 2019, *personal communication*).

Virtually all Mountain Plovers wintering in Texas occur in the southwestern part of the state (Collins 2006). Wintering habitats there are like those used on breeding grounds: heavily grazed pastures, burned fields, fallow fields, and tilled fields (Hunting et al. 2001, Knopf and Wunder 2023). In Texas, Mountain Plovers are often observed on private lands consisting of large, flat, tilled fields that have some crop stubble (Fennell 2002), irrigated agricultural fields (W. Sekula, Brooks Air Force Base, 2019, *personal communication*), coastal prairies and flats, Bermuda grass fields (Oberholser 1974), and turf farms (B. Ortego, retired Texas Parks and Wildlife, 2019, *personal communication*).

Because a quantitative survey to accurately evaluate the number of wintering Mountain Plovers in Texas is lacking, we investigated the abundance and habitat distribution of this species using distance sampling. Our objectives were to provide a statistically rigorous estimate of the wintering plover population in Texas and information on ecoregions and land cover types used by wintering plovers.

METHODS

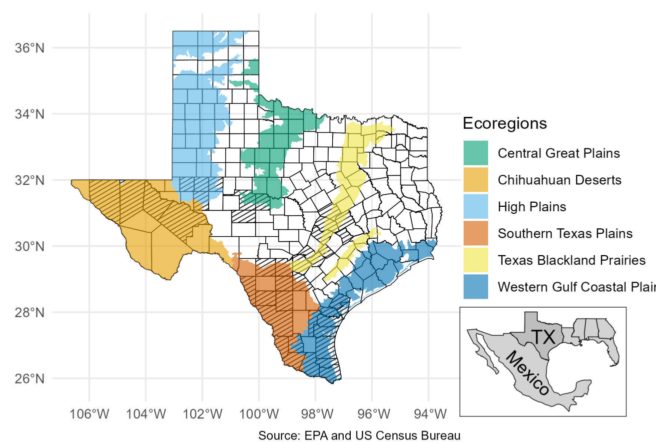
General survey approach

To estimate the annual wintering population size and assess land cover use of Mountain Plovers wintering in Texas, we conducted roadside surveys using distance sampling methods. Surveys were carried out between January and February during the winters of 2019 and 2020 in all Texas counties with recent wintering records of the species. We employed a two-stage stratified sampling approach to create road-based transects. In the first stage, we used the broad land cover classes of the National Land Cover Database (NLCD; USGS 2019) to identify Mountain Plover habitat in the counties with winter records. This stage ensured that our sampling encompassed all the likely habitats in the state, including agricultural and non-agricultural habitats. In the second stage, we used the Cropland Data Layer (USDA 2017) to further classify specific agricultural and non-agricultural habitats as suitable, marginal, or unsuitable (defined below) for Mountain Plovers. Finally, we used the amount of suitable or marginal habitat along secondary roads to create a set of road-based transects that included all known roadside habitat. During the roadside surveys, observers recorded flock sizes, distances to flocks, and habitat characteristics at regular intervals. This general approach allowed us to use an efficient survey method, line transects, to model detection probabilities and extrapolate density estimates across all known suitable habitat (along and away from roads).

Spatial sampling framework and transect selection for road-based surveys

In stage 1 of our sampling plan, we identified Texas counties with recent winter (December–February) records of Mountain Plovers, using literature (e.g., Collins 2006), GPS-tagged bird locations (Pierce 2023), local biologist interviews, and 2010–2019 eBird data. This process highlighted 41 counties, which we categorized into 6 ecoregions for stratified sampling (Fig. 1): Chihuahuan Deserts (4 counties), High Plains (4), Central Great Plains (3), Texas Blackland Prairies (10), Western Gulf Coastal Plain (10), and Southern Texas Plains (10).

Fig. 1. Texas counties with Mountain Plover (*Anarhynchus montanus*) winter records (December–February). Counties with records (diagonal lines) were identified using published literature, GPS-tagged locations, interviews with biologists, and eBird records from 2010–2019. Distance sampling surveys in January and February of 2019 and 2020 were concentrated in appropriate habitat in these counties in the 6 ecoregions shown.



We then applied a 10 × 10 km grid across these counties and selected the grid cells that were dominated (by area extent) by Mountain Plover wintering habitats using the National Land Cover Database (USGS 2019): Cultivated Crops, Pasture/Hay, and Grassland/Herbaceous. This created a sampling frame of 907 cells encompassing all known non-breeding habitat in Texas. Although the "Barren" type was excluded, we realize that small numbers of plovers (1–2 individuals) have been recorded in recent years on coastal sand and mudflats (2010–2019 eBird data).

In stage 2, we refined habitat classification using the Cropland Data Layer (USDA 2017), which further classifies agricultural landcover types, focusing on the Mountain Plover's preference for

Table 1. Sample frame used to select transects to survey for Mountain Plovers (*Anarhynchus montanus*) in Texas, United States. A 400-meter buffer was created along secondary roads in counties with known occurrence of Mountain Plovers during winter. We used the amount of suitable and marginal habitat inside the buffered area to select survey routes based on the amount of appropriate habitat. We extrapolated average bird density estimates to only suitable habitat (inside and outside the road buffer).

	Inside road buffer (km²)			Outside road buffer (km²)			
Ecoregion	Suitable	Marginal	Unsuitable	Suitable	Marginal	Unsuitable	Total
Chihuahuan Deserts	35	47	2099	248	166	19,806	22,400
High Plains	131	3	1023	511	20	4611	6300
Central Great Plains	330	2	491	684	4	990	2500
Texas Blackland Prairies	841	1122	3043	725	1014	1455	8200
Western Gulf Coastal Plain	2375	709	1688	2969	1817	2942	12,500
Southern Texas Plains	364	526	2257	1215	3465	16,173	24,000
Total	4076	2409	10,601	6351	6487	45,976	75,900

bare, tilled ground and low vegetation (Knopf and Wunder 2023). Habitats in all grid cells were categorized as suitable (corn, cotton, grains, sod, vegetable crops, fallow fields), marginal (grass/pasture, alfalfa, other hay/non-alfalfa), or unsuitable (e.g., orchards, forests, wetlands, barren). With this two-stage sampling plan, we thus selected 907 grid cells (10 × 10 km) and calculated the amount of suitable, marginal, and unsuitable habitat in each.

Within each grid cell, we identified secondary roads (USCB 2017) and buffered them by 400 m on each side to assess roadside habitats. In 2019, cells were then partitioned into 7 coverage categories, which were derived mainly from examining the distribution of percent coverages for natural breaks, reflecting the coverage of suitable and marginal habitat. The 7 categories of suitable and marginal roadside habitat included: < 0.1% (category 1), 0.1–4% (2), 4.1–8% (3), 8.1–16% (4), 16.1–24% (5), 24.1–32% (6), and > 32% (7). Within an ecoregion, we selected all grid cells from category 4 and above (> 16.1% suitable/marginal) for roadside sampling, to ensure cells with the highest amounts of suitable habitat would be included in the sample. If the total unsuitable roadside habitat summed across all cells within an ecoregion was > 70%, we then also selected cells from category 3. We also selected cells from category 2 within any ecoregion if Mountain Plovers had been recorded there previously or GPS data indicated presence. In 2020, we used the same categories but restricted the sampling to only suitable habitats because of low detection rates in marginal habitats in 2019. Note that only suitable habitat (inside and outside the buffer) was used for density extrapolations (see Table 1).

Selected transects, ranging from 3.3 to 78.4 km, were manually delineated in ArcMap10 to maximize suitable habitat coverage and driving efficiency (e.g., reduce doubling back), and to eliminate route overlap. Because of a government shutdown in 2019, which delayed our field season, we were only able to survey 62% of the selected routes; most un-surveyed routes were in the Blackland Prairies. However, we were able to survey 93% of selected routes in 2020. The survey effort metric for distance sampling is the sum of all transect lengths. Adjustments to transect length were made post-survey to reflect any deviations due to conditions encountered in the field (e.g., private road or otherwise impassable). The transects are available in a shapefile (see Data Availability).

Field methods

Selected transects (routes) were surveyed a single time by a driver-observer between 31 January and 28 February 2019 or 6 January and 13 February 2020. Observers drove the predetermined route at 32 km/hour (20 mph) searching for Mountain Plover flocks. When Mountain Plovers were encountered, observers recorded flock size, the distance to the flock by using a digital rangefinder, and the angle from road to the flock using an analog or digital compass. For the purposes of distance sampling, a flock was defined as one individual or multiple individuals < 2 m from each other and sharing the same behavior and microhabitat and moving together. Detection type was recorded as driving (i.e., detected flock on ground while driving), stopped (i.e., detected flock while stopped to record cover type data), or flyover (i.e., flock flying over transect but not landing). Observers recorded weather (cloud cover, precipitation, and wind speed) at the start and end of the route, along with starting and ending times. Observers stopped every 3.2 km (2 mi) to collect cover type data using slightly modified NLCD classes: grass/hay, crops, developed, barren, forest, shrubs, wetlands, or open water. We combined the NLCD classes grassland/herbaceous and pasture/hay into one cover class (grass/hay). At each stop we recorded (1) the dominant NLCD class within a 400-m radius on each side of the road, and (2) additional information about grass/hay or crop conditions. At stops dominated by grass/hay, we recorded a visual estimate of average vegetation height using 2 categories, low (≤ 7.6 cm) and high (> 7.6 cm). For stops dominated by cultivated crops, we recorded crop stature and condition using 4 categories: tilled (< 10% cover of new growth and ≤ 7.6 cm tall), sparse low vegetation (10–30% cover of new growth ≤ 7.6 cm tall), dense low vegetation (> 30% cover of new growth and ≤ 7.6 cm tall), or high vegetation (> 30% cover and > 7.6 cm tall). If the field was tilled or had low vegetation, we also recorded if there was residual vegetation > 7.6 cm tall present from the prior season or dead vegetation leftover after harvest/tillage (i.e., residue or stubble). Residual growth did not form a continuous vegetation layer, was scattered and irregularly distributed throughout fields, and was seldom > 30 cm. We included this measure to distinguish between bare high-disturbance fields (tilled with no residue/stubble) from those with less disturbance (tilled with stubble/residue) or none (fallow/idle fields, low vegetation with residue).

Statistical methods

To account for imperfect detection of plovers, we used conventional distance sampling to estimate plover density. This method assumes that (1) birds are distributed independently of the transect line, (2) birds directly on the line have perfect detection, (3) exact measurement of distance from the line, and (4) birds are detected at their initial location (Buckland et al. 2001). A key concept in distance sampling is the detection function, which models the decrease in detection probability as a function of distance from the transect (e.g., Appendix, Fig. A1). Once the detection function has been fitted to the observed distances, the parameter estimates of the detection function are used to estimate probability of detection and bird density. Bird density can then be extrapolated to the sampling frame for abundance estimates. To produce a population size estimate for this study, which encompasses all known habitat in Texas, we extrapolated bird density to all known suitable habitat as defined above (along and away from roads; Table 1).

We modeled detection probability using binned distances and explored histograms of the data, using a variety of distance bins, to check for violations of assumptions and find a suitable truncation point (Buckland et al. 2001). We excluded 2 detections at extreme distances (> 300 m) to improve the fit of the detection function. We pooled data across years, which allowed for a more reliable detection function to be fitted. When individual yearly datasets have small sample sizes, the detection function may not be well-calibrated because of insufficient data points, leading to unreliable or biased estimates (Buckland et al. 2001). In this 2-year study, combining years was justified because there was no strong evidence of year-to-year variation in population structure or the detection process; the number of detections, mean distance to detection, and histograms of distance data were similar for the 2 years. Combining years provides a way to maximize the use of available data and ensure that meaningful results can still be obtained. Our population estimates thus represent the average density and population size for 2019 and 2020.

We fit 4 a priori candidate models of the detection function. We restricted our candidate model set to simple models (i.e., ≤ 2 parameters) because the number of flocks we detected was small and the data would not support complicated models. Our first 2 models included key functions suggested by Buckland et al. (2001) without adjustments: a half-normal and a hazard-rate model. We also fit a half-normal detection function with flock size as a covariate because we hypothesized that flock size would influence detection probability. Our fourth model was a uniform distribution with one cosine adjustment. We used the R package "Distance" to fit the models, and we evaluated goodness-of-fit using Chi-square tests (Miller et al. 2019).

We used Akaike's information criterion adjusted for small sample sizes (AIC*c*) to select the most parsimonious model (Burnham and Anderson 2002). There was considerable model uncertainty, so we averaged density and abundance estimates using Akaike weights (Burnham and Anderson 2002) with the R package "AICcmodavg" (Mazerolle 2023). We constructed unconditional log-normal 95% confidence intervals for each averaged estimate to account for increased variance from model selection uncertainty (Buckland et al. 2001).

In addition to distance sampling analysis to estimate population size, we also evaluated land cover and habitat characteristics. We tested for differences in land cover among ecoregions using log-linear models and analysis of deviance (Crawley 2013). Specifically, we fit an interaction model (ecoregion × land cover type) and compared the fit of this model to main effects model (ecoregion + land cover type). If land cover varies among regions, the interaction model will provide a better fit to the data than the main effects model (i.e., reduced residual deviance). We examined standardized residuals to identify which land cover classes were significantly different among ecoregions. To compare flock sizes among crop condition classes (e.g., tilled vs. vegetated), we used a Kruskal-Wallis test (Zar 1984). To assess presence of residual vegetation in fields with and without Mountain Plovers, we used Fisher's exact test (Zar 1984). For these hypothesis tests, we selected an alpha level of 0.05 for Type 1 error. All analyses were conducted using the R environment for statistical computing (R Core Team 2023). The data used in this study are publicly available.

RESULTS

Density and abundance

We conducted surveys across 255 routes, covering over 8000 km (Table 2). A total of 1016 Mountain Plovers were detected, distributed across 37 flocks. Three of these flocks, which included 1 flyover and 2 sightings more than 300 m from the transect, were excluded from the distance sampling analysis. The distribution of detections included 34 individuals in the Texas Blackland Prairies, 83 in the Central Great Plains, 186 in the Western Gulf Coastal Plain, and 713 in the Southern Texas Plains (Table 2). Additionally, 3 supplementary flocks, totaling 57 plovers, were observed in the Central Great Plains outside the pre-determined survey routes. These ancillary flocks were incorporated into the habitat analysis but excluded from the distance sampling analysis. No plovers were detected in the High Plains or Chihuahuan Desert regions.

Flock size significantly influenced the probability of detection (Appendix, Fig. A1), with the half-normal model including flock size as a covariate being identified as the best model according to AIC*c* (Table 3). However, the relatively small number of detected flocks introduced some model uncertainty, as evidenced by 3 models having a weight of ≥ 0.18. Nonetheless, none of the candidate models exhibited a lack of fit (Chi-square test P-values ranged from 0.63 to 0.98), allowing us to apply model averaging for estimates of detection probability, density, and abundance.

We estimated the total population across the 6 ecoregions to be 3096 individuals (95% CI: 1464–6547), with 2176 (95% CI: 871–5439) located in the Southern Texas Plains (Table 4). The highest plover densities were observed in the Southern Texas Plains and Central Great Plains (Table 4). The model-averaged probability of detection was 0.66 (95% CI: 0.47–0.93).

Habitat use and landscape composition

Using all on- and off-route observations except the flyover flock, we detected 1065 Mountain Plovers in 39 flocks. Virtually all detections were in cultivated crops (1043 [98%] individuals in 38 [97%] flocks). Approximately 40% of all individuals detected were at sod farms. Only a single flock of 22 plovers was detected in land cover other than cultivated crops; these birds were in a wet grass/hay pasture with short vegetation (< 7.6 cm). When found in cultivated crops, plovers seemed to prefer recently tilled fields and dense, low croplands (e.g., sod farms and other cultivated crops). Of 1043 plovers in 38 flocks that we detected in cultivated crops, 466 (45%) individual plovers in 24 (63%) flocks were in tilled fields. Another 483 (46%) individuals in 8 (21%) flocks were in fields with dense, low vegetation (6 of these 8 flocks were at

Table 2. Survey effort to determine Mountain Plover (*Anarhynchus montanus*) density and abundance in 6 ecoregions of Texas, United States, 2019– 2020. We used distance sampling along road-based transects in appropriate habitat. Number of road-based transects (n [routes]) and total length surveyed (L) indicate survey effort. Numbers of flocks (n [flocks]) and birds (n [birds]) detected reflect encounter rate in each ecoregion. Mean and standard error (SE) of flock size were calculated using model averaging from the models in Table 3.

Ecoregion	*n* (routes)	*L* (km)	*n* (flocks)	*n* (birds)	Mean flock size	SE
Chihuahuan Deserts	2	44.9	0	0	-	-
High Plains	6	247.1	0	0	-	-
Central Great Plains	15	559.4	6	83	11.4	5.8
Texas Blackland Prairies	74	1987.5	2	34	16.5	3.5
Western Gulf Coastal Plain	125	4293.4	11	186	11.9	10.3
Southern Texas Plains	33	915.6	18	713	37.5	13.9
Total	255	8047.8	37	1016	22.6	8.4

Table 3. The best-supported model for Mountain Plover (*Anarhynchus montanus*) probability of detection in Texas, United States included flock size as a covariate (half normal function). There was considerable model uncertainty, however. Other competitive models (model weight ≥18%) were half-normal without the flock size covariate and a uniform distribution with a cosine adjustment. Density and abundance estimates were averaged using the Akaike's information criterion adjusted for small sample sizes (AICc) model weights. Minimum AICc was 96.69.

Model	df	log L	ΔAIC*c*	Density (birds km^{-2})	CV	Model weight
Half normal + flock size	2	- 46.15	0	0.26	0.34	0.52
Half normal	1	- 48.15	1.73	0.34	0.39	0.22
Uniform + cosine	1	- 48.32	2.07	0.35	0.38	0.18
Hazard rate	2	- 47.99	3.68	0.30	0.37	0.08

sod farms). The remainder, 9% of all individuals and 15% of all flocks, were in fields with sparse, low vegetation. Again, there was an association with sod farms: 2 of the 6 flocks detected on sparse, low stature croplands were on fields where sod had been recently harvested. Flocks were generally larger on dense, low stature croplands (e.g., sod farms; Kruskal-Wallis $\chi^2 = 8.4$, df = 2, $P = 0.014$; Fig. 2) In all crops combined, 850 (96%) plovers in 28 (90%) flocks used fields without residual vegetation (i.e., residue, stubble; 7 flocks lacked data on residual vegetation). Given the amount of residual vegetation in crop fields throughout the study area (see below), plovers preferentially selected crop fields without residual vegetation (Fisher's exact test, odds ratio = 5.2, 95% CI = [1.5, 27.3], $P = 0.003$).

Systematic stops along the routes were dominated by cultivated crops and grass/hay, although landcover composition varied among the 6 ecoregions (Fig. 3; analysis of deviance, residual deviance = 1441.6, df = 15, $P < 0.001$). Routes in the Western Gulf Coastal Plain (WGCP) and the Central Great Plains (CGPL) had more cultivated crops than other ecoregions, whereas the Texas Blackland Prairies (BLPR) and Southern Texas Plains (SOPL) had less. Conversely, the WGCP and CGPL had less cover of grass/hay, and the BLPR and SOPL more grass/hay than other regions. The SOPL had more shrub cover than other ecoregions (Fig. 3).

At systematic stops classified as cultivated crops, 75% were tilled, 18% were tall vegetation (> 7.6 cm), 5% were sparse low vegetation (< 7.6 cm), and only 2% were dense low vegetation. Less than half (44%) of all cultivated crop fields had residual vegetation. Fields in the WGCP, however, had less residual vegetation (29% of fields) than other ecoregions. The percentage of fields with residual vegetation in the CGPL, BLPR, and SOPL ranged from 68 to 78%. At systematic stops classified as grass/hay, vegetation height was generally too tall for Mountain Plovers; 86% of grass/hay stops were > 7.6 cm. In the CGPL, BLPR, and WGCP ecoregions, where most of the grass/hay occurred, the percentage of tall vegetation (> 7.6 cm) ranged from 78 to 92%.

DISCUSSION

We provide the first estimate of Mountain Plover abundance for Texas, a key part of the non-breeding range, and describe factors influencing cropland and grassland habitat use. Our results indicate that > 3000 plovers wintered in Texas during 2019–2020. This large concentration of plovers demonstrates the importance of the region for this species. The current population size estimate for the Mountain Plover is about 18,000 birds (Andres et al. 2012). Our results therefore suggest that about 17% of the population wintered in Texas in 2019–2020. Similarly, surveys in southern California indicate a minimum wintering population of 3500 plovers (Audubon California 2012); 89% of plover observations there were made in the historical wintering area of the Imperial Valley (Wunder and Knopf 2003). Farther south in Mexico, Macias-Duarte and Panjabi (2010) estimated a population of 8200 Mountain Plovers wintering in the Chihuahuan Desert. Therefore, these 3 regions likely support most (82%) of the wintering population of Mountain Plovers, with smaller numbers occurring in southern Arizona and New Mexico and northwestern Mexico (Andres and Stone 2010, Macias-Duarte and Panjabi 2010). We acknowledge that small numbers of Mountain Plovers may use coastal habitat within our survey area and other counties along the Gulf of Mexico Coast. Although we did not record any plovers on the 2 routes in the Chihuahuan Desert, small numbers of plovers have been irregularly observed in agricultural areas and prairie dog colonies in this ecoregion. Most of the Chihuahuan Desert ecoregion in Texas is shrublands (95%, USDA 2017). The general spatial distribution of our Mountain Plover detections in Texas generally followed the patterns described by B. Holliday in Collins (2006), although our results emphasized the importance of sites in the Southern Texas

Table 4. Mountain Plover (*Anarhynchus montanus*) estimated density and abundance in 6 Texas ecoregions, United States, 2019–2020. Density (D) and abundance (N) are model-averaged estimates from the distance sampling models in Table 3. CI = confidence intervals, SE = standard error, and CV = coefficient of variation. No plovers were detected in Chihuahuan Deserts or High Plains ecoregions. "–" indicates no data.

Ecoregion	Density (birds km^{-2})				Abundance		
	D	SE(D)	95% CI	CV	*N*	SE(N)	95% CI
Chihuahuan Deserts	0	-	-	-	0	-	-
High Plains	0	-	-	-	0	-	-
Central Great Plains	0.35	0.25	(0.10–1.23)	0.71	353	253	(100–1245)
Texas Blackland Prairies	0.04	0.03	(0.01–0.15)	0.75	62	47	(17–230)
Western Gulf Coastal Plain	0.09	0.07	(0.03–0.34)	0.72	505	366	(141–1803)
Southern Texas Plains	1.38	0.68	(0.55–3.44)	0.49	2176	1075	(871–5439)
Total	0.30	0.12	(0.14–0.63)	0.40	3096	1227	(1464–6547)

Fig. 2. Average winter flock size (and 95% confidence interval) of Mountain Plovers (*Anarhynchus montanus*) observed in cultivated crops in Texas, 2019–2020. Sample size (n = number of flocks detected) was 24, 6, and 8 flocks in tilled, low-sparse cover, and low-dense cover, respectively. One additional flock (22 birds) was detected in grass/hay (not shown).

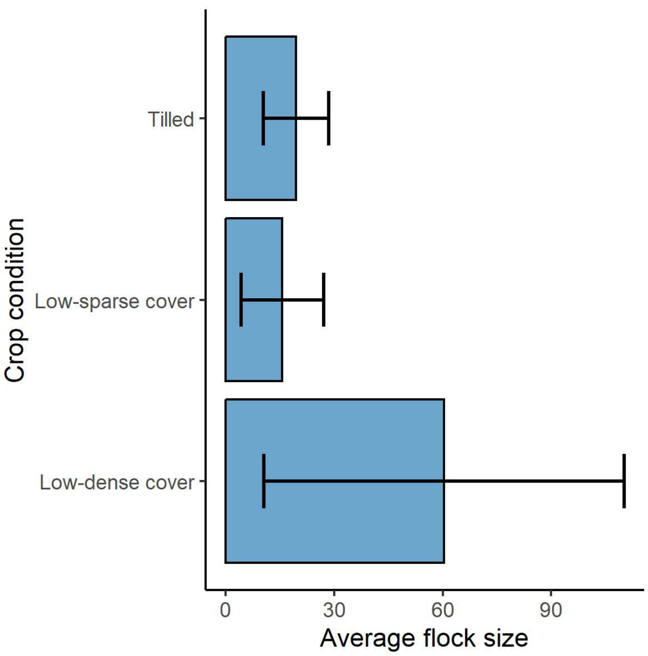
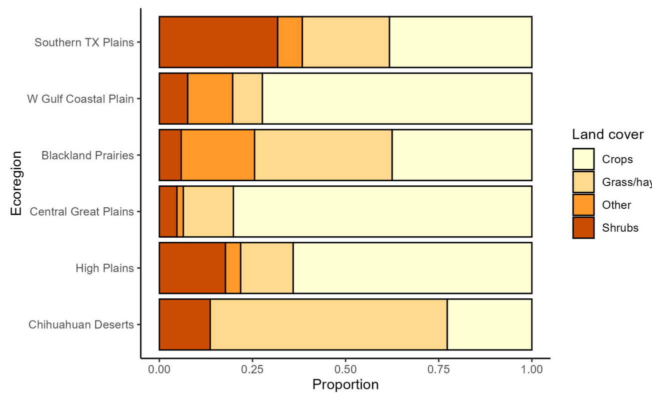


Fig. 3. Land cover types recorded at systematic stops (n = 3,475) made by observers along road-based transects in Texas, United States, 2019–2020. Sample sizes: Chihuahuan Deserts, n = 11 stops; High Plains, n = 111; Central Great Plains, n = 238; Texas Blackland Prairies, n = 913; Western Gulf Coastal Plain, n = 1792; and Southern Texas Plains, n = 410. "Other" category includes developed land, forest, open water, emergent and woody wetlands, and barren land.



Plains and the Central Great Plains. High densities in these 2 ecoregions may relate to the patchiness of suitable crop fields in landscapes with a high proportion of shrublands (USDA 2017).

Average flock size was highest on dense low croplands, mainly sod farms, and on tilled fields. In tilled fields, we detected most flocks in fields that lacked post-harvest crop residue (i.e., stubble). Late-autumn disking to reduce stubble, without exacerbating soil loss, could enhance the fields for plovers during winter (Wunder and Knopf 2003). Disking reduces the amount of residual standing vegetation and increases invertebrate biomass (Robel et al. 1996). Our impression that plovers preferred large, finely tilled fields with minimal disturbance from traffic concurs with the observations of cropland use made by Fennell (2002) around Granger, Texas. Our results also corroborated past observations of Mountain Plover's propensity for bare ground, short vegetation, and a flat topography (Knopf and Miller 1994, Beauvais and Smith 2003). A number of fields where plovers were detected were either newly sprouting wheat or sod farms, especially those that were being irrigated. Across all counties and ecoregions, the use of sod farms and grain and vegetable crop fields is emphasized, given that these comprised only 2.2% of the land cover: the highest percentages were in the Central Great Plains, Texas Blackland Prairies, and Southern Texas Plains. Recent land use changes in the Texas Blackland Prairies, including development and other habitat conversion, have likely reduced field size and use of the region by Mountain Plovers compared to previous years (e.g., Collins 2006).

Vegetation height was too tall for Mountain Plovers in most grass/hay fields that we surveyed in Texas. We had one observation in grass/hay fields, a flock of 22 plovers on a heavily grazed, wet pasture. Wintering Mountain plovers prefer low, sparse vegetation approximately 2–4 cm tall (Knopf and Miller 1994, Merayo García 2024). Although Mountain Plovers overwintering in California spend about 65% of their time on tilled fields, they also use heavily grazed annual grasslands and burned fields (Knopf and Rupert 1995, Wunder and Knopf 2003); at 2 sites in California, plovers preferred heavily grazed, native rangelands (Knopf and Rupert 1995). In northern Mexico, high densities of Mountain Plovers (21 km^{-2}) occurred on prairie dog colonies, and plovers have been observed in overgrazed pastures (Macias-Duarte and Panjabi 2010). Aldabe et al. (2019) found that vegetation height in managed grasslands was a primary driver of occurrence and abundance of American Golden-Plovers (*Pluvialis dominica*) during winter; probability of occurrence was relatively high when grass height was 2–5 cm; occurrence was much lower when grass height was > 10 cm (Aldabe et al. 2019). Heavily grazed pastures and recently burned grasslands could provide habitats for Mountain Plovers wintering in Texas (Colwell and Dodd 1997, Wunder and Knopf 2003, Aldabe et al. 2019, Shaffer et al. 2019, Knopf and Wunder 2023).

Our results confirm that Texas supports an important wintering population of Mountain Plovers. Although density and population estimates had relatively high coefficients of variation, our results will help reduce variability in the development of future studies. For example, multiple visits to fields that provide ideal conditions for Mountain Plovers (e.g., finely tilled fields with little residual vegetation, sod farms, irrigated croplands) may increase detections. Furthermore, our study was limited to public roads, which may have precluded detection of plovers using large tracts of private inaccessible rangelands. Securing access to survey these areas, particularly large rangelands, could increase detection of flocks and better inform habitat use preferences. Movement patterns of Mountain Plovers during winter may make it difficult to increase the number of detections, however. Opportunistic re-visits during our study to fields where plovers had been detected indicated lack of consistent use within and among days in our study. Data ascertained from GPS-tagged individuals in southwestern Texas indicated mean daily movements of 3.5 km ranging up to 300 km (Pierce 2023). In a telemetry study of Mountain Plovers wintering in California, Knopf and Rupert (1995) observed highly variable movement patterns; birds tended to stay in one area for a few days and then move to another area. Given the results of these tracking studies, there is a potential for movements to result in double counting and biased estimates; given the vast amount of habitat available, the risk of double counting appears minimal, but this assumption is difficult to test. A tracking study to better understand Mountain Plover movement and activity patterns during winter could help us test this and other assumptions and improve future study design.

Our study advances the understanding of Mountain Plover distribution and habitat preferences during the non-breeding season, providing the first population estimate for this species in its Texas wintering grounds. We also elucidate factors influencing land cover use, showing a strong association with cultivated crops, particularly tilled fields and sod farms, which emerge as preferred habitats. Fine-scale habitat features, such as crop residue and vegetation height, play a crucial role in shaping habitat suitability for this species and other grassland shorebirds (Knopf and Rupert 1995, Wunder and Knopf 2003, Aldabe et al. 2019). These findings have significant conservation implications, suggesting that management practices like late autumn disking to reduce residual vegetation without increasing soil loss, grazing, and prescribed fire could improve wintering habitats. Further research into specific field conditions required by Mountain Plovers in winter will help inform conservation strategies in Texas. Additionally, our study emphasizes the importance of full annual cycle assessments (Martin et al. 2007, Hostetler et al. 2015) to effectively conserve migratory species like the Mountain Plover. Although extensive research exists for the breeding grounds (see Dinsmore et al. 2010 and references therein), limited information on the wintering areas hinders comprehensive conservation efforts for Mountain Plovers across their life cycle. Few studies have employed distance sampling or other methods to estimate density and population size in wintering habitats. Addressing this gap and further research on agricultural practices and habitat requirements in winter will enhance conservation efforts, ensuring the species' long-term viability.

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Data Availability:

Original data collected during this study are available from the USGS ScienceBase-Catalog at: Lyons, J. E., B. A. Andres, A. K. Pierce, and K. L. Stone. 2023. Mountain Plover population and habitat assessments in Texas, 2019–2020. U.S. Geological Survey data release, https://doi.org/10.5066/P9Y7ZH24.

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Appendix

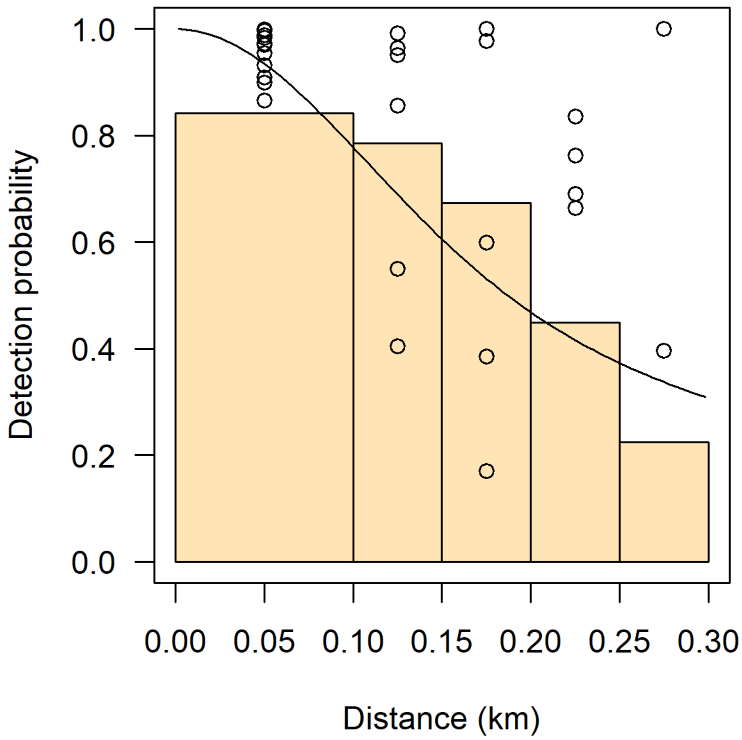

Figure A1. Detection function from the half-normal model with Mountain Plover flock size as a covariate ("Half normal + flock size" in Table 3). The x-axis is perpendicular distance of flocks from the transect. The open circles reflect variation in probability of detection, which is a function of flock size and distance. This model and the other models in Table 3 were averaged using model weights for overall density and abundance.