Survey of Free-Ranging Horses (*Equus caballus*) on the Navajo Nation in 2025
Final Report

Prepared for:
Navajo Nation Department of Fish and Wildlife
Post Office Box 1480
Window Rock, Arizona 86515

Prepared by:
Ryan Nielson, Megan Ruehmann, and Dale Stahlecker
Eagle Environmental, Inc.
30 Fonda Road, Santa Fe, New Mexico 87508

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RECOMMENDED CITATION

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ABSTRACT

Free-ranging, feral horses (*Equus caballus*) occur throughout the arid regions of western North America. Effective management of feral horses requires reliable knowledge of the sizes and locations of herds in an area. In 2016, Navajo Nation Department of Fish and Wildlife contracted Eagle Environmental, Inc. (EEI) to conduct the first systematic survey and density estimate for free-ranging horses on the Navajo Nation. The 67,089-km^2 study area was defined by the external boundary of the contiguous Navajo Nation, excluding the Reservation of the Hopi Tribe and Grand Canyon National Park Special Flight Rules Area. We stratified the study area by forest cover and used a double-observer distance sampling protocol to produce estimates of horse abundance corrected for detection bias in both forested and open areas. From July 24 to August 3, 2016, we used a fixed-wing aircraft to survey a systematic random sample of 89 transects across the Navajo Nation with a total length of 4,975 km. The Nation again contracted EEI to quantify the horse population nation-wide in 2025. We surveyed the same transects from Oct 8 to Oct 20, 2025; this time a total of 91 transects and 4,998 km were surveyed but we limited the survey area width to 1,000 m (1,500 m in 2016). We observed 2,660 horses across 416 groups. The average group size in forested and open habitats was 4.82 (n = 154; range: 1–15) and 7.22 (n = 310; range: 1–46), respectively. We estimated a total of 36,291 horses of all ages occurred within the study area during the survey period (90% CI: 29,208 to 44,733), including 28,759 horses in open areas (90% CI: 22,178 to 36,386) and 7,532 horses in forested areas (90% CI: 5,488 to 11,801). We estimated horse density was 0.606 horses/km^2 in open areas (90% CI: 0.467–0.767) and 0.384 horses/km^2 in forested areas (90% CI: 0.280–0.601; Table 3) during the study period. In comparison, estimated total abundance during the 2016 survey was 38,223 free-ranging horses

INTRODUCTION

All free-ranging horses currently populating the continent are untamed animals of domestic stock. In March 2025, an estimated 53,797 feral horses occupied 119,478 km^2 of rangeland managed by the Bureau of Land Management (BLM) across 10 western states (BLM 2026). The physiology and behavior of horses make them less selective grazers than other ungulates and domestic livestock (Beever 2003). As a result, feral horses graze rangeland more intensively than other species, which can reduce forage available to native wildlife and domestic livestock, decrease vegetation amount and diversity, and impair water quality (Beever and Brussard 2000). Concerns about unregulated commercial use of feral horses led to the implementation of the Wild and Free-Roaming Horses and Burros Act of 1971 (Pub.L. 92–195), which established protections and population targets for feral horses and burros on lands managed by the U.S. Government. However, these regulations and associated population monitoring mandates do not apply to tribal lands, where relatively little is known about current abundance and management of feral horses.

Management and oversight of grazing permits have gradually been transferred from the BIA to the Navajo Nation Department of Agriculture (NNDA), and efforts to codify legal authority under a Navajo Rangeland Improvement Act initiated in the 1990s have yet to be accomplished. In the 2020 U.S. census, the official count of the Dine' was 165,158 on Trust lands and/or off Trust but adjacent lands (U.S. Census Bureau 2026) and fewer than 8,000 (<3%) holding grazing permits (NNDA, unpublished data). Tally counts are compiled from reports by permittees to the elected members of local Livestock and Grazing Boards and are intended be a complete census of permitted livestock on the Navajo Nation. While tally counts provide a minimum number of livestock grazing on the Navajo Nation, they do not address feral livestock, including horses and burros.

Objectives

In response to ongoing environmental impacts of feral horse populations and recent concerns about potential increases in their abundance, the BIA and Navajo Nation Department of Fish and Wildlife (NNDFW) contracted Eagle Environmental, Inc. in 2016 to conduct the first systematic survey of free-ranging horses on the Navajo Nation (Wallace et al. 2020). Our objective in 2025 was to repeat the survey to produce estimates of horse abundance for comparison to the estimates from 2016. In addition, we sought to produce a map of free-ranging horse abundance across the study area and estimates of abundance within 5 BIA Agency boundaries.

METHODS

Study Area

Our study area was defined by the external boundary of the contiguous Navajo Nation, excluding the Reservation of the Hopi Tribe and Grand Canyon National Park Special Flight Rules Area (Figure 1). This 67,089-km^2 area contained diverse vegetation and topography, including extensive desert shrublands and grasslands, forested mountains and foothills, pinyon-juniper woodlands, mesas, buttes, and canyons. Elevation ranged from >3,000 m on Navajo Mountain in Arizona and the Chuska Mountains on the Arizona-New Mexico border to 830 m at the confluence of the Little Colorado and Colorado Rivers on the western boundary of the Navajo Nation with Grand Canyon National Park. Annual precipitation in this region averages 25.4 cm (Western Regional Climate Center 2016).

Sampling Design

We conducted an aerial survey along a sample of transects using mark-recapture line transect distance sampling (Wallace et al. 2021, Laake et al. 2004). We stratified the study area in 2016 by forest cover to account for potential differences in horse density and detectability in forested and open areas. We predicted that horses in forested areas would both occur at lower densities and be more difficult for observers to see from aircraft than horses in open areas, and the results from the 2016 survey supported this prediction (Wallace et al. 2020). In 2016, we identified large, contiguous areas of forest using remotely sensed data layer of forest cover type (LANDFIRE 2013). We processed forest cover data using the following steps in a geographic information system (GIS; QGIS Development Team 2016): (1) selected all 30-m^2 cells classified as forest vegetation, (2) buffered forested cells by 1 km, (3) removed groups of adjacent cells with area <5 km^2, (4) dissolved borders of overlapping areas into larger connected polygons, (5) filled holes in polygons, and (6) removed polygons with <100 km^2 area. The resulting forested stratum consisted of 11 discrete polygons that captured 95.7% of forested cells from the vegetation data layer and covered 19,629 km^2 (29%) of the study area. All other areas were included in the open stratum, which covered the remaining 47,460 km^2 of the study area (Fig. 1). Additional transects were allocated to the forested stratum to increase precision in areas where we expected lower horse density and reduced detectability. We maintained the same stratification for the 2025 survey for consistency.

We established a systematic random sample of east-west transects across the study area, based on a grid with a random start point. The same transects were flown in both 2016 and 2025. The north-south spacing of transects was 16 km in the open stratum and 8 km in the forested stratum. This resulted in a potential sample of 91 transects totaling 4,998 km, including 2,834 km in the open stratum and 2,164 km in the forested stratum. Transects averaged 55 km in length (range: 10–100 km), depending on the shape of the Navajo Nation boundary and forested areas

(Fig. 1).

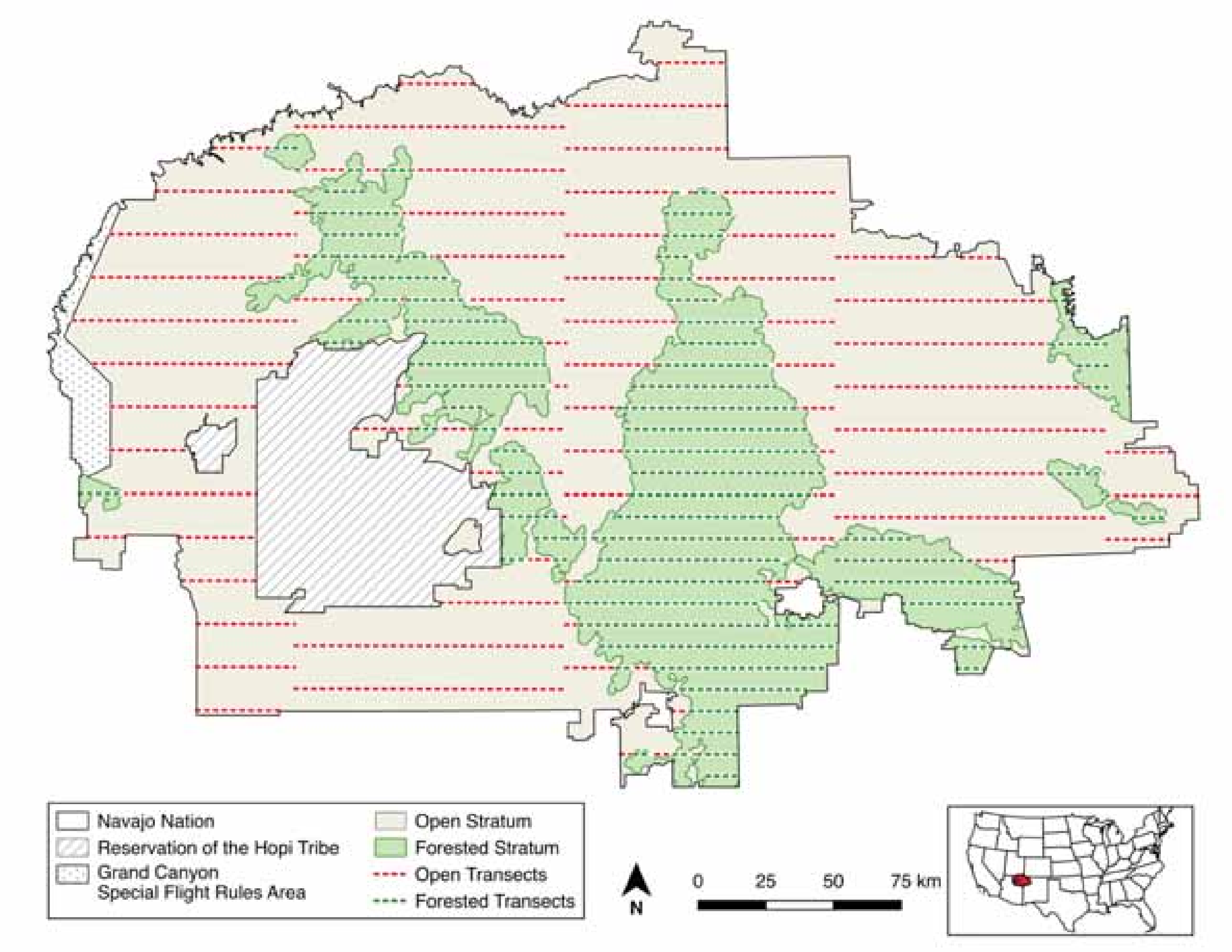

Figure 1. Study area for survey of free-ranging horses on the Navajo Nation, including forest cover strata and line transects. The inset shows the location of the Navajo Nation in the United States.

Survey Protocol

Transects were surveyed in a Cessna 205 plane, 122 m (400 ft) above ground level (AGL), traveling at approximately 100 knots (185 kph). Surveys generally began by 0730 h with a west-bound transect to avoid flying towards the rising sun and ended by 1530 h to minimize observer fatigue. With three observers, we employed a double-observer independent-observer protocol on 62 transects with two observers on the right side (front-right [FR] and back-right [BR]) and one on the left side (back-left [BL]). Observers occupied the back-left (BL) and FR seats on the remaining 29 transects. On double-observer transects, the FR and BR observers independently recorded sightings of horse groups on the right side of the aircraft. To ensure independence between observers, a cardboard partition separated the front-right and back-right seats, and observers on the right side waited several seconds before announcing detections. This allowed both observers to independently detect or not detect each horse group. The BL observer independently recorded sightings on the left side of the aircraft on all transects and was not part of the double-observer trials. Observer positions were randomly assigned each day to prevent confounding observer skill with seat position.

We used an on-board global positioning system (GPS) to follow survey routes and record flight tracks. For each horse group detected, we recorded which observer(s) made the detection, a GPS waypoint where the group was first seen, the number of horses in the group, estimated distance of the group from the transect line and from the nearest occupied dwelling, and habitat type. Observations were truncated at a left distance of 44 m (directly below the aircraft), and observers attempted to focus their efforts within ~1,000 m, yielding an effective strip half-width of 956 m. We narrowed the transect search width from 1,500 m in 2016 to 1,000 m in 2025 to reduce fuel, observer fatigue, risk of running wildlife or livestock, and risk of double-counting horse groups.

At the request of NNDFW, we counted all horses that were not inside a corral or fenced pasture, including those near dwellings. Upon completing the survey, we used GIS software to measure the perpendicular distance of each horse group from the transect line using GPS waypoint locations and survey flight tracks.

Statistical Analysis

Our approach to estimating horse abundance for the 2025 aerial surveys differed slightly from that used for the 2016 survey (Wallace et al. 2021). The reasoning was that we desired estimates of horse abundance at the agency level and a predictive map of abundance across the study area. These objectives were most efficiently met using a density surface model (DSM; Hedley and Buckland 2004, Miller et al. 2013). In addition, the distribution of detection distances peaked near the transect line in 2025 rather than some distance from it, as observed in the 2016 survey (~500 m; Wallace et al. 2021). This difference is most likely due to the shortening of the search width from 1,500 m to 1,000 m (see Discussion).

We estimated detection probability (p) using mark-recapture distance sampling (MRDS; Laake and Borchers 2004, Burt et al. 2014) implemented in the mrds package (Laake et al. 2024) in R (R Core Team 2025). The MRDS framework combines a distance sampling (DS) component, which models the decline in detection probability with distance from the transect line, with a mark-recapture (MR) component, which estimates the conditional probability that each observer detects a group given that it was detected by the other observer. This hybrid approach relaxes the assumption of certain detection on the transect line ($g(0) = 1$) that is required in conventional distance sampling (Borchers et al. 2006, Burt et al. 2014).

The DS component uses a baseline key function to fit the distribution of detection distances (Buckland et al. 2001). We considered the half-normal, hazard-rate, and uniform key functions. The goodness of fit of key functions can be improved using expansion terms (e.g., cosine, simple polynomial; Buckland et al. 2001) or making them functions of covariates like strata (Forest/Open). We fit all three key functions with and without cosine and polynomial expansion terms and covariates for habitat, the log of the horse group size, and an indicator for whether the observation was of a lone horse or a group. We used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) and visual comparison of the histogram of observed distances and the DS model fit to the data to select the best model.

The MR component was modeled using a logistic regression (independent-observer configuration; Laake and Borchers 2004). We compared 11 candidate MR models, each incorporating combinations of log group size, lone horse, habitat, observer identity, and distance from the transect line as covariates on the conditional detection probability. Observed horse group sizes differed by habitat type, so log group size, lone horse, and habitat were not allowed in the same MR models. Candidate detection function models were compared using AIC, and goodness-of-fit was assessed using chi-square (X^2; Buckland et al. 2001) and Cramér-von Mises (W^2; Buckland et al. 2001, 2015) tests on the distance sampling component. Goodness-of-fit was assessed for the MR component using chi-square.

Estimation of Total Horse Abundance

We estimated total abundance using a Horvitz-Thompson (HT) estimator post-stratified by habitat type (Thompson 2012). We computed abundance directly as

$$\hat{D}_h = (1 / (2 \times w\_eff \times L_h)) \times \Sigma\, (s_i / \hat{p}_i),$$

where $\hat{D}_h$ is the estimated density in habitat stratum h, $w\_eff = w_2 - w_1 = 956$ m was the effective strip half-width, L_h was total transect effort (m) within stratum h, s_i was the group size of observation i, and $\hat{p}_i$ was the estimated detection probability for observation i. Stratum-level abundance was obtained as $\hat{N}_h = \hat{D}_h \times A_h$, where A_h is the area (m^2) of stratum h. Total abundance was the sum across strata: $\hat{N}_{total} = \Sigma\ \hat{N}_h$.

We estimated confidence intervals using a nonparametric bootstrap with 9,999 iterations. In each iteration, whole transects were resampled with replacement (preserving within-transect correlation), the detection function was refitted using the same model specification, and the post-stratified HT estimator was recomputed. We report percentile confidence intervals for model parameters and Bias-corrected and Accelerated confidence intervals (BCa; Efron 1987) for estimates of densities and total abundance at the 90% level. The BCa acceleration constant was estimated from a leave-one-transect-out jackknife (Efron and Tibshirani 1993). The BCa method is often preferred when the data is skewed, or the distribution is non-normal.

Density Surface Modeling

To estimate the spatial distribution of horse abundance and produce agency-level estimates, we fit a density surface model (DSM; Hedley and Buckland 2004, Miller et al. 2013) to the observed horse groups inflated by their probability of detection. DSMs are a two-stage approach: the first stage estimates detection probability using MRDS methods (described above), and the second stage models the spatial variation in detection-adjusted encounter rates using a generalized additive model (GAM; Wood 2017). In this second stage, we divided the transects into approximately 1 km segments, and each horse group observation was assigned to its nearest segment. Horvitz-Thompson-adjusted counts ($\Sigma\ s_i / \hat{p}_i$ within each segment) served as the response variable, with log (segment area) as an offset to model density on the per-unit-area scale. The DSM was fit as a Tweedie GAM using the mgcv package (Wood 2017) in R, with restricted maximum likelihood (REML) used for smoothness selection. The spatial smooth was fit using a thin-plate regression spline ($k = 300$). The effective complexity of the fitted surface was automatically determined by REML penalization, which balances goodness of fit with overfitting. We used the Tweedie response distribution because it accounts for the continuous HT-adjusted abundance estimates and models the mean-variance relationship through an estimated power parameter (Miller et al. 2013).

We evaluated candidate spatial covariates, including habitat type (Forest/Open), GAP land cover classes (USGS 2024), elevation, cosine of aspect, terrain ruggedness, distance to nearest road, percent tree canopy cover (NLCD Tree Canopy Cover; MRLC 2023), distance to nearest water source (lake, stream, spring), and distance to nearest windmill. All covariates were extracted from raster layers at segment midpoints. A two-dimensional thin-plate regression spline on the UTM coordinates s(x, y) was included in all models to capture spatial autocorrelation.

Model selection was conducted using spatially blocked 10-fold cross-validation to evaluate predictive performance. Transects were grouped into 10 spatial folds using k-means clustering on transect centroids, ensuring that held-out data were spatially separated from training data to prevent the spatial smooth from exploiting spatial proximity during prediction. Models were compared using mean predictive Tweedie deviance across folds. Covariates were evaluated in a structured sequence: (1) vegetation classification (habitat alone, GAP classes alone, or both were compared with the spatial smooth), (2) addition of ecological covariates (distance to stream, canopy cover, ruggedness), and (3) addition of anthropogenic covariates (distance to road, distance to windmill). We used the k-index diagnostic (Wood 2017) to assess the adequacy of the basis dimension for the Tweedie. The DSM was used to predict expected horse density across the study area at 300 m resolution for mapping purposes.

Agency-Level Estimates

Bureau of Indian Affairs agency-level abundance estimates were derived using a ratio-adjustment approach that combines the spatial information from the DSM with the design-based HT total. The DSM was used to predict expected horse density across the study area on a 300 m resolution grid. Predicted counts were summed within each of the five management agency boundaries to compute agency-level proportions ($\hat{\pi}_a = \hat{N}\_DSM_a / \hat{N}\_DSM_{total}$). Agency-level abundance was then estimated as $\hat{N}_a = \hat{\pi}_a \times \hat{N}\_HT_{total}$, ensuring that agency estimates summed exactly to the design-based total. This approach leverages the spatial modeling strengths of the DSM to allocate abundance across agencies while anchoring the total to the design-based HT estimate.

Uncertainty in agency-level estimates was quantified by combining two sources of variation: (1) uncertainty in the spatial allocation (agency proportions), estimated via posterior simulation from the GAM coefficient distribution (1,000 draws from MVN($\hat{\beta}$, $\hat{V}$_β); Wood 2017), and (2) uncertainty in the overall abundance, estimated from the HT bootstrap (described above). Posterior simulation was conducted on a 1 km resolution grid to allow construction of the full linear predictor matrix in memory; agency proportions at 1 km resolution were verified to differ by less than 1% from those at 300 m resolution. Each posterior draw of agency proportions was paired with a random draw from the bootstrap distribution of $\hat{N}_{total}$ to produce a combined distribution of agency-level abundance incorporating both sources of uncertainty. We report 80% and 90% percentile confidence intervals for each agency.

All analyses were conducted in R version 4.51 (R Core Team 2025). Detection function modeling used the mrds package (Laake et al. 2024). GAMs were fit using mgcv (Wood 2017). Spatial data processing used the sf (Pebesma 2018) and terra (Hijmans 2024) packages.

RESULTS

We surveyed 91 transects totaling 4,998 km across the Navajo Nation from October 8 to 20, 2025. We observed 2,660 horses across 416 groups (Fig. 2). The average group size in forested and open habitats was 4.82 (n = 154; range: 1–15) and 7.22 (n = 310; range: 1–46), respectively. The number of burros detected was insufficient to estimate density inside the study area. We estimated 12.5% of horse groups were ≤ 250 m from a dwelling, with larger horse groups occurring farther from dwellings. Only 15 groups (3.6%) were running when detected or ran ahead of the circling aircraft. For comparison, the locations of observed horse groups in July and August of 2016 are presented in Figure 3.

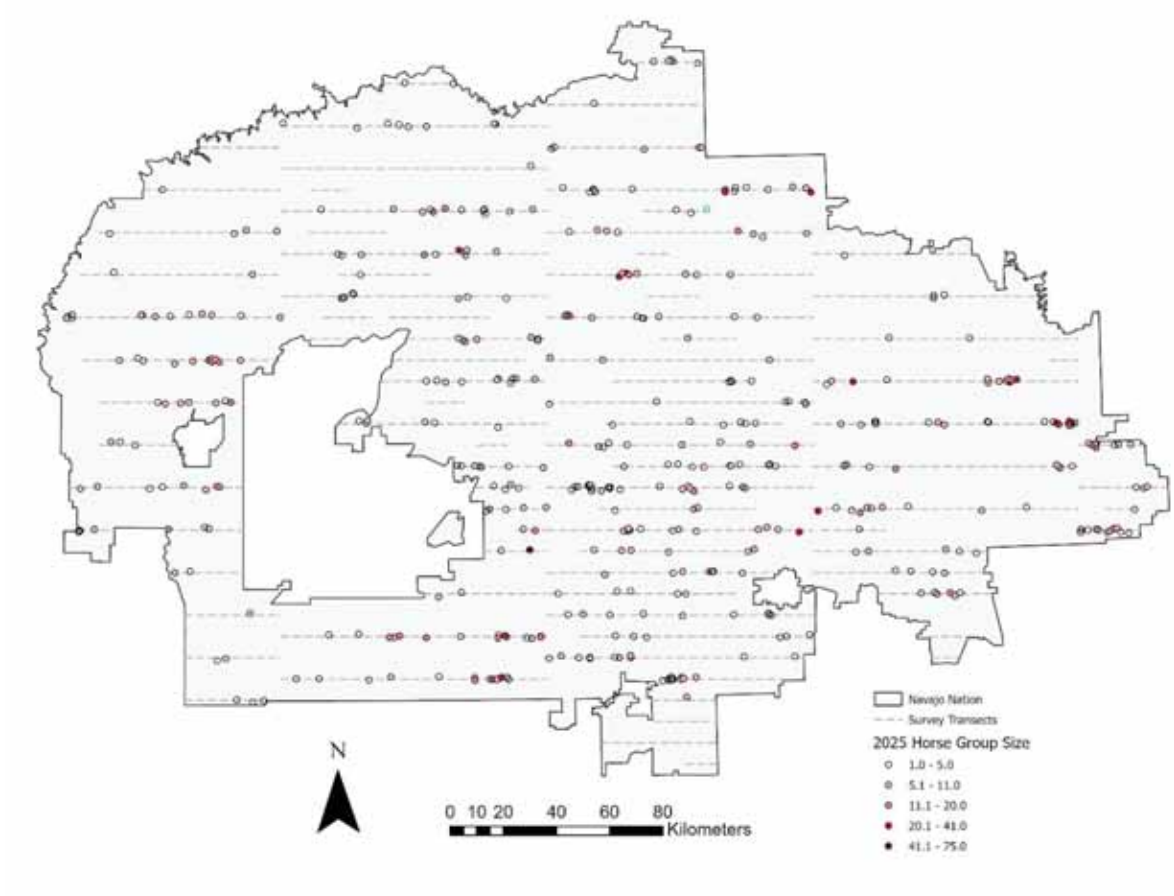

Figure 2. Locations and sizes of horse groups detected during fixed-wing aerial surveys of the Navajo Nation study area, October 2025.

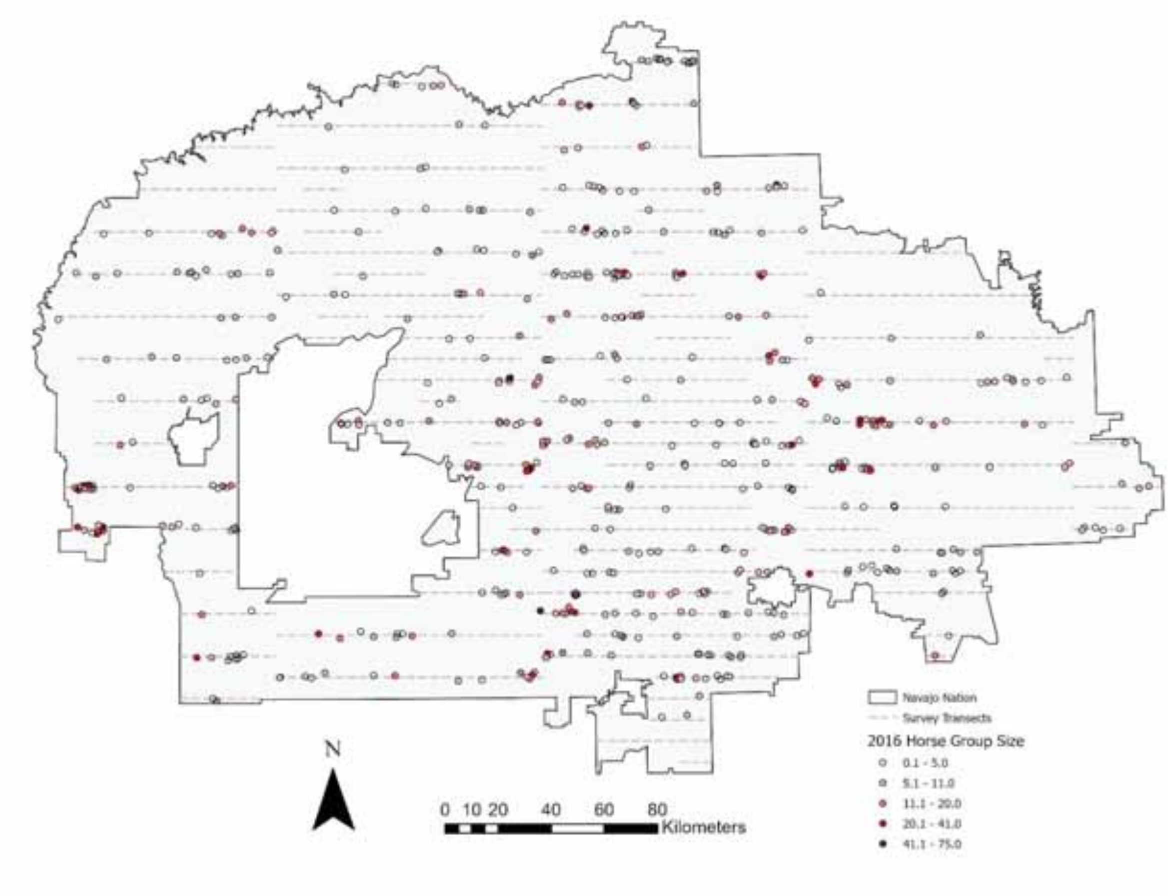

Figure 3. Locations and sizes of horse groups detected during fixed-wing aerial surveys of the Navajo Nation study area, July and August 2016.

Horse Abundance

The AIC-selected DS model was the half-normal with a covariate for strata and used habitat as a covariate on the scale of the half-normal detection function with the log of horse group size as the sole covariate on the MR component (Table A1), indicating that larger groups were more likely to be detected conditional on availability. The probability of detection was highest near the transect line and did not differ between front and rear seats. The estimated probability of detection by one observer in any position in aircraft surveying the open stratum was 0.491 (90% CI: 0.255 to 0.666; Table 1; Fig. 4) for a single horse, 0.858 for a group of 10 horses (90% CI: 00.675 to 0.901), and 0.828 (90% CI: 0.645 to 0.866) for the average group size of 7 in the open strata. The relatively small negative trend in probability of detection with distance from the transect line in open habitat reflects that for a particular group size, detection doesn't change with distance. There were fewer observations at greater distances but the model attributes that to the mark-recapture component with group size rather than distance-dependent availability. The average group size increased with distance in the open habitat (p-value = 0.06). The relatively small negative trend in probability of detection with distance from the transect line in open habitat (Fig. 4) reflects that for a particular group size, detection doesn't change with distance. However, average group size increased with distance in the open habitat (p-value = 0.06). There were fewer observations at greater distances but the model attributes that to the mark-recapture component with group size rather than distance-dependent availability. The estimated probability of detection by one observer in any position in the aircraft when surveying the forest stratum was 0.347 (90% CI: 0.191 to 0.507; Table 2; Fig. 4) for a single horse, 0.605 for a group of 10 horses (90% CI: 0.467 to 0.769), and 0.547 for the average group size of 5 in the forested strata (90% CI: 0.431 to 0.703). In the forested stratum, detections declined more rapidly with distance from the transect line compared to the open stratum.

We estimated horse density was 0.606 horses/km^2 in open areas (90% CI: 0.467–0.767) and 0.384 horses/km^2 in forested areas (90% CI: 0.280–0.601; Table 2) during the study period. We estimated a total of 36,291 horses of all ages occurred within the study area during the survey period (90% CI: 29,208 to 44,733; Coefficient of variation = 13%), including 28,759 horses in open areas (90% CI: 22,178 to 36,386) and 7,532 horses in forested areas (90% CI: 5,488 to 11,801; Table 3). Goodness-of-fit tests indicated adequate fit of both the distance sampling component ($x^2 = 9.07$, df = 7, P = 0.25; $w^2 = 0.052$, P = 0.87) and the mark-recapture component ($x^2 = 20.08$, df = 16, P = 0.22).

Wallace et al. (2020) estimated that horse densities in July 2016 were 0.619 horses/km^2 in open areas (SE: 0.116, 90% CI: 0.449–0.789, Table 2) and 0.450 horses/km^2 in forested areas (SE: 0.119, 90% CI: 0.276–0.624). Their overall estimate of horse abundance was 38,223 individuals within the study area July 24 to August 3, 2016 (SE: 6,052, 90% CI: 29,365–47,080). The estimated change in abundance on the Navajo Nation from 2016 to 2025 was a decline of ~5.3%. Based on the BLM estimates (BLM 2026), the estimated change across 10 western states (AZ, CA, CO, ID, T, NV, NM, OR, UT, WY) from 2016 to March 1, 2026, was an increase of 11.2%.

Table 1. Parameter estimates for the distance sampling (DS) and mark-recapture (MR) components in the top mark-recapture distance sampling model (lowest AIC), along with the SE, coefficient of variation (SE / Estimate), and lower and upper bounds of a 90% CI for the estimate. The log of horse group size is represented by lgs. In addition, estimates of the average probability of detection ($\bar{p}$) over forest and open strata are provided.

				90% CI	
Parameter	Estimate	SE	CV	Lower limit	Upper limit
DS Intercept	6.467	0.383	0.059	6.143	6.972
DS habitat = open	1.730	2.822	0.867	0.024	7.266
MR Intercept	-0.019	0.497	9.638	-0.912	0.729
MR lgs	0.815	0.312	0.372	0.358	1.367
$\bar{P}$ (forest)	0.478	0.074	0.156	0.369	0.617
$\bar{P}$ (open)	0.649	0.062	0.100	0.568	0.714

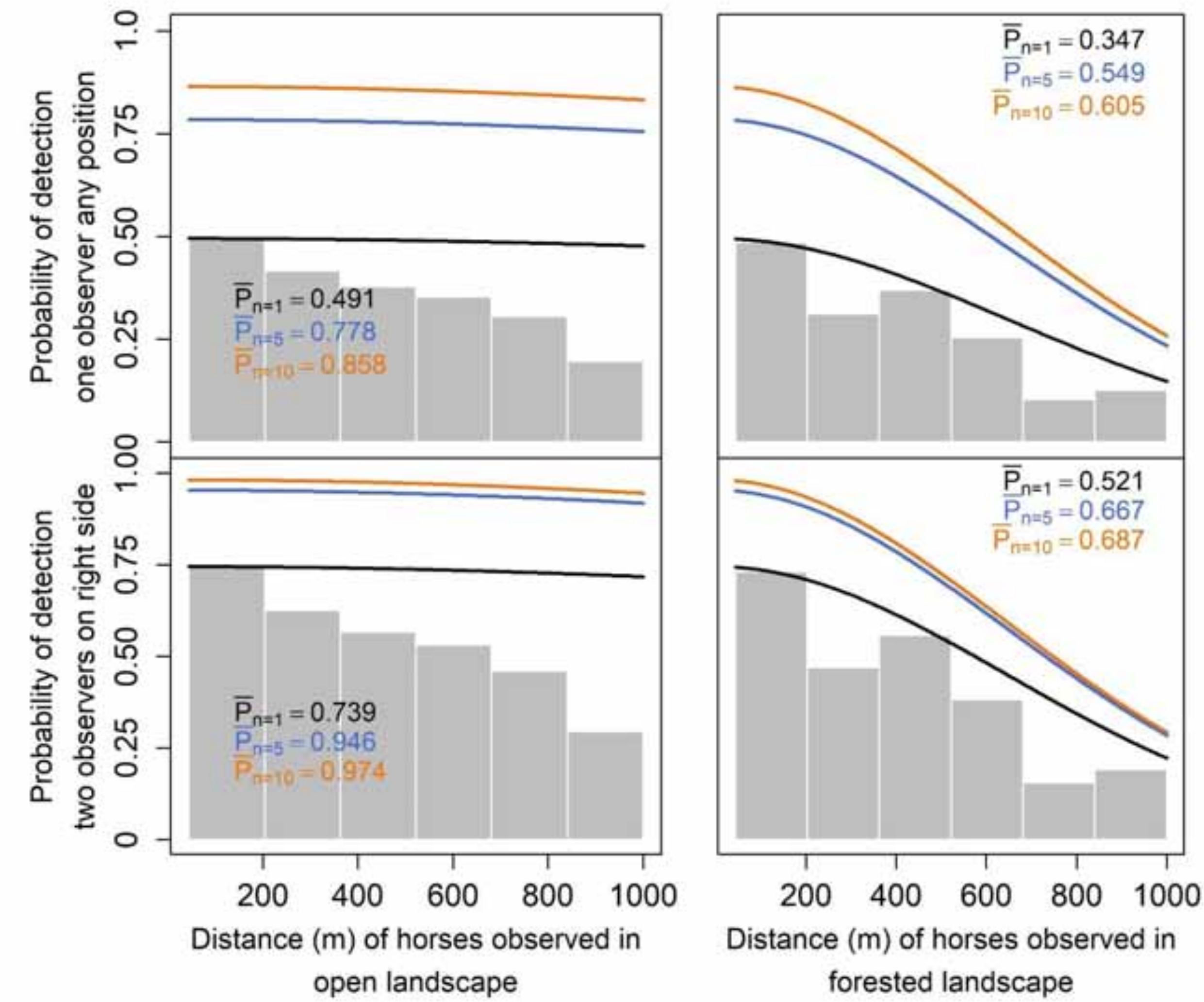

Figure 4. Probability of detection of free-ranging horses from 122 m above ground level (AGL) in open areas (left) and forested areas (right) of the Navajo Nation study area. Solid lines represent scaled detection functions for the average horse group size in each stratum and the average detection ($\overline{P}$) within 1,000 m of the transect line.

Table 2. Estimated densities and total numbers of free-ranging horses of all ages in open and forested strata of the Navajo Nation study area during surveys in 2016 (July 24 to August 3, 2016) and 2025 (October 8 to 20, 2025), with upper and lower 90% CIs.

2025	Density		Aundance	
Stratum	Estimate	90% CI	Estimate	90% CI
Open	0.606	0.467 0.767	28,759	22,178 36,386
Forested	0.384	0.280 0.601	7,532	5,488 11,801
Overall	0.540	0.440 0.670	36,291	29,208 44,733

2016	Density		Aundance	
Stratum	Estimate	90% CI	Estimate	90% CI
Open	0.619	0.789 0.449	29,394	37,460 21,328
Forested	0.450	0.624 0.276	8,829	12,240 5,417
Overall	0.570	0.702 0.438	38,223	47,080 29,365

Density Surface Model

Cross-validation selected the simplest model, comprising only the two-dimensional spatial smooth s(x, y) with no additional covariates. Environmental covariates did not improve the model's predictive accuracy beyond the spatial smooth alone. This reflects the fact that habitat and other environmental variables are themselves spatially structured — the spatial smooth implicitly captures these gradients through their geographic distribution across the study area. The k-index diagnostic (k-index = 0.71, edf = 66.1, $p < 0.01$) indicated there was a residual spatial pattern beyond what the smoothing captured. However, increasing the basis dimension from k = 300 to k = 500 did not change the k-index, indicating the residual pattern reflects fine-scale spatial clustering of horse groups rather than unresolved broad-scale spatial structure. Based on the DSM (Fig. 5), the density of horses in the five agencies ranged from 0.389 in the Western agency to 0.802 in Ft. Defiance (Table 3) and abundance ranged from 4,123 in Chinle (90% CI: 3,100 to 5,211) to 11,043 in Ft. Defiance (90% CI: 9,155 to 12,618). Approximately

1% of the predicted DSM abundance fell in areas outside the five named management agencies; these were allocated proportionally across agencies in the ratio adjustment.

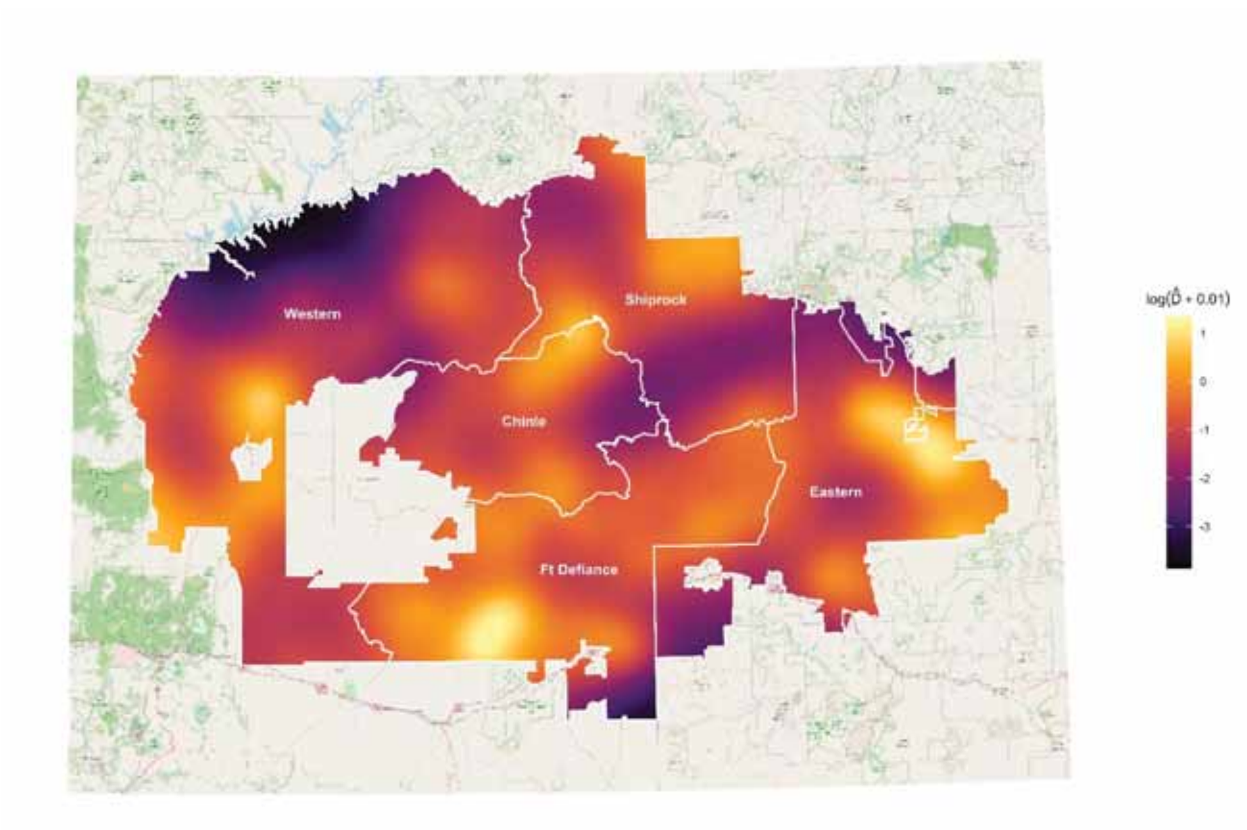

Figure 5. Predicted density surface for free-ranging horses in the study area during the survey period (October 8 to 20, 2025), represented as log(density + 1) for better visualization.

Table 3. Estimated densities and total numbers of free-ranging horses of all ages in five BIA Agencies of the Navajo Nation study area October 8 to 20, 2025, with upper and lower 90% CIs.

				Abundance	
Agency	Area (km^2)	Density	Log(density+1)	Estimate	90% CI
Chinle	7,779	0.530	0.185	4,123	3,100 5,211
Eastern	11,988	0.665	0.222	7,976	6,342 9,560
Ft. Defiance	13,771	0.802	0.256	11,043	9,155 12,618
Shiprock	11,022	0.409	0.149	4,512	3,427 6,059
Western	22,179	0.389	0.143	8,636	7,150 10,846

DISCUSSION

We conducted the second systematic survey of free-ranging horses on the Navajo Nation in October 2025, resulting in an estimate of overall horse abundance that was 5% lower than the 2016 population estimate. However, the 90 % CI for the 2025 estimated total abundance included the 2016 estimate, and vice versa, indicating we did not find a statistically significant change at the alpha level of 0.10.

The average density we estimated within study area was approximately 27% greater than the density of 0.45 horses/km^2 reported for the 119,479 km^2 of Herd Management Areas managed by the BLM across 10 western states in 2025 (BLM 2016). The current number of horses on BLM lands is more than double that agency's target Appropriate Management Level (AML), defined as "the number of wild horses … that can thrive in balance with other public land resources and uses" (BLM 2016).

We decreased the maximum distance for observation data in our analysis from 1,500 m in 2016 to 1,000 m in 2025. Decreasing the search width complicates comparisons of horse groups or average group sizes and probabilities of detection between the 2016 and 2025 surveys, but it allowed the observers more time to search for horses closer to the transect line, resulting in the probability of detection being highest near the line in 2025, whereas searching out to 1,500 m in

2016 resulted in more observations occurring about 500 m from the transect line. That change in the optimal detection distances and general shapes of the detection functions allowed us to use a semi-parametric method (half-normal detection function) rather than the non-parametric kernel density approach used by Wallace et al. (2020) to estimate the DS component. Assuming a statistical distribution over a fully non-parametric one can result in narrower confidence intervals and allow for inclusion of covariates and the use of AIC to compare models. In this case it allowed us to use a covariate for open vs forested strata in the modeling, whereas in 2016 the analysis was conducted separately for the two strata and comparisons were made post-hoc. The MR component of the detection function used the same approach (binomial regression) for both years, although in 2016 the average group size was used rather than including the log of group size in the MR model.

To alleviate any concerns that the two analysis approaches cannot produce similar estimates of abundance using the same survey data, thus precluding comparisons of total horse abundance between 2016 and 2025, we analyzed the horse detections in 2025 using the 2016 method keeping the maximum search distance at 1,000 m and using the log group size in the MR component. The estimate based on the 2016 method was 36,720 horses (90% CI: 27,996 to 50,849); nearly identical to that reported here. The CV for this modeling approach was 19%; much higher than what was obtained using the current analysis approach (13%).

Many of the assumptions behind the two statistical methods (2016 and 2025) were identical: group sizes and locations were recorded with minimal error that was non-directional (e.g., always overestimating), horse groups were not counted more than once and were spotted before movement away from the aircraft, and the two observers on the right side of the aircraft operated independently. While GPS technology allows sufficiently precise locations to be recorded, accuracy of locations is contingent on the ability of observers and pilots to identify and navigate to the point at which each group was first detected. We expect this bias was minimal in our study because horse groups are relatively easy to locate and mark. Horse density and detectability were higher in open areas than forested areas, and we accounted for these differences by stratifying the study area by forest cover. Lower horse density in forests likely reflected less suitable grazing habitat in pinyon-juniper woodlands and montane forests than open rangelands.

Estimates of abundance from distance sampling rely on the assumption that individuals within the survey strip are available to be detected. Thus, individual horses that could not have been seen by either observer due to their location in the landscape (e.g., under 100% canopy cover) are not represented in estimates of detectability or abundance. We acknowledge that any horses that were not available for detection during our survey could cause our estimates of total abundance to be lower than those from surveys using different methods or conducted at other times of the year. Given the timing of the survey in early October, we were less concerned than in July of 2016 that horses in open habitats would seek shade under trees or in canyons where they would not be available for detection. In 2025, two back-to-back weather systems dropped heavy rains on the Navajo Nation after two days of surveys, so that transects on the last nine days were surveyed while water was abundant and widespread. This may have allowed horses to be more widespread than they were in the heat of the summer of 2016.

Unlike public rangelands, where all horses unaccompanied by a person can be defined as feral, horses on the Navajo Nation represent a continuum from domestic to feral. This spectrum extends from domesticated horses that are corralled and fed, to groups of free-ranging horses that live near dwellings and may receive some supplementary feeding, to large herds distant from dwellings. On most western rangelands, a small number of large ranches control livestock grazing on extensive tracts of deeded and leased acreage. By contrast, the Navajo Nation is more continuously settled, with numerous small homesteads of tribal permittees located within grazing allotments, each of which supports an assortment of livestock that typically includes horses. Given the complexity of this situation, and to be consistent with Navajo Nation grazing regulations, NNDFW recommended we count all horses that were not in corrals, in part because stallions that are claimed and fed but free-ranging could breed with and thus contribute to the feral population. Our results should, thus, be interpreted as a point-in-time estimate of the number of uncorralled horses in the study area. Accordingly, we used the term “free ranging” for the horse population sampled by this survey and acknowledge that our estimates may have contained an unknown number of horses that were not technically feral, insofar as they were owned or supported by humans. To explore this issue, we made visual estimates of the distance of each horse group to the nearest apparently occupied dwelling. We estimated 22% of horse groups and 14% of total horses were ≤ 250 m from a dwelling when observed, with larger horse groups tending to occur farther from dwellings. While these results confirm that some free-ranging horses are associated with towns and dwellings, they confirm that most horses documented during this survey did not occur near dwellings.

If conditions (enough food and water) for horses were optimal between 2016 and 2025, it would be reasonable to expect that numbers would have increased steadily during the nine years between surveys. However, ongoing drought conditions during the past several decades significantly impacted vegetation productivity in the Navajo Nation at the forest stand scale (Yazzie et al. 2025), as well as in grassland and shrubland vegetative communities (El-Vilaly et al. 2018). Additionally, the main water sources for livestock in the region are supplied by surface water runoff (Crimmins et al. 2013) and the limitation of these sources could have dramatic impacts. In 2018, for example, 191 feral horses were found dead on the Navajo Nation after becoming trapped in mud while seeking out a water source (Scasta et al. 2022). In terms of management, the Navajo Department of Agriculture has organized horse roundups: for example, in 2024 they reported 2,456 horses were removed from Navajo Nation. Many Chapters have independently initiated roundups to control horse numbers.

The systematic random sample of transects established here could be surveyed in future years to estimate trends in free-ranging horse populations, or at other times of year to understand seasonal changes in horse abundance and distribution on the Navajo Nation. A statistical power analysis could be conducted to determine the minimum sampling effort necessary to detect a desired magnitude of trend in the population over a given period. Finally, we recommend submission of a manuscript based on this report to a refereed scientific journal. Peer review of methods and publication of results reported here would support any management actions taken by NNDFW in response to our findings.

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APPENDIX

Table A1. Mark-recapture distance sampling models for horse groups detected, along with the difference (dAIC) between the AIC value for each model and the best model (lowest AIC). The log of horse group size is represented by lgs.

Mark-recapture model covariates	AIC	dAIC
lgs	2510.90	0.00
lgs + observer	2512.10	1.19
lgs + distance	2512.56	1.66
lone	2518.02	7.12
lone + observer	2519.22	8.32
lone + distance	2519.79	8.89
null	2521.82	10.92
habitat	2522.16	11.26
observer	2523.02	12.12
habitat + observer	2523.35	12.45
distance	2523.78	12.88
habitat + observer + habitat*observer	2524.83	13.93