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

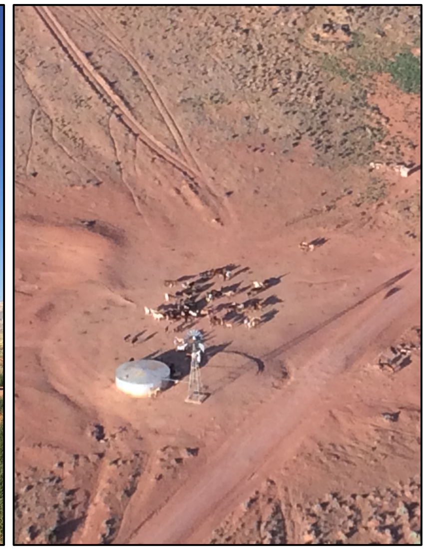

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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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 a given area. In 2016, Navajo Nation Department of Fish and Wildlife contracted Eagle Environmental, Inc. to conduct the first systematic survey and density estimate for free-ranging horses within 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 east-west transects across the Navajo Nation with a total length of 4,975 km. We observed 527 horse groups, comprising 4,290 horses, with average group size of 8.14 horses (range: 1–75). We estimated a total of 38,223 horses of all ages occurred within the study area during the survey period (90% confidence interval: 32,188 to 52,033), with 29,394 horses in open areas (90% confidence interval: 23,804 to 41,822) and 8,829 horses in forested areas (90% confidence interval: 5,955 to 13,513). Based on the ratio of horses classified as foals to the total number of horses observed, we projected a total of 5,604 horses would have been classified as foals (90% confidence interval: 4,573 to 7,552), comprising 4,483 foals in open areas (90% confidence interval: 3,489 to 6,254) and 1,151 foals in forested areas (90% confidence interval: 709 to 1,855). Overall horse density was 0.570 horses/km^2 (90% confidence interval: 0.480–0.776), with 0.619 horses/km^2 in open areas (90% confidence interval: 0.502–0.881) and 0.450 horses/km^2 in forested areas (90% confidence interval: 0.303–0.688). Detection probabilities were lower in forested areas ($\bar{P}$: 0.426, 90% confidence interval: 0.326–0.491) than open areas ($\bar{P}$: 0.608, 90% confidence interval: 0.508–0.646) and varied among observer seating positions. Additionally, we observed 55 burros (*Equus asinus*) in 17 groups, with an average group size of 3.24 burros. Sample size of burros was not sufficient to estimate density in the study area.

INTRODUCTION

Feral horses (*Equus caballus*) have existed in North America since the 15th century, when they were introduced by Spanish colonists. Several native horse species that once inhabited North America went extinct approximately 10,000 years ago, and all free-ranging horses currently populating the continent are untamed animals of domestic stock. In 2016, an estimated 55,311 feral horses occupied 127,881 km^2 of rangeland managed by the Bureau of Land Management (BLM) across 7 western states (BLM 2016). 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 (*Equus asinus*) 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.

By the time the first Spanish settlers arrived in the Rio Grande region with 7,000 head of livestock in 1598, the Navajo people had established an agrarian society in what is now northwestern New Mexico (Weisiger 2009). Over the next two centuries, horses enabled a gradual shift from farming to nomadic pastoralism and the expansion of the Navajo's use area to the south and west. Persecuted for raiding Rio Grande pueblos and Spanish villages for livestock, many Navajos were killed, while others were forcibly relocated between 1862 and 1866 to Hwe'eldi (Bosque Redondo or Fort Sumner, New Mexico). Returning from internment in 1868, surviving Navajos rejoined their kin that had escaped incarceration and returned to herding; women with sheep and goats, and men with cattle and horses (Weisiger 2009).

Overgrazing and erosion were concerns of many who observed the Navajo Nation around the turn of the last century and anecdotal accounts suggest high densities of livestock during this period: in the 1880s one man was reported to have 600 horses near Black Mountain, and another had 1000–3000 horses in Monument Valley (Iverson 2002). In a 1915 census, one man near Chinlee owned 400 horses and 21 others owned at least 100 horses each (Weisiger 2009). By 1930, approximately 40,000 Navajos were grazing an estimated 67,500 horses, 575,000 sheep, 187,000 goats, and 37,500 cattle on their approximately 70,000-km^2 reservation (Young 1955). A major western drought in the 1930s led to forced reductions of livestock over the next two decades, beginning with sheep and goats, and progressing to include horses (Iverson 2002, Weisiger 2009). In 1943, the Bureau of Indian Affairs (BIA) implemented the system of District and Central Grazing Committees under the Navajo Nation Counsel to establish carrying capacity for each land management unit on the Navajo Nation (CFR 25:167.6). Carrying capacity was measured in Sheep Units Yearlong (SUY), with goats equivalent to 1 SUY; horses, mules, and burros 5 SUY; and cattle 4 SUY. Perhaps most importantly, this plan tied permitted livestock to specific geographic units, ending for the most part the transhumance movements of flocks following better forage (Weisiger 2009). While mandated livestock reductions were understandably unpopular with the Navajo people, they had a measurable effect on livestock numbers: for the period 1951–1955, average annual reported livestock numbers were 27,000 horses, 250,000 sheep, 49,000 goats, and 10,000 cattle (Young 1955). Through at least the early 1950s, many Navajo traveled on horseback or in horse-drawn wagons (Young 1955). The necessity of horses in everyday life declined thereafter, as more cash and credit entered the economy, and pickups and all-terrain vehicles diminished the need for horses.

Management and oversight of grazing permits has 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. By the 2010 U. S. census, there were more than 332,000 Navajos, with approximately half living on reservation lands (Norris et al. 2012) and fewer than 8,000 (<3%) holding grazing permits (NNDA, unpublished data). NNDA compiles annual tally counts from reports by permittees to elected members of local Livestock and Grazing Boards. Tally counts are intended be a complete census of permitted livestock on the Navajo Nation, and while they provide a minimum estimate, they do not address feral livestock, including horses and burros.

A variety of methods are available to estimate density of feral horses, and studies comparing methods suggest differences in sampling design, survey methodology, and analytical approach can strongly affect the accuracy of resulting population estimates. For example, Lubow and Ransom (2009) suggested that failure to account for factors affecting detection of horses produced estimates that were 22.7% less than actual densities. Numerous factors affect the ability of observers in aircraft to detect feral horses, including horse group size, distance of horse groups from aircraft, vegetative cover, direction of sun during surveys, observer experience, observer fatigue, and position of observers in front or back seats of aircraft (Ransom 2012). Some of these issues can be avoided in survey design (i.e., observer experience, fatigue, and sun direction), while others must be addressed using analytical methods (i.e., horse group size, distance from aircraft, observer seating position, and vegetative cover). Although additional random factors may influence the accuracy of density estimates, current methods for survey design and analysis have greatly improved accuracy of population estimates for feral horses.

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. (EEI) to conduct the first systematic survey of free-ranging horses on the Navajo Nation. Accordingly, our main objective was to apply the most current methods in survey design and analysis to generate a scientifically robust estimate of the density of free-ranging horses on the Navajo Nation.

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 stratified the study area by forest cover to account for potential differences in density and detectability of horses in forested and open areas. We predicted 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. We identified large and contiguous areas of forest using a remotely sensed data layer of forest cover (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. This approach yielded 11 discrete forest polygons that covered 29% of the study area and captured 95.7% of forested cells from the vegetation data layer. The total area of the forested stratum was 19,629 km^2 and the unforested area, or open stratum, was 47,460 km^2 (Figure 1).

We established a systematic random sample of east-west transects across the study area, based on a grid with a random start point. To ensure adequate sample sizes and approximately equal effort for both strata, north-south spacing of transects was 16 km in the open stratum and 8 km in the forested stratum. This resulted in a hypothetical sample of 91 transects with a total length of 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 (Figure 1). We surveyed 5 50-km transects during early-June to test our survey method and generate coarse estimates of time per transect, horse density, and detection probability. We based our sampling intensity on information from practice survey transects, scientific literature, and available funding.

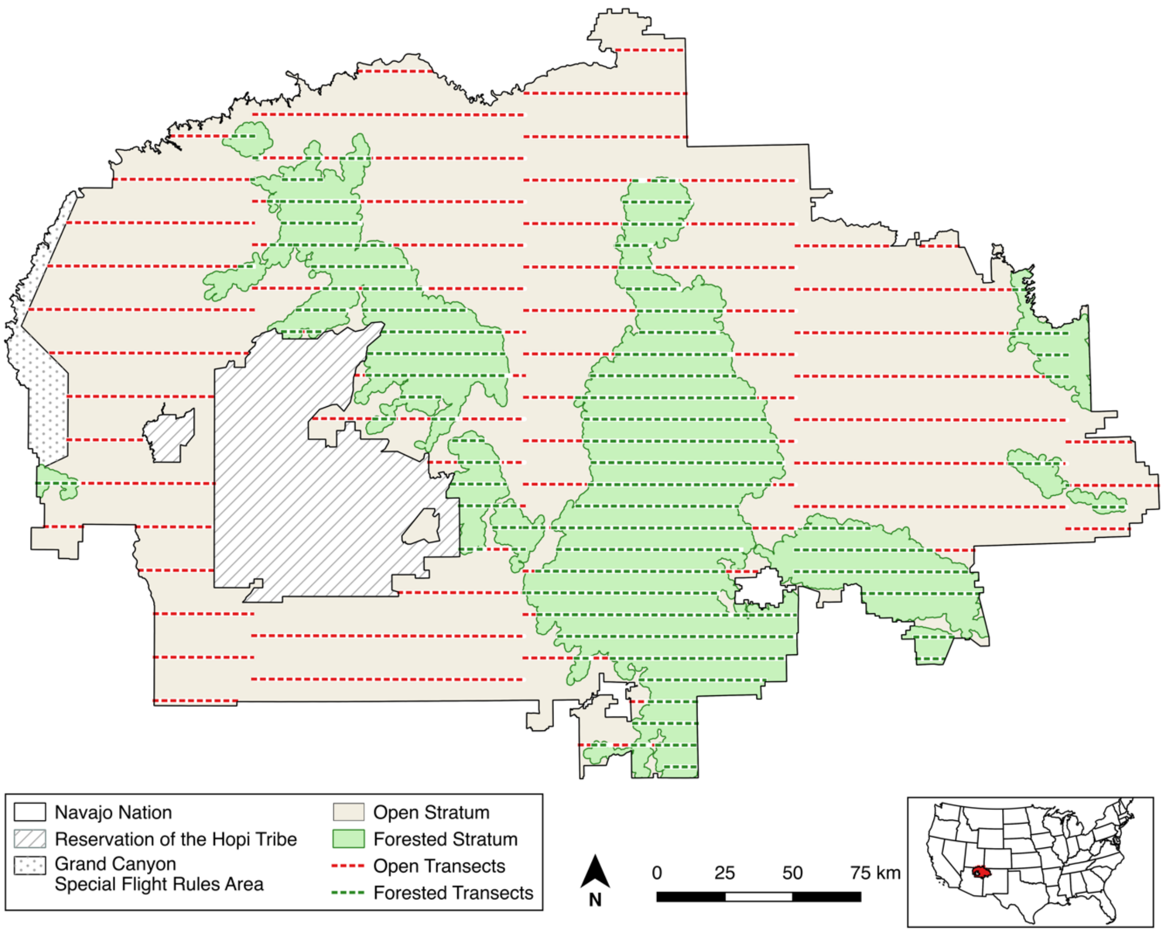

Figure 1. Study area for survey of free-ranging horses on the Navajo Nation, including forest cover strata and line transects. Inset shows the location of the Navajo Nation in the United States.

Survey Protocol

Transects were surveyed in a Cessna 206 plane, 122 m (400 ft) above ground level (AGL), travelling at approximately 100 kn (185 kph). Surveys generally began by 0730 h with a west-bound transect to avoid flying towards the rising sun and ended by 1330 h to minimize observer fatigue. We used a simultaneous double-observer distance sampling (DS) protocol that enabled us to produce estimates of horse density that accounted for the distance of detected horse groups from the transect line, and different detection rates from the front and back seats of the aircraft. Three observers (seated front-right, back-right, and back-left) searched independently for horse groups. Seating positions were determined daily using a random number table and all observers had a minimum of 800 hrs aerial wildlife survey experience. To ensure independence between observers, a cardboard partition separated the front-right and back-right seats, and observers on the right side allowed several seconds to pass before announcing detections. This allowed time for both observers to independently detect or not detect each horse group. 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. The pattern of detections and misses from this survey method were then used in a mark-recapture-style analysis to correct for differences in detection efficiency between the front and back seats of the aircraft. We timed surveys to occur in mid-summer after foaling was complete, and recorded the number of foals in each horse group based on their smaller size. At the request of NNDFW, we counted all horses that were not inside a corral or fenced pasture, including those near dwellings. Upon completion of the survey, we used GIS software to measure the perpendicular distance of each horse group from the transect line based on their GPS waypoint locations and survey flight tracks.

Statistical Analysis

Our approach to estimating horse abundance based on aerial surveys closely followed that used to estimate abundance of golden eagles (*Aquila chrysaetos*) by Nielson et al. (2014). This method generally followed the mark-recapture DS procedure described by Borchers et al. (2006) and consisted of 4 steps: (1) estimating the shape of the detection function, (2) using the mark-recapture data to properly scale the detection function, (3) integrating the scaled detection function to estimate the average probability of detection within the search width, and (4) applying standard DS methods to inflate the number of horses observed by the average probability of detection and estimate horse density (Buckland et al. 2001).

Lower detection probabilities at the nearest available sighting distance compared to greater distances farther from the transect line have been documented for surveys from fast moving aircraft (e.g., Becker and Quang 2009, Nielson et al. 2014). Given the speed at which the aircraft moves, objects closer to the transect line can be in an observer's field of view for less time, and thus, more difficult to detect. For this reason, we used a non-monotonic, non-parametric, Gaussian kernel estimator (Wand and Jones 1995) to model the shapes of detection functions (step 1; Chen 1999, 2000) as a function of distance from the transect line. The kernel density estimator used was of the form

$$\hat{f}(x) = (nh)^{-1} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h} \right), \quad [1]$$

where x was a random perpendicular distance within the range of observed distances, x_i was one of the n observed distances, h was a smoothing parameter (bandwidth), and K was a kernel function satisfying the condition $\int K(x)dx = 1$. Estimation of the smoothing parameter (h) followed the "plug-in" procedure described by Sheather and Jones (1991). Based on theoretical considerations and recommendations in Park and Marron (1992), we used 2 iterations (l) of functional estimation for our analysis.

Instead of assuming probability of detection was known at some distance from the transect line (Buckland et al. 2001), we used the mark-recapture trials to estimate probability of detection at the distance from the transect line where probability of detection was highest, assuming point independence at that distance (Borchers et al. 2006). At the distance where detection rates were highest, we assumed that the kernel distance function should equal the mark-recapture detection probability, and so we scaled the kernel function appropriately (step 2; Borchers et al. 2006).

Analysis of the mark-recapture data involved estimating the conditional probability of detection by the front-seat observer (observer 1) given detection by the back-seat observer (observer 2) at distance x_i (labeled $p_{1|2}(x_i)$), and the probability of detection by observer 2, given detection by observer 1 (labeled $p_{2|1}(x_i)$). We used logistic regression (McCullagh and Nelder 1989) to model the conditional probability of detection for observer j (j=1,2) using the equation

$$p_{j|3-j}(x_i) = \frac{\exp(\beta_{j|3-j} X_i)}{1 + \exp(\beta_{j|3-j} X_i)}, \quad [2]$$

where $\beta_{j|3-j}$ was the vector of coefficients to be estimated for observer j given detection by observer 3–j, and X_i was a matrix of distance covariates. We considered 3 logistic regression models where probability of mark-recapture success was (1) constant at all distances (i.e., intercept term only), or related to a (2) linear or (3) quadratic function of distance from the transect line. For each observer position, we chose the model with the lowest value of the second-order variant of Akaike's Information Criterion (AIC_c; Burnham and Anderson 2002). Since mark-recapture trials were only conducted on the right side of the aircraft, we assumed probability of detection by the back-left observer (observer 3) was same as $p_{2|1}$ because both back-seat positions had the same visibility, and we accounted for differences in individual skill by rotating observers randomly among seating positions in the aircraft.

Although observers behaved independently within the aircraft, observers on the right side shared the same sighting platform, and thus, groups of horses that were more likely to be detected by observer 1 were also more likely to be detected by observer 2. To properly scale the detection function (equation [1]), we needed to assume that the unconditional probability of detection $p_j(x_i)$ equaled the conditional probability of detection $p_{j|3-j}(x_i)$ at some distance from the transect line. The conditional probability is related to the unconditional probability as $p_{j|3-j}(x_i) = p_j(x_i)\delta(x_i)$, where $\delta(x_i)$ can be thought of as a bias factor (Borchers et al. 2006). Because $\delta(x_i)$ cannot be estimated from mark-recapture data (Borchers et al. 2006), we chose the distance from the transect line at which most observations occurred as the most likely candidate for offering a scenario where $\delta(x_i) = 1$, which allowed us to use the conditional estimates of probability of detection (equation [2]) to scale the detection functions. We identified where the largest number of observations by the front- and back-seat observers occurred based on the location of the maximum value of the estimated kernel detection functions (Borchers et al. 2006). Observations at this distance were least likely to depend on unmeasured factors that might have affected the detection process, and most likely to provide point independence. We then scaled the detection function (equation [1]) so that the maximum height of the function was equal to mark-recapture probability (equation [2]) at the distance where the maximum occurred. For example, if the maximum of the kernel detection function for the back-left observer was at a distance of $x_{max[\hat{f}(x)]} = 200$ m, and the mark-recapture probability of detection at 200 m for the back-seat observer was estimated as $\hat{p}_{2|1}(200) = 0.8$, then the kernel function (equation [1]) would be scaled such that $\hat{f}(200) = 0.8$. We calculated the conditional probability of detection on the right side of the aircraft at distance x_i by at least 1 observer when both observers were present was calculated as (Borchers et al. 2006)

$$\hat{p}_{.}^{c}(x_i) = \hat{p}_{1|2}(x_i) + \hat{p}_{2|1}(x_i) - \hat{p}_{1|2}(x_i)\hat{p}_{2|1}(x_i), \quad [3]$$

and the detection function for observations on the right side of the aircraft when both right-side observers were present was scaled such that $\hat{f}\left(x_{\max[\hat{f}(x)]}\right) = \hat{p}^c_{\cdot}\left(x_{\max[\hat{f}(x)]}\right)$.

We estimated detection functions and average group sizes for groups of horses observed while flying at 122 m AGL. The minimum available sighting distance for aerial horse surveys (W_1) was set to 55m. Observers recorded all horse observations regardless of distance from the transect line, though the average probability of detection was estimated out to 1,500 m (W_2).

We calculated density estimates for all horses, including foals, within each stratum using a standard distance formula (Buckland et al. 2001),

$$\hat{D} = \frac{\sum_{i=1}^{n} s_i}{2(W_2 - W_1)L\overline{P}}, \quad [4]$$

where n was the number of observed horse groups; s_i was the size of the i^{th} group; W_1 and W_2 were the minimum and maximum sighting distances, respectively; L was the total length of transects flown (thus, $2[W_2 - W_1]L$ was the total area searched); and $\overline{P}$ was the estimated average probability of detection within the area searched ($\widehat{P_a}$ in Buckland et al. 2001:53).

We first calculated the total area searched for horses across all transects based on the AGL flown and estimated the density of horses $(\widehat{D})$ for each stratum. We calculated the estimated density for the entire study area as an area-weighted average of strata densities (Buckland et al. 2001).

More large groups of individuals may be detected from a transect line compared to smaller groups or individuals (Buckland et al. 2001). If so, average group size could be overestimated (Buckland et al. 2001) and introduce bias in equation [4]. We used Pearson’s correlation analysis to investigate the relationship between group size and distance from the transect line. If the 90% CI for the estimated correlation coefficient did not include 0.0, indicating a statistically significant relationship, we used the regression method (Buckland et al. 2001) to estimate average group size. In this method, horse group size is regressed against distance from transect, and the horse group size at the maximum value of the kernel detection function is determined from this relationship and considered the average group size.

We bootstrapped (Manly 2006) individual transects to estimate 90% CIs for projected horse abundance within the entire study area. This process involved taking 10,000 random samples with replacement and re-running the analysis steps 1–4 to produce new estimates of horse abundance. We calculated CIs based on the central 90% of the bootstrap distribution (the percentile method). We used the R language and environment for statistical computing (v3.3.1; R Development Core Team 2016) to estimate densities and population totals of all horses and foals within strata and the entire study area.

RESULTS

Survey Effort and Observations

From July 24 to August 3, 2016, we surveyed 89 transects across the Navajo Nation with a total length of 4,957 km, excluding only 23 km of transects due to logistical constraints. Survey flights traversed a total of 2,820 km in the open area and 2,137 km in the forested area. We observed a total of 4,290 horses in 527 groups, with average group size of 8.14 horses (range: 1–75). Additionally, we opportunistically recorded 222 horses in 27 groups seen off transect. We included in the analysis 502 observations that were within 1500 m on either side of the aircraft, comprising 344 horse groups in the open stratum and 158 in forested stratum. We observed 55 burros in 17 groups, with an average group size of 3.24 burros. Sample size of burros was not sufficient to make a density estimate for the study area (Appendix A includes further information and a map of burro locations). We estimated 22% of horse groups and 14% of total horses observed were ≤ 250 m from a dwelling, with larger horse groups occurring farther from dwellings. Only 16 of 527 groups (3%) were running when detected or ran ahead of the circling aircraft.

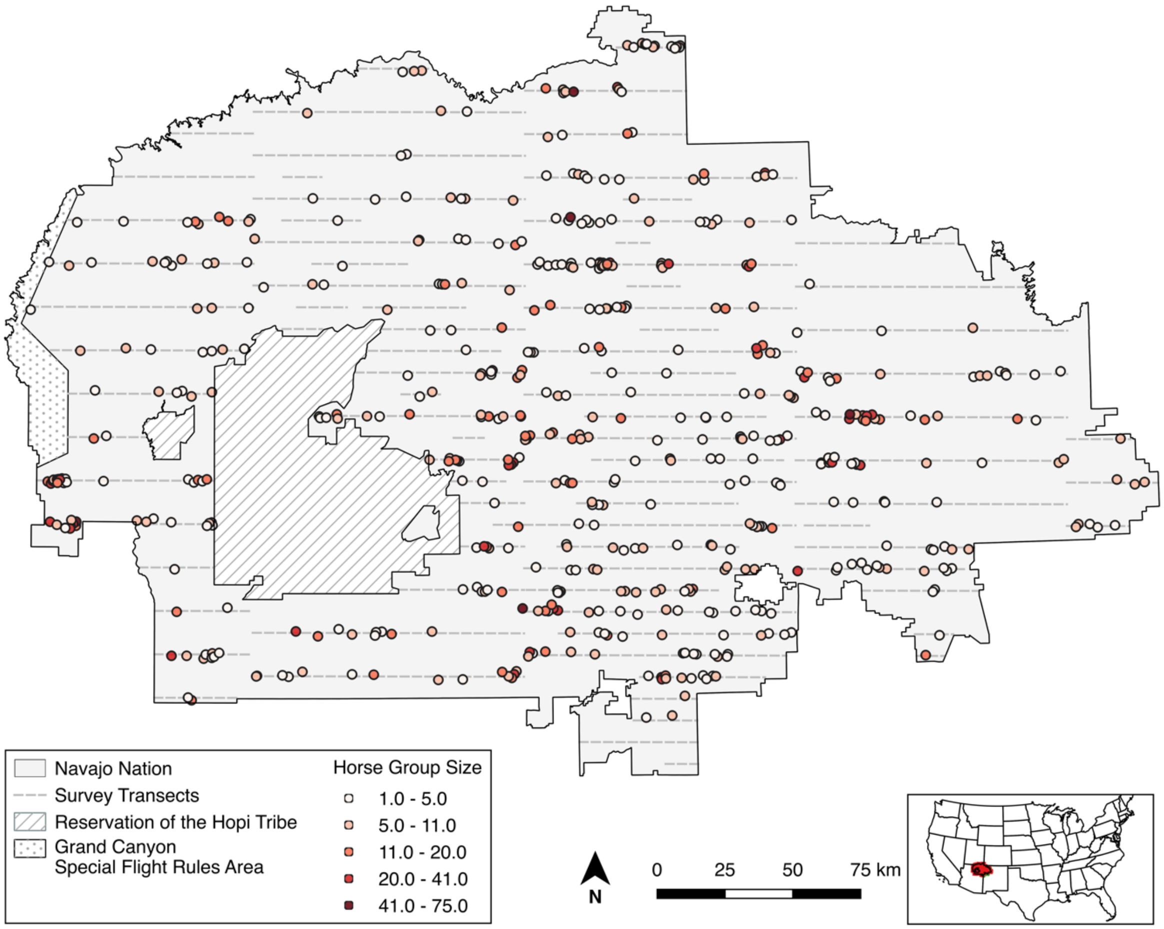

Figure 2. Locations and sizes of horse groups detected during fixed-wing aerial surveys of the Navajo Nation study area.

Detection probabilities

Detection probabilities were lower in forested areas ($\bar{P}$: 0.426, 90% CI: 0.326–0.491) than open areas ($\bar{P}$: 0.608, 90% CI: 0.508–0.646) and varied among observer seating positions (Table 1 and Figure 3). The top logistic regression model for probability of mark-recapture success was constant (i.e., intercept term only) for all combinations of observer position and forest cover strata, except for front-seat observer in the open strata, which used a linear model.

Table 1. Average probabilities of detection ($\bar{P}$) for free-ranging horse groups observed in open and forested strata of the Navajo Nation. Shown are the number of horse groups observed from each seating position in the aircraft (N) and estimated $\bar{P}$ with upper and lower limits of 90% confidence intervals (CI).

Stratum	Position	N	$\bar{P}$	CI
Open	Back	159	0.433	0.485 0.344
	Front	137	0.526	0.569 0.430
	Both	NA	0.608	0.646 0.508
Forested	Back	60	0.329	0.392 0.244
	Front	64	0.308	0.361 0.235
	Both	NA	0.426	0.491 0.326

Horse Abundance

We estimated a total of 38,223 horses of all ages occurred within the study area during the survey period (90% CI: 32,188 to 52,033), including 29,394 horses in open areas (90% CI: 23,804 to 41,822) and 8,829 horses in forested areas (90% CI: 5,955 to 13,513; Table 2). Based on the ratio of horses classified as foals to the total number of horses observed ≤1500 m from the transect line, we projected a total of 5,604 horses would have been classified as foals (90% CI: 4,573 to 7,552), comprising 4,483 foals in open areas (90% CI: 3,489 to 6,254) and 1,151 foals in forested areas (90% CI: 709 to 1,855). Overall horse density was 0.570 horses/km^2 (90% CI: 0.480–0.776), with 0.619 horses/km^2 in open areas (90% CI: 0.502–0.881) and 0.450 horses/km^2 in forested areas (90% CI: 0.303–0.688; Table 3).

Table 2. Estimated numbers of free-ranging horses of all ages and of foals in open and forested strata of the Navajo Nation study area, with upper and lower limits of 90% confidence intervals (CI).

	All Age Classes		Foals	
Stratum	**Abundance**	**CI**	**Abundance**	**CI**
Open	29,394	41,822 23,804	4,483	6,254 3,489
Forested	8,829	13,513 5,955	1,151	1,855 7,09
Overall	38,223	52,033 32,188	5,604	7,552 4,573

Table 3. Estimated mean densities of free-ranging horses (horses/km^2) in open and forested strata of the Navajo Nation study area, with upper and lower limits of 90% confidence intervals (CI).

Stratum	Density	CI
Open	0.619	0.881 0.502
Forested	0.450	0.688 0.303
Overall	0.570	0.776 0.480

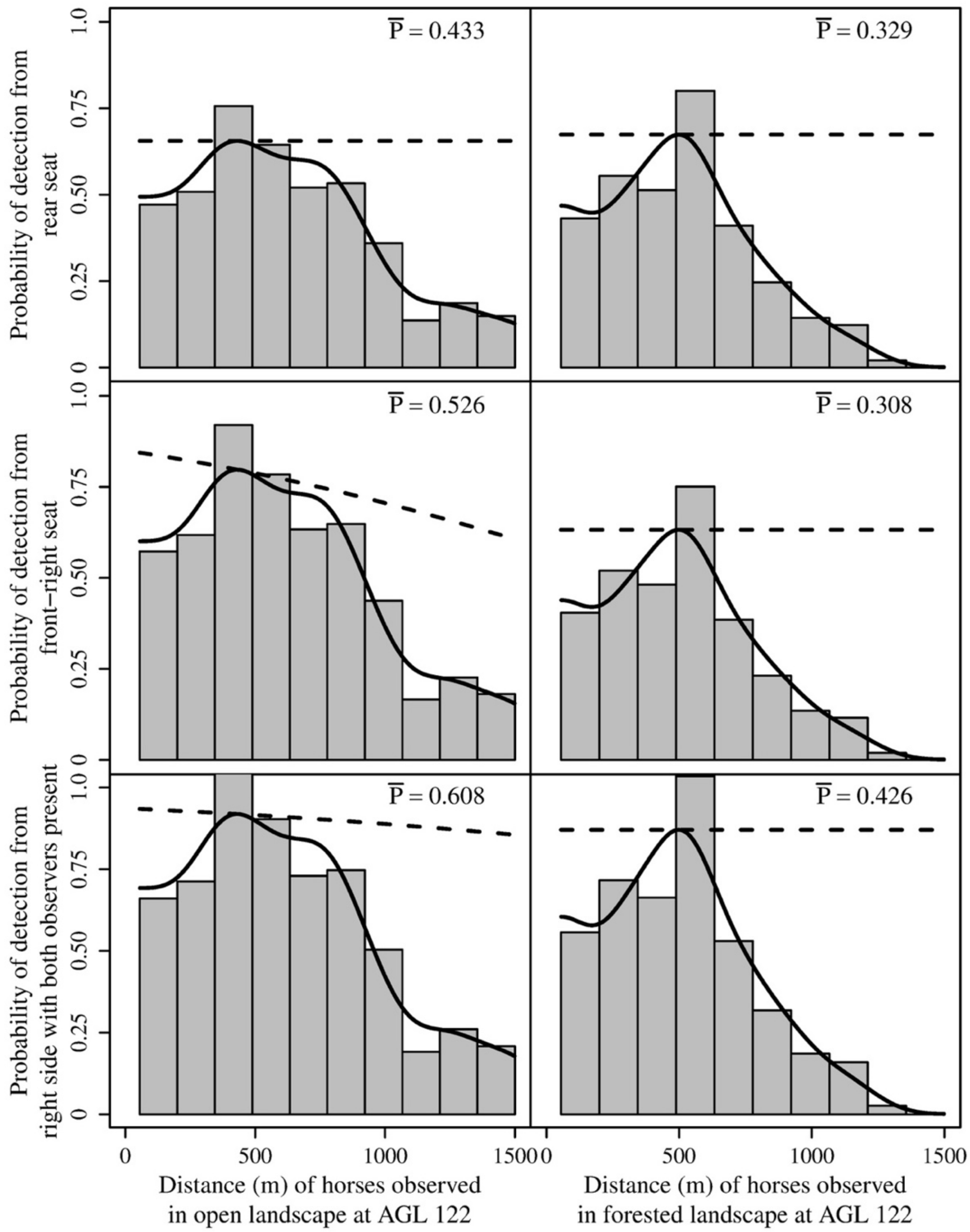

Figure 3. Probability of detection of free-ranging horses from 122 m above ground level (AGL) in open areas (left) and forested areas (right) of the Navajo Nation study area. Dashed lines represent probabilities of detection estimated from mark-recapture sampling. Solid lines represent scaled detection functions that were integrated and divided by the search width to estimate the average probability of detection ($\overline{P}$) within 1,500 m of the transect line. Histograms show the relative numbers of observations in each distance interval.

DISCUSSION

We conducted the first systematic survey of free-ranging horses on the Navajo Nation and provided robust estimates of abundance, density, and detectability. While comparisons of our estimates with historical and anecdotal reports from the Navajo Nation are problematic due to differences in survey methods, comparisons with current estimates from other areas suggest density of horses on the Navajo Nation is high. The average density of 0.570 horses/km^2 that we estimated within our 67,089-km^2 Navajo Nation study area was approximately 30% greater than the density of 0.433 horses/km^2 reported for the 127,881 km^2 of lands managed by the BLM in 2016 (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).

Overall detection probabilities from our study were within the range of other aerial surveys of horses (Lubow and Ransom 2016, Nielson et al. 2016). 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. Detection probabilities in forested areas were also more similar among front- and back-seat observers, suggesting the higher detection probability from the front seat that we observed in open areas was offset by lower visibility from both seats in forested areas.

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 are not represented in equation 4 (see *Statistical Analysis* above). 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 mid-summer, we were initially concerned that horses in open habitats would seek shade under trees or in canyons where they would not be available for detection. However, during the survey we were encouraged by observing many horse groups on the open range during mid-day. This may have been influenced by a monsoon-season green-up that occurred before our survey, compared to the substantially drier range conditions we observed in prior months while flying practice transects and raptor surveys in the study area. Repeating this survey in other seasons or comparing results with ground-based counts could address potential availability bias (e.g., Lubow and Ransom 2016).

Estimates from distance sampling also depend on accuracy of recorded locations and flight tracks used to measure perpendicular distances of observations from transects. 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. Furthermore, almost all groups remained still while we circled to record a GPS location: only 16 of 527 groups (3%) were running when detected or ran ahead of the circling aircraft. We suggest future surveys should also document running behavior of horses, and use fixed-wing aircraft because they may be less likely to flush horses than helicopters (Lubow and Ransom 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 in close proximity to 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. 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 occurring farther from dwellings. While these results confirm that some free-ranging horses are associated with towns and dwellings, they confirm that the majority of horses documented during this survey did not occur in close proximity to dwellings.

The systematic random sample of transects established here could be resurveyed 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 time period. Surveys could also be repeated after round-ups or other management actions to assess their effectiveness, or could be used in concert with other field methods to compare estimates. Additional analyses possible using the data already collected include developing habitat-use models to predict distribution of horses across the study area and identify environmental factors driving habitat selection. Resulting "heat-maps" of horse occurrence could be coupled with spatial data on stocking rates and range condition to identify areas where efforts to manage horses would be most beneficial. Given relatively large sample sizes from this survey, it would also be possible to generate estimates of abundance at a finer scale within the study area, for example within Agencies, Grazing Districts, or NNDFW hunt units. 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 A: LOCATIONS OF BURRO GROUPS

We observed 55 burros in 17 groups on transects, with an average group size of 3.24 burros (Figure B1). Additionally, we recorded 1 group of 4 burros seen off transect. Sample size of burro groups was not large enough to estimate density in the study area.

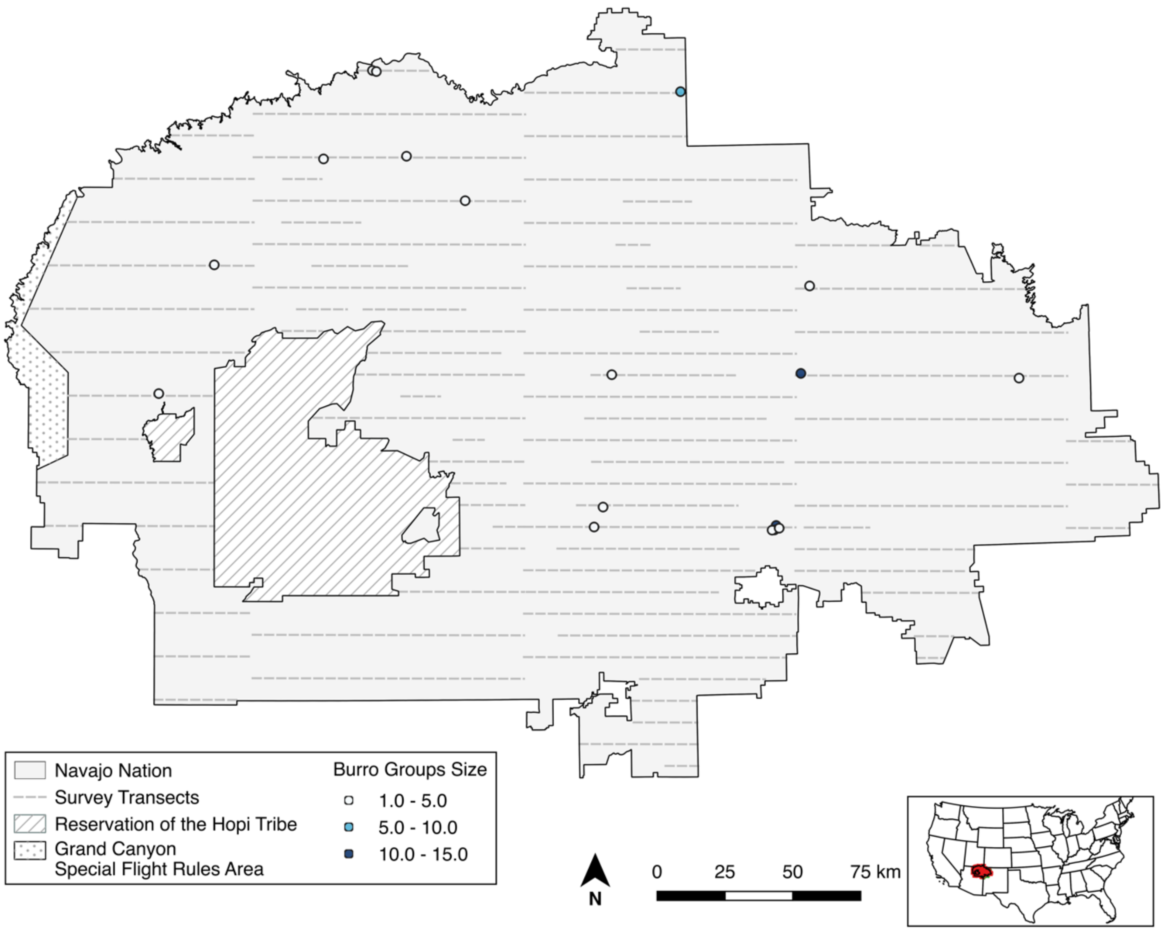

Figure A1. Location and size of burro groups detected during fixed-wing surveys of the Navajo Nation study area.