Gambel's Quail (*Callipepla gambelii*) Nest Site Selection and Habitat Use in Oracle Junction, Arizona

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Final Report for Task Order 23-6

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Female Gambel's quail with GPS transmitter (*photo: Alexis Rickert*)

Abstract

Gambel's quail (*Callipepla gambelii*) is the most widespread, abundant, and heavily harvested species of game quail in Arizona. Gambel's quail population dynamics in Arizona are strongly influenced by seasonal weather conditions. This is particularly relevant for Gambel's quail management as drought conditions are expected to increase in Arizona, and this may exacerbate inter-annual variation in Gambel's quail abundance and recruitment. The goal of this study is to provide information on Gambel's quail population demographics, habitat use, and movement to inform land management decisions for Gambel's quail in southeast Arizona in a way that mitigates the effect of drought. We used multiple trapping methods to capture Gambel's quail from February–July 2024 and February–15 May 2025. We found noose mats (n = 57) to be more effective than drop traps (n=14) in capturing Gambel's quail, with multiple types of walk-in traps proving ineffective. We deployed 33 GPS backpack transmitters on female Gambel's quail to monitor their movements and locate nests. We documented eight mortalities of tracked quail from apparent predation. Quail home range sizes ranged from 3 ha-100 ha (mean = 25 ha) in 2024 and from 7–57 ha (mean = 29 ha) in 2025. We identified four nest sites with 6-15 eggs and all nests were predated. We collected vegetation measurements at nest and brood sites and corresponding random points to examine nest and brood site selection although our small sample sizes limited our ability to make inferences about Gambel's quail habitat selection.

Introduction

Background

Gambel's quail (*Callipepla gambelii*) are found across arid lands of the southwest USA and are the most abundant and heavily harvested quail species in Arizona. A socio-economically valuable species, Gambel's quail hunting contributes to cultural and traditional practices and financially to conservation initiatives (Brown 2012). Like other species of quail in the southwest, Gambel's quail population dynamics demonstrate substantial inter-annual fluctuations due to their r-selected reproductive strategy often described as "boom-and-bust" dynamics (Peterson 2001). For quail populations undergoing such dynamics, years with low abundance are the result of low juvenile recruitment and low adult survival through the winter (Peterson 2001). Although population fluctuations are normal in many quail populations, the nature of long-term population trends in Gambel's quail is less clear. For example, the most recent assessment of Gambel's quail population trends using community science observations across their range shows an overall decline (eBird 2020) while Breeding Bird Survey data (across their range) did not indicate a clear trend (Ziolkowski *et al.* 2022).

Seasonal weather patterns, particularly winter precipitation and pre-monsoon summer temperature, strongly influence quail population dynamics, including Gambel's quail, in arid environments (Lusk *et al.* 2001; Heffelfinger *et al.* 1999; Swank and Gallizioli 1954; Peterson 2001). Dry winters can limit quail food availability (Heffelfinger *et al.* 1999) while high pre-monsoon summer temperatures can suppress reproductive success in female quail (Guthery *et al.* 1988). The impact of precipitation is particularly relevant for this species as drought conditions are expected to increase in Arizona (Seager *et al.* 2007) and this may exacerbate inter-annual variation in Gambel's quail abundance and recruitment. Climate change has been suggested as a cause of decline for southwest quail species by exacerbating the effects of variation in winter precipitation with drought, leading to limited food availability (Heffelfinger 1999) and through increased temperatures suppressing reproductive success (Guthery *et al.* 2000). Drought as a product of climate change could induce unsustainable population fluctuations (e.g., Accatino et al. 2017) where a lack of winter precipitation negatively impacts chick recruitment during the following breeding season, potentially leading to population decline. Other factors that could potentially influence Gambel's quail population dynamics and long-term trends include hunter harvest intensity and timing, an increase in predator abundance, and over grazing (Brown 2012).

Much previous research on Gambel's quail has focused on using indices of abundance to monitor population trends. Two important abundance indices used by Arizona Game and Fish Department (AGFD) are spring call counts and hunter harvest records, which have been collected near Oracle Junction in southeast Arizona since the 1970s (Brown 2012). These indices are valuable for monitoring long-term population trends, determining how weather patterns correlate with population dynamics, and predicting hunter success (Heffelfinger *et al.* 1999; Arizona Game and Fish Department, unpublished data). However, indices provide relatively little information about the underlying demographic parameters (e.g., survival and fecundity) driving population dynamics and the factors influencing those demographic parameters. Population demographics of quail are influenced by a variety of factors including weather conditions, water and food availability, and available cover and nesting material (Kauffman *et al.* 2021; Luna *et al.* 2017; Temple *et al.* 2017). While weather patterns are inherently variable and difficult to predict, habitat characteristics (i.e. cover, water availability, nutrition) can be modified through habitat management (planting, managed grazing, brush management) (Heffelfinger *et al.* 1999). Therefore, there is a need to investigate the fundamentals of Gambel's quail population demographics and habitat selection, how these processes are influenced by habitat and environmental conditions, and how these relationships translate to population dynamics. Having a deeper understanding of the factors influencing the population demographics and habitat selection of Gambel's quail provides managers with the information necessary to mitigate the impacts of future drought conditions and maintain robust Gambel's quail populations.

Habitat Selection and Reproduction

Gambel's quail are most common in the Sonoran Desert and associated semiarid ecosystems of Arizona and Sonora, Mexico (Downey *et al.* 2023). Gambel's quail are a scrub-adapted species that have wide habitat tolerances and can occupy a range of semiarid ecosystem types (Acevedo *et al.* 2023; Kuvlesky *et al.* 2002). Temple *et al.* (2017) estimated a mean breeding season home range size of ~130 ha for Gambel's quail for one season in New Mexico and home range size was found to vary depending on resource availability. Moreover, home range size during recruitment was generally larger than nesting season home range size due to specific nutrition requirements of juvenile quail (Temple *et al.* 2017). Within Arizona, nesting and egg laying begins in April and May, and the hen incubates her clutch for approximately 21-24 days (Gee *et al.* 2020). Nest-site selection for quail is usually dependent on vegetation characteristics that provide suitable thermal conditions and protective cover from predators (Downey *et al.* 2023). Quail nests are built on the ground beneath herbaceous, succulent, or shrubby vegetation, but Gambel's quail also lay inconspicuous camouflaged eggs in areas with minimal vegetative cover due to their adaptation to arid sparsely vegetated environments (Brennan 2007). Brood rearing is performed by both sexes and a single brood may contain approximately 10-14 chicks (Downey *et* *al.* 2023). Gambel's quail chicks are precocial and remain dependent on the adults until approximately three months of age (Gullion 1960b).

Gambel's quail often select habitats containing brush composed of thorny woody legumes, particularly mesquites [*Prosopis* spp.]), cacti, and other leaf-succulent plant species throughout the year for cover and food (Brennan 2007). Gambel's quail consume more mast than other southwest quail species and use shrubs and small trees for cover and roosting purposes (Luna *et al.* 2017). Gambel's quail are commonly found close to washes and drainages dominated by mesquites and use woody litter, tree, brush, and/or grass canopy cover as shelter from predators (Downey *et al.* 2023). A primarily herbivorous species as an adult, Gambel's quail derive water and nutrients from seeds of forbs, woody plants, and grasses, legumes, and fruits from cacti (Kamees 2008; Medina 2003). However, insects are important seasonally for recruitment as they make up most of the diet of young Gambel's quail because of the need for higher protein intake during the early life-stages (Medina 2003).

Effects of Grazing

Cattle grazing is common throughout the range of the Gambel's quail and may influence Gambel's quail populations. It has been suggested that heavily grazed, shrub-invaded grasslands in Arizona may actually benefit Gambel's quail due to the succession from grassland to shrubland that occurs after over-grazing (Brown 1989; Kuvlesky et al. 2002). Woody shrub encroachment may enhance quail habitat through the increase of critical cover, woody canopy cover reduces visibility for aerial predators (Luna et al. 2017). However, very little recent research in Arizona has examined the impacts of grazing on Gambel's quail since 1981 (Brown 2012). Studies of Gambel's quail in Arizona examining indices of quail abundance between grazed and ungrazed areas did not demonstrate consistent differences in these indices (Brown 1989; Brown 2012). Understanding the impacts of grazing on Gambel's quail population dynamics is important given the potential of grazing to alter vegetative features important to Gambel's quail and as a management tool to help promote Gambel's quail populations.

Research Goals and Objectives

The goal of this study is to provide information on Gambel's quail population demographics, movement, and habitat selection that can inform Gambel's quail management in southeast Arizona to mitigate the effects of drought. Our specific objectives are to: 1) quantify Gambel's quail nest success and its response to landscape- and nest-level vegetation features and disturbance, 2) evaluate Gambel's quail nest-site selection as a function of landscape- and nest-level vegetation features and disturbance, 3) identify mortality causes and estimate survival rates of adult female Gambel's quail, and 4) evaluate habitat selection by adult female Gambel's quail during brood-rearing. We expected that Gambel's quail will select areas with higher protection from predation and more thermal cover. We therefore predicted that nest success and nest-site selection would both show the strongest positive associations with horizontal visual obstruction, shrub density, and canopy cover and the strongest negative associations with the amount of grass cover.

Study Area

Our study area was approximately 40 km north of Tucson within an Arizona Upland Desert Scrub vegetation community. The topography is characterized by rolling hills (approximately 1,000 m in elevation) bisected by large washes. Dirt roads are present throughout our study area with varying degrees of use by utility service vehicles and off-highway vehicles (OHV). Dominant vegetation species include saguaro (*Carnegiea gigantea*), palo verde (*Parkinsonia* spp.), mesquite (*Prosopis* spp.), cholla (*Cylindropuntia* spp.), and prickly pear cacti (*Opuntia* spp.) with a lower proportion of grass cover relative to the surrounding vegetation. Substantial mesquite encroachment has occurred over the past several decades (J. Heffelfinger, Arizona Game and Fish Department, personal communication). Our study area is a popular destination among recreational quail hunters and the AGFD has conducted annual spring call count surveys since 1965 and collected hunter harvest data through check stations since 1940 within our study area (Brown 2012).

Methods

Quail Trapping

2024 Season

We concentrated our trapping efforts around a stock tank called "Lower Tank" which is approximately 30 km north of Oracle Junction and approximately 3 km east of Highway 79. We began trapping Gambel's quail on 19 February 2024 after the quail hunting season ended and before winter coveys broke up for the spring. We continued trapping until 11 July 2024 but greatly reduced our trapping effort from 27 June 2024, due to reduced quail activity and the need to prioritize tracking efforts. We placed traps in areas where we observed concentrations of quail and pre-baited traps with bird seed containing milo (*Sorghum bicolor*), and/or commercial quail food blocks daily for approximately one week. We used three trapping methods to compare their efficacy. Our first method was the drop box method used by Acevedo *et al.* (2023). This method involved propping up a wire box trap (1 m x 1 m x 0.25 m) with a short pole attached to a rope, placing a small pile of seed under the trap, hiding 10-15 m away from the trap, and then pulling the rope to drop the trap. Our second method was a walk-in trap (1 m x 0.5 m x 1 m) with either funnel entrances or one-way doors. Our third method was a noose mat following the design of Learn (2020). Our noose mats were 1 m x 1 m with ½ inch wire mesh with monofilament slip nooses placed every 6 cm. We placed noose mats on the ground and sprinkled quail seed over the mat. We set all traps or noose mats at or immediately after first light and continuously monitored drop traps and noose mats, checking walk-in traps approximately every 30 minutes. We removed all traps by noon. We also employed some evening trapping where traps were set approximately two hours before dusk and removed shortly after dusk.

2025 Season

We observed very few quail during preliminary visits to and camera trap deployments at our 2024 trapping location (Lower Tank). We therefore relocated our trapping efforts to two water catchments located approximately 5 km and 10 km southwest of Lower Tank. These water sources were built and maintained by AGFD specifically for wildlife and were surrounded by fences to exclude cattle. For the period 17 February through 4 April 2025, we trapped quail at a water catchment named "Owl's Head #9." Quail activity at this location declined markedly in early April, so we relocated our trapping efforts to a second water catchment called "Tortolita Mountain #1." We trapped at this second catchment from 9 April through 15 May 2025. Both water catchments were composed of the same concrete catchment leading to a drinking hole that remained filled with water throughout the season.

We used noose mats and drop traps again during 2025 and baited all traps with commercial bird seed. We also deployed a larger variety of walk-in trap called a "kennel trap." This was a modified dog kennel approximately 3 m x 2 m x 2m with a roof installed to prevent quail from flying out. Mesh chicken wire, with 1” x 1” openings, was wrapped around the base of the kennel to ensure quail could not escape through the larger openings in the walls of the kennel. A swinging door was left open with a rope attached to be rapidly closed in the event that quail walked in. We deployed traps beginning around six am and concluded trapping each between 0900 and 1200 depending on quail activity. We continuously monitored all traps and immediately removed captured quail for processing.

Quail Measurements and Transmitter Deployment

We sexed, banded, and weighed each quail at its time of capture. We used metal bands provided by AGFD. We deployed either combination GPS/VHF backpack units or VHF necklace style units on select quail such that the transmitter and attachment device did not exceed 5% of the quail’s body mass (Caccamise and Hedin, 1985). Our combination GPS/VHF units followed the protocol of Buckley *et al.* (2022) on northern bobwhite (*Colinus virginianus*). We epoxied a 2-g VHF transmitter (Holohil, BD-2) to the side of a 4-g solar-powered GPS transmitter (Ecotone Telemetry, PICA GPS-UHF, https://en.ecotone.com.pl/produkty/logger-pica-gps-uhf.html). The pulse rate of the 2-g VHF transmitters was reduced by the manufacturer to 20 ppm to produce an expected 200-day battery life. We attached 0.65 cm Teflon ribbon to the entire unit and created backpack-style harness to attach the unit to a quail (Buck *et al.*, 2021; Buckley *et al.*, 2022; Marquardt *et al.*, 2017). The unit did not exceed a weight of 7.5 g and was only deployed on quail weighing >150 g. We initially programmed the data collection schedule to record a location every hour during the entire 24-hr period. However, we found that this drained the unit’s battery to a point where it could not be recharged through the solar panel. We therefore used a portable ultra-high frequency (UHF) base station (Ecotone Telemetry, EP-BS Base Station Set) to remotely reprogram our units to record a location every hour during only daytime hours. In April of 2025 we observed that even restricting hourly location data to sunrise through sunset would lead to gaps in data from battery drain so we limited hours of data collection to six am through three pm. We also reprogrammed other settings, including level of accuracy of data points and number of data points taken at one time (called a "burst" of points), to improve battery life. We used 6-g VHF transmitters (American Wildlife Enterprises, 9-12 month battery life) attached with neck collars and deployed them on quail weighing >130 g.

We evaluated GPS location precision, download distance, and battery life of our GPS/VHF units in environments with varying levels of vegetation cover (approximately no cover, a range of partial cover, full cover, and one additional cover class deemed "brush clump") using beacon tests. We put a 15 cm tall PVC pipe into the ground and glued a datalogger at a ~45° angle on top of the pipe to simulate the angle and height of the GPS backpacks on the quails. We estimated the percentage of vegetation cover with a spherical densiometer placed at a height of ~10 cm above the ground. Cover class #1 was located on a patch of bare ground with an estimated 0% cover. Cover class #2 was located under the edge of a mesquite canopy with an estimated cover of 23%. Cover class #3 was located under a rubber rabbit brush (*Ericameria nauseosa*) with an estimated cover of 45%. Cover class #4 was located under a cholla cactus with an approximate cover of 71%. Cover class #4 was located in a thick rubber rabbit brush clump to simulate thick cover that may be used by nesting quail hens. Cover class #6 was located at the base of a mesquite with a cover of approximately 88%. GPS point accuracy and battery life were measured for 9 days under each cover class as 60-minute GPS fix intervals. Each unit was active 24 hours per day during 15–25 February 2024. To measure download distance, we started 200 m from each datalogger and walked until we were connected wirelessly to the unit. We used a hand-held Garmin GPS unit (GPSMap 65s) to record the true location of the loggers.

Telemetry Tracking

We monitored telemetered quail using hand-held radio telemetry with a receiver (Telonics, Model TR-8) and a 3-element Yagi antenna attachment (Vertebrate Systems) on foot through triangulating and homing. We located each telemetered quail once every 3-5 days with increasing frequency immediately preceding incubation to facilitate nest location. We recorded the coordinates of each quail location using the OnX Hunt app. We used the UHF base station to remotely download GPS locations from GPS-telemetered quail. We could download the data when within approximately 30 m from a GPS-telemetered quail and attempted to download data from each GPS-telemetered quail weekly but were often unable to do so because of vegetation obstruction, quail movement, or an inability to locate a quail during a given week. We also deployed a UHF base station in the field at our final 2024 trapping location which would automatically download GPS data if a GPS-telemetered quail passed close enough to the base station. Our remote base station consisted of a five-gallon bucket filled with sand to support a 2 m aluminum pole with the base station antenna fixed at the top at a 45-degree angle. The base station was powered by a 12.6 V battery and deployed from 1 October 2024 through 31 January 2025.

We determined the female quail's reproductive status (i.e. nest initiation, incubation, brooding) by assessing their movements and behavior through informed field observations and remote data assessment. Behavioral patterns that indicate an incubating quail include observations of smaller groups of two to six quail in one place, particularly observations of paired up males and females, increased hesitation in the individual females to flush or run away when we approached, and shorter distances moved from their initial location prior to disturbance by the researcher (Coates and Delehanty 2008; Raitt 1960; N. Lindenauer, U.S. Geological Survey, personal communication). We modified our triangulation techniques throughout the season to limit disturbance and premature flushes to get close enough to the individual telemetered females to identify behavioral changes throughout the breeding season. We assumed that telemetered quail were on their nest when we were able to circle them within a 15 m radius without flushing and when they were found in the same location after two consecutive nest checks (Coates and Delehanty 2008). We also continuously monitored the fine scale hourly data gathered from the GPS transmitters to remotely evaluate the reproductive status of each female. Quail that remained in one exact location over the course of multiple days were prioritized in our tracking efforts to attempt to find nests. We introduced intentional flushes of telemetered individuals from close distances (< 15m) as the season progressed to positively identify whether a quail was nesting or a mortality.

We determined nest fate by assessing the state of the eggshells that remained on and/or near the nest bowl after the quail had moved off the nest. Eggshells that had an apparent crown and base indicated a successful hatch. Eggshells that appeared crushed or chewed, or eggs that were missing indicated a predation event. We monitored broods by tracking the location of the hen once every two to three days and looking for any chicks with the hen (Coates *et al.* 2017).

Vegetation Measurements

We measured a series of vegetation features at nest sites, female quail locations with broods, and paired random points to quantify nest-site and brood-site selection under a used-available study design (Manly *et al.* 2002; Johnson *et al.* 2006). We considered both types of selection to approximate a third-order habitat selection process (i.e., selection of locations within an individual's home range; Johnson 1980). Because our quail home ranges were unknown at the beginning of the study, we used the mean home range size reported by Temple *et al.* (2017) from Gambel's quail in New Mexico (129 ha) to create a circular buffer with an area equal to this estimate and which had a 640 m radius buffer. We placed this buffer around each nest and around the centroid of each quail's VHF telemetry locations where it was observed with a brood. We then randomly selected two points per nest and one point per VHF telemetry location with a brood from within this buffer. We used the SDRAW package (McDonald *et al.* 2020) in Program R (R Core Team 2024) to select the random points.

To measure vegetation features, we placed two 20 m perpendicular transects (Kauffman 2021; Pleasant *et al*. 2006; Bristow and Ockenfels 2006) centered at each nest, brood, or random point. The first 20 m transect was oriented randomly, and the subsequent transect was oriented at 90° angles from the previous transect. We recorded a visual obstruction reading (VOR) at the nest/random point, percent vegetation cover of five cover classifications (bare ground, litter, forb, grass, shrub), maximum vegetation height of four different vegetation classes (shrub, grass, forb, litter), and percent canopy cover within a 1 m^2 Daubenmire frame (hereafter quadrat) placed at the nest/random point in addition to the 5 m and 10 m points along each transect line. Two observers independently measured each vegetation metric resulting in 19 measurements per point.

We documented cattle presence during our vegetation surveys by conducting standardized dung counts as an index of cattle abundance at vegetation sampling plots on quail nest locations and their corresponding random points (Milchunas 1989). We recorded all cow pies and observed within 2 m laterally down the 10 m of each transect.

In addition to cow pies, we documented proximity to burrows by recording all burrows observed within 2 m laterally down the 10 m of each transect. Following the commencement of our field work, burrows were observed to be a possible compounding factor for the quail nest site selection and/or nest success. For this reason, burrow counts were included in the transect surveys.

Data Analysis

During the 2024 season we recorded the number of times per trapping session that quail approached our traps, hereafter called encounters. We then compared the number of encounters per seven days between drop traps and noose mats.

For both the 2024 and 2025 season we calculated the number of days each telemetered quail was monitored as the number of days between an individual's first and last location (either GPS or VHF location) and the number of days during which we obtained at least one GPS location. We used GPS locations to calculate the Euclidean distance of each GPS location to each quail's first GPS location. We estimated quail home range sizes from 95% utilization distributions of autocorrelated kernel density estimators (Fleming *et al.* 2015; Fleming and Calabrese 2017) calculated using the CTMM package (Calabrese *et al.* 2016) in R. We used only GPS locations for home range calculations. We calculated a population-level mean home range that accounts for the uncertainty in individual home range size estimates using the *meta* function in CTMM.

For the 2024 vegetation data, we calculated the mean value for each vegetation metric at each nest, brood, or random location across all 18 measurements taken for that metric at each point. These mean values were used as the covariates in subsequent habitat selection analyses.

We estimated conditional resource selection functions for nest-site selection using a Cox proportional hazards model (Cox 1972) which allowed us to explicitly match each used point (nest or brood location) with its corresponding random point. We were unable to measure vegetation at corresponding random points for all brood-site locations, so we evaluated brood-site selection using a binomial generalized linear model. Owing to our small sample size, we only included one covariate per model and z-score standardized each covariate. Many covariates had entirely or mostly zero values which again attribute to our small sample size. We therefore only considered four covariates with relatively high levels of variability: percent grass cover, percent bare ground, canopy and shrub cover, and horizontal visual obstruction. We fit the Cox proportional hazard models using the SURVIVAL package (Therneau and Grambsch 2000; Therneau 2024) in R and report the coefficient estimates and *p* values.

Results

Quail Captures

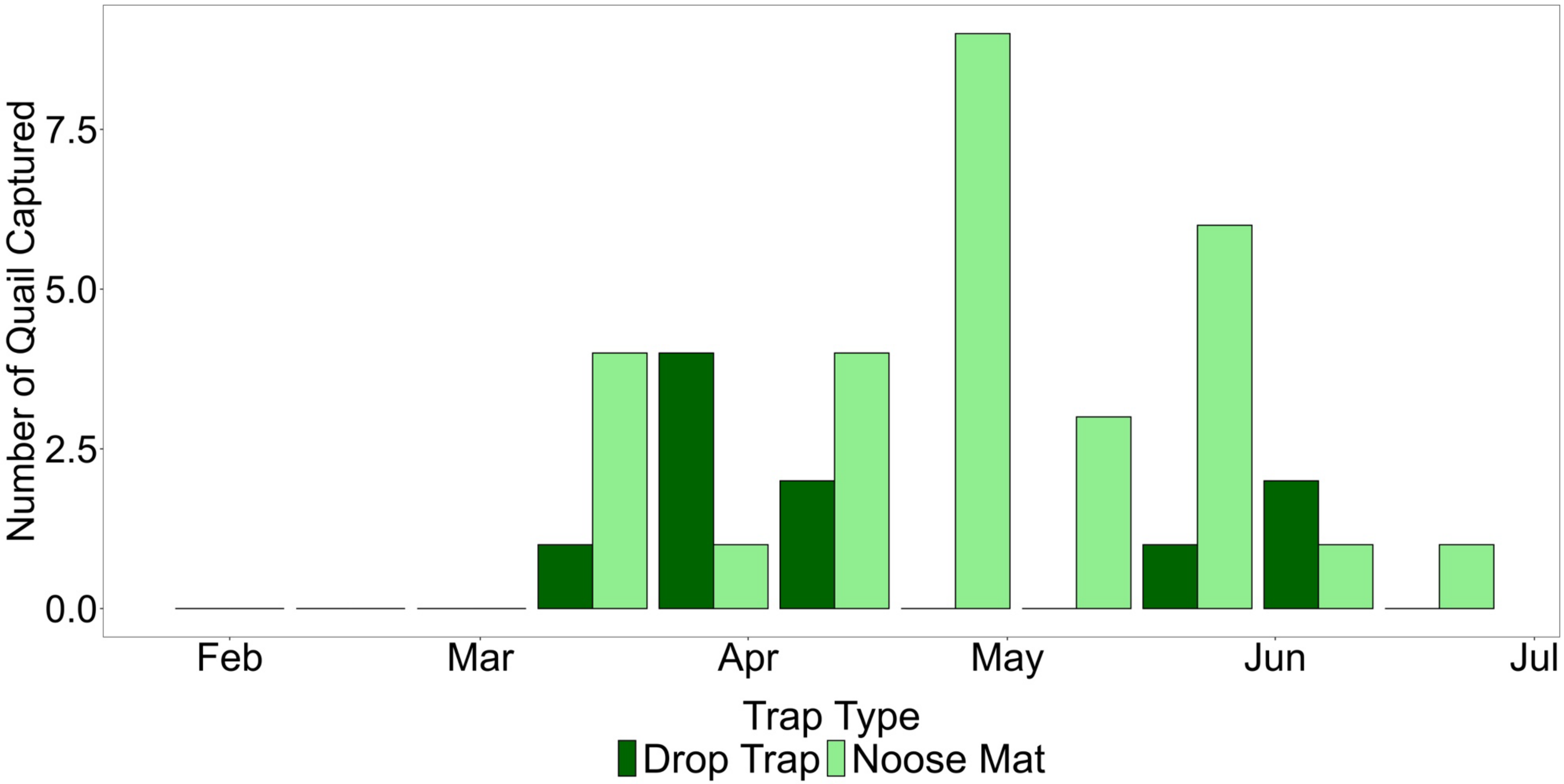
2024 Season

We captured a total of 39 Gambel's quail (22 females and 17 males) between 20 March and 25 June 2024. All captures were made during the morning. Quail captures peaked in the first week of May (n = 8; Figure 1). We captured more quail using noose mats (n = 29) than drop traps (n = 10) and did not capture any quail using walk-in traps. Average trap encounters were higher for noose mats (17.7 encounters per week) than drop traps (3.5 encounters per week).

2025 Season

We captured a total of 30 Gambel's quail (14 females and 16 males) between 17 February and 15 May 2025. We captured more quail using noose mats (n= 28) than drop traps (n = 4) and we did not capture any quail using the kennel trap.

Figure 1. Number of Gambel's quail captures per week during 19 February through 11 July 2024 in southeast Arizona by drop traps and noose mats.



GPS Transmitter Beacon Tests

The vast majority of GPS locations collected during our beacon tests were within 30 m of the centroid of each unit's locations (Table 1). Fewer GPS locations were within 10 and 5 m of the centroids although there was no clear trend of decreasing precision with increasing vegetation cover around the unit (Table 1). There were virtually no differences in these proportions when using the centroid of the GPS locations vs. the coordinates recorded by the handheld Garmin GPS unit. The maximum download distance ranged from 46 m for the unit on bare ground (0% cover) to 5 m for the units under a cholla (71% cover) and at the base of mesquite tree (88% cover) (Table 1).

Table 1. Results of beacon tests of combination GPS/VHF units during 16–23 February 2024 for monitoring the movements of Gambel's quail in southeast Arizona. GPS location data were collected hourly over the entire 24-hour period. Vegetation cover and cover type refers to the environment in which the unit was placed. Battery life was the voltage of the GPS transmitter on that unit's last reading. Proportion within 30, 10, and 5 meters are the proportion of GPS locations that were within those distances of the centroid of all locations. Proportion missing is the proportion of hourly readings where no GPS coordinates were recorded by the unit. Maximum download distance was the maximum distance from the unit at which we were able to remotely download its data.

GPS ID	Percent Vegetation Cover	Cover Type	Ending Battery life (V)	Proportion Within 30 m	Proportion Within 10 m	Proportion Within 5 m	Proportion Missing	Maximum Download Distance (m)
GAM13	0%	Bare ground	4.19	0.90	0.75	0.38	0.06	46
GAM02	23%	Edge of mesquite canopy	4.19	0.94	0.72	0.58	0.03	16
GAM30	45%	Rubber rabbitbrush	4.05	0.93	0.72	0.58	0.04	23
GAM24	71%	Cholla	4.2	0.96	0.75	0.62	0.03	5
GAM29	NA*	Rubber rabbitbrush	4.08	0.97	0.88	0.74	0.03	45
GAM07	88%	Base of mesquite	4.17	0.92	0.66	0.51	0.02	5

*Placed within a rubber rabbitbrush clump to represent a potential nesting female quail

Quail Movement

2024 Season

We deployed 23 GPS/VHF combination units on 21 female quail and two male quail and one necklace-style VHF transmitter unit on a female quail. We were unable to collect data on one male and four females (four with GPS/VHF units and one with a VHF transmitter). This was due to battery drainage from improper unit programming on the first two GPS/VHF units that were deployed, and the remaining two GPS/VHF units and one VHF transmitter either malfunctioned or the quail went missing which was determined based on our lack of ability to pick up a signal during and following the first attempt to locate them. We monitored the remaining 18 telemetered quail for a mean of 62 days (SD = 29, range = 18 – 102). As the GPS transmitters' solar panels often did not fully recharge a unit's battery, we averaged a mean of 24 days per individual (SD = 20, range = 1-67). We downloaded a mean of 515 GPS locations per individual from quail with GPS/VHF transmitters (SD = 646, range = 4-2737) (Table 2, Figure 2). We did not collect any GPS locations using our remote base station during the fall and winter. We recorded a mean of 12 VHF telemetry locations per individual (SD = 6.74, range = 1–25).

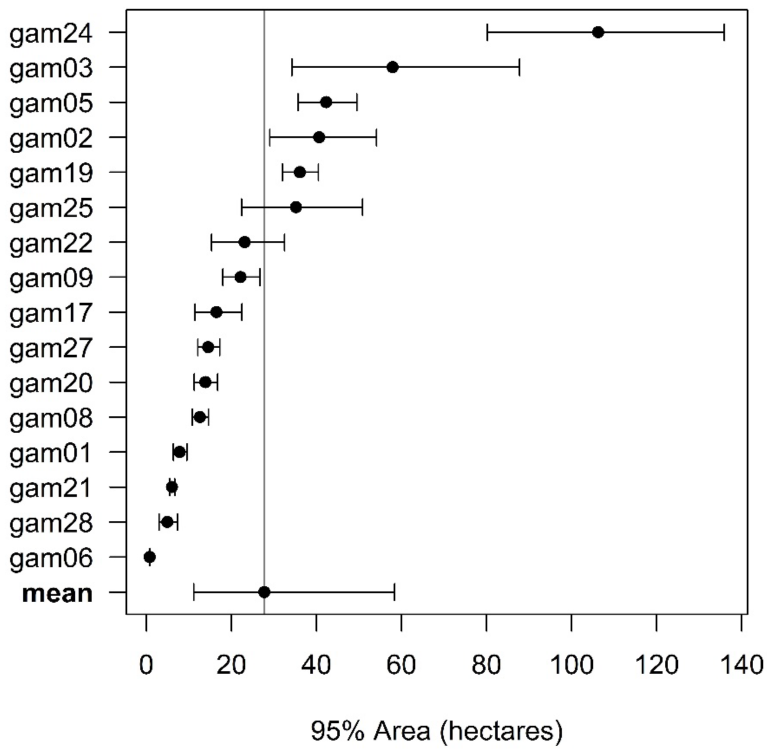
The maximum distance moved by each of our 18 GPS-telemetered quail from their respective capture location averaged 792 m (SD = 579 m, range = 107-2390 m; Table 2). The mean distance a quail resided from its capture location also varied widely among individuals (mean = 354 m, SD = 311 m, range = 33-1277 m; Table 2). We estimated home range sizes for 15 females and one male that had ≥19 GPS locations (Table 2). The mean home range size estimate was 25 ha (SD = 25.58, range = 3–100 ha; Figure 2). Our home range size estimates were not strongly correlated with the total number of days a quail was monitored (r = 35, P =

0.185), the number of days during which at least one GPS location was obtained ($r = 0.26$, $P = 0.339$), or the number of GPS locations ($r = 0.10$, $P = 0.711$).

Table 2. Summaries of GPS and VHF telemetry data collected from Gambel's quail in southeast Arizona during March through August 2024. Notes indicate birds that were presumed mortalities, went missing, or other pertinent information. Distances are Euclidean distances from a quail's first GPS location (i.e., point of capture).

Bird ID	**Date deployed**	**Notes**	**Days of at least one GPS location**	**Days monitored after transmitter deployment**	**GPS locations**	**VHF locations**	**Maximum distance moved from capture (m)**	**Mean maximum distance moved from capture (m)**	**Home range size (ha)**
GAM01	4/23/2024	Mortality	24	44	293	13	382	98	8
GAM02	5/9/2024	NA	19	95	369	20	987	250	41
GAM03	5/9/2024	NA	10	95	103	20	621	457	58
GAM04	6/2/2024	Missing	1	28	4	7	115	91	NA
GAM05	4/30/2024	NA	67	94	1385	19	2390	579	42
GAM06	4/13/2024	Mortality	13	20	278	6	329	213	1
GAM08	5/24/2024	Brooding at capture	41	80	510	19	875	241	13
GAM09	4/4/2024	NA	49	95	543	20	782	188	22
GAM10	3/20/2024	Mortality	NA	NA	NA	NA	NA	NA	NA
GAM11	6/25/2024	NA	1	46	6	8	255	239	NA
GAM14	5/8/2024	Missing	NA	NA	NA	NA	NA	NA	NA
GAM17	5/23/2024	Missing	5	18	99	4	625	337	16
GAM18	6/13/2024	Missing	NA	NA	NA	NA	NA	NA	NA
GAM19	4/9/2024	NA	63	93	2737	26	1748	1277	36
GAM20	5/3/2024	NA	28	75	564	15	487	129	14
GAM21	5/3/2024	Mortality	25	75	542	8	721	408	6
GAM22	5/28/2024	NA	4	49	73	8	1258	984	23
GAM24	6/19/2024	NA	36	54	408	10	1459	377	106
GAM25	5/2/2024	NA	17	102	270	17	578	111	35
GAM27	4/16/2024	Missing	19	37	1072	9	538	353	15
GAM28	3/20/2024	Male	4	22	19	1	107	33	5

Figure 2. Home range estimates (95% utilization distributions from autocorrelated kernel density estimators) for 15 female and one male Gambel's quail monitored using GPS telemetry during March through August 2024 in southeast Arizona. We present the estimated home range size (black circle) and its 95% confidence interval (CI, error bars) for each individual and a population-level average (25 ha) and 95% CI.



2025 Season

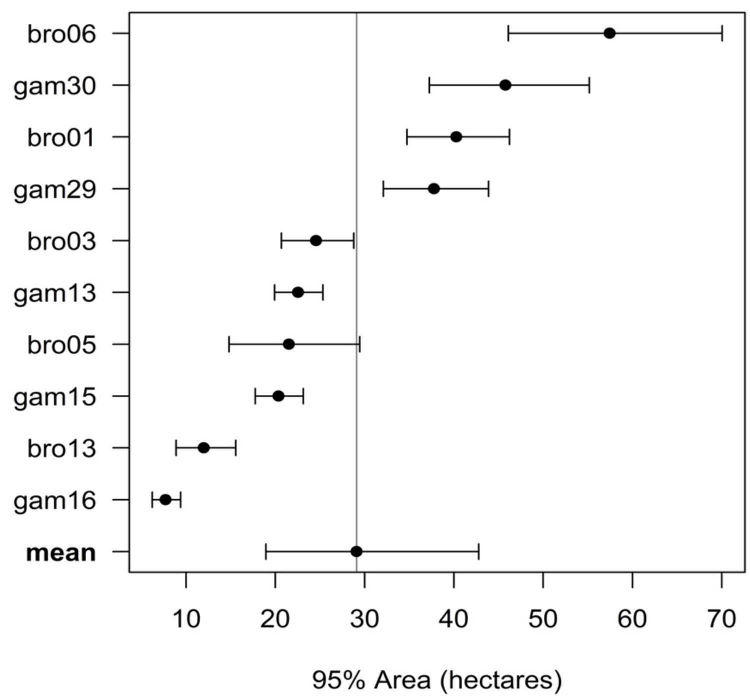
We deployed 12 GPS/VHF combination units on female quail and two necklace-style VHF transmitter units on female quail. We were unable to collect data on one female with a GPS/VHF unit because we could not pick up a signal on her transmitter post-deployment. We recorded a mean of five total VHF telemetry locations to date for the remaining 14 telemetered quail (SD = 2, range = 1 – 8 days). We averaged a mean of 33 days of at least one data point collected per day per individual (SD = 21, range = 2-73). We downloaded a mean of 726 GPS locations per individual from quail with GPS/VHF transmitters (SD = 914, range = 13-2860) (Table 3, Figure 3). We did not collect any GPS locations using our remote base station during the fall and winter.

The maximum distance moved by each of our 12 GPS-telemetered quail from their respective capture location averaged 792 m (SD = 263 m, range = 13-2860 m; Table 3). The distances quail moved from their capture locations also varied widely among individuals (mean = 338 m, SD = 158 m, range = 154-625 m; Table 3). We estimated home range sizes for 10 females that had ≥71 GPS locations (Table 3). The mean home range size estimate was 29.10 ha (95% CI = 18.94-42.78, SD = 14.93, range = 8–57 ha; Figure 3). Our home range size estimates were not strongly correlated with the total number of days a quail was monitored (r = -0.10), the number of days during which at least one GPS location was obtained (r = 0.01), or the number of GPS locations (r = 0.10).

Table 3. Summaries of GPS and VHF telemetry data collected from Gambel's quail in southeast Arizona during March through 15 May 2025. Notes indicate birds that were presumed mortalities, went missing, or other pertinent information. Distances are Euclidean distances from a quail's first GPS location (i.e., point of capture).

Bird ID	Date deployed	Notes	Days of at least one GPS location	Days monitored after transmitter deployment	GPS locations	Maximum distance moved from capture (m)	Mean maximum distance moved from capture (m)	Home range size (ha)
BRO01	3/9/25	Missing	34	42	417	1210	524	40
BRO03	3/9/25	Mortality	29	43	263	531	186	25
BRO05	5/4/25	NA	11	12	71	488	197	22
BRO06	4/13/25	NA	33	34	341	953	386	57
BRO13	4/9/25	low voltage	11	31	124	386	159	12
GAM13	3/5/25	NA	73	74	809	763	308	23
GAM15	3/6/25	NA	69	73	2860	708	154	20
GAM16	3/1/25	Mortality	34	35	425	764	625	8
GAM23	3/8/25	Missing	2	24	13	699	468	NA
GAM29	3/8/25	Mortality	25	26	318	995	475	38
GAM30	3/6/25	NA	41	42	2343	1213	240	46

Figure 3. Home range estimates (95% utilization distributions from autocorrelated kernel density estimators) for 10 female Gambel's quail monitored using GPS telemetry during March through 15 May 2025 in southeast Arizona. We present the estimated home range size (black circle) and its 95% confidence interval (CI, error bars) for each individual and a population-level average (25 ha) and 95% CI.



Quail and Nest Survival

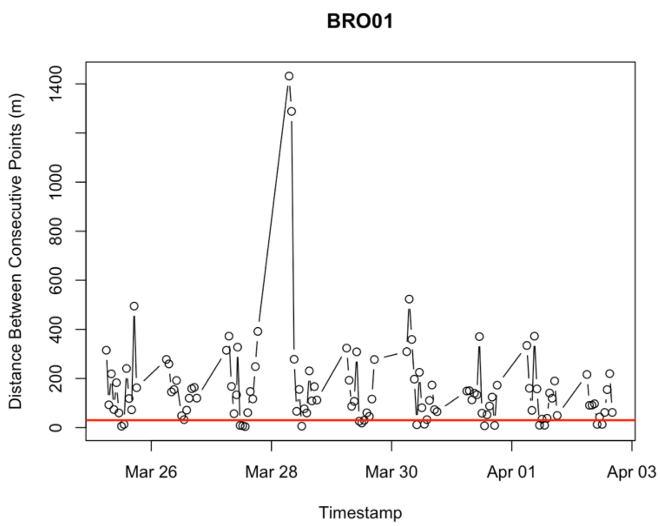
2024 Season

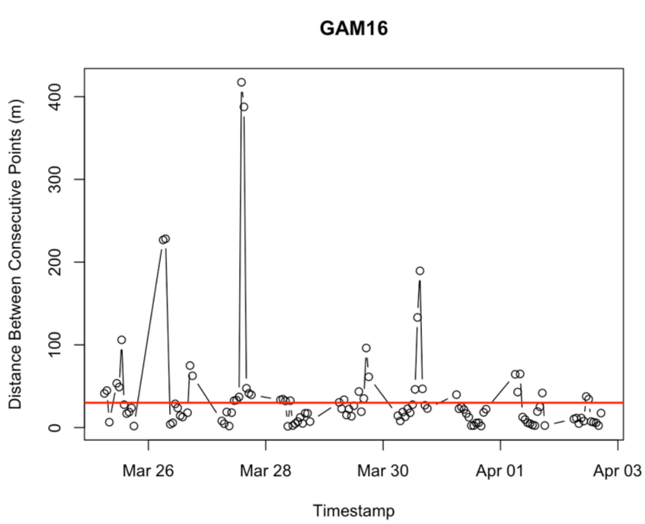
We documented four mortalities out of 10 telemetered quail. All four mortalities appeared to be from predation. We located 3 nests from 3 different individuals with 6 eggs (located 10 June 2024), 8 eggs (located 7 June 2024) and 15 eggs (located 28 March 2024). Two nests were found depredated on 10 April 2024 and 3 May 2024 and the third nest was found to be abandoned on 18 June 2024. Three out of 21 Gambel's quail appeared to have broods by the beginning of August, and all three broods were not observed with the hen appeared to have failed by the end of August.

2025 Season

We documented 4 mortalities out of 14 telemetered quail prior to May 15th. All four mortalities appeared to be from predation. Transmitters located on mortalities were found without evidence of quail remains on all but one mortality which had Gambel's quail feathers 1 m from the transmitter. All transmitters were recovered except for one which was located in a packrat midden out of reach. One nesting female was identified after multiple VHF checks positioned her in the same exact location and was confirmed after comparing GPS data from this individual (Figure 4) to other non-nesting quail (Figure 4). Nest initiation was determined to be on 20 March 2025. This nest was predated along with the female and no evidence of eggs were found. No broods were found with any telemetered or non-telemetered quail and there was no evidence of brood patches on any quail that were handled during trapping.

Figure 4. Euclidean distance between consecutive points for two female Gambel's quail monitored using GPS telemetry during 25 March through 2 April 2025 in southeast Arizona. We present the movement patterns of a nesting (top image) and a non-nesting (bottom image) quail. Distance between consecutive points indicates the range of daily movement of the individual. The red line is placed at 30 m which indicates the threshold for GPS error that should be accounted for when an individual may be stationary. Please note the difference in range of y-axis values between nesting and non-nesting quail.





Nest and Brood Site Habitat Selection

2024 Season

We collected vegetation measurements at all three nests during June and July and at two random points per nest during August. We collected vegetation measurements at six brood locations for one telemetered quail during July and at six corresponding random locations during August. We also collected vegetation measurements from a second telemetered quail with a brood at one brood location during July and at one corresponding random location during July. We did not find evidence that vegetation features at nest and brood sites differed from what was available (Table 4).

2025 season

We collected vegetation measurements at our one identified nesting site in addition to two random points during April and May. Analyses using these vegetation measurements have not been conducted at the time of this report.

Table 4. Vegetation measurements at Gambel's quail nest and brood locations and corresponding paired random points in southeast Arizona during June through August 2024. We report the mean values of each covariate across all used (nest or brood site) and random points, the coefficient estimate, and the P value for that estimate.

Covariate	**Point Type**	**Mean (Used)**	**Range (Used)**	**Mean (Random)**	**Range (Random)**	**Coefficient**	***P* value**
% Grass Cover	Nest	21.67	10-40	17.92	5-50	1.045	0.37
% Bare Ground	Nest	18.33	10-27.5	25.83	5-70	0.4575	0.527
Canopy Cover	Nest	37.5	0-85	25.75	0-88	0.8192	0.33
% Shrub Cover	Nest	19.17	12.5-25	8.75	0-27.5	49.46	0.998
% Grass Cover	Brood	34.58	15-67.5	18.75	10-27.5	0.7911	0.413
% Bare Ground	Brood	32.08	10-57.5	43.75	25-57.5	0.4859	0.496
Canopy Cover	Brood	30	0-78.5	8.88	0-20	0.6225	0.449
% Shrub Cover	Brood	3.333	0-10	12.5	0-27.5	0.354	0.653

Discussion

Quail Trapping

Our study shows that noose mats are a successful method for capturing Gambel's quail in non-urban environments. While drop box traps have been used successfully to trap Gambel's quail in urban environments (e.g., golf course; Acevedo *et al.* 2023), we had much less success in our study. Gambel's quail may have a higher affinity for being trapped in noose mats because the low profile and discrete positioning of noose mats may be less intimidating compared to larger traps. Many additional factors likely influenced the efficacy of our trapping efforts including quail behavior, our specific trapping locations, previous hunting activity, and available resources. Previous quail studies have used similar baits in their trapping; however, these studies began trapping earlier in the winter (December and January; Marquardt *et al.* 2017; Buckley *et al.* 2022) when quail may have less food resources compared to resources available to Gambel's quail during February in our study. We were unable to start baiting and trapping until the end of quail hunting season for both years (mid-February) which limited the duration of our prebaiting. Our study area is also a popular site for recreational quail hunting and human activity during hunting season may have influenced quail behavior in our study area. For example, our first trapping location in 2024 appeared to receive more hunting pressure, and quail at this site appeared more skittish than quail at our final trapping sites. The winter of 2023-2024 also had exceptionally high precipitation which resulted in substantial amounts of green vegetation during our trapping period. The correspondingly high density and abundance of quail food may have reduced interest by quail in the bait at our trapping locations. This was evident from in-person observations and camera trap footage of quail walking up to drop traps and walk-in traps, seeing the seed, and still choosing to walk away from the traps, seemingly uninterested in the seed or the trap.

To address these challenges, we moved our trapping efforts in 2024 to a less hunted area (Lower Tank) and began using noose mats in addition to our other trap types. We also experimented with using a taxidermy quail under a drop trap to attract quail and playing quail calls from a small remote speaker placed under a drop trap. However, neither of these approaches seemed to attract quail to the drop traps. Trapping during the evening was also unsuccessful. We attribute most of our trapping success to trapping in an area less frequented by hunters and to our use of noose mats.

In contrast with the high level of precipitation of the winter prior to our first field season, the winter of 2024-2025 had notably low amounts of precipitation. January 2025 was the 25th driest on record, and February 2025 was the 27th driest and 2nd warmest on record (NOAA 2025). We anticipated this unseasonably dry and warm winter to have a variety of effects on our second field season, including higher rates of captures. This was based on our assumptions from 2024 that quail may be more interested in seed amid a dry landscape with minimal green vegetation. We noticed much more interest in seed on the traps during 2025 compared to 2024, resulting in observations of increased noose mat encounters. It was apparent that the quail fed on the seed opportunistically as they passed by the traps, although, these interactions with the baited traps are likely due to chance encounters during their daily movements rather than quail using our bait as a known food source. Based on our observations, regular visits and movements around the trapping sites were more likely due to the presence of a regular water source.

Quail movements

Previous studies on Gambel's quail and other quail species reported larger home range sizes than we observed for Gambel's quail in southeast Arizona. For example, Temple *et al.* (2017) reported mean breeding season home range sizes for Gambel's quail in west Texas estimated from VHF telemetry locations were 129 ha (2012) and 105 ha (2013). This same study reported mean breeding season home range sizes of scaled quail (*Callipepla squamata*) of 151 ha (2012) and 96 ha (2013). Chavarria *et al.* (2017) reported a mean home range size for Montezuma quail (*Cyrtonyx montezumae mearnsi*) in southeast Arizona estimated from VHF telemetry locations of 99 ha (range = 8-287 ha). We are unsure of the factors potentially influencing these differences. Both Temple *et al.* (2017) and Chavarria *et al.* (2017) used VHF telemetry locations rather than GPS locations and different home range estimators (adaptive kernel and fixed kernel utilization distributions, respectively) which could have contributed to differences among studies. Variation in tracking duration among studies could also have contributed to differences although we note that our home range estimates were insensitive to tracking duration or number of locations which is to be expected when using autocorrelated kernel density estimators. It is possible that Gambel's quail resources occurred at a relatively high density in our study area, particularly since our trapping occurred at water sources, which may have contributed to our smaller home range sizes. We also found that we did not have to travel far from the trapping location to locate each bird toward the end of the season. Many of the quail we monitored resided a few to several hundred meters away from the tank with occasional visits to the tank. This facilitated our telemetry efforts as we could frequently depend on quail to remain within a relatively consistent area. However, we often observed telemetered quail running away from the researcher when tracking them using VHF telemetry, which made it challenging to get within range to remotely download the GPS locations from birds marked with GPS/VHF units. During July of 2024, we changed our approach for remotely downloading GPS locations. Specifically, we changed from holding the UHF beacon approximately 2 m above the ground to taping the UHF beacon on the end of an aluminum pole approximately 4 m above the ground. This greatly improved our ability to remotely download GPS locations.

Quail nests

Our small sample size of nests (four in total) limits our ability to make inferences regarding Gambel's quail nesting ecology. It is possible that very few of our quail nested and/or that their nests are very difficult to find using our searching methodology. If the latter is true, our observations suggest that quail can very discretely hide their nests and then walk away from the nest as we approach them using radio telemetry. As we became more familiar with the VHF signal strength and its corresponding distance from the quail, we discovered that it was very common for the quail to walk away from their original locations as we got within approximately 50 m. This often occurred before we were able to triangulate the position of the telemetered quail which inhibited our ability to locate nests. Nesting behavior was also not immediately apparent when looking at the GPS telemetry locations of our female quail, with the exception of one individual in 2025 (Figure 5). This female was the first and only individual in this study to exhibit movement patterns that reflect expected movements of a ground nesting upland game bird (Coates and Delehanty 2008). We often observed multiple small clusters of locations over several days during the nesting season rather than a single clear cluster of locations which could indicate an incubating female. In addition to the lack of nesting attempts for telemetered quail during the 2025 season, we did not observe nesting behavior or nests of non-telemetered quail in our study area. Group sizes of quail in 2025 to date remain relatively large, ranging from six to

20 individuals per group. These observations in the field and remotely through GPS data contradict the behavioral and movement patterns we expected to encounter during the Gambel's quail breeding season. The lack of evidence for reproductively active females in 2025 is likely due to the limited availability of resources necessary to support the energetic costs of nesting, owed to the lack of winter precipitation prior to the 2025 breeding season. Stressors during periods of drought such as heat and limited water availability have been linked to fewer nesting attempts and lower reproductive success in several species of quail, including Gambel's quail. This exacerbates the boom-and-bust effect on the population dynamics (Alagawany et al. 2017, Cain & Lien 1985). Quail remaining in relatively large groups may also be a product of these environmental factors as habitat is likely limited to smaller areas.

Quail survival

We positively identified 8 mortalities out of the 33 telemetered quail throughout the entirety of the 2024 and 2025 season. Hernandez *et al.* (2009) reported that the fate of all Montezuma quail affixed with backpack-mounted VHF transmitters (at least four individuals) as mortalities. However, these individuals were also translocated which likely contributed to the study's 100% mortality rate across all 14 individuals affixed with either necklace-style or backpack-mounted VHF transmitters. Buckley *et al.* (2022), who used the same style of GPS/VHF transmitter as we used, mentioned a concern of negative physical effects of the backpack harness on northern bobwhite in addition to the potential for an increase of predator attraction due to the reflective nature of the solar panel. We took precautions to minimize any potentially negative effects of our GPS transmitters on our Gambel's quail. We carefully observed each bird before and after deployment and did not note any adverse effects of the transmitters on the individuals. All mortalities were discovered a minimum of one week following deployment, indicating that the quail's acute survival was not negatively affected by the physical placement of the GPS/VHF and VHF units. Quail mortalities that occurred earlier in the 2025 season compared to the 2024 season may also be the result of the dry season which rendered a habitat lacking in the resources necessary to sustain the abundant quail population.

Brood survival is notoriously difficult to track without attaching transmitters to the individual chicks (Orange et al. 2016). While we did not find any chicks with the females determined to have broods by the end of August 2024, we cannot definitively state that these broods were unsuccessful. Various factors could explain the absence of chicks with marked hens at the end of the season including brood adoption by unmarked quail or prematurely fledged chicks.

Continued Efforts for 2025

We plan to continue trapping and tracking telemetered birds for the remainder of the summer until August 2025. To maximize the use of all tracking devices in our inventory, we plan to deploy the remaining VHF collars on males in addition to females. This could provide us with accurate estimating of adult Gambel's quail survival and causes of mortality. However, we will continue to reserve the GPS/VHF units to be deployed on females to maximize the opportunity to collect fine scale data on habitat that is selected by this sex during the breeding season. We plan to conduct at least three additional randomly selected habitat surveys to use in our analysis for the known 2025 nest site. We plan to continue to closely monitor our telemetered birds to identify additional nests and/or broods for the remainder of the season. We plan to finish our analyses using our updated data and draft a manuscript with the purpose of fulfilling the MS thesis requirements as well as for future publications.

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