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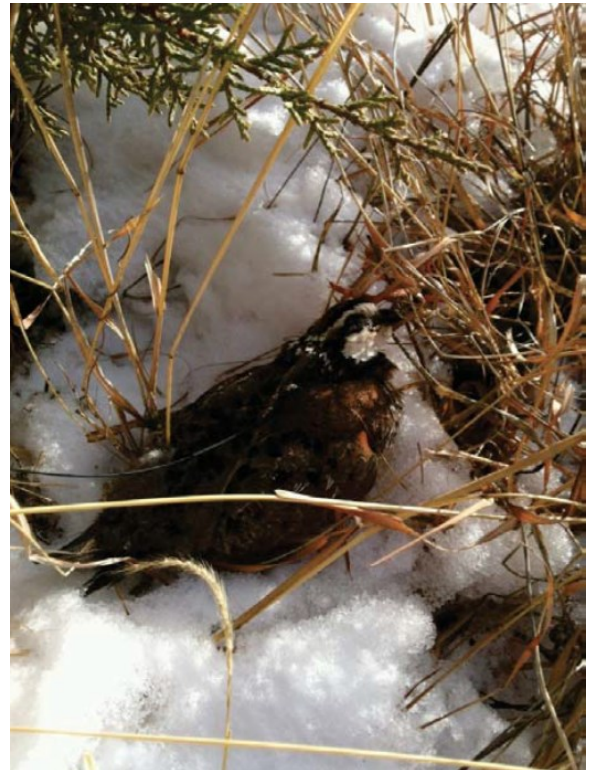


FULFILLING OUR MISSION: 2

By Brad Dabbert

In February of this year we sent you a bulletin with the same title and announced a research publication and placement of Quail-Tech Alliance Alumni into significant positions within state and nongovernmental conservation agencies. I am very proud to be repeating this announcement just a few months later. The foremost mission of the Quail-Tech Alliance is to develop methods of sustaining bobwhite populations in the Rolling Plains of Texas. As you are aware, we have been evaluating the influence of broadcasting supplemental feed directly into the habitat on bobwhite survival and reproduction since 2010. I am proud to announce the publication of our third research article in this area regarding the benefits of this supplemental feeding program for bobwhite survival. The article titled, "Broadcast Supplemental Feeding and Northern Bobwhite Demographics in Texas," is published in the Journal of Wildlife Management (attached at the end of this bulletin). We are proud of this accomplishment, because it fulfills our mission through the last step of the scientific method, publication, the Holy Grail for scientists. I think it is useful to repeat my explanation concerning the scientific method from a previous bulletin. The scientific method is a process by which we observe events in nature, formulate hypotheses describing the cause of these events, conduct experiments to test our hypotheses, and finally report our results to the scientific community. Experiments must be replicated in space and across years to guard against spurious results that are not causation. This is all important to you, because the validity of our work is judged within the scientific community by a process called peer-review. Peer-review is the process by which journal editors use the recommendations of 2 or more independent and anonymous reviewers to accept or reject scientific reports for publication in scientific journals. As you can imagine, this is a lengthy process. It is, however, a very healthy process, because it generally results in a quality filter for science.

When we started the Quail-Tech Alliance, we strived to test management techniques using sound science that would pass the stringent test of publication in a scientific journal. We have been testing the use of supplemental feed in Texas with experiments (feed vs no feed) that evaluate the influence of supplemental feed on wild bobwhite survival and reproduction in the field on a large scale. Specifically, this feeding method broadcasts grain sorghum directly into the habitat along ranch roads. Modern radiotransmitters allow us to monitor the survival and nest success of wild bobwhites. We have continued these feeding experiments for the past several years; using radiotransmitters to monitor more than 600 bobwhites in the process. Of course, none of this work would have been possible without the generous support of the 6666 Ranch, the Burnett Foundation, and the Park Cities Chapter of the Quail Coalition.



The research article announced in this bulletin details how many bobwhites, like this male in a control unit that did not have the benefit of supplemental feed, lost significant body weight and died during a winter storm. Birds that had constant access to supplemental feed suffered far less mortality. Supplemental feed was beneficial during a milder winter during the study as well.



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It is important to note that broadcasting supplemental feed is an add on benefit, not a replacement for proper habitat management to maintain sufficient vegetative cover for bobwhites. Without sufficient cover, bobwhites and their nests are more easily depredated. Nevertheless, this research article provides classic evidence of the benefits of this supplemental feed technique for increasing winter survival of wild bobwhites. The specific benefits that the article details for bobwhite survival are stated in the bullet points below:

- The average probability of surviving the winter period for birds receiving feed broadcast into the habitat (starting October 1) was 66%, but only 39% for birds not receiving feed
- This feeding approach increases the number of females available to start the breeding season, an obvious benefit for populations
- Reactively providing supplemental feed a few days before a winter storm event is ineffective for increasing bobwhite survival
- Snow depth was negatively related to bobwhite survival during winter, but broadcasting supplemental feed as described still benefited bobwhites during less severe winter conditions

These results directly link the management practice of broadcasting supplemental grain sorghum into roadside habitat to survival benefits measured in wild bobwhite populations and provides a management tool that can be employed to benefit bobwhites. Our biologists are currently in the field fitting many more bobwhites with radio-transmitters. Watch for future bulletins about our ongoing efforts to develop management tools that have measurable benefits to bobwhites in the field. Updates concerning our predator management and chick survival studies will be coming shortly.



Quail-Tech Alliance Alumni Isaac Young (left) and Bo Reid hold the first hen fitted with a radiotransmitter for their Predator Management study on the 6666 Ranch during February 2017. Isaac is now a Farm Bill Biologist for Pheasants Forever and Bo is a Private Lands Biologist for the Arkansas Game and Fish Commission.

In addition to developing management tools, the mission of the Quail-Tech Alliance is to educate future biologists to function as the next generation of leaders in both governmental and nongovernmental agencies. We are very proud to be fulfilling that mission as well, evidenced by announcements during the past year that two of our Quail-Tech Alliance (Texas Tech University, Department of Natural Resources Management) alumni have been hired for significant positions in conservation agencies. Mr. Bo Reid was hired as a Private Lands Biologist by the Arkansas Game and Fish Commission and is stationed in the Northeast portion of the state near Jonesboro, Arkansas. Mr. Isaac Young was hired to be a Farm Bill Biologist for Pheasants Forever and is stationed in North Platte, Nebraska. Bo and Isaac worked together for 2 years directing the supplemental feeding research efforts for the Quail-Tech Alliance on the 6666 Ranch during 2016 and 2017. You can look forward to seeing the results of their

Quail-Tech Alliance research efforts published in the scientific literature in the future. We are very proud of Bo and Isaac and look forward to watching the excellent careers they will have in their respective agencies. It should be noted that two of the authors of the research article previously mentioned, John McLaughlin and Derek Wiley, are also Quail-Tech Alumni who now work for Texas Parks and Wildlife and Quail Forever, respectively. Once again, we must thank the 6666 Ranch, the Burnett Foundation, and the Park Cities Chapter of the Quail Coalition. Their support directly contributed to the education and research efforts of these fine biologists.



Research Article

Broadcast Supplemental Feeding and Northern Bobwhite Demographics in Texas

JOHN W. McLAUGHLIN,^{1,2} *Department of Natural Resources Management, Goddard Building, Box 42125, Texas Tech University, Lubbock, TX 79409, USA*

DEREK S. WILEY,³ *Department of Natural Resources Management, Goddard Building, Box 42125, Texas Tech University, Lubbock, TX 79409, USA*

C. BRAD DABBERT, *Department of Natural Resources Management, Goddard Building, Box 42125, Texas Tech University, Lubbock, TX 79409, USA*

THERON M. TERHUNE, *Tall Timbers Research Station and Land Conservancy, 13093 Henry Beadel Drive, Tallahassee, FL 32312, USA*

ABSTRACT Northern bobwhite (*Colinus virginianus*) abundance is declining. Food limitations have been hypothesized to exacerbate the boom and bust cycle exhibited by bobwhites, with supplemental feeding advocated as a way to mitigate this annual variability in demographics. A new technique (i.e., broadcast feeding) has exhibited positive effects on the seasonal survival of bobwhites. To ensure the safe adoption of any management practice, replication is necessary. We employed a randomized, crossover experimental design to evaluate the effect of 3 different supplemental feed rates (full [69.1 kg/km], half [34.6 kg/km], control [no feed]) on bobwhite survival and used the known-fate data type to assess the fate of radio-marked individuals within the Rolling Plains of Texas, USA. We assessed temporal (biological vs. calendar season) and treatment-level (feed vs. control) effects on survival. Our top temporal model included an interaction between year and calendar season as the most parsimonious model. Survival was lowest during winter. The most parsimonious treatment-level model included an interaction between feed and winter, plus the additive effect of snow depth. The application of the full and half feed treatments had positive effects on survival during winter compared to control units in both years, across all pastures. Our data indicated there was no difference between the full and half feed rates. Snow accumulation had a negative effect on survival in both years. Broadcast feeding improved winter survival rates and subsequently, the number of females available entering the breeding season. Broadcast feeding serves as an additional management tool for wildlife managers within a strategic management program to benefit bobwhite survival during periods of physiological stress. We recommend the continued use of this management technique in regions where similar range and weather conditions exist to further evaluate its effectiveness. 2018 The Wildlife Society.

KEY WORDS *Colinus virginianus*, crossover design, demographics, known-fate, northern bobwhite, supplemental feed, survival, Texas, winter.

Once widespread throughout the eastern, southern, and central United States, intensive agricultural and silvicultural practices, a disparity in management objectives, and rapid urbanization have led to extensive declines in northern bobwhite (*Colinus virginianus*; bobwhite) abundance (Rollins 2002, Williams et al. 2004, Brennan and Kuvlesky 2005, Jones et al. 2010). The North American Breeding Bird Survey indicated a 3.5% annual decline in bobwhite abundance nationwide and a 1.8% decline in Texas during

1966–2015 (Sauer et al. 2017). Related to habitat deficiencies, researchers have hypothesized that food limitations (e.g., during drought years) and resource accessibility (e.g., during heavy snow periods) may exacerbate population instability during periods of corporeal stress (Leopold 1977, Guthery 1997, Miller 2011, Janke et al. 2017). For galliformes, food availability varies spatially (e.g., landscape, local level), along environmental gradients (e.g., elevation, latitude; Balasubramaniam and Rotenberry 2016), and temporally (e.g., within seasons or among years). Reduction in food resources may elicit inter- and intraspecific competition (*in situ* density-dependence; Guthery 1997) such that the survival of individuals may be adversely affected. The influences of regional climate patterns in xeric ecoregions, particularly annual precipitation, are strong determinants of bobwhite demographics (Lusk et al. 2001, Hernández et al. 2005). Jackson (1962) hypothesized that

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¹E-mail: john.mclaughlin@tpwd.texas.gov

²Current affiliation: Texas Parks and Wildlife Department, 5325 N 3rd Street, Abilene, TX 79603, USA.

³Current affiliation: Pheasants Forever, Inc. and Quail Forever, 109 W Chestnut Street, Throckmorton, TX 76483, USA.

drought, livestock grazing practices, plant succession, and periods of heavy rain are primary factors influencing the bobwhite population boom and bust cycle observed in the Rolling Plains eco-region; independently or in combination, these circumstances may alter the quantity of, and accessibility to, food resources (Errington 1939, Doerr and Silvy 2006, Miller 2011).

Beyond predominant weather and range conditions, anthropogenic modification of vegetation has disrupted plant succession, reducing food and cover resources for bobwhites at different life stages (Roseberry et al. 1979, Seckinger et al. 2008). The intensification of farming (Washburn et al. 2000) and timber practices (Jones et al. 2010) and the creation of monocultures for grazing (i.e., improved grasses; Burger 2001) eliminate the grasses, forbs, and shrubs essential for bobwhites (Flanders et al. 2006). Increased homogeneity of vegetation affects numerous bird communities in the central United States; since the mid-1800s the estimated loss of grassland ecosystems has surpassed 80% (Brennan and Kuvlesky 2005). The manipulation and disappearance of habitat and food resources necessary for population growth (Guthery et al. 2000, Riddle et al. 2008) and genetic diversity (Westemeier et al. 1998) generate questions regarding current and past land use and future wildlife management strategies. Targeting the underlying, proximate mechanisms that affect population growth is critical for wildlife agencies responding to changing landscape conditions. For bobwhites, environmental conditions may exacerbate the negative influence of poor habitat quality (Jackson 1962). Thermal stress due to insufficient food resources or inadequate herbaceous and brush cover can affect reproductive effort and success (Guthery et al. 2005, Hernández and Guthery 2012) and stress associated with winter conditions (e.g., extended cold periods) can compromise a bobwhite's immune system (Dabbert et al. 1997) and ultimately, survival. In conjunction with proper habitat management (Hernández and Guthery 2012), providing an energy source for birds to mitigate these environmental stressors has been advocated by land and wildlife managers (Buckley et al. 2015).

Nutritional deficiencies resulting from the absence of, or limited availability to, quality food resources present challenges to the bobwhite and managers. Food limitations during drought conditions (Guiliano et al. 1996, Hernández et al. 2005) and periods of extended snow coverage (Roseberry and Klimstra 1984), and the increased caloric requirements to thermoregulate during winter (Swanson and Weinacht 1997, Janke et al. 2017), typify periods when bobwhites are unable to meet their energy requirements (Wood et al. 1986, Buckley et al. 2015). Guiliano et al. (1996) reported that diets low in energy were closely tied to body mass loss and Leif and Smith (1993) acknowledged that when given high energy food sources, quail were better able to respond to changing climactic conditions. For many, the supplementation of feed during these periods has seemed a logical step in addressing resource concerns (Hernández et al. 2007, Rollins 2007). Using bobwhites as a model species and survival as a proxy for the overall fitness of individuals,

researchers have tested whether supplemental feeding, as a management strategy to address food limitations, can provide appreciable survival benefits for local and regional populations (Ellis et al. 1969, Doerr and Silvy 2002, Buckley et al. 2015). Traditionally wildlife managers have used food plots (Joselyn 1965, Robel 1969, Robel et al. 1974, Madison et al. 2002), stationary feeders (Dumke 1982, DeMaso et al. 1998, Guthery et al. 2004), and road baiting (Haines et al. 2004, Hernández et al. 2007), or a combination thereof (Townsend et al. 1999), to improve the survival rates of northern bobwhites or enhance hunting opportunities (Schulz et al. 2003); the results have been mixed with a majority of studies indicating conventional feeding regimes are not a viable strategy. Notably, The Wildlife Society's position statement cautions against supplemental feed as a panacea, citing the potential to affect gamebird behavior (e.g., intraspecific competition), alter predation rates, facilitate disease transmission, and affect non-target species (Sonant and Maestro 2006). After decades of research dating back to the 1950s, questions remain about the ethics and efficacy of feeding programs and their economic feasibility for landowners and wildlife agencies (Jackson 1969, Sonant and Maestro 2006, Hernández and Guthery 2012).

In the early 1990s, researchers at the Tall Timbers Research Station (TTRS) in Tallahassee, Florida, USA, and the Albany Quail Project in Albany, Georgia, USA, began evaluating the effects of food supplementation on the survival of bobwhites (Sisson et al. 2000, Whitelaw et al. 2009, Palmer and Sisson 2017), and the persistence of feed on the landscape (Miller 2011). Building upon their techniques, Buckley et al. (2015) implemented a feeding program in west Texas centered on broadcasting supplemental feed into areas adjacent to roadways using regularly available ranch equipment. This technique incorporated a modified truck-mounted cattle feeder that spread feed away from the roads and allowed quail to feed on a readily accessible resource under the concealment of adjacent vegetation; foraging in this manner presumably allows birds to feed with less interruption, meet their energy demands more quickly (Whitelaw et al. 2009), and minimize their exposure to predation. Using this technique, the TTRS showed improvements in bobwhite survival and productivity and observed longer nesting seasons and higher body masses for birds with access to feed (W. E. Palmer, TTRS, unpublished report). Subsequently, Buckley et al. (2015) reported female birds used feed to their advantage (e.g., improved survival) during drought years, or periods of limited food availability, suggesting the benefits exceed that of the natural landscape's capacity and that resource limitations may exist.

To date, no method of feeding has consistently yielded improvements in bobwhite demographics under multiple iterations. Our primary objective was to replicate and substantiate the work by Buckley et al. (2015). We predicted the survival of birds would be higher on food-supplemented sites than on our control sites. Our secondary objective was to assess whether we could reduce the feed rate used in the Buckley et al. (2015) study by half and observe comparable

results to their original treatment. We predicted there would be no difference in the survival rates of birds receiving feed, at either rate. Finally, we wanted to evaluate multiple temporal periods (biological season vs. calendar season) as they related to bobwhite survival. We predicted the finer temporal periods associated with calendar seasons would better explain bobwhite survival than the often used biological, or classic quail, seasons.

STUDY AREA

We conducted our research on the 6666 Ranch (also referred to as the Four Sixes) between 1 October 2013 and 31 August 2015. Biological seasons were defined as over-winter (1 Oct–31 Mar) and summer-breeding (1 Apr–31 Sep; Sandercock et al. 2008). We delineated calendar seasons into 4 periods using equinox and solstice dates (fall = 22 Sep–20 Dec, winter = 21 Dec–19 Mar, spring = 20 Mar–20 Jun, summer = 21 Jun–21 Sep; Strahler 2013). The Ranch was headquartered out of Guthrie, Texas in central King County, Texas, part of the Rolling Plains Ecoregion. The region was characterized by 2 major land uses: ranching (beef cattle) and agriculture (dryland wheat and cotton). The county received an average of 61 cm of precipitation annually, with 48 cm falling between April and October; average annual snowfall was 12 cm (Natural Resources Conservation Service [NRCS] 2007).

Within the research area, we selected 2 separate sites known as the Southwest and Hackberry pastures; our study sites were 3,700 and 1,200 ha, respectively. Elevation varied between 450 and 600 m above sea level with flat to rolling topography and interspersed creek canyons. The Southwest pasture was located 12 km southwest (33.52764°N, –100.39809°E) of Guthrie and the Hackberry pasture was located 5 km north (33.66941°N, –100.39809°E) of Guthrie (Fig. 1). Dominate resident fauna included red-tailed hawks (*Buteo jamaicensis*), northern harriers (*Circus hudsonius*), white-tailed deer (*Odocoileus virginianus*), feral swine, coyotes (*Canis latrans*), bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), spotted skunks (*Spilogale* spp.), cotton rats (*Sigmodon hispidus*), several species of mice (*Peromyscus* spp.), western diamondbacks (*Crotalus atrox*), and western massasaugas (*Sistrurus catenatus*). The primary land uses for both pastures were cattle grazing and wildlife habitat management for bobwhites and white-tailed deer. According to Buckley (2013), the Southwest pasture received a combination of juniper (*Juniperus* spp.) grubbing and strip disking in late 2009 and early 2010, to promote quail cover and natural food sources. Range conditions were primarily manipulated with cattle. Both pastures were rested from grazing in 2011–2012 because of an extended regional drought. In mid-2013 cow-calf pairs (~200) were gradually brought back onto the rangeland. The soil was comprised of Woodward and Paducah loam, Grandfield fine sandy loam, and very fine sandy loam with level to steep slopes (Andes et al. 2012, Buckley 2013).

Rangelands conditions were similar to those described by Rollins (2007). Average vegetation structure preceding this study was 0.78 m in height and 85.6% cover of which 29.6%, 54.3%, and 14.4% was woody, grass, and succulent cover,

respectively (Andes et al. 2012). The dominant woody cover consisted of mesquite (*Prosopis glandulosa*), redberry juniper (*Juniperus coahuilensis*), and lotebush (*Ziziphus obtusifolia*), supplemented with sand sagebrush (*Artemisia filifolia*), vine ephedra (*Ephedra antisyphilitica*), yucca (*Yucca glauca*), and netleaf hackberry (*Celtis reticulata*). Grass cover primarily consisted of silver bluestem (*Bothriochloa laguroides*), fall witchgrass (*Digitaria cognata*), little bluestem (*Schizachyrium scoparium* var. *frequens*), sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*). Other abundant species were western ragweed (*Ambrosia psilostachya*), common broomweed (*Amphichyris dracunculoides*), annual sunflower (*Helianthus annuus* L.), Mexican sagewort (*Artemisia ludoviciana mexicana*), pricklypear (*Opuntia* spp.), and tasajillo (*Opuntia leptocaulis*).

METHODS

Supplemental Feed

We broadcast supplemental feed into cover (Buckley et al. 2015). We divided the Southwest pasture into 9 distinct, 404.6-ha units, with an additional 3 units on the Hackberry pasture (Fig. 1). We used 404.6-ha units (~10–15× larger than the average bobwhite home range size; Tri et al. 2014, Buckley et al. 2015) to minimize unit overlap and decrease the risk of birds traveling between individual feed units. We distributed grain sorghum (*Sorghum* spp.; milo) on a bi-weekly basis behind a truck using a trailered trip hopper cattle feeder (T&S Manufacturing, Jermyn, TX, USA) with a feed spreader modified from a cattle siren fan (J&J Sirens, Old Glory, TX, USA). We broadcast milo at 3 different rates: full feed (69.1 kg/km), half feed (34.6 kg/km), and control (no feed). We distributed feed in a broadcast fashion using a modified electric 12-volt motor attached to the cattle feeder; this design threw feed leaving the hopper into the right side roadside vegetation, traveling 0.3–18 m as documented by Buckley et al. (2015). The average length of road available for feeding was 5.0 km/unit. The length of roads fed varied throughout the year because precipitation and ranch work made portions of the pastures unavailable (e.g., washouts, deep snow, ephemeral creeks, calving). We spread feed beginning 1 October of each year and fed year-round.

We randomly assigned each of the 12 units to a treatment (full, half, control). We assigned treatments without replacement independently for each pasture. There were 4 units/treatment within each of the 2 study years. We used a crossover design, alternating treatment units from 2013–2014 (year 1) to 2014–2015 (year 2; Fig. 1). We obtained snow depth from climatological datasets developed by the National Oceanic and Atmospheric Administration (National Centers for Environmental Information [NCEI] 2016). Our research was approved by the Texas Tech University Animal Care and Use Committee (approval number 12074-10).

Capture and Telemetry

We captured bobwhites using standard funnel traps baited with milo (Stoddard 1931, Smith et al. 1981) during fall,

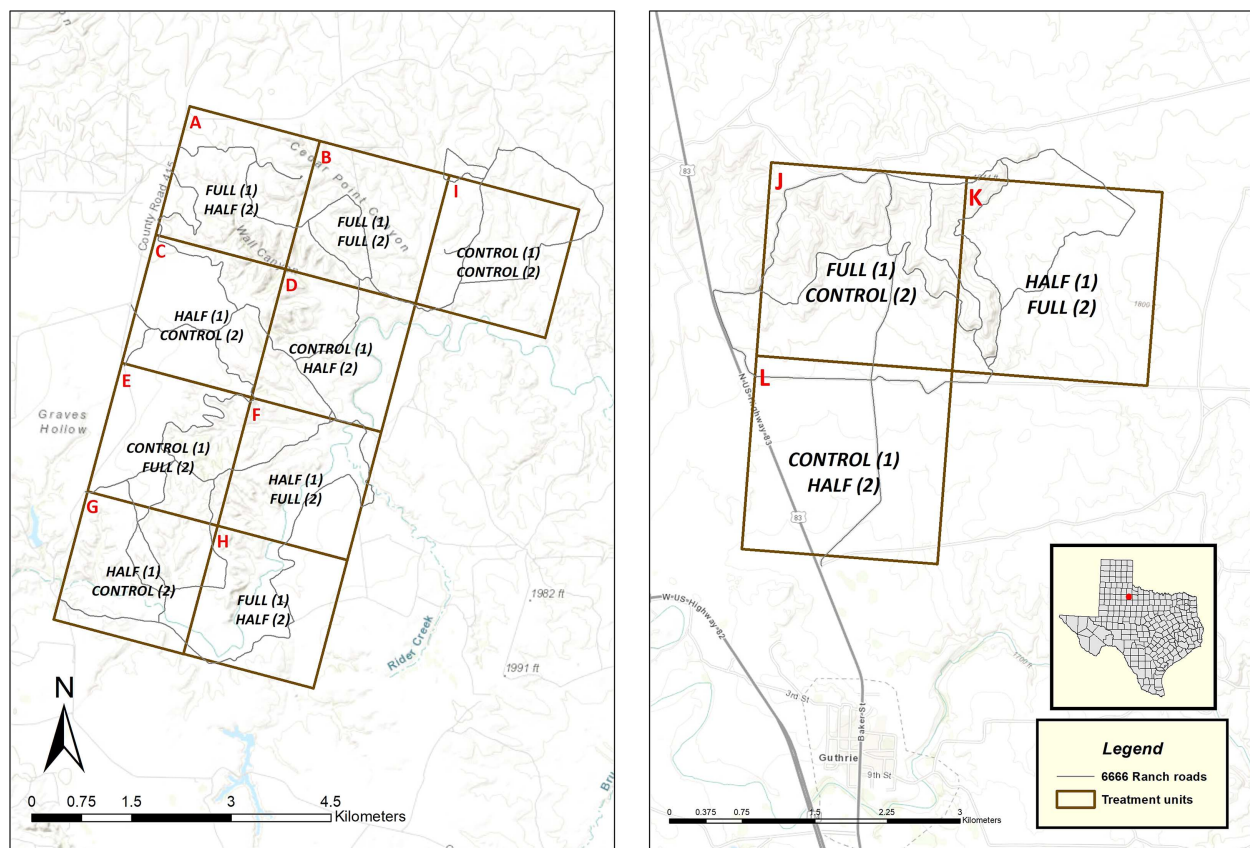


Figure 1. Experimental layout of supplemental feed units (A–L) and feed rates (full, half, control) on the Southwest (left) and Hackberry (right) pastures, 2013–2014 (1) and 2014–2015 (2), 6666 Ranch, Guthrie, Texas, USA.

winter, and spring (Oct–Mar) of 2013–2014 and 2014–2015. The addition of individuals into the study over time was consistent with the staggered entry design for survival presented by Pollock et al. (1989). We placed an average of 4 traps/unit and did not trap within 500 m of any border to minimize the likelihood that a radio-tagged bird would by chance move between units. We primarily trapped at night, setting and baiting traps 4 hours prior to sunset and checking those traps 30–45 minutes after sunset. We removed bobwhites, placed them in individual cotton bags for processing, and, if necessary because of cold temperatures, placed them underneath a lightweight wool blanket. We determined sex and age of bobwhites according to Leopold (1939, 1945) and weighed birds to the nearest gram using an Ohaus HH120 Pocket Digital Scale (Ohaus Corporation, NJ, USA). Bobwhites weighing ≥ 150 g received a pendant-style radio-tag (6.5 g with mortality switch; American Wildlife Enterprises, Monticello, FL, USA).

We used an H style very high frequency antenna (model RA-23K; Telonics, Mesa, AZ, USA) in combination with a 148–174 MHz receiver (model R1000, Communication Specialists, Orange, CA, USA) to home-in on birds (White and Garrott 1990, Fuller et al. 2005) ≥ 1 time/week (Baxter et al. 2008, Anthony and Willis 2009). We allowed an acclimation period of 7 days post-capture before considering an individual part of a cohort and including them in the survival analysis (White and Garrott 1990, Burger et al.

1995, Lohr et al. 2011). We censored birds surviving through year 1 and began anew in year 2. We censored birds from survival analysis that had an unknown fate or experienced radio failure or loss (Burger et al. 1995, Williams et al. 2000, Palmer and Wellendorf 2007). If a radio-tag switched to a mortality signal, we located the bird as soon as possible to identify the cause of death based on sign at the field site (Dumke and Pils 1973).

Analytical Approach

We developed 2 candidate suites of models to explicitly evaluate biologically relevant *a priori* hypotheses. The first model suite incorporated temporal effects (e.g., year, season) to determine which time periods best explained the variation in survival. Many northern bobwhite studies have evaluated survival using 2 biological seasons (Sandercock et al. 2008), whereas other researchers have used finer temporal resolutions, more consistent with climatic seasonal variation (i.e., calendar season), to understand survival in galliformes (Palmer et al. 1993, Blomberg et al. 2013). We used model selection to inform which period was most appropriate for explaining the variation in our data. We used independent, time-varying covariates (TVC) to model our temporal data based on biological season versus calendar season. We coded each season, biological and calendar, with a binary (0 or 1) indicator variable for all 52 weekly intervals (biological season = 104 TVC; calendar season = 208 TVC). We tested

several models using linear (T) and quadratic (TT) trends (Cooch and White 2014).

Our second model suite evaluated treatment-level effects (e.g., feed vs. control); we chose to use only the informative parameters from our top-ranked temporal model as determined by their beta estimates (95% CIs not overlapping 0), rather than the top model in its entirety. This method allowed us to isolate and evaluate treatment-level effects of select covariates (Anderson et al. 2000, Nakagawa and Cuthill 2007, Anderson 2008, Terhune et al. 2010). Specifically, we were interested in assessing the hypotheses related to the additive and interactive effects of our treatments, study sites, seasons, and snow depth, an indicator of environmental severity (Janke et al. 2017). We used 2 groups to delineate birds between years, 2013–2014 and 2014–2015, and 52 independent TVCs for each feed rate (full, half, and control; total = 156 TVC). This approach allowed us to account for inconsistent feeding schedules, or lack thereof, among treatments in our analysis (e.g., we applied feed in a control treatment unit for 1 weekly interval). We modeled snow depth (weekly max.) using a TVC for each time interval in our study.

We employed a multi-model inference approach using Akaike's Information Criterion (AIC) to compare candidate models and we considered the model with the lowest AIC value to be the best approximating model, given the data (Akaike 1973, Johnson and Omland 2004, Anderson 2008). We further assessed the relative plausibility of each model using Akaike model weights (w_i ; Anderson et al. 2000, Burnham and Anderson 2002), where the best approximating model had the greatest Akaike weight. We assessed additional inference and made direct comparison of covariates by reporting model beta estimates (β) and respective 95% confidence intervals for variables of interest (i.e., year, full rate, half rate; Nakagawa and Cuthill 2007, Terhune et al. 2010). Nakagawa and Cuthill (2007) state that reporting betas and their associated confidence intervals are mandatory to assess the magnitude and precision of any

effects; these estimates were directly related to the biological importance of our parameters of interest.

We estimated weekly survival rates using the known-fate data type in Program MARK (Baxter et al. 2008, Anthony and Willis 2009, Terhune et al. 2010, Cooch and White 2014) allowing for staggered entry of individuals. We recorded birds as either alive or dead or censored during any given interval. We used 52 weekly intervals for year, which acted as our grouping variable. We adjusted for small sample size bias using AIC_c and AIC_c model weights to compare models (Cooch and White 2014). We considered models with a ΔAIC_c value ≤ 2 to have substantial support in explaining survival; however, Anderson (2008) suggested that models with ΔAIC_c values upwards of 6–7 may contain meaningful support for the data. The advantage of this method was that we were not restricted to a single model within each model set and it gave us a quantitative measure where models could be ranked and weighted (Johnson and Omland 2004). We selected the logit link function, which enforced real restrictions on proportions and constrained parameters (Baxter et al. 2008, Stephenson et al. 2011). Our nomenclature and syntax of the model representations follows Lebreton et al. (1992).

RESULTS

We radio-marked 259 birds in 2013–2014 (year 1) and 231 birds in 2014–2015 (year 2). We censored 18 birds in year 1 and 13 birds in year 2 that did not survive the 7-day acclimation period. Two birds died during recapture events in year 1 and were censored from the study. The average weight of radio-tagged birds was 175 g for year 1 and 177 g for year 2. Our sample size across treatments was relatively balanced for full ($n = 86, 76$), half ($n = 88, 68$), and control ($n = 67, 74$), during year 1 and year 2, respectively. In both years, most birds were juveniles (76% in year 1 and 85% in year 2). We marked 89 and 84 males and 152 and 154 females in year 1 and year 2, respectively. We marked 218 birds in year 1 and 180 birds in year 2 on the Southwest pasture, and

Table 1. Akaike's Information Criterion, adjusted for small sample size ($n = 459$), ranking temporal effects models for northern bobwhite survival (S), 6666 Ranch, Guthrie, Texas, USA, 2013–2015.

Model ^a	AIC_c^b	ΔAIC_c^b	w_i^b	L^b	K^b	Deviance
S (year \times calendar season)	2,244.469	0.000	0.979	1.000	8	2,228.450
S (year + calendar season)	2,252.399	7.930	0.019	0.019	5	2,242.391
S ($T_{\text{season}} + TT_{\text{season}}$)	2,256.664	12.195	0.002	0.002	3	2,250.661
S (T_{season})	2,270.347	25.878	0.000	0.000	2	2,266.346
S (T + TT)	2,291.882	47.413	0.000	0.000	3	2,285.879
S (year + T + TT)	2,293.204	48.735	0.000	0.000	4	2,285.199
S (biological season)	2,300.090	55.621	0.000	0.000	2	2,296.088
S (T)	2,302.304	57.835	0.000	0.000	2	2,298.303
S (year \times biological season)	2,302.483	58.014	0.000	0.000	4	2,294.478
S (year \times T)	2,302.734	58.265	0.000	0.000	3	2,296.731
S (.)	2,303.407	58.938	0.000	0.000	1	2,301.406
S (year + T)	2,303.740	59.271	0.000	0.000	3	2,297.737
S (year)	2,304.968	60.499	0.000	0.000	2	2,300.966

^a Calendar season = fall (22 Sep–20 Dec), winter (21 Dec–19 Mar), spring (20 Mar–20 Jun), and summer (21 Jun–21 Sep); biological season = winter (1 Oct–31 Mar), summer (1 Apr–31 Sep); T_{season} = survival as a linear function of time by season; TT_{season} = survival as a non-linear (e.g., concave) function of time by season; T = linear trend; TT = quadratic trend.

^b AIC_c = Akaike's Information Criterion adjusted for small sample size, w_i = model weight, L = likelihood, K = number of parameters.

23 birds in year 1 and 38 birds in year 2 on the Hackberry pasture. Raptors accounted for the largest percentage of mortalities in both years (47% in year 1 and 37% in year 2), followed by mammals (39% and 30%, respectively), and unknown causes (10% and 33%, respectively). We observed 37.4 cm of snowfall in year 1 and 15.4 cm in year 2. Maximum snow depth was 27.9 cm in year 1 and 7.6 cm in year 2.

Our top temporal model included an interaction between year and calendar season as the most parsimonious model ($w_i = 0.979$; Table 1). This top-ranked model was >50 times more likely to explain the variation in survival than the second ranked model, the additive effect of year and calendar season ($\Delta AIC_c = 7.930$, $w_i = 0.019$; Table 1); survival was lower during the winter period ($\beta_{\text{winter}} = -1.036$ [95% CI = -1.732, -0.339]). Year had no effect on survival (Table 3). Survival did not vary within the fall, spring, or summer seasons (Table 3), with or without a year interaction term. Models incorporating biological season did not merit support based on Akaike weights and ΔAIC_c values >10 (Table 1).

For our second model set we used calendar season, the only relevant, informative parameter from our first model suite, to build out additional models and evaluate treatment-level effects. The most parsimonious model included an interaction between feed and the winter calendar season, plus the additive effect of snow depth ($w_i = 0.974$; Table 2). The application of full and half feed treatments had positive ($\beta_{\text{full}} = 0.993$ [95% CI = 0.372, 1.614]; $\beta_{\text{half}} = 1.135$ [95% CI = 0.459, 1.812]; Table 3) effects on survival during winter ($\beta_{\text{winter}} = -1.202$ [95% CI = -1.538, -0.867]) compared to control units in both years, across both pastures (Fig. 2). The 95% confidence intervals of associated treatment beta values for the full and half feed rates overlapped, suggesting no difference between the 2 treatments (Table 3). The next best model was nearly 40 times less likely to explain the variation in survival and did not incorporate a term for winter ($\Delta AIC_c = 7.246$, $w_i = 0.026$; Table 2). Models incorporating snow accumulation accounted for all the model weight in the

second candidate set of models whereby snow accumulation had a strong, negative effect on survival in both years ($\beta_{\text{snow}} = -0.050$ [95% CI = -0.067, -0.034]; Fig. 3). In year 1, we eliminated the control treatment unit in the Hackberry pasture (Unit L) because those individuals were exposed to feed on an adjacent pasture, outside of our study area. As such, we had only 3 control treatment units in year 1.

DISCUSSION

We found biological evidence that survival in winter may limit bobwhite populations during harsh winter weather events. Furthermore, we unequivocally found support that provisioning of supplemental feed for northern bobwhites via a broadcast method abated winter effects by improving survival, especially during periods of extended snow accumulation. We did not, however, detect survival advantages associated with feeding during the other calendar seasons (i.e., spring, summer, fall) in relation to acute weather or other prevailing climactic conditions. We did not assess the effects of feeding on other vital rates (e.g., nest production, brood production) germane to fitness; however, previously Buckley et al. (2018) observed increased number of nests/female, an extended nesting season, and more chicks/female for bobwhites with access to supplemental feed via a broadcast method. Additionally, Wiley (2017) observed larger clutch sizes for birds on food-supplemented sites compared to birds on sites without food supplementation in a concurrent research project with our study. We did not detect a difference between feeding rates (full vs. half) on survival despite the application of feed being advantageous. Finally, we determined the finer temporal resolution of calendar seasons better explained bobwhite survival than the classic biological, or quail, seasons.

The deleterious effects of winter weather on bobwhite survival and population growth is established (Janke et al. 2015, 2017). We observed lower survival during winter periods in our study compared to other seasons and other studies (Sandercock et al. 2008). Within the first winter of our study, we observed a storm during February 2014. This

Table 2. Akaike's Information Criterion, adjusted for small sample size ($n = 459$), ranking treatment-level effects models for northern bobwhite survival (S), 6666 Ranch, Guthrie, Texas, USA, 2013–2015.

Model ^a	AIC_c^b	ΔAIC_c^b	w_i^b	L^b	K^b	Deviance
S (feed \times winter + snow)	2,203.097	0.000	0.974	1.000	7	2,189.082
S (year \times calendar season + snow)	2,210.343	7.246	0.026	0.027	9	2,192.319
S (feed \times winter)	2,231.486	28.389	0.000	0.000	6	2,219.475
S (feed + year \times calendar season)	2,233.473	30.376	0.000	0.000	10	2,213.444
S (feed \times calendar season)	2,238.572	35.475	0.000	0.000	12	2,214.531
S (year \times calendar season + pasture)	2,240.768	37.670	0.000	0.000	9	2,222.744
S (year \times calendar season)	2,244.469	41.372	0.000	0.000	8	2,228.450
S (year + snow)	2,263.684	60.587	0.000	0.000	3	2,257.681
S (feed \times pasture)	2,296.070	92.973	0.000	0.000	6	2,284.059
S (feed \times year)	2,299.471	96.374	0.000	0.000	6	2,287.460
S (pasture)	2,302.200	99.103	0.000	0.000	2	2,298.198
S (.)	2,303.407	100.310	0.000	0.000	1	2,301.406

^a Feed (grain sorghum) = full rate (69.1 kg/km), half rate (34.6 kg/km), control (no feed); snow = weekly max.; calendar season = fall (22 Sep–20 Dec), winter (21 Dec–19 Mar), spring (20 Mar–20 Jun), and summer (21 Jun–21 Sep); pasture = Southwest, Hackberry.

^b AIC_c = Akaike's Information Criterion adjusted for small sample size, w_i = model weight, L = likelihood, K = number of parameters.

Table 3. Regression coefficients for parameters within 2 model suites, evaluating temporal and treatment-level effects for northern bobwhite survival, 6666 Ranch, Guthrie, Texas, USA, 2013–2015.

Model parameters ^a	β	SE	95% CI
Temporal model effects			
Intercept	3.649	0.338	2.987, 4.311
Year	−0.413	0.423	−1.242, 0.416
Fall	0.808	0.445	−0.065, 1.681
Winter ^b	−1.036	0.355	−1.732, −0.339
Spring	0.118	0.410	−0.685, 0.921
Year \times fall	−0.439	0.548	−1.513, 0.634
Year \times winter	0.846	0.456	−0.047, 1.740
Year \times spring	0.331	0.517	−0.682, 1.344
Treatment model effects			
Intercept	3.748	0.132	3.490, 4.006
Full	−0.071	0.227	−0.516, 0.375
Half	0.147	0.241	−0.326, 0.620
Winter ^b	−1.202	0.171	−1.538, −0.867
Full \times winter ^b	0.993	0.317	0.372, 1.614
Half \times winter ^b	1.135	0.345	0.459, 1.812
Snow ^b	−0.050	0.008	−0.067, −0.034

^a Fall = 22 Sep–20 Dec; winter = 21 Dec–19 Mar; spring = 20 Mar–20 Jun; summer (reference category) = 21 Jun–21 Sep; full = 69.1 kg/km (grain sorghum); half = 34.6 kg/km; control = no feed; snow = weekly max.

^b We considered parameters with 95% confidence intervals that did not overlap 0 to be informative.

weather system dropped 31.8 cm of snow over 2 days and we observed maximum snow depths of 27.9 cm (NCEI 2016). We observed sustained snow depths of >10.0 cm for ≥ 6 days and depths of >5.0 cm for ≥ 9 days following the event (NCEI 2016). Daily maximum temperatures averaged 1°C and daily minimums were close to -11°C during this 9-day period (NCEI 2016). Porter et al. (1980) suggested that during such periods, snowfall may inhibit a galliformes ability to locate and use food resources. More recently in Maryland and Ohio, Janke et al. (2017) submitted that access to food resources was limited during snowfall events, which severely handicapped bobwhite thermoregulation and the birds' ability to forage, and increased their exposure to predation. The inability to forage becomes of critical concern for bobwhites who, during periods of low ambient temperatures, have high energy requirements and metabolic demands for thermoregulation (Guthery 1999, Townsend et al. 1999). Bobwhites are reliant upon effective insulation for cold resistance and as their metabolic rates increase to cope with declining temperatures (Robbins 1993, Root 1988, Swanson and Weinacht 1997), and when thermal cover is limited (Holt et al. 2009), their need for high energy food resources becomes heightened. The survival consequences in year 1 held true in year 2, even during a less severe winter

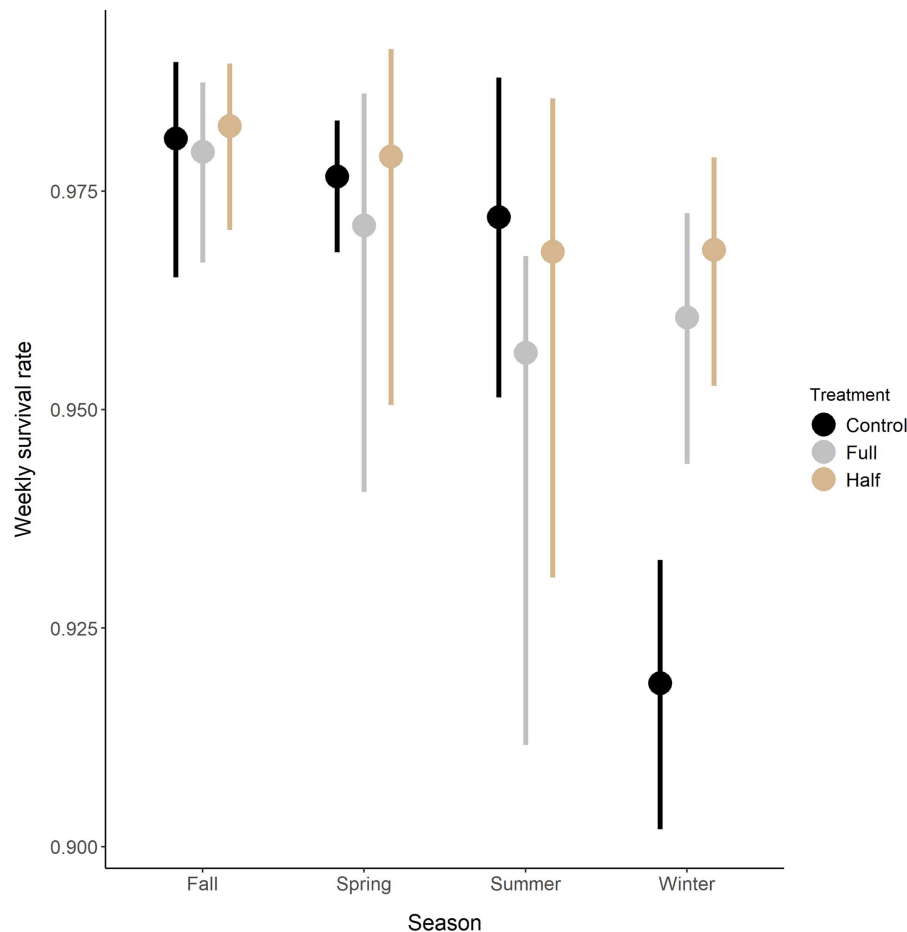


Figure 2. Effect of supplement feed rates (full, half, control) on weekly survival rates of northern bobwhites, with 95% confidence intervals, by calendar season (fall = 22 Sep–20 Dec, winter = 21 Dec–19 Mar, spring = 20 Mar–20 Jun, summer = 21 Jun–21 Sep), 2013–2015, 6666 Ranch, Guthrie, Texas, USA. Years are pooled; year had no effect on survival (S) in the most parsimonious temporal model: $S(\text{year} \times \text{calendar season})$.

when the average accumulation of snow was lower and occurred over a shorter duration but when temperatures (7°C in year 1 and 9°C in year 2) remained low (NRCS 2007, NCEI 2016). The loss of bobwhites during winter has a direct consequence on populations such that low winter survival results in fewer breeders entering the breeding season (Sandercock et al. 2008); this loss of females may yield a reduction in fall recruitment and lower overall population fitness.

Despite the importance of feed during winter, we did not detect differences in bobwhite survival during the spring, summer, and fall seasons. However, we suspect that the improvements in survival rates during winter were related to the body condition of birds heading into, during, and following harsh winter weather events (e.g., a conditioning effect). During periods of extended snow cover and when birds are exposed to temperatures nearing 0°C, an individual's fat reserves provide fuel in meeting increased metabolic demands (Roseberry and Klimstra 1984, Dabbert et al. 1997), which can be upwards of 2.5 times that of their basal metabolic rate (Robbins 1993, Root 1988). When comparing initial capture weights to weights of frozen birds located after the storm event, obvious muscle atrophy was present among birds on unfed sites. For example, we recorded a weight loss of 76 g for a deceased bird located in a control (unfed) unit (8 Feb 2015); from the time of capture (18 Jan 2015) this was a >42% loss in total body mass. Robel et al. (1979) postulated that a bird meeting 100% of their daily energy requirements would be able to maintain their body mass for 6 days at 2°C, whereas a bird obtaining ≤60% of their energy needs may lose up to 20% of their body mass during the same period; at this point they suggested a bird

would be at severe risk of mortality. Changes in body condition were most likely due to the extended snow cover combined with low ambient temperatures and an inability to access food resources. Whitelaw et al. (2009) observed that bobwhites can hold close to 400 sorghum seeds in their crops (~3,200 kJ/kg of metabolizable energy), underscoring that at low temperatures having a readily available, high energy food source can limit the amount of foraging time (~1–2 times/day) necessary to meet an individual's energy needs. The lack of fat and energy reserves on birds may exacerbate their inability to thermoregulate.

Sandercock et al. (2008) suggested that for declining populations, over-winter survival (Oct–Mar) of adults had the greatest potential to affect population growth and suggested a supplemental feeding program could be used to cope with adverse weather conditions. They also stated that to ensure population viability, winter survival >0.52 is necessary. The average probability of surviving the winter period in our study (21 Dec–19 Mar) was $64 \pm 0.046\%$ (SE) and $68 \pm 0.045\%$ for the full and half treatment (adults and juveniles), respectively, compared to $39 \pm 0.050\%$ for the control treatment (Fig. 3). Despite a shorter exposure period than reported by Sandercock et al. (2008), the much lower survival on the control areas would ostensibly have long-term population consequences. Buckley (2013) demonstrated that over-winter survival (Oct–Mar) was important for bobwhite population stability, especially for carrying females into the breeding season. Hernández and Guthery (2012) suggest that harsh winter conditions are rare throughout most of Texas, and therefore argue against the need to provide any food supplementation; however, they only reviewed traditional feeding methods (e.g., stationary feeders, road-baiting,

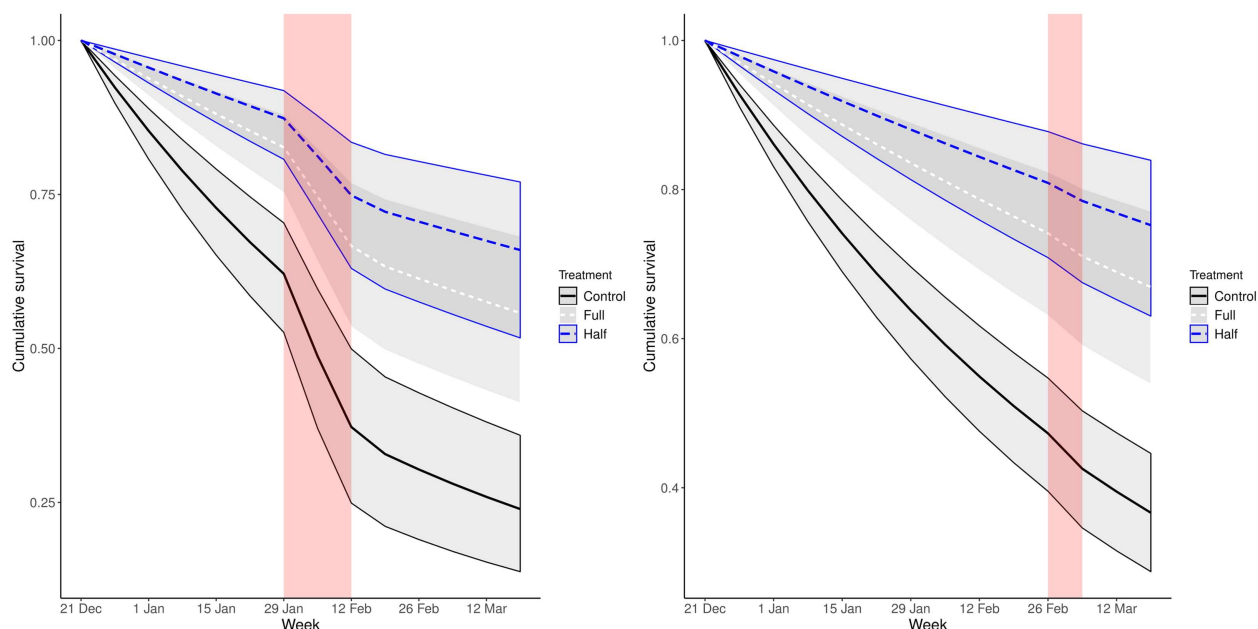


Figure 3. Weekly survival rates of northern bobwhites using 3 different feed treatments (full, half, control), with 95% confidence intervals, for winter calendar season (21 Dec–19 Mar) in 2013–2014 (left) and 2014–2015 (right), 6666 Ranch, Guthrie, Texas, USA. Red shading represents periods when snow was present at depth ≥ 0.1 cm. Survival (S) is displayed as cumulative survival by obtaining the product of constrained weekly survival rates for weeks with and without snow based on the model $S(\text{feed} \times \text{winter} + \text{snow depth})$.

food plots). It is evident from our study that in areas where winter conditions can be severe, the benefits of broadcast feeding can have salient effects on survival and purported population stability.

A single winter storm may result in dramatic population effects when coupled with drought conditions during the spring and summer, which are more common in Texas, when periods of natural food limitations exist (Buckley et al. 2015). Buckley et al. (2015) observed feed benefits to bobwhite during these drought periods. Coupled with our results, the survival benefits of food supplementation extend into both climatic extremes. Supplemental feeding may ensure adequate food resources during winter and extended droughts and reduce the risk of catastrophic losses or population declines. Proper application of supplemental feeding (i.e., broadcast feeding as opposed to feeding stations or food plots) is essential to prevent ecological (Battin 2004) and predator traps (Turner et al. 2008). We believe the continuous broadcasting of supplemental feed conditioned birds over time and led to the increase in winter survival. However, based on our study design (year-round, systematic bi-weekly feeding) we were unable to discern how long that conditioning period needs to be (e.g., 2 weeks, 1 month, 2 months) and cannot assert whether year-round feeding or a variation thereof is necessary.

That said, we found that despite the one-time application of feed during the winter period in year 1 on the control units, birds still experienced significant mortality (Fig. 3). This outcome suggests that the short-term, reactive application of supplemental feed as proposed by Wiseman (1977) does not likely have the same benefits as scheduled feeding over time. In contrast, the presence of year-round or long-term provisions of supplemental feeding may boost lipid and fat reserves, add body mass, and improve the overall condition of birds ahead of, during, and after severe weather events (Leif and Smith 1993, Whitelaw et al. 2009). This evidence supports the idea that although there was no difference in fall survival, feeding may have been critical in physiologically preparing birds for the upcoming winter conditions. However, it is reasonable to assume behavioral conditioning to a supplemental food source may reduce the consumption of feed during one-time application periods. Future research is warranted to better understand the physiological response to feeding both temporally and spatially on sites experiencing harsh winter weather.

We did not observe survival benefits to fed birds in the spring or summer of either year, which may have been the result of improved range conditions and good rainfall. During the spring and summer of 2013 and 2014, the Guthrie area experienced 34.2 cm and 54.5 cm of rain, respectively (NCEI 2016), facilitating a recovery from the recent drought. Increased precipitation during our 2 study years likely influenced the nutritional quality, quantity, and availability of food resources and improved the structure of vegetation communities (e.g., cover). This precipitation reasonably increased food abundance and cover across the region. As Jackson (1962) and Hernández et al. (2005) suggest, precipitation is the primary, or ultimate factor

influencing the boom-bust cycles exhibited by bobwhites. Buckley et al. (2015) reported that the effects on survival between birds with access to supplemental feed via broadcast feeding versus birds on control sites during summer (Apr–Sep) were neutral ($62 \pm 0.006\%$ and $59 \pm 0.009\%$, respectively) during 1 season and positive ($72 \pm 0.011\%$ and $55 \pm 0.011\%$, respectively) during another. Combined with our data, their results suggest that food limitations may not be a compelling factor for survival during all seasons.

Future research should investigate whether food supplementation is required year-round or if similar benefits can be achieved under different feeding schedules (e.g., only feeding during a particular calendar season). Furthermore, research evaluating population fitness in relation to feed to improve breeding season demographics as observed by Buckley et al. (2018) and Wiley (2017) would be beneficial to shed light on the effects of supplemental feeding on productivity. Subsequent investigations should also focus on direct measurements of forage availability, selection and preference, and the development of indices (e.g., stored fat) to test the food limitation hypothesis directly. Additionally, we suggest investigating predation risks in conjunction with broadcast feeding and any behavioral differences related to the persistence of feed on the landscape (Miller 2011). Finally, it remains unclear as to whether the positive survival effect of supplemental feeding we observed during winter and those by Buckley et al. (2015) improved bobwhite density the following fall or if compensation occurs.

MANAGEMENT IMPLICATIONS

Although food supplementation is not in any way meant to serve as a replacement for other management practices that directly promote and improve habitat (e.g., prescribed fire, prescribed grazing, brush, or herbaceous cover management), its use should not be overlooked as a practice to help bobwhites overcome nutritional shortfalls common during periods of drought or severe winter conditions. Broadcast supplemental feeding serves as an additional management tool within a strategic management program to benefit bobwhites and may mitigate the effects of stochastic boom and bust cycles observed in Texas. In areas with risk of winter weather events, we recommend broadcast feeding during winter (Dec–Mar) to mitigate survival effects on bobwhites and increase breeding populations. We encourage the continued use and evaluation of this feeding program in different eco-regions and climates to better understand its effectiveness on a range-wide scale.

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