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THE EFFECT OF AGE-AT-RELEASE ON SURVIVAL OF ADOPTIVE PARENT-REARED BOBWHITE CHICKS

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ABSTRACT

Translocation of wild northern bobwhites (*Colinus virginianus*) to restore local populations is a viable conservation tool under some scenarios; however, the supply of wild bobwhites is limited. Bobwhites can be artificially propagated, as an alternative to translocation, using methods that mimic natural brood-rearing. The parent-rearing adoptive process (PRAP) uses wild-strain bobwhite adults to brood and foster newly hatched wild-strain chicks in outdoor aviaries that emulate a natural environment. Adoptive parent-reared bobwhites have higher survival rates than artificially-reared bobwhites but only a single age-of-release (i.e., 6-weeks) has been tested. We tested the effect of age-at-release (3, 6, and 9-weeks) on adoptive parent-reared chicks released on the same date in Hanna Hammock of Tall Timbers Research Station. All chicks were marked with patagial wing tags and a subset of the group received radio transmitters. The 3-week-olds ($n = 25$) received suture-style transmitters and 6-week-olds ($n = 30$) and 9-week-olds ($n = 30$) received necklace-style transmitters. Our adoptive parent-reared chicks had low survival rates over 3 months post-release, the 9-week age group had the highest overall survival rates which could portend that increased physiological development may aid in increasing the survivability of adoptive parent-reared bobwhites. The low survival rates across all 3 age classes calls into question the efficacy of the PRAP as a bobwhite restoration method. Our results do suggest that additional modifications to release age (> 9-weeks) should be explored along with further modifications to the PRAP. Additional modifications include incorporating predator avoidance training, altering release dates, and changing nutritional regimes. These results should caution the bobwhite community to remain suspect when deriving conclusions about the PRAP until all process modifications have been fully evaluated by scientific research.

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Northern bobwhite (*Colinus virginianus;* hereafter bobwhites) populations have been in continual decline at a rate of 4.2% per year during 1966-2015 (Sauer et al. 2015). The primary reason for the decline in bobwhite populations has been broad-scale habitat loss, habitat degradation through advancements in agriculture technology as well as afforestation and lack of prescribed fire (Brennan 1991). In response, habitat restoration (Palmer et al. 2012) and restocking efforts have been undertaken in many parts of the bobwhite range (Buechner 1950, Perez et al. 2002, Jones 2004, Cass 2008, Terhune et al. 2010). In spite of these efforts, landscape level change has reduced the quality and quantity of habitat for bobwhites, which has resulted in localized and even regional extirpations (Guthery 1999, Veech 2006). The anthropogenic influence on the landscape has heightened habitat fragmentation, habitat isolation and decreased landscape permeability, thus reducing colonization and recolonization rates (Bowling et al. 2014). These factors underscore the need for understanding how reintroduction techniques can aid bobwhite restoration and to identify limitations as a means to recover populations.

A variety of bobwhite reintroduction methods have been employed to establish, reestablish or augment bobwhite populations across their range, including both captive-reared (e.g., pen-reared and Surrogator® systems) and wild translocation programs. The value of releasing pen-reared birds to supplement hunting stock is commonly acceptable but this technique is not an effective population restoration tool (Buechner 1950, Devos and Mueller 1989). Numerous studies have documented low survival rates of pen-raised bobwhites (Baumgartner 1944, Roseberry et al. 1987, DeVos and Speake 1995, Oakley et al. 2000, Hutchins and Hernández 2003) and

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their potential adverse effects on survival rates of wild bobwhites by predators attracted to release areas is further cause for concern (DeVos and Speake 1995). Similarly, birds reared in Surrogators had low overall survival rates (0.35) over 8-weeks after release (Thacker et al. 2016). The limited proportional return (0.005; 19 marked harvest returns from 3859 marked total releases) of Surrogator birds to hunter bags over a 5-year study conducted in Alabama, Georgia, and Kentucky not only diminishes the possibility of the Surrogator as a viable option for population recovery but also calls into question its use for stock supplementation for hunting purposes (Thackston et al. 2002).

Translocation of wild bobwhites after habitat restoration has been successfully used to recover and augment existing wild populations (Terhune et al. 2006a, 2010). Terhune et al. (2006b) found that resident and translocated bobwhites had similar survival rates, reproductive effort, and daily nest survival rates. Translocated and resident bobwhites also had similar home range sizes and mean daily movement distances (Terhune et al. 2006b, 2010). These results indicate that translocation of wild bobwhites can be a reliable method to restore bobwhite populations. However, source populations of wild bobwhites are limited (Martin et al. 2017) and the financial constraints of wild bird translocations is high (Sisson et al. 2017). Therefore, the efficacy of translocation for broad-scale population recovery is limited.

Recognizing the limitations of translocation and the need for population recovery through restocking, the Game Bird Program at Tall Timbers Research Station and Land Conservancy began investigation of a technique to foster wild-strain birds with learned cues from adoptive parents. Stoddard (1931) was one of the first to experiment with this type of artificial propagation of bobwhites in the mid-to-late 1920s. He used bantam chickens (*Gallus gallus*) as brooders, male bobwhites as foster parents, and released the birds to the wild – he called this process the adoption system of rearing. Similarly, Tall Timbers' method used F1 birds (or first generation removed from true wild stock) as foster parents coupled with hen vocalizations before and after hatching to increase adoption rates. Adult birds were removed after 5–7 weeks and chicks were wing-tagged and released on sites with high quality habitat during July-October depending on latitude and coinciding with natural peak hatching in the wild. Initial investigation of the success of this technique was has shown promise (Palmer et al. 2012). Survival to the following spring for bobwhite chicks reared using the PRAP (parent-reared adoptive process) ranged from 0.035–0.111 in 2005, and 0.128–0.262 in 2006 for July, August, and September releases in each respective year (Cass 2008). However, mixed results have been observed with replication of the PRAP (Palmer et al. 2012, Macaluso et al. 2017, D.C. Sisson, personal communication). Current research has shown some improvement in survival rates over traditional pen raised, artificially brooded bobwhites thus warranting further research into the PRAP.

We tested the effect of age-at-release on post-release survival of adoptive parent-reared bobwhite chicks. We hypothesized that modification of age-at-release will have an effect on the survival of adoptive parent-reared chicks. We predicted that survival rates would decrease with age if human habituation is the strongest effect. Conversely, we predicted survival rates would increase with age if physiological development is the strongest effect. Adoption rates may vary by chick age at release into the wild and differences in physiological development (increased wing and leg development) among ages (i.e., cognitive ability) may impact survival. We predicted that 3-week-old adoptive parent-reared chicks would have higher survival rates due to adoption by wild adults (Faircloth et al. 2005). Our intent for this research was to modify the parent-rearing system to achieve higher survival rates and productivity resulting in a more robust population recovery tool.

STUDY AREA

We released adoptive parent-reared chicks in the Hanna Hammock section of Tall Timbers Research Station located in the Red Hills Region approximately 33.5 km north of Tallahassee, Florida. Aviaries were located in Hanna Hammock and the Tower Course tract of Tall Timbers Research Station. The habitat in Hanna Hammock is similar to the rest of the Tall Timbers property, primarily comprised of old-field upland pine with a mix of shortleaf (*Pinus echinata*), loblolly (*Pinus taeda*), and longleaf (*Pinus palustris*) and an understory consisting of sweetgum (*Liquidambar styraciflua*), American beautyberry (*Callicarpa americana*), and a variety of grasses and forbs including little bluestem (*Schizachyrium scoparium*) and common ragweed (*Ambrosia artemisiifolia*). The property is intensively managed for bobwhites which includes prescribed fire, timber harvesting, herbicide application, supplemental feeding, and seasonal predator control. The upland pine section of Hanna Hammock is approximately 94 hectares and is bounded on its east and west sides by hardwood drains leading down to Lake Iamonia. Hanna Hammock is the western-most section of Tall Timbers that is intensively managed for bobwhites. Hanna Hammock is separated from the main portion Tall Timbers by a large hardwood drain. Tall Timbers Research Station currently practices "strict wild bird management" which prohibits the release of artificially-reared bobwhites anywhere on the main portion of the property. However, the Hanna Hammock tract of Tall Timbers has had releases of artificially reared bobwhites in the past in an attempt to augment the current population.

METHODS

Aviaries

Aviaries (Tower Course and Hanna Hammock) were constructed away from high traffic areas to minimize any human habituation and tampering with birds throughout the rearing process. Both sets of aviaries used wood framing for pen construction and walls were enclosed with poultry netting. Aviaries were also fortified to prevent intrusion of snakes by burying wood framing below ground level. Both aviaries contained natural vegetation (*Callicapra americana* and *Rubus* spp.) to imitate natural brood-rearing habitat. The Tower Course aviaries followed the design used by Stoddard (1931). This design used trapezoidal-shaped pens with brooding houses located on the narrower section to facilitate capture and removal. The aviaries were covered with netting and about half of each pen was covered with vinyl roofing to prevent mortality associated with severe rain events. The Hanna Hammock aviaries were rectangular in shape with brooding/feeding houses located at the front of each aviary. Aviary walls were covered with shade cloth to limit visibility in hopes of minimizing human habituation during the rearing process. Aviary rooftops were also constructed using netting and shade cloth to minimize sunlight, decrease visibility, and reduce rainfall impact.

Rearing Process

Quail Call Farms (Beachton, GA) provided all eggs used in our study. We used F1 eggs indicating that the parents of each egg are only one generation removed from wild bobwhites. Eggs from wild bobwhites were collected from partially depredated and abandoned nests at Tall Timbers Research Station and other associated properties. These eggs are hatched in captivity to produce breeders so that wild genetics can be maintained in release groups. Eggs were collected daily (as they were laid) at Quail Call Farms from each laying hen in a captive wild-strain breeding stock. Incubation periods were initiated on select dates (9-Week Age Class: 04 June 2015, 6-Week Age Class: 25 June 2015, 3-Week Age Class: 16 July 2015) to ensure that all chicks were the proper age on the day of release (06 Aug 2015). We placed all eggs from each age class in a Model 1500 Series incubator (G. Q. F. Manufacturing Company, Savannah, GA). We relocated eggs to another incubator (G. Q. F Manufacturing Company, Savannah, GA) the day before hatch (Day 22). We also placed the next batch of eggs in the original incubator at this time to maintain a consistent number of chicks. We periodically examined eggs to identify any eggs exhibiting signs of failure (no yellow glow when candled) throughout the incubation process and discarded eggs that did not emit a yellow hue upon examination.

Quail Call Farms (Beachton, GA) provided the adult brooding stock (40–45 captive-reared adults) for each adoption period. We systematically alternated male and female adults during the adoption period to eliminate any bias by only choosing one sex as brooding stock. We placed each brooding adult into the brood boxes prior to the addition of newly hatched chicks. We prepared brooding boxes by placing cedar shavings on the floor of each box prior to each adoption and cleaned all boxes after the adoption period. We selected chicks for adoption by assessing their post-hatch condition (when feathers had begun to dry) and placed approximately 18 chicks with each brooding adult. Chicks and adults were given approximately 10 min to bond before behavioral observations began. We conducted behavioral observations to determine if broods were accepted or rejected by the adult. Adults that exhibited aggressive behavior (pecking, etc.) were immediately removed and placed in a discard box. Adults that approached chicks but did not readily brood chicks were given more time (up to 10 min) to adopt. We attempted to facilitate the adoption process by moving chicks closer to the foster parent if chicks were not being brooded immediately. If the adult did not adopt following manipulation, we then removed the individual and placed another adult with chicks and repeated the process described above. We allowed an additional 5 min of bonding time if adoption occurred immediately, then transferred the brood to a transport box for placement in aviaries. This process continued until all chicks were prepared for release into aviaries.

Aviaries were examined for damages prior to full release. Any aviaries needing repair were fixed prior to release to prevent any chances of escape or mixing of chicks between pens. We prepared brooding houses for the holding period (1–5 days pre-full release) by lining brood house floors with cedar shavings and setting disposable trays filled with gamebird feed (Purina Mills, Gray Summit, MO) and a waterer. We secured brood houses by fastening a wooden door onto house entrances with wood screws until chicks were ready for full-release. We closely monitored weather forecasts until optimal release conditions were predicted (24–48 hours of no rain) after which all chicks were released into aviaries for rearing. Two F1 adults and their respective broods were assigned to each aviary pen (multiple pens per aviary) throughout the rearing period for all age classes. Age groups were unevenly distributed among aviaries. The 9-week group was split between the Hanna Hammock and Tower Course aviaries (Hanna, $n = 26$ & Tower, $n = 4$), and the 6-week group ($n = 24$) were all raised in the Tower course aviary. The 3-week group ($n = 25$) were all raised in the Hanna Hammock aviaries. Age groups did not comingle, and were only reared with adoptive adults and brood mates designated at the beginning of the adoptive process.

We fed chicks and F1 adults a game bird starter feed (Purina Mills, Gray Summit, MO), approximately 28% protein, throughout the rearing process. We scattered proso millet (*Panicum miliaceum*) after 1 week in each aviary (approximately three handfuls per pen each visit) and at 3-weeks of age milo (*Sorgum bicolor*) was scattered with millet at the same rate. Rodents were controlled using Sherman traps (H. B. Sherman Traps, Tallahassee, FL) as needed when holes under brooding houses and aviaries were observed. Red-imported fire ant (*Solenopsis invicta*) mounds were treated them with Amdro, 0.73% hydramethylnon, (AMBRANDS, Atlanta, GA). All care, rearing, and housing of adoptive parent-reared chicks were in compliance with Tall Timbers Institutional Animal Care and Use Committee (GD - 2001-15).

Release

We organized release groups into 4 single-age aggregations (3-, 6-, and 9-weeks) and 4 mixed-age groups of 15 (5 per age class in each group) prior to release. These aggregations were released at 16 sites across Hanna Hammock. We used ArcGIS (ESRI, Redlands, California, USA) to place a 200 × 200 m grid over the entire study area, and then generated two random points per grid block using the "Create Random Points" tool in ArcGIS. Two-hundred meter grids were used to ensure release sites. Random points were generated with a 40-m buffer using the "Buffer" tool in ArcGIS to allow for the selection of optimal release sites. Random points were visited by researchers to determine optimal release sites and one random grid block was chosen. The 40-m buffer allowed researchers to select release sites that avoided undesirable landscape features such as roads, hardwood drains, plowed fields, or any other open areas that lacked vegetative cover for concealment. Optimal sites were determined by presence of nearby escape cover (woody vegetation), proximity to feed line, and proximity to hardwood drain. A random number generator was used to assign chick groups to release sites.

Brooding adults were separated from chicks before data collection and attaching transmitters or wing tags. We weighed all adoptive parent-reared chicks prior to release. We attached patagial wing tags to all adoptive parent-reared chicks on the day of release (6 Aug 2015). We used wing banding pliers to affix tags to the right wing of all chicks. Each patagial wing tag contained a unique ID for each chick that included year, band series number, and ID number for each respective chick. We fitted necklace-style radio collars (3.5 g American Wildlife Enterprises, Monticello, FL) to 6 ($n = 24$) and 9-week-old ($n = 30$) adoptive parent-reared chicks, and we sutured transmitters (0.7 g American Wildlife Enterprises, Monticello, FL) onto the interscapular region of 3-week-old chicks ($n = 25$) due to their smaller size (Terhune et al., unpublished data). All transmitters were attached on the day of release. All release groups were liberated using a 'soft release' technique. We placed chicks in fruit crates, scattered grain (millet and milo) around release areas, and removed one end of the fruit crate after it was placed in cover so chicks could slowly leave the crate and assimilate to the area.

Telemetry

We located radio-marked chicks every day for the first 28 days after release, and 3 days per week thereafter. We used hand-held 3-element Yagi antennas and ATS Telemetry Receivers (ATS, Isanti, MN, USA) to locate birds over the duration of the study. We recovered radio collars immediately to determine the cause of mortality when transmitters emitted mortality signals. Mortality causes were determined by analyzing evidence (plucked feathers, chewed transmitter, etc.) discovered at kill site, and assigning appropriate fates (mammal, avian, etc.) (Dumke and Pils 1973).

Survival Estimation and Data Collection

Survival estimates for our study period were estimated during 6 August 2015 to 11 November 2015 (97 days) to determine how many individuals survived to fall. Birds that left the release area or were lost due to transmitter failure were right-censored from the study sample. We used the known fates model in Program MARK (White and Burnham 1999) to analyze survival data. We used the logit-link function to restrict survival probabilities between 0 and 1 (Paasivaara and Pöysä 2007). We used *a priori* hypotheses to develop 9 candidate models proposed to explain the variation in survival rates of parent-reared bobwhites (Burnham and Anderson 1998, Johnson and Omland 2004). We tested effect of age on survival rates of parent-reared bobwhites. We also included variables that potentially affected survival rates including aviary, release group, linear time, and quadratic time. Age was separated into three dummy variables (Age3, Age6, and Age9) where each bird was coded a 1 in its respective age group and a 0 if not. Aviary was modeled as a dummy variable where birds were coded a 1 if they were reared in the Hanna Hammock aviaries and a 0 if not. Group Type (single or mixed age) was included as a covariate to determine the effect of group type on survival rates. Birds were coded a 1 if they were released in a mixed-age group and a 0 if they were released in a single age group. We included time variables (linear and quadratic) to examine if there was time variation in survival rates throughout the study period. The best approximating models were chosen using Akaike's Information Criterion (AICc) and we considered the model with the lowest AICc value to be the best approximating model (Burnham and Anderson 1998). The selection of best approximating models was based on ΔAICc values calculated in program MARK as the differences in current AICc value and the minimum AICc value. Relative plausibility of each model was assessed using Akaike weights, w_i (Burnham and Anderson 1998, Anderson et al. 2000), where the best models had the highest Akaike weights. We used model averaging across our entire candidate model set to derive daily survival rates (DSR) for each age class (Akaike 1974, 1978; Burnham and Anderson 1998). We also reported beta estimates, their standard errors, and 95% confidence intervals to allow for stronger inference and comparison among covariates. Probabilities for surviving the study period were calculated in MARK (White and Burnham 1999) and included in the derived estimates from our top candidate models. Cause-specific mortality percentages were calculated by dividing the total number of mortalities by each type by the total number of mortalities for each age class.

RESULTS

Mortality rates were highest during the first three weeks post-release with 70 observed mortalities over this period. Only two 6-week and 12 9-week-old adoptive parent-reared bobwhites remained on the study area after the first 3 weeks. The majority of 6-week-old mortalities

Table 1. Akaike's Information Criterion rankings for models approximating the daily survival rates of adoptive parent-reared bobwhite chicks released in the Hanna Hammock section of Tall Timbers Research Station, Tallahassee, FL, USA, 2015.

k	Model	AICc	ΔAICc	wi	Model Likelihood	Deviance
5	Age+LinTime+QuadTime	493.6752	0	0.33195	1	483.6143
4	Age+LinTime	495.036	1.3608	0.1681	0.5064	486.9954
6	Age+Group+LinTime+QuadTime	495.496	1.8208	0.13356	0.4024	483.4106
6	Age+Aviary+LinTime+QuadTime	495.6203	1.9451	0.12552	0.3781	483.535
5	Age+Group+LinTime	496.7247	3.0495	0.07226	0.2177	486.6638
5	Age+Aviary+LinTime	496.7884	3.1132	0.06999	0.2108	486.7275
3	Age	497.2477	3.5725	0.05563	0.1676	491.2234
4	Age+Group	499.0965	5.4213	0.02207	0.0665	491.0559
4	Age+Aviary	499.208	5.5328	0.02088	0.0629	491.1675
1	Null	513.1082	19.433	0.00002	0.0001	511.1041
2	Aviary	514.034	20.3588	0.00001	0	510.0219
2	Group	514.6537	20.9785	0.00001	0	510.6416

occurred within 6 weeks of release and all but 4 birds survived for more than 2 weeks after the release date. Compared to 3-week-olds (0.68) and 6-week-olds (0.67), the 9-week-old group had much lower mortality rates (0.2) in the first 7 days following release.

Our most parsimonious model included the effects of age, linear time, and quadratic time. Three of our 4 top candidate models included all three of these variables along with aviary and group effects and our second competing model only contained the effect of age and linear time (Table 1). Based on model weights, our top model approximated survival estimates were nearly 2 times better than our second candidate model [Age + LinTime] (0.332/0.168), 2.5 times better than our third competing model [Age + Group Type + LinTime + QuadTime] (0.332/0.134), and 2.6 times better than our fourth competing model [Age + Aviary + LinTime + QuadTime] (0.332/0.126) (Table 1). The sum of the Akaike weights of models containing the effect of Age, Linear Time, and Quadratic Time totaled 0.75 (Table 1), indicating these three variables were important factors in our data set. Model-averaged Beta coefficients indicate that age had an effect on DSR of adoptive parent-reared chicks, along with linear time. The 95% confidence intervals of the remaining beta coefficients (quadratic time, aviary, and group) overlapped zero indicating their effects were uninformative (Table 2).

Table 2. Beta coefficient estimates for all included covariates from our model-averaged set approximating daily survival rates of adoptive parent-reared bobwhite chicks released in the Hanna Hammock section of Tall Timbers Research Station, Tallahassee, FL, USA, 2015.

Parameter	β	SE	95% LCI	95% UCI
Age9	3.71	0.50	2.72	4.70
Age3	-1.76	0.41	-2.57	-0.95
Age6	-1.14	0.43	-1.99	-0.30
LinTime	-0.05	0.03	-0.10	-0.01
QuadTime	0.00	0.00	-0.00	0.00
Aviary	-0.22	0.64	-1.47	1.03
Group	-0.13	0.26	-0.64	0.38

Our model averaged results for daily survival rates (hereafter DSR) for each age class indicated low survival rates for our 3-week age group (DSR = 0.827, SE = 0.422, 95% CI: 0.113–0.994; Fig. 1) and 6-week age group (DSR = 0.898, SE = 0.458, 95% CI: 0.186–0.997; Fig. 1). Our 9-week group experienced higher DSRs over the course of the study (DSR = 0.965, SE = 0.492, 95% CI: 0.625–0.998; Fig. 1). The probabilities for surviving study period (14 weeks) were marginally above zero for all age classes (3-week: 0.578E-13, 6-week: 0.137E-06, 9-week: 0.005).

Avian (*n* = 8, 32%) and mammalian (*n* = 7, 28%) predators contributed almost evenly to sources of mortality for 3 week-old chicks. Other mortalities were classified as unknown due to lack of evidence at kill site (*n* = 8, 32%) and snake depredations (*n* = 1, 4%). One 3-week-old was censored due to unknown fate or possible collar loss. Mammals were the leading cause of mortality among the 6-week age group (*n* = 11, 46%). Other causes of mortality for the 6-week age group include avian (*n* =

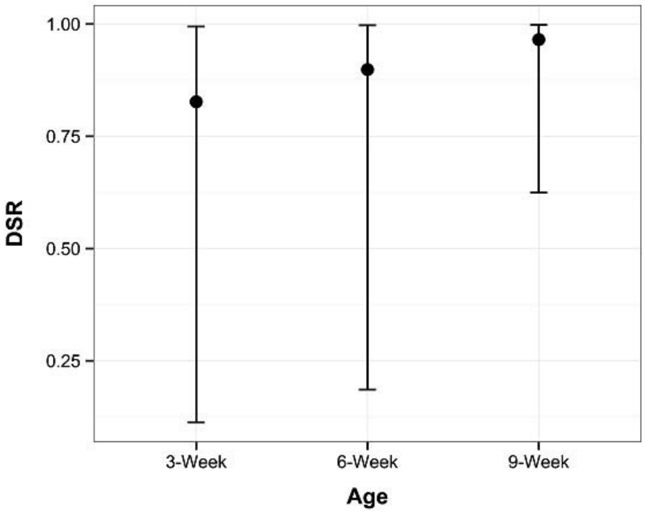

Fig. 1. Model-averaged daily survival estimates (DSR) (error bars represent 95% confidence intervals) for 3-, 6-, and 9-week old adoptive parent-reared bobwhite chicks released in Hanna Hammock, Tall Timbers Research Station, 6 Aug 2015 to 11 Nov 2015.

8, 33%), snake ($n = 1$, 4%), transmitter-related ($n = 1$, 4%), and unknown due to lack of evidence ($n = 3$, 13%). The mortality causes for 9-week age group were mammalian ($n = 15$, 50%), avian ($n = 9$, 30%) and unknown due to lack of evidence ($n = 3$, 10%). The fates of 3 9-week-olds were unknown and were censored from the sample.

DISCUSSION

Our results indicate that a high level of mortality should be expected for adoptive parent-reared bobwhites, especially during the first few weeks post-release. The higher survival rates observed in our oldest age class indicate that age has some effect on survival rates of adoptive parent-reared bobwhites after release. This could indicate that increased physiological development prior to release confers survival advantages. The extremely low survival rates of 9-week old PRAP chicks does not portend success of this method as a population restoration technique.

The low overall survival rates for our chicks was consistent with other studies examining survival rates of captive-reared bobwhites (Baumgartner 1944, DeVos and Speake 1995, Oakley et al. 2000, Hutchins and Hernández 2003). Survival rates for our 6- and 9-week old age classes was lower (all studies) than reported by Palmer et al. (2012). A study of PRAP bobwhites (5–8 weeks in age) near our study area found over-winter survival was 0.14 (0.08–0.44 95% CI) and 0.3 (0.19–0.41 95% CI) in 2005 and 2006 (Cass 2008). Additionally, survival of adoptive parent-reared chicks to spring varied from 0.03-0.11 and 0.12–0.26 in 2005 and 2006 (Cass 2008). Breeding season survival of PRAP bobwhites in South Carolina was 0.27 (0.15–0.39 95% CI) (Palmer et al. 2012). Survival to the next breeding season and producing viable offspring is the ultimate metric by which the success of PRAP should be judged in the short-term. Released individuals surviving to and through breeding seasons can reproduce successfully and contribute to population growth. Palmer et al. (2012) found that parent reared bobwhites were able to produce 0.29 and 0.33 nests per hen in 2006 and 2007 on their Georgia site and 0.64 nests per hen on their South Carolina study site. Parent-rearing has also been tested in red-legged partridges (*Alectoris rufa*). The average survival periods for adoptive parent-reared red-legged partridges did not significantly differ from wild partridges (107.8 ± 20.9 days vs. 160 ± 19.4 days) (Pérez et al. 2015). Natural rearing, a rearing method that allows captive birds to freely choose mates, nest, and brood in a large aviary amongst other captive pairs, also improved re-sighting rates (Natural = 0.23 vs. Artificial = 0.00) of red-legged partridges when compared to artificially reared (incubator hatched and artificially heated) partridges over a 6-month period (Santilli et al. 2012). As such, factors other than age-at-release such as weather (heat, abundant rainfall, etc.) and predator dynamics may better elucidate the success of the parent-rearing adoptive system.

A possible reason for the high mortality rates experienced in our study is the lack of proper anti-predator behaviors imprinted on chicks during the rearing process (Beani and Dessi-Fulgheri 1998). Chicks were reared in pens with all precautions taken to eliminate any opportunity for chicks to encounter predators while being brooded. High mortality rates among released adoptive parent-reared bobwhites may indicate limitations of the rearing system to provide proper cognitive abilities and encourage physiological development among adoptive parent-reared chicks (Pérez et al. 2015). Other studies have documented behavioral differences and predator vigilance of captive-reared and wild bobwhites (Jung and Hayslette 2016). There were significant differences in mean flight speeds of released wild and captive-reared bobwhites in south Texas (Perez et al. 2002) offering some evidence that differences in physiological development may impact survival rates. Reactions to predator stimuli differed among captive-reared and wild bobwhites in a study conducted in north Texas (Newman 2015). Captive-reared bobwhite tended to flush when exposed to terrestrial and raptorial threats during attack simulations, while wild bobwhite tended to freeze or run, suggesting that these behaviors are absent in captive-reared bobwhites (Newman 2015). The tendency for captive-reared bobwhites to immediately flush in reaction to predator stimuli reveals the location of a bird to a predator (potentially easing subsequent predation attempts), which may explain the low survival rates of captive-reared bobwhites after release (Newman 2015). Differences in threat responses have also been observed in other galliformes. Flush distances in response to an approaching human and trained dog were greater for wild greater prairie-chickens (*Tympanuchus cupido*) than pen-reared Attwaters's prairie chickens (*T. cupido attwateri*) (Hess et al. 2005). The lack of these behaviors suggest that artificial rearing systems may cause an ethological and physiological deficit for game birds raised in captivity (Pérez et al. 2015). Maximizing survival of released individuals will ultimately increase breeding opportunities in the future and assist in establishing populations more effectively (Hardman and Moro 2006). The extremely high mortality rates experienced by chicks in our study limits the efficacy of the PRAP technique to establish viable bobwhite populations.

Future studies of adoptive parent-reared systems should include testing earlier release dates (prior to August) and behavioral conditioning. Anti-predator conditioning may trigger anti-predator/predator evasion responses deficient in adoptive parent-reared chicks. Anti-predator training worked with houbara bustards (*Chlamydotis undulata*) when reared birds were exposed to a live red fox (*Vulpes vulpes*) prior to release indicating that the development of anti-predator behavior may increase post-release survival (van Heezik et al. 1999). We expected habituation through extended periods in aviaries, but 9-week old chicks had higher survival rates potentially warranting the evaluation of releasing of older birds. Planting artificially hatched chicks with surrogate parents has been successfully tested with sage grouse (*Centrocercus urophasianus*), with adoption rates of

0.887 over three breeding seasons (Thompson et al. 2015). High rates of brood amalgamation and adoptions among bobwhites has been documented in the past and may allow testing of this technique as a tool for population augmentation (Faircloth et al. 2005). Strategically releasing captive-reared bobwhite chicks with known wild broods nearby or with potential adoptive wild parents using radio-telemetry may increase survival and warrants further investigation.

MANAGEMENT IMPLICATIONS

Our attempts to release chicks at different ages only minimally improved survival of adoptive parent-reared birds. However, the release of older individuals (10–12 weeks of age) may offer distinct survival advantages not observed in our study. Quality habitat existed on our study site suggesting that other factors are linked to the low survival of adoptive parent-reared chicks post-release. We do not recommend the release of PRAP bobwhites <9 weeks old as a bobwhite restoration tool. We recommend those interested in releasing adoptive parent-reared bobwhites to establish or augment current populations increase the number of birds released (>1 bird per acre of release area) to offset the low survival rates that we observed, especially in the first few weeks after release. The refinement of this technique to incorporate behavioral conditioning may increase survival rates of adoptive parent-reared birds after release by improving threat recognition and response. The cost to produce the number of chicks necessary for population recovery likely does not outweigh the return in the number of birds contributing to population viability—resources should be focused on wild bobwhite management.

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