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Early Hatch and Managed Native Grasslands Minorly Improve Bobwhite Juvenile Body Condition

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Abstract.—Precocial young leave their nest immediately after hatch to move and forage as a group during a rapid period of development. Growth and body condition are correlated with survival; young are better able to thermoregulate as they become larger, and they are better able to escape predators as they become more mobile. Environmental conditions can influence development and ultimately survival. We evaluated weather, cover type, and temporal factors affecting northern bobwhite juvenile body condition. We captured 216 individuals from 33 broods >16 d old on five conservation areas in southwest Missouri in 2017 and 2018. Brood hatch dates ranged from 26 May through 19 September. Body condition was measured as the residuals from a linear regression of juvenile tarsus length and body mass on capture. We found some support for improved body condition earlier in the breeding season and in native grasslands that were burned and grazed within the previous 2 y. However, models representing these effects had similar support to the null model (*i.e.*, ΔWAIC<2), indicating weak support. Limited support for these effects may have been due to limited data or the influence of other environmental factors not considered in our competing model set. Our top model supported negative effects of later hatching date and agricultural crop cover on juvenile body condition. The early breeding season is an important period for successful bobwhite productivity, and native grasslands managed with rotational fire and grazing may create higher quality brood rearing habitat for improved juvenile body condition.

Introduction

Body size and condition directly influence mobility and survival of young precocial birds. Larger chicks are better able to thermoregulate and are more mobile than smaller ones, which may improve foraging efficiency, predator avoidance, and survival of young (Visser and Ricklefs, 1995; Anderson and Alisauskas, 2001; Flint *et al.*, 2006; LeFer *et al.*, 2008; Schekkerman and Boele, 2009). Effects from the pre-fledging period can carry over to influence post-fledging survival. For example, individual body condition of Greater Sage-Grouse (*Centrocercus urophasianus*) during the pre-fledging period positively affects post-fledging survival probability (Blomberg *et al.*, 2014). Understanding environmental drivers of body condition of precocial young provides insight into factors affecting fitness (*i.e.*, survival) and brood success. Such insight into a vulnerable life stage may inform management decisions aimed at improving brood success and recruitment or inform predictions of population response to climate change, which will be particularly important for declining species.

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The quantity and nutritional quality of food resources for young broods are patchily distributed and can be affected by season, weather, and vegetation cover type (Guthery *et al.*, 2002; Le Fer *et al.*, 2008). Variation in growth and body condition of young chicks may reflect variation in food resource abundance and can be used to assess local forage quality and habitat suitability of brood-rearing areas (Le Fer *et al.*, 2008; Flint *et al.*, 2006; Blomberg *et al.*, 2013; Anteau *et al.*, 2014). In contrast, environments with lower food quality or abundance may result in starvation-induced weakness, reduced body mass and lower chick survival (Loegering and Fraser, 1995). Environments with higher food quality or abundance may result in better chick development, advanced mobility, improved foraging success and predator avoidance, and reduced risk of exposure in cold or wet weather (Jones *et al.*, 2017). Environmental conditions that constrain or enhance growth may be an ultimate factor affecting survival of precocial young (Flint *et al.*, 2006).

Northern bobwhite (*Colinus virginianus*, hereafter bobwhite) are a culturally and economically important gamebird experiencing rapid decline throughout most of their range (Burger *et al.*, 1999; Hernández *et al.*, 2013). Bobwhite are a shrub-obligate species occupying grasslands and other early successional habitats often within agricultural landscapes (Roseberry and Sudkamp, 1998; Crosby *et al.*, 2015). Bobwhite have low annual survival and rely on high productivity and recruitment to maintain populations (McConnell *et al.*, 2018). Quantifying juvenile bobwhite physiological responses to environmental conditions and habitat management will enhance our understanding of mechanisms underlying population dynamics (Guthery *et al.*, 2002; Kentie *et al.*, 2013).

Mortality of juvenile bobwhite is high until young reach a mass of >50 g (Lusk *et al.*, 2005). Bobwhite juveniles have high protein requirements for rapid growth (Nestler *et al.*, 1942). Young consume mainly insects for the first 2 wk post-hatch and then gradually increase the proportion of seeds and plant material in their diet (Hurst, 1972). Brood-attending adults select environments with higher invertebrate abundance, and brood home range sizes are inversely related to invertebrate abundance (DeVos and Mueller, 1993). Local abundance and availability of insects influences development, body condition, and survival of young (Nestler *et al.*, 1942; Hurst, 1972). Habitat management and weather (*i.e.*, temperature and precipitation) and seasonality (*i.e.*, intra-seasonal temporal trends) likely affect the growth and energy budgets of bobwhite chicks.

Our objective was to assess environmental influences on body condition of dependent juveniles younger than 30 d old. We predicted body condition would be better for individuals hatching earlier in the summer and during warmer, drier periods, because cold temperatures experienced by late-season broods and wet periods early in the breeding season may reduce foraging time and fitness for young birds (Spiers *et al.*, 1985; Schekkerman and Boele, 2009; Terhune *et al.*, 2019). We also predicted body condition would be better for individuals occupying native grasslands managed with fire and grazing, because prescribed fire and grazing increase insect abundance and facilitate chick mobility by removing thick vegetation litter (Hurst, 1972; Engle *et al.*, 2008; Doxon and Carroll, 2010). We predicted body condition would be poorer for individuals hatching later in the summer, during colder, wetter periods, and for those occupying agricultural crop fields or idle native grasslands.

METHODS

Our study occurred in southwest Missouri on a landscape that was historically the eastern edge of the tallgrass prairies, but has been largely converted to cool season pastures, agricultural row crops, and development (94°1′19″W, 37°31′47″N). Our study sites included

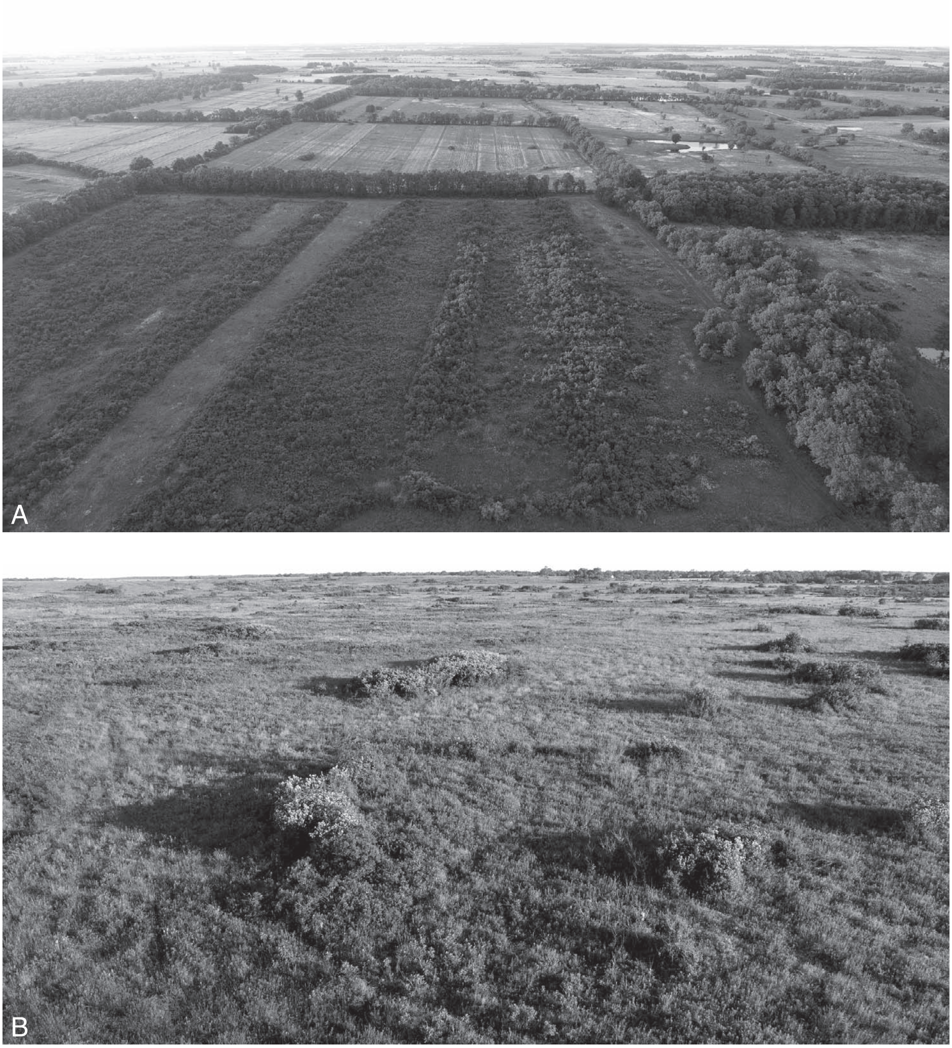

FIG. 1.—Aerial photo of A) Robert E. Talbot Conservation Area, an intensively managed site that applies fine-scale traditional management practices such as fields of strip crop and linear woody vegetation cover for wildlife; and B) Stony Point Prairie, an extensively managed site of native grassland maintained with fire, grazing, and mowing practices in southwest Missouri (photos by David Stonner, courtesy of Missouri Department of Conservation, 2018)

two intensively managed conservation areas, three extensive prairies owned or managed by Missouri Department of Conservation, and surrounding private lands. Shawnee Trail (1471 ha) and Robert E. Talbot Conservation Areas (1764 ha) are intensively managed public lands. These sites had small grassland units interspersed with strip crop or food plot plantings and woodland cover (Fig. 1A; Table 1). Shelton Memorial Conservation Area (129 ha), Stony Point Prairie (389 ha), and Wah'Kon-Tah Prairie (1226 ha) are extensively

TABLE 1.—Proportion cover of vegetation types and area (ha) of five study sites in southwest Missouri on which northern bobwhite broods were tracked 2017–2018. Shawnee Trail Conservation Area (SHT) and Talbot Conservation Area (TAL) were intensively managed sites. Shelton Memorial Conservation Area (SLT), Stony Point Prairie Conservation Area (STP), and Wah'Kon-Tah Prairie (WKT) were extensively managed native grassland sites

	SHT	SLT	STP	TAL	WKT
Agriculture	0.181	0.000	0.000	0.095	0.000
Idle agriculture	0.075	0.000	0.000	0.025	0.000
Native grassland	0.273	0.958	0.891	0.262	0.826
Grasslands	0.597	0.958	0.891	0.518	0.882
Shrubs	0.045	0.027	0.051	0.047	0.043
Trees	0.102	0.015	0.058	0.315	0.074
Area (ha)	1471	129	389	1764	1226

managed sites characterized by larger, continuous tracts of native grasslands and limited woodland cover (<6%; Fig. 1B; Table 1). Grasslands on all public lands in our study area were managed with fire, grazing, and/or mowing practices. Private lands surrounding public lands were largely agricultural row crop and cool-season grass pastures and hay fields.

TRACKING ADULTS, CAPTURE AND MARKING OF YOUNG

Missouri Department of Conservation funnel-trapped bobwhite and fit individuals with 5.5 g pendant-style radio collars beginning in February prior to each breeding season (model AWE-QII from American Wildlife Enterprises, Monticello, FL, U.S.A). Across all five study sites, 103 females and 92 males were tracked from May 1, 2017, and 81 females and 111 males were tracked from May 1, 2018. Nests hatched from late May through late September. We tracked adults during the breeding season, monitored nests, and captured young broods from June through October 2017 and 2018. Nests were located from May through September by following radio-collared adults and systematically searching areas in which adults were tracked two or more consecutive days. Nests were monitored at least three times per week during the incubation period and daily around estimated time of hatch. After hatch, we tracked brood attending adults once daily and recorded brood identity, date, time of day, and UTMs for each location. We tracked broods to within 10 m or projected their location based on signal strength and triangulation if a brood was on private land or otherwise not accessible. We tracked broods to at least one roost location before sunrise per week and rotated daytime tracking order to reduce bias associated with daily movement patterns of broods. We captured broods approximately 3 wk old before first light using thermal imaging cameras and the corral technique (Smith *et al.,* 2003; Andes *et al.,* 2012). We marked young with a patagial tag, weighed each individual with a digital scale, and measured tarsus length with calipers (Carver *et al.* 1999). Capture and handling protocols were approved by the University of Missouri Animal Care and Use Committee (Protocol 8766).

VEGETATION TYPE AND WEATHER COVARIATES

We classified cover type and management practices across our study extent using primarily descriptive maps from wildlife managers and our field observations to verify classifications. We also used aerial photos from National Agriculture Imagery Program (NAIP; USDA, 2016) and cropland data layers to classify cover type on private lands where access was restricted (CropScape; USDA, 2018). Herbaceous cover was identified as agricultural row crop, idle agricultural fields, native grassland, mixed grassland, or cool-season grasslands. Agricultural crops included corn (*Zea mays*), soybeans (*Glycine max*), winter wheat (*Triticum aestivum*), and sunflower (*Helianthus* spp). Native grasslands were either remnant or reconstructed prairies, or native grass plantings. Common grass species included little bluestem (*Schizachyrium scoparium*), and Indian grass (*Sorghastrum nutans*), common flowering plants included prairie blazing star (*Liatris pycnostachya*), pale purple coneflower (*Echinacea pallida*), and black-eyed susan (*Rudbeckia hirta*), and woody plants included species, such as sumac (*Rhus* spp.) and plum (*Prunus* spp.).

Management practices were classified based on a 2 y fire and grazing history of each management unit within a Conservation Area. We only evaluated the influence of agricultural crop and native grassland management on juvenile body condition. Idle native grasslands were areas not grazed or burned in the previous 2 y and not mowed within that growing season. We also evaluated the influence of native grasslands that had been grazed only, burned only, or both burned and grazed at least once in the previous 2 y. Prescribed burns and low-intensity grazing were applied on native grasslands within patch burn grazing units. These units were grazed at 1 animal unit per 4–5 acres for 90 to 120 d, 1/3 of units were burned September–April every 1–3 y, and patch burn grazing units were rested every 1–4 y. We quantified the average percent cover of each habitat type within 50 m of all daily locations from hatch to capture as our habitat predictors of juvenile body condition (McGarigal *et al.*, 2012). We collected daily temperature and precipitation data from Missouri Mesonet weather stations in Lawrence County for Talbot Conservation Area and Barton County for Shawnee Trail, Shelton, and Stony Point Prairie Conservation Areas. We collected weather data from one MesoWest station in Cedar County for Wah'Kon-Tah Prairie. Temperature variables considered in our analyses included average high and low daily temperatures (C) and maximum high and low daily temperatures (C) from hatch to capture for each brood. Precipitation variables included average and maximum daily precipitation (mm) and number of days of precipitation from hatch to capture for each brood.

STATISTICAL ANALYSIS

Residuals derived from regressions of body mass on structural body size measurements are used to describe fat mass as an index of body condition (Laboch and Hayes, 2012). We used the residuals from a linear regression of juvenile tarsus length and body mass ($P < 0.01$, $r^2 = 0.88$) as an index of bobwhite juvenile body condition (Vitz and Rodewald, 2011; Jones *et al.*, 2017). Data were not transformed before deriving residuals, given the relationship between body mass and tarsus length was linear (Fig. 2; Labocha and Hayes, 2012). Residuals were normally distributed with a mean of 0 and we assumed positive values were indicative of better body condition.

We used a normally distributed generalized linear mixed model in a Bayesian framework to evaluate effects of temporal and environmental factors on bobwhite juvenile body condition J_{jki}. We included brood identity, B_j, and site, S_k, as random effects for individuals (i) in brood j at site k in all models to account for intra-brood and site dependence (Eq. 1). Priors for these random effects were normally distributed with a mean of zero and a vague hyperprior for variation (*e.g.*, $\sigma_B^2 \sim Uniform(0,10)$). We evaluated the influence of hatch date, H, as a fixed temporal effect, temperature and precipitation variables as fixed weather effects, and agricultural, idle native grassland, and managed native grassland cover as fixed

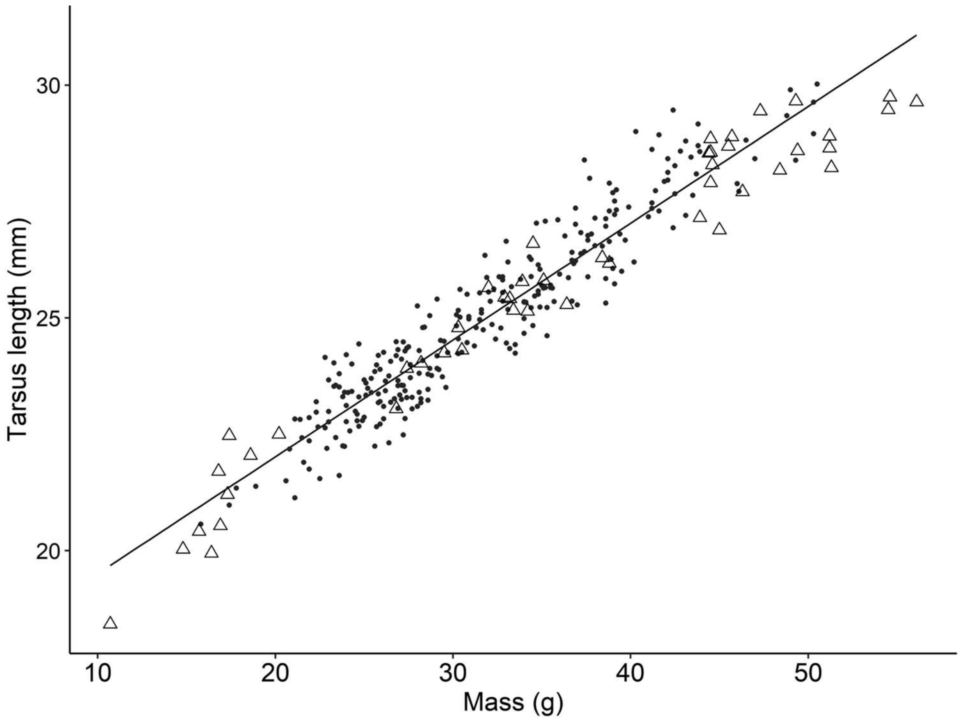

FIG. 2.—We used residuals of a regression of tarsus length on body mass for broods captured in southwest Missouri 2017–2018 as an index of body condition; residuals were normally distributed and are the vertical displacement of points from the regression line. As an example of covariates evaluated, broods, whose daily locations were ≥50% agricultural row crop cover (△), were plotted against broods, whose daily locations were <50% agricultural row crop cover (•).

habitat effects within 13 single effect models (Table 2). We assigned vague priors for an intercept term, α, and all fixed effects with a mean of zero and low precision (*e.g.*, $\alpha \sim Normal(0,0.001)$; Eq. 1). We assumed unaccounted for variation ε_i was normally distributed around zero, with a prior standard deviation uniformly distributed between 0 and 10. Our regression estimated the effects of hatch date (H) on juvenile body condition (J_{jki}) and can be written mathematically as:

$$J_{jki} = \alpha + B_j + S_k + H * hatch_i + \varepsilon_i \qquad \text{Eqn. 1}$$

Thirteen total fixed effects parameters were considered singly in models identical to Eqn. 1 in which habitat and weather variables were each evaluated in place of hatch date (Table 2). Brood age was not included in our body condition model, because nests were not observed for all broods captured and measured. Among broods included in the analysis with known hatch dates, there was no correlation between brood age and residuals of body mass and tarsus length ($r = 0.06$; Fig. 2B).

We fit body condition models in Program R version 3.6.1 (R Core Development Team 2019) using JAGS (Plummer, 2003) via the JagsUI package (Kellner, 2019). We first evaluated each of the 13 effects related to season, habitat, and weather in single parameter

TABLE 2.—Mean, 2.5% and 97.5% of observed values across all individual chicks of season, cover type (proportion within 50 m), and weather effects on northern bobwhite juvenile body condition in southwest Missouri 2017–2018

Data	Mean (2.5%, 97.5%)
Residual index of body condition	0.00 (–1.24, 1.33)
Nest hatch date	17 Jul. (26 May, 10 Sept.)
Agricultural crop cover	0.14 (0.00, 0.82)
Idle native grass cover	0.09 (0.00, 0.64)
Native grass burned and grazed	0.16 (0.00, 1.00)
Native grass burned only	0.16 (0.00, 0.90)
Native grass grazed only	0.04 (0.00, 0.46)
Average daily low temperature (C)	19.0 (14.1, 22.3)
Average daily high temperature (C)	30.4 (27.0, 34.0)
Minimum daily low temperature (C)	14.4 (5.9, 18.8)
Maximum daily high temperature (C)	34.5 (31.3, 37.3)
Average daily precipitation (mm)	3.1 (0.4, 6.9)
Maximum daily precipitation (mm)	31.3 (0.4, 68.8)
Number of days of precipitation	5.4 (1.0, 10.0)

models and compared their predictive ability relative to our null model (Table 2; Hooten and Hobbs, 2015). We ranked model performance by calculating Watanabe-Akaike Information Criterion (WAIC) values using the R package loo to interpret effects among competing models (Watanabe, 2010; Gelman *et al.,* 2014; Vehtari *et al.,* 2016). We included the most supported parameters from the single effect models in a set of multiple effects candidate models to quantify whether predictive performance improved. We considered models useful with ΔWAIC scores >2 from the null model. The null model included an intercept and random effects for site and brood but no environmental or temporal parameters. For each effect we present the posterior mean, 85% credible intervals, and *f*-values, which are the proportion of posterior samples above or below zero, representing the strength of positive or negative effects (Arnold, 2010; Jones *et al.,* 2017).

RESULTS

We captured and measured body condition of 316 individuals >16 d old from 46 broods on five sites in 2017 and 2018. Brood ages ranged from 16- to approximately 30 d old at capture and hatch dates ranged from May 26 through September 19.

Single-effect models incorporating hatch date, burned and grazed native grassland, and agricultural cover performed better than the null model. However, none of these models was >2 WAIC better than our null model, indicating only weak support for single effects (Table 3). Average daily high temperature and minimum daily low temperature were not supported based on WAIC values greater than the null model. Average daily high temperature was considered in subsequent multiple effects models, given 97% of the posterior distribution was greater than zero in the single effect model (Fig. 3A).

Based on parameters estimates from single effect models with >85% posterior support, we considered combinations of hatch date, burned and grazed native grassland, agricultural cover, and average daily high temperature in multiple effect models (Fig. 3A; Table 3). Five models were ranked above the null model and included different combinations of 2–4 of the variables considered (Table 4). The strongest support was for hatch date and agricultural

TABLE 3.—Single effect candidate models explaining the influence of hatch date, habitat, and weather factors on northern bobwhite juvenile body condition in southwest Missouri 2017–2018. Models are ranked by Watanabe-Akaike Information Criterion (WAIC). The mean, 7.5 and 92.5% percentiles, and proportion of posterior distribution with the same sign as the mean (*f*) are presented for model fixed effects

Rank	Parameter	Mean	7.5%	92.5%	*f*	ΔWAIC	WAIC
1	Nest hatch date	–0.205	–0.300	–0.107	0.999	0.0	549.6
2	Native grass burned and grazed	0.123	0.005	0.239	0.933	0.4	550.0
3	Agricultural crop cover	–0.094	–0.201	0.015	0.894	0.4	550.0
4	Null					0.6	550.2
5	Native grass grazed	–0.069	–0.168	0.030	0.843	1.0	550.6
6	Average daily precipitation	–0.030	–0.125	0.065	0.681	1.1	550.7
7	Average daily high temperature	0.146	0.042	0.253	0.973	1.3	550.9
8	Native grass burned	0.011	–0.101	0.121	0.559	1.4	551.0
9	Maximum daily precipitation	–0.014	–0.111	0.084	0.580	1.4	551.0
10	Maximum daily high temperature	0.057	–0.052	0.163	0.781	1.5	551.1
11	Number of days of precipitation	–0.020	–0.104	0.066	0.630	1.6	551.2
12	Idle native grass cover	0.011	–0.091	0.113	0.565	1.7	551.3
13	Minimum daily low temperature	0.091	–0.012	0.189	0.899	2.0	551.6
14	Average daily low temperature	0.111	0.011	0.208	0.944	2.1	551.7

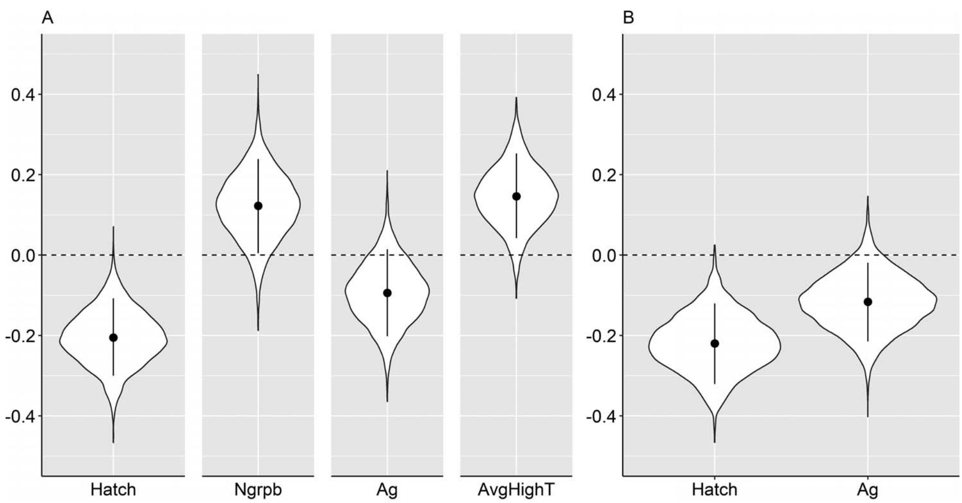

FIG. 3.—Posterior distributions (violin), means (point) and 85% credible intervals (line) of effect sizes from single effect models (A) and the top ranked multiple effects model (B) explaining variation in juvenile bobwhite body condition for broods captured in southwest Missouri 2017—2018. Single effect models showed support for negative effects of late hatch dates (Hatch) and agricultural crop cover (Ag), and positive effects of native grassland cover that was burned and grazed at least once in the previous two years (Npbgr). Average daily high temperature effects were credible; however, the single effects model did not perform better than the null model based on WAIC (AvgHighT; 3A). The top ranked multiple effects model included negative effects for later hatch dates (Hatch) and percent agricultural crop cover within 50 m of brood locations (Ag; 3B)

TABLE 4.—Multiple effects candidate models explaining variation in northern bobwhite juvenile body condition associated with hatch date, weather, and habitat factors in southwest Missouri 2017–2018. Models are ranked by Watanabe-Akaike Information Criterion (WAIC). The mean, 7.5 and 92.5% percentiles, and proportion of posterior distribution with the same sign as the mean (*f*) are presented for each parameter in multiple effects models

Rank	Parameters	Mean	7.5%	92.5%	*f*	ΔWAIC	WAIC
1	Nest hatch date	–0.220	–0.321	–0.120	0.998	0.0	548.1
	Agricultural crop	–0.116	–0.215	–0.019	0.958		
2	Nest hatch date	–0.216	–0.318	–0.116	0.998	0.7	548.8
	Native grass burned and grazed	0.068	–0.042	0.180	0.813		
	Agricultural crop	–0.090	–0.196	0.014	0.896		
3	Nest hatch date	–0.202	–0.302	–0.103	0.998	0.9	549.0
	Native grass burned and grazed	0.107	0.003	0.210	0.930		
4	Nest hatch date	–0.199	–0.312	–0.083	0.993	1.2	549.3
	Native grass burned and grazed	0.064	–0.052	0.178	0.789		
	Agricultural crop	–0.088	–0.194	0.020	0.884		
	Average daily high temperature	0.036	–0.083	0.154	0.682		
5	Agricultural crop	–0.056	–0.177	0.062	0.760	1.7	549.8
	Native grass burned and grazed	0.097	–0.035	0.224	0.860		
6	NULL					2.1	550.2
7	Nest hatch date	–0.176	–0.287	–0.062	0.986	2.4	550.5
	Average daily high temperature	0.062	–0.052	0.173	0.782		

cover, which occurred in the top model (Fig. 3B). Over 99% of the posterior distribution was below zero for the effect of hatch date on body condition, providing strong evidence of a negative effect for later hatch dates (Table 4). Body condition decreased from 0.37 to –0.43 as hatch date ranged from 26 May to 19 September (Fig. 4A). Ninety-six percent of the posterior distribution was below zero for the effect of agricultural cover on body condition (Table 4). Body condition decreased from 0.07 to –0.30 as agricultural cover ranged from 0 to 82% (Fig. 4B). Models with burned and grazed native grassland in combination with other parameters were ranked 2, 3, 4, and 5 and above the null model, and 79–93% of the posterior distribution was above zero, providing evidence of a minorly positive effect (Table 4). Based on model 3, mean predictions of body condition increased from 0.05 to 0.27 as the percent of burned and grazed native grassland increased from 0 to 100 percent (Fig. 4C). Average daily high temperature appeared in models 4 and 7 but the posterior distributions did not provide evidence of a positive effect ($f = 0.68$ and 0.78, respectively; Table 4).

DISCUSSION

While bobwhite occupy a variety of early-successional landscapes and juvenile survival is low and sensitive to environmental conditions, the effects of cover type, management practices, and weather conditions on juvenile body condition have not yet been evaluated. We found support for positive effects of earlier hatch date and burned and grazed native grasslands, and a negative effect of agricultural crop cover on juvenile body condition, which aligned with our predictions. While we expected precipitation and idle native grassland management would negatively influence body condition, these two parameters were not well-supported based on their posterior sample distributions and the fact those single-effect models performed worse than the null model. Poor predictive capacity of our models

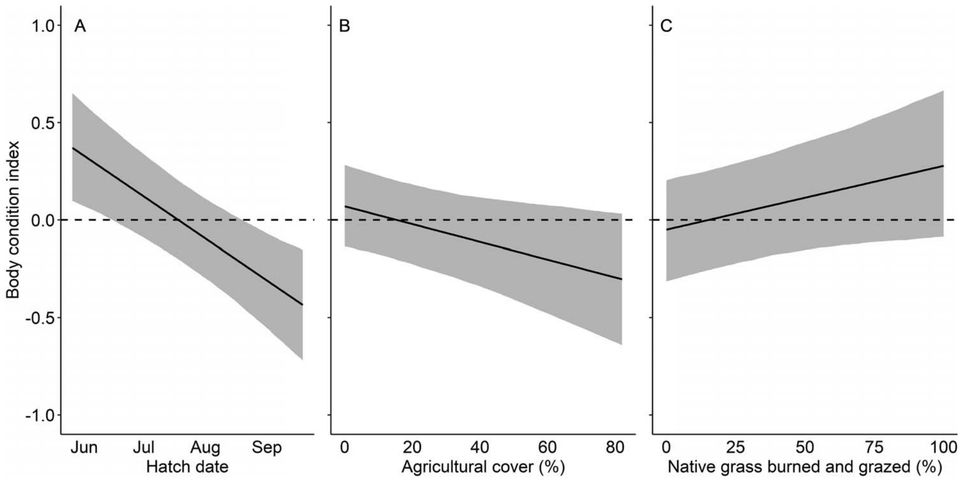

FIG. 4.—Predicted changes in juvenile bobwhite body condition indices over a range of hatch dates and environmental conditions broods experienced in southwest Missouri 2017–2018. All parameters had greater than 85% posterior support for positive or negative effects based on *f*-values. Hatch date (A) and agricultural cover (B) predictions were estimated from parameters in the top model, while the predicted effect of changes in percent cover of native grassland that was burned and grazed (C) was estimated from the third-ranked multiple effects model.

suggests either data were insufficient or other intrinsic, temporal, or environmental factors, such as parental care or extreme weather conditions, were more important contributors to bobwhite chick body condition. Yet, we have reason to believe these effects influence bobwhite juvenile body condition.

Earlier hatch dates resulted in greater bobwhite juvenile body, though hypothesized positive effects of warmer temperatures were not supported. Warmer temperatures benefit development of other precocial species, such as golden plover (*Pluvialis dominica*), for which weight gain was positively associated with warmer temperatures (Pearce-Higgins and Yalden, 2002). We may have found stronger support for effects of earlier hatch dates than warmer temperatures because it captured phenological events that affected food availability better than our weather variables. Alternatively, we may not have measured the most important weather effects. For example, we did not evaluate effects of extreme hot temperatures. During peak diurnal temperatures on days >39 C, bobwhite brood movement sharply declines as broods seek refuge in cooler microclimates of tall vegetation (Carroll *et al.*, 2015). Thermal stress and reduced foraging time may result in lower juvenile body condition.

We found support for our hypothesized positive effects of burned and grazed native grasslands and negative effects of agricultural row crop on juvenile bobwhite body condition. Patch burn grazing on native grasslands promotes heterogeneity in plant community structure and composition and can lead to concentrated areas of high invertebrate biomass for foraging broods (Engle *et al.,* 2008). Invertebrate-rich diets during the first 4 wk post hatch result in more rapid growth (Blomberg *et al.,* 2013). Burning can create brood foraging habitat and increase growth rates of bobwhite chicks (Kamps *et al.*, 2017). We found support for a negative influence of row crop cover on juvenile body condition. Although juvenile foraging and growth rates may be lower in croplands, weedy fields may provide sufficient invertebrate prey (Palmer *et al.,* 2001; Doxon and Carroll, 2007, 2010; Lohr *et al.,* 2011).

We found no relationship between precipitation patterns and juvenile body condition; however, other studies have found rainfall increased brooding time and decreased foraging time for young chicks (Schekkerman and Boele, 2009). Inclement weather can reduce foraging efficiency, body condition, and survival of adults and their young (Sergio, 2003; Anctil *et al.,* 2014; Fisher *et al.,* 2015; Terraube *et al.,* 2017). Precocial young are susceptible to hyperthermia in wet and cold conditions (Stoddard, 1931; Conley and Porter, 1986). Wet and cold conditions that limit foraging activity and reduce insect availability may reduce body condition of young during a vulnerable period of rapid growth, ultimately depressing survival and population recruitment (Stoddard, 1931; Schekkerman and Boele, 2009; Terhune *et al.*, 2019).

We did not evaluate prehatching condition effects on juvenile growth. Mean hatching weight of golden plover chicks was positively correlated with mean egg volume within a clutch and also positively correlated with weight gain of 2 d old young (Pearce-Higgins and Yalden, 2002). While hatching weight may not predict juvenile survival, weight gained in the first few days of life was greater for plover chicks that survived, and the heaviest chicks at 2 d old were the most likely to survive (Pearce-Higgins and Yalden, 2002). For bobwhite heavier eggs also produced larger chicks, which may in turn improve juvenile growth (Skewes *et al.,* 1988). We did not consider factors potentially influencing egg weight, but this should be evaluated in future study designs.

Understanding environmental drivers of bobwhite juvenile body condition is an important component of brood ecology. We provide limited evidence that body condition is related to hatch date and cover type and management. Earlier hatch dates may improve foraging time and prey abundance, whereas patch burn grazing on diverse native grasslands may improve foraging efficiency and invertebrate availability. Longer term data and larger sampling of broods would provide greater perspective on the strength of these anticipated relationships between habitat and weather on juvenile body condition. Additionally, evaluating multiple measures of body condition may aid identification of metrics that perform best for analyses of bobwhite and precocial young of other gallinaceous birds (Labocha and Hayes, 2012). Although predation rates are high for precocial chicks, habitat and weather conditions that constrain growth rates may ultimately affect survival of bobwhite young. The influence of growth on juvenile survival and the sensitivity of population growth to this demographic rate make body condition an important contributor to recruitment and full annual cycle population dynamics.

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