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Donald M. Yow
Eastern Kentucky University

Jeremy P. Orange
Kentucky Department of Fish and Wildlife Resources

John J. Morgan
Kentucky Department of Fish and Wildlife Resources

Gary Sprandel
Kentucky Department of Fish and Wildlife Resources

Danna L. Baxley
Kentucky Department of Fish and Wildlife Resources

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Temperature Assessment on a Reclaimed Surface Mine During Northern Bobwhite Breeding Season: Considerations for Habitat Management

Authors

Donald M. Yow, Jeremy P. Orange, John J. Morgan, Gary Sprandel, Danna L. Baxley, and Eric Williams

TEMPERATURE ASSESSMENT ON A RECLAIMED SURFACE MINE DURING NORTHERN BOBWHITE BREEDING SEASON: CONSIDERATIONS FOR HABITAT MANAGEMENT

Donald M. Yow¹

Department of Geosciences, Eastern Kentucky University, 521 Lancaster Avenue, Richmond KY 40475, USA

Jeremy P. Orange

Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort KY 40601, USA

John J. Morgan

Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort KY 40601, USA

Gary Sprandel

Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort KY 40601, USA

Danna L. Baxley

Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort KY 40601, USA

Eric Williams

Kentucky Department of Fish and Wildlife Resources, 1 Sportsman's Lane, Frankfort KY 40601, USA

ABSTRACT

Ground-level air temperatures were assessed within 4 distinct habitat areas on a managed reclaimed surface mine at Peabody Wildlife Management Area, Kentucky, 26 June–17 July 2015, during the northern bobwhite (*Colinus virginianus*) brood season. Habitat consisted of disked and nondisked areas of native grass and an invasive species, sericea lespedeza (*Lespedeza cuneata*). Disked areas offered more open space for bobwhite mobility and experienced higher average temperatures than nondisked sites. Although statistically significant, differences in air temperature between disked and nondisked areas were likely too small to have practical implications for bobwhite habitat management in Kentucky under current climatic conditions. This will likely change in the future as the regional climate warms and periods of excessive heat are more likely to occur. Consequently, managers may want to consider microclimate when making management decisions.

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Key words: *Colinus virginianus*, conservation, habitat management, *Lespedeza cuneata*, northern bobwhite, Peabody WMA, reclaimed surface mine, temperature

More than 8 billion tons of coal have been extracted from Kentucky's Eastern and Western Coalfields since the state's first commercial coal mine opened in 1820 (KGS 2016). Following the removal of the coal deposits, thousands of hectares of mine lands have undergone reclamation and wildlife managers are tasked to find the best way(s) to transform the postreclamation landscape into productive habitat. Several researchers have studied the viability of reclaimed mine land as habitat for grassland birds (e.g., Scott et al. 2002, Monroe and

Ritchison 2005, Galligan et al. 2006). Although regulations encourage mining companies to establish native vegetation during the reclamation process, nonnative species are often planted instead, particularly sericea lespedeza (*Lespedeza cuneata*). Sericea provides little value to northern bobwhite (*Colinus virginianus*) as habitat because it tends to grow very densely, its seeds are indigestible by bobwhite, and it may limit the abundance of insects that bobwhite eat (Blocksome 2006). Sericea presents challenges for northern bobwhite conservation as it spreads readily and produces large numbers of seeds that can remain viable for many years and grows in virtually any soil type. Controlling sericea requires regular treatment over a number of years and

¹ E-mail: don.yow@eku.edu

there is no known method for its eradication (Silliman and Maccarone 2005).

Prior research on a reclaimed surface mine in western Kentucky has shown that bobwhite populations exhibit low production of young, lower than normal hatchability of eggs, and extremely low adult survival in the summer (Brooke 2015, Brooke et al. 2015, Peters et al. 2015). In a 4-year study, Peters et al. (2015) found that bobwhite survival varied annually, ranging from 0.139 (SE = 0.031) to 0.301 (SE = 0.032), and seasonally (summer, 0.148 [SE = 0.015]; winter, 0.281 [SE = 0.022]). Excessive heat may contribute to lower summer survival and production in this area because high temperatures are known to negatively impact bobwhites. High summer temperatures can limit bobwhite reproduction (Guthery et al. 1988), and hyperthermia reduces avian embryo survival (Webb 1987). Reyna and Burggren (2012) specifically identified 40° C as the upper limit for bobwhite egg survival and Guthery et al. (2005) identified 39° C as a threshold where quail become hyperthermic. Guthery et al. (2005) also found that approximately 90% of incubating adult bobwhites tracked in their study were employing gular flutter to regulate body temperature when air temperature exceeded 35° C. This thermoregulatory behavior may interact with food and water availability because gular flutter dramatically increases water loss and increases energy demand to some degree.

Carroll et al. (2015) discovered large temperature variations across their study area that provided unique microclimates affecting bobwhite behavior during the brood-rearing period. Hot microclimates can thermally fragment bobwhite habitat as the birds avoid areas with extremely high temperatures (Forrester et al. 1998, Guthery et al. 2000). We measured ground-level air temperatures (T_a) during the warm season to characterize this aspect of epigeal microclimates found in 4 habitat types (disked and nondisked native grass, disked and nondisked sericea). Our goal was to gain insight into how management practices affect T_a in our study area. Specifically, we wanted to know how much the presence-absence of sericea lespedeza would affect T_a . We also wanted to find out how much T_a was affected by whether areas had been disked or not because the surface microclimate becomes more extreme (i.e., higher maximum temperature and lower minimum temperature) with decreased vegetation soil covering and shading (Geiger et al. 2003).

Distler et al. (2015) predict that climate change will cause decreases in bird species richness in summer over much of North America, including Kentucky. Lusk et al. (2001) suggest that bobwhites may be able to adapt to increases in average temperature but caution that the pace at which climate change occurs may affect their resilience. They also state that bobwhites are particularly sensitive to high summer temperatures that exceed their ability to cope. Climate models predict that average temperatures in our study area will increase 2–3° C by the end of this century and days warmer than 32.2° C will become more common (USGCRP 2014). The warmer climate will exacerbate negative effects that excessive heat has on bobwhites at our study site. Current

management practices there focus on removing sericea and providing more open space for birds. Although these actions provide appropriate substrate, they may also result in elevated local temperatures.

STUDY AREA

Our study site was a reclaimed surface mine; approximately 580 ha on the Sinclair tract of Peabody Wildlife Management Area in western Kentucky (hereafter, Peabody). Western Kentucky lies in the northern part of the humid subtropical climate zone of the southeastern United States. This is a transition zone just south of the humid continental climate of the US Midwest, which has much colder and longer winters than Kentucky. Maximum temperatures in the summer often exceed 32° C and occasionally rise above 38° C. Winter minimum temperatures rarely fall below –18° C. The highest ground-level air temperature observed at Peabody during our study period was 37.3° C. Average annual precipitation in western Kentucky measures 1,250 mm with no distinct wet or dry seasons. Precipitation during our study period was similar to long-term climatological averages for the region.

All vegetation and soil at Peabody was stripped during the mining process. The bedrock was subsequently covered with a thin layer of ‘fill’ of varying quality and thickness that was compacted by heavy equipment during reclamation. The resultant topography is relatively flat with elevations ranging from 122 m to 180 m. Land-use classification derived from satellite imagery showed the following: 57.4% open herbaceous, 19.7% scrub shrub, 9% native warm season grass, 5% water or emergent wetland, 4.2% deciduous forest, 2.2% firebreaks, 1.4% covered by roads or other development, and 1.1% used for annual grain production.

METHODS

Native grass and sericea lespedeza (the dominant nonnative species) are the primary nesting options at Peabody. However, given the limited value of sericea as a nesting substrate, disking is regularly implemented as a management strategy. We divided the study area into sections having 4 different habitats (NG = native grass, DN = disked native grass, SL = sericea lespedeza, DS = disked sericea lespedeza; Fig. 1). Disking occurred approximately 3 years to 3 months prior to temperature-logger deployment, although the specific time since disking for any given location was unknown and therefore unfortunately not considered in this analysis. Thirty temperature loggers (Onset HOBO Pendant Temperature and Light Data Loggers; Onset Computer Corporation, Bourne, MA, USA) were randomized spatially in each habitat type and deployed at ground level beneath radiation shields. Shielding the instruments was necessary because the temperature loggers we used are incapable of obtaining accurate readings in direct sunlight. Loggers collected data at 10-minute intervals from 25 June through 30 September 2015. Previous research at Peabody

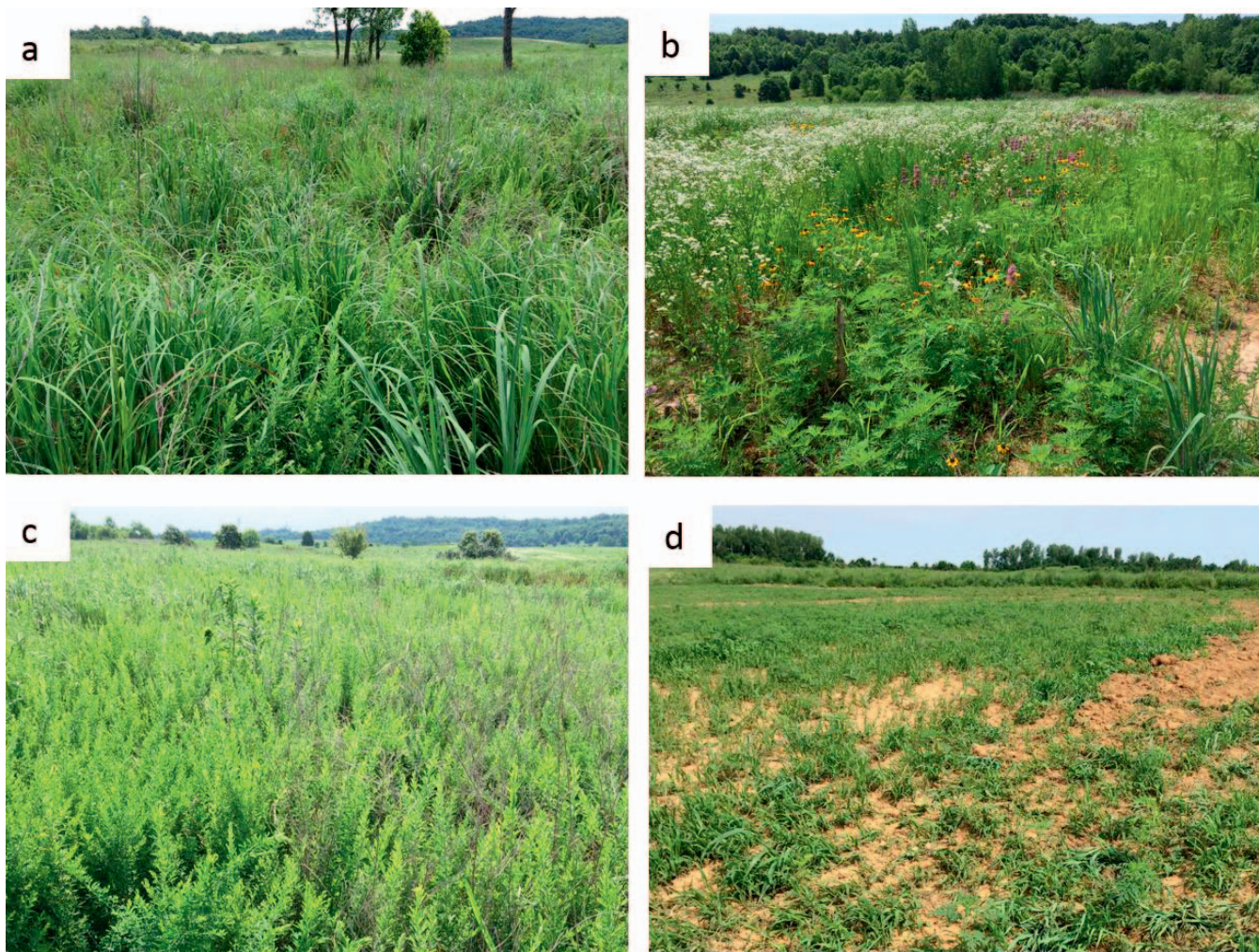


Fig. 1. Examples of each habitat type in northern bobwhite nesting habitat at Peabody Wildlife Management Area, Kentucky, USA (26 Jun–17 Jul 2015). a) native grass (NG), b) disked native grass (DN), c) sericea lespedeza (SL), d) disked sericea lespedeza (DS).

identified the peak nesting time period as 29 May through 3 July, and peak timing for chicks on the ground as 26 June through 17 July (Brooke 2015). We focused this analysis on data collected 26 June through 17 July to concentrate on peak brood-rearing. We removed suspect or biased data from consideration prior to data analysis (e.g., if a logger had been washed out from under its radiation shield during a storm). The final numbers of loggers with reliable data were NG = 28, DN = 30, SL = 27, DS = 25 (Fig. 2).

We assessed the habitat at each temperature logger location using established methods. We quantified percent ground cover of primary vegetation categories (Grass, Forb–Legume, Bare Ground, and Leaf Litter) using a 1-m $\times$ 1-m Daubenmire cover frame (Daubenmire 1959; Table 1). We used a vertical cover–profile board (Nudds 1977) to measure vegetation structure at each location. We measured litter depth (cm) at the plot center using a plastic ruler. We also recorded slope and orientation at each site. We computed correlation coefficients and coefficients of determination between air temperature and quantitative variables (e.g., percent vegetation cover, litter depth, and slope). We conducted

one-way analysis of variance (ANOVA) tests to look for significant differences ($\alpha = 0.05$) in T_a between habitat types and slope aspect. We identified all observations $>40^\circ\text{C}$ based on Reyna and Burggren (2012), and those $>35^\circ\text{C}$ and $>39^\circ\text{C}$ based on Guthery et al. (2005).

RESULTS

Compared with nondisked areas, disked areas are generally more open, offering more bare ground for bird mobility. DN areas had an average of 25.3% more bare ground than NG; DS had an average of 34.2% more bare ground than SL (Table 1). These differences are significant at the 95% confidence level. Litter depth was significantly different ($\alpha = 0.05$) in each habitat type with SL having the greatest average followed by NG, DS, and DN with the least.

Percentages of various land covers (grass, forb, bare ground, and leaf litter) and leaf litter depth were moderately to weakly correlated with daily maximum and minimum temperatures ($T_{\max}$, $T_{\min}$); however, all

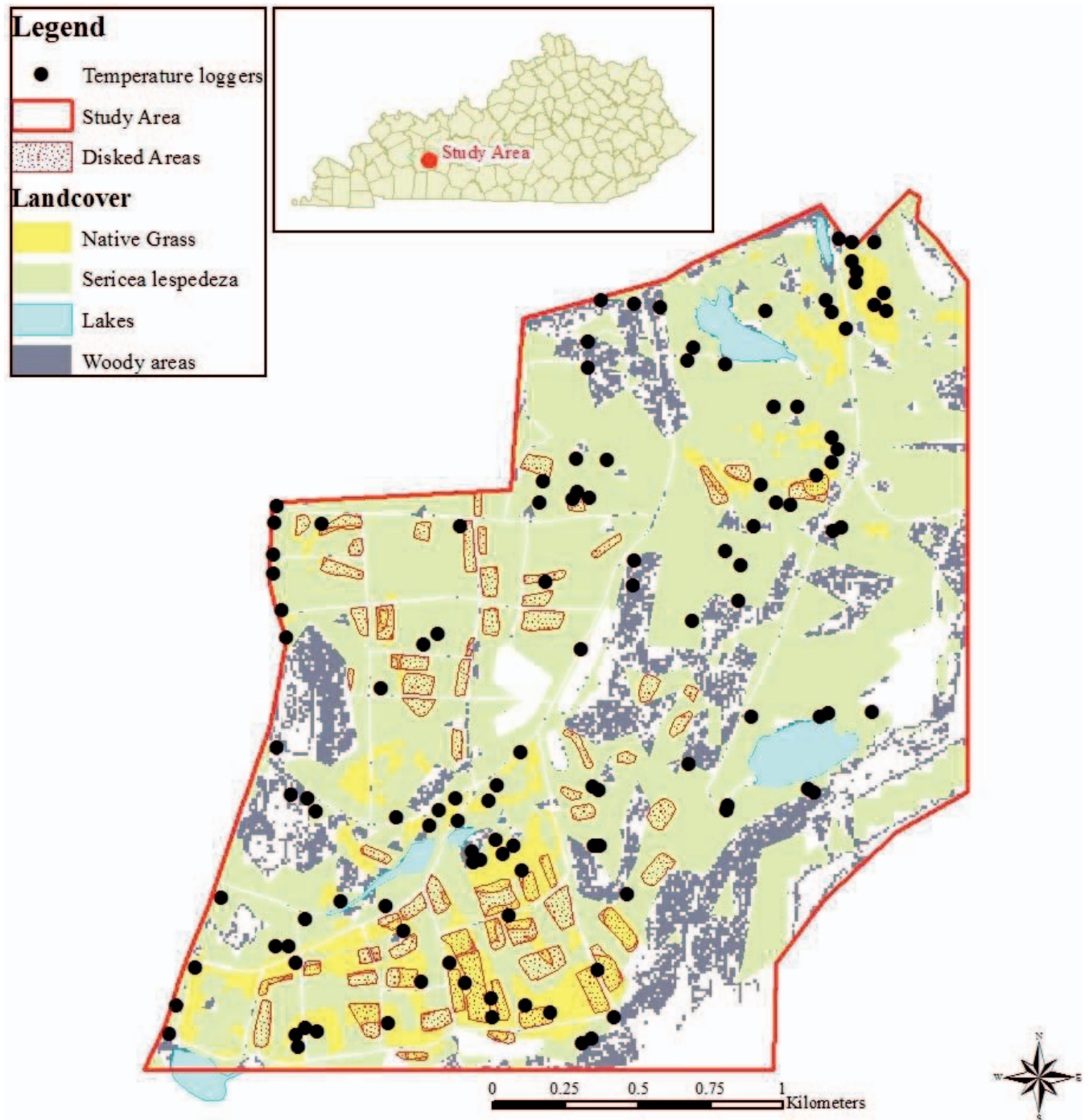


Fig. 2. Study area and temperature data logger locations (Sinclair tract of Peabody Wildlife Management Area, Muhlenberg County, KY, USA) within northern bobwhite nesting habitat, 26 June–17 July 2015. Native grass and sericea lespedeza (the dominant nonnative species) are the primary nesting options at Peabody. Managed areas were either left in their natural state (nondisked) or disked to provide more open space for bobwhites by removing excess vegetation.

correlations were statistically significant at the 95% confidence level (Table 2). The strongest positive correlation with daily temperatures occurred with percent bare ground, which explained 15.2% and 21.3% of the variation in daily $T_{\max}$ and $T_{\min}$, respectively. Moreover, the highest maximum temperatures observed during our study occurred at locations with the highest percent of bare ground (Fig. 3). The strongest negative correlation

with daily temperatures occurred with percent leaf litter, which explained 19.5% and 25.3% of the variation in daily $T_{\max}$ and $T_{\min}$, respectively. A site's slope aspect could affect daily $T_{\max}$. One-way ANOVA tests revealed that loggers located on west-facing slopes recorded significantly warmer daily $T_{\max}$ than loggers on all other slopes ($\alpha = 0.05$). $T_{\min}$ was not significantly affected by slope aspect.

Table 1. Summary of vegetation assessment of northern bobwhite nesting habitat at Peabody Wildlife Management Area, Kentucky, USA, conducted during 26 June–17 July 2015. Mean [SD] is reported for 4 habitat classifications (disked and nondisked native grass, disked and nondisked sericea). The percent ground cover of primary vegetation categories (Grass, Forb–Legume, Bare Ground, and Leaf Litter) was quantified using a 1-m × 1-m Daubenmire cover frame (Daubenmire 1959). Note: vegetation cover values of canopy (% grass and % forb or legume) and ground cover (% bare ground and % leaf litter) were estimated independently allowing for a total sum >100%. Disked areas had greater percentages of bare ground and less litter depth, allowing more sunlight to reach and warm the ground in those areas.

	% Grass	% Forb–Legume	% Bare ground	% Leaf litter	Litter depth (cm)
Disked native grass ($N = 30$)	29.0 [27.6]	64.3 [27.5]	41.8 [26.7]	37.5 [28.3]	0.6 [1.3]
Disked sericea ($N = 25$)	26.6 [31.4]	63.2 [26.6]	37.2 [24.6]	40.6 [32.1]	1.4 [1.8]
Native grass ($N = 28$)	57.1 [23.8]	33.6 [24.1]	17.0 [16.2]	63.8 [23.2]	2.6 [2.0]
Sericea ($N = 27$)	7.0 [11.8]	85.4 [11.2]	3.0 [4.8]	83.0 [7.6]	4.5 [2.8]

Differences in the average daily maximum and minimum temperatures between habitat types were small (Table 3). Disked areas were generally warmer and areas of nondisked sericea were coolest. Differences in average daily $T_{\max}$ and $T_{\min}$ were exceeded by the standard deviation within each habitat type but some differences were statistically significant. One-way ANOVA tests using habitat type as the factor showed that disked areas had significantly higher average daily $T_{\max}$ and $T_{\min}$ than nondisked areas ($\alpha = 0.05$). There was no significant difference between temperatures recorded in areas of disked native grass and disked sericea. Loggers in nondisked native grass recorded significantly higher $T_{\max}$ than nondisked sericea but there was no significant difference in $T_{\min}$ at nondisked sites.

Temperatures never reached the 39° C or 40° C thresholds during our study. $T_a > 35^\circ \text{C}$ occurred 99 times during the study period (<0.03% of all 10-min observations). These events were concentrated during 5 days at 9 different observation sites. Eight of the 9 sites in this

subset were disked. Eighty-two of the 99 $T_a > 35^\circ \text{C}$ events happened at just 3 sites. All 3 sites were disked and had 60%, 80%, and 85% bare ground exposed. $T_a > 35^\circ \text{C}$ events were not exclusive to freshly disked areas with ample bare ground, however, because temperatures exceeding 35° C were occasionally observed in areas having abundant grass and forb shading the ground (Fig. 4).

DISCUSSION

Surface mining has scarred huge amounts of land that intensive management can transform into high-quality bobwhite habitat. Determining best management practices requires considering a myriad of factors, including microclimate. The highest ground-level temperature observed during our study period (37.3° C) was below the 40° C threshold that Reyna and Burggren (2012) reported as being fatal to bobwhite embryos and below the 39° C threshold that causes quail to become hyperthermic (Guthery et al. 2005). Some of our observations exceeded 35° C, which Guthery et al. (2005) found to initiate gular flutter in approximately 90% of incubating bobwhites. Although temperatures high enough to induce gular flutter occurred infrequently

Table 2. Correlation coefficients (r) and coefficients of determination (r^2) between variables related to northern bobwhite nesting habitat site characteristics and daily maximum and minimum temperature ($T_{\max}$, $T_{\min}$) at Peabody Wildlife Management Area, Kentucky, USA (26 Jun–17 Jul 2015). All values are statistically significant at the 95% confidence level. Percent ground cover of primary vegetation categories (Grass, Forb–Legume, Bare Ground, and Leaf Litter) was quantified using a 1-m × 1-m Daubenmire cover frame (Daubenmire 1959). Percent bare ground had the strongest positive correlation, with both $T_{\max}$ and $T_{\min}$ indicating that warmer temperatures were observed in areas with increased amounts of bare ground. Percent leaf litter and litter depth were negatively correlated with $T_{\max}$ and $T_{\min}$, suggesting that leaf litter had a cooling effect on temperatures near the ground. Slope, percent grass, and percent forb–legume all had very weak correlations with daily maximum and minimum temperature.

	Daily $T_{\max}$		Daily $T_{\min}$	
	r	r^2	r	r^2
Slope	−0.073	0.005	−0.188	0.035
% Grass	0.057	0.003	0.075	0.006
% Forb–legume	−0.174	0.030	−0.123	0.015
% Bare ground	0.389	0.152	0.462	0.213
% Leaf litter	−0.442	0.195	−0.503	0.253
Litter depth (cm)	−0.295	0.087	−0.425	0.181

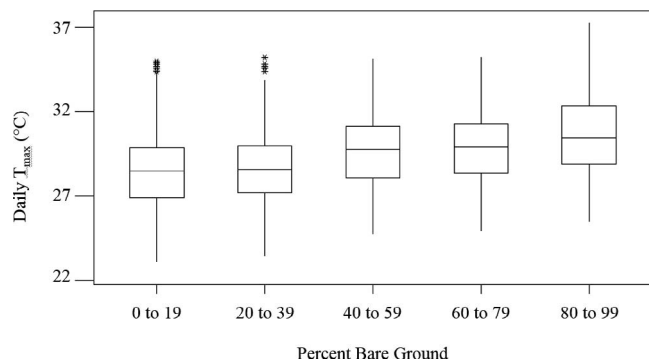


Fig. 3. Boxplots of daily maximum temperature and percentage of bare ground exposed at observation locations of northern bobwhite nesting habitat at Peabody Wildlife Management Area, Kentucky, USA (26 Jun–17 Jul 2015). Areas of sparse vegetation, including freshly disked areas, experience the highest maximum temperatures. This, combined with the lack of shade, means there is greater risk of bobwhite heat stress in areas having high percentages of bare ground.

Table 3. Daily maximum ($T_{\max}$) and minimum ($T_{\min}$) air temperature by northern bobwhite nesting habitat type (disked and nondisked native grass, disked and nondisked sericea) at Peabody Wildlife Management Area, Kentucky, USA (26 Jun–17 Jul 2015). Disked areas had higher daily maximum and minimum temperatures on average. The highest maximum temperature was observed in a disked native grass area.

	Daily $T_{\max}$ ($^{\circ}$ C)				Daily $T_{\min}$ ($^{\circ}$ C)			
	$\bar{x}$	SD	Hi	Low	$\bar{x}$	SD	Hi	Low
Disked native grass	29.66	2.20	37.27	24.55	22.48	1.81	26.59	15.47
Disked sericea	29.70	2.15	35.22	24.74	22.42	1.68	26.59	15.76
Native grass	28.46	2.30	35.22	23.48	21.71	1.76	26.49	14.71
Sericea	28.11	2.18	34.16	23.10	21.34	1.73	25.51	14.61

at Peabody during our study, extreme high temperatures are expected to become more common in the future (IPCC 2013). Climate models project that if global emissions of greenhouse gases continue to grow, summertime temperatures in the United States that ranked among the hottest 5% in 1950–1979 will occur $\geq 70\%$ of the time by 2035–2064 (USGCRP 2014). Furthermore, our findings likely underestimated actual thermal load on bobwhites because temperature loggers were shielded from direct sunlight.

The largest factor affecting ground-level temperature variability in our study was whether or not an area had been disked. Disked areas were warmer than nondisked areas, which could be a concern in warmer areas and/or during hotter summers. Maximum and minimum daily temperatures were lowest in areas of SL, most likely on account of less direct sunlight reaching the surface (only 3% bare ground on average). Doxon and Carroll (2010) found that bare ground cover had a profound impact on bobwhite chick survival because it enhanced invertebrate availability and diversity, and chick mobility influenced

feeding rates. Disking opens up areas of bare ground, which is necessary at Peabody because areas of NG and SL only had an average of 17% and 3% bare ground, respectively. Future work at Peabody should monitor the speed of regrowth following diskings to help determine optimal intervals between habitat disturbances.

Greater vegetation nutrition was available for quail in disked areas than in areas of nondisked native grass given greater amounts and diversity of forbs and legumes present ($>63\%$ forb cover on average in disked areas compared with 33.6% in NG areas). It is possible that reducing sericea and increasing vegetation species diversity also aids in attracting insects (Blocksome 2006). This potential benefit has been enhanced in disked areas at Peabody through the successful seeding of plants such as bee-balm (*Monarda didyma*) and black-eyed Susan (*Rudbeckia hirta*; Fig. 1b). Accordingly, we recommend studies assessing the impact of diskings on the biomass and diversity of bobwhite food sources.

None of the metrics we tested explained $>19.5\%$ of the variance in daily maximum temperature at ground level. Although increased vegetation cover should theoretically reduce daytime $T_{\max}$, the percentage of bare ground alone did not reliably predict where thermal hot spots would occur in this reclaimed mine landscape. This suggests that the compacted subsurface geology in reclaimed mine sites can outweigh the effects vegetative forcing has on surface T_a . Future work on reclaimed surface mines should investigate how the spatial variability of soils affects microclimate and vegetation success.

Climate change will affect bobwhite populations in the future. Throughout much of the world, temperatures are expected to increase, growing seasons to lengthen, precipitation to become more variable and erratic, and droughts to become more severe (IPCC 2014). The magnitude of climatic changes and associated impacts depends on future greenhouse gas emissions and changes will also be different for different parts of the globe. Under all future emissions scenarios, however, the number of days with high temperatures $>32.2^{\circ}$ C is expected to increase throughout the United States, especially toward the end of this century (USGCRP 2014). Climate model runs produced for the Intergovernmental Panel on Climate Change's 5th Assessment Report project temperatures in Kentucky to be $2\text{--}3^{\circ}$ C warmer at the end of this century than they were at its



Fig. 4. Ground-level temperature of northern bobwhite nesting habitat at Peabody Wildlife Management Area, Kentucky, USA, which exceeded 35° C at this site located within disked native grass habitat 4 times during the study period (26 Jun–17 Jul 2015). This illustrates that thermal stress can be a concern for bobwhite in what otherwise appears to be a well-suited habitat (30% grass, 65% forb, 40% bare ground, and 20% leaf litter). The white square in lower right is the solar radiation shield protecting the temperature logger. Note that multiple thermal refuges are available nearby.

beginning (IPCC 2013). Those same models predict a 0–20% increase in Kentucky's annual precipitation over the same period. Phenology changes and species distribution shifts will likely affect forage quality in Kentucky as species composition of pastures changes (Vincelli et al. 2011). Simulating warming (+3° C above ambient temperature) and increased precipitation (+30% long-term normal precipitation) over pasture in central Kentucky, McCulley et al. (2014) observed significant changes in plant species composition. Such changes could greatly affect bobwhite health, further exacerbating the need for habitat management. Climate change directly affects birds as well. Several bird species have experienced changes in breeding age, timing of migration, breeding performance (egg size, nesting success), population sizes, and population distributions (Crick 2004). As Kentucky's climate warms, microclimate will become increasingly important in habitat management. Several strategies have been proposed for conserving biodiversity that incorporate uncertainties associated with climate change (e.g., Burgman et al. 2005, Bagchi et al. 2013). Unfortunately, none of these approaches provide sufficient information to guide conservation decisions concerning specific species or communities. Management strategies incorporating climate change scenarios are needed for northern bobwhite conservation.

MANAGEMENT IMPLICATIONS

Our findings, coupled with future climate projections, underscore the importance of considering appropriate thermal climates when developing management strategies. Vegetation at Peabody tends to grow very densely, which degrades bobwhite habitat. Disking creates open space birds need but also results in higher air temperatures at ground level. The lack of shade in newly disked areas could stress birds. Disking should be focused on areas near existing thermal cover or thermal cover should be added to disked areas without it. Our discovery that excessive T_a can also occur in areas with little bare ground exposed advocates offering more thermal refuges throughout managed areas. Projected climatic warming will further increase the need for thermal cover. Climate models predict average temperature across Kentucky to increase 2–3° C over the next century. If these models are correct, temperature thresholds critical to bobwhite well-being will be exceeded regularly. Therefore, managers may want to consider microclimate and proximity to thermal refuges in addition to trade-offs in substrate (e.g., more grass vs. forbs, open canopy vs. closed) when contemplating management actions.

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