DENNING CHRONOLOGY OF AMERICAN BLACK BEARS IN EASTERN OKLAHOMA AND THE EFFECTS OF ENVIRONMENTAL CONDITIONS

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Bachelor of Science in Agriculture in

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2022

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Date of Degree: MAY 7, 2022

Title of Study: DENNING CHRONOLOGY OF AMERICAN BLACK BEARS IN EASTERN OKLAHOMA AND THE EFFECTS OF ENVIRONMENTAL CONDITIONS

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Changing climate and rapid increase in human development strongly affect habitat use and behavior patterns in wildlife. These changes in infrastructure and animal behavior may lead to increased interaction between humans and wildlife, especially when food resources are limited. Previous studies have suggested that warmer temperatures are strongly associated with reduced duration of black bear (*Ursus americanus*) hibernation, which may increase bear-human conflict. However, most studies were performed in areas of high latitude and elevation. The effects of warming temperatures on hibernation could be even more dramatic near the southern parts of black bear range, but this has not been well studied.

We used GPS collar data for a population of black bears (n=37) in the Ouachita Mountains region of southeastern Oklahoma to determine the effects of environmental conditions on hibernation chronology, including denning duration, den entrance, and den emergence dates from 2014-2021. By comparing these dates to the average daily minimum temperatures, average daily maximum temperatures, and total precipitation around the denning period, we analyzed the effects of environmental conditions on hibernation chronology. Additionally, we estimated the effects of sex, age, reproductive status, and den type on denning behavior.

We found that average daily maximum temperature and precipitation were negatively associated with den emergence and the duration of denning. Additionally, we found reproductive status to strongly affect den entrance, emergence, and duration. This study will serve as baseline data to detect changes in black bears denning behavior in response to environmental conditions, which will help wildlife managers to better predict activity patterns in black bears, equipping them to help mitigate future human-bear conflicts.

ACKNOWLEDGEMENTS

A big thank you to everyone who made my honors thesis possible. I have had a wonderful 4 years as an undergraduate at Oklahoma State University, and I cannot thank all of my professors enough for helping me to grow as a researcher and wildlife professional. Thank you to The Honors College for enriching my undergraduate experience in and out of the classroom. Thank you especially to my thesis advisor and academic advisor, Dr. W Sue Fairbanks, for all of her guidance, advice, and support along the way. Thank you to my second reader, Dr. Bo Zhang, for her instrumental contributions to the analysis of this study. I also want to thank Courtney Dotterweich and Jake Humm for introducing me to the bear woods of Oklahoma and for their encouragement and support during this project. Thank you to the Oklahoma black bear research team for all of the data collected throughout the years, without which this project would not be possible. I am so thankful for the opportunity to study black bears in Oklahoma.

Lastly, thank you especially to my friends and family for their unrelenting support throughout my academic career. Their love, patience, and encouragement along the way has meant the world to me.

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INTRODUCTION

Changing climate and rapid increase in human development strongly affect habitat use and behavior patterns in wildlife. These changes in infrastructure and animal behavior may lead to increased interaction between humans and wildlife, especially when food resources are limited. For instance, black bears (*Ursus americanus*) can cause extensive property damage and lead to high management costs when searching for anthropogenic food sources. Previous studies have suggested that warmer temperatures are strongly associated with reduced duration of black bear hibernation, which may increase bear-human conflict. Many of these studies were performed in areas of high latitude and elevation, but the effects of warming temperatures on hibernation may be even more dramatic near the southern parts of black bear range.

In Colorado, variation in average minimum temperature negatively affected black bear hibernation patterns and has the potential to cause an increase in human-bear conflict (Johnson et al. 2017). Previous studies have also shown that long-term trends of warming winters may lead to bears entering dens later in the fall and emerging from dens earlier in the spring (Fowler et al. 2019; Johnson & Pelton 1980; Lindzey & Meslow 1976). The implications of a shorter hibernation include an increase in human-bear conflicts as bears change their behavioral patterns in response to a warming climate.

In southeastern Oklahoma, black bear populations inhabit an even warmer climate at a lower latitude than the bears studied in Colorado (Johnson et al. 2017). If black bears in Oklahoma similarly adjust hibernation in response to environmental cues as they did in Colorado, we hypothesized that warming temperatures may result in a shorter duration of bear hibernation. There is also a potential that some bears, except for pregnant females, could abandon hibernation entirely (Oli et al. 1997). To test our hypothesis, we used a population of

black bears in the Ouachita Mountains of southeast Oklahoma, which has been studied since the early 2000s. Researchers use GPS collars to track bears, observe denning behavior, and record demographic data. Given this broad, long-term data set, we are able to understand the effects of environmental conditions on changing the behavior of black bears in Oklahoma.

To understand the influences of varying environmental conditions on black bears in southeast Oklahoma, we examined weather factors associated with den entrance, den emergence, and the full duration of black bear hibernation. Additionally, in order to account for individual attributes of the bears, we looked at the effects of sex, age, and reproductive status on denning behavior because numerous studies have indicated a strong correlation between denning chronology and these factors (Fowler et al. 2019; Immel et al. 2013; Johnson & Pelton 1980; Schooley et al. 1994, Waller et al. 2012). Additionally, we included den site characteristics as an additional factor in our long-term dataset to investigate the correlation between denning chronology and den site characteristics for the bears in southeast Oklahoma.

Our research objective was to assess the effects of temperature, precipitation, den type, and individual bear attributes on the timing of hibernation. If black bears adjust their denning in response to environmental conditions, studies such as this one may be useful in helping to understand how bear hibernation may change in future winters. This has key implications to help wildlife managers to predict future activity patterns in black bears given the inevitability of a changing climate and expanding wildland-urban interface. Our study may also better equip managers to mitigate human-bear conflicts.

METHODS

Study Area

Our study occurred throughout the Ouachita Mountains region of southeast Oklahoma, USA. Fieldwork was conducted on both private and public lands (Ouachita National Forest) surrounding this area. Topography in this area consists of east-west ridges ranging in elevation from 91.4 - 817 m (Yaklin 2017). The Ouachita Mountains region has a humid subtropical climate with annual temperatures ranging from an average low of -2.2°C to an average high of 35°C (Yaklin 2017). Mean annual precipitation averages 107 to 137 cm (Tyrl et al. 2008). Oak-pine forest is the most common vegetation community in this area. Shortleaf pine (*Pinus echinata*) and oak species (*Quercus spp.*) dominate south-facing slopes, while white oak (*Q. alba*) and mockernut hickory (*Carya tomentosa*) dominate the upper and middle north-facing slopes (Johnson 1986).

Data Collection

Data for this project was collected as part of a long-term project from 2014 through 2021. Black bears captured in the Ouachita Mountains region were immobilized and equipped with GPS collars. A vestigial first upper premolar was extracted for age estimation through cementum annuli analysis. Collared bears were tracked to their dens to their dens each winter to collect data on reproductive status (female with cubs, female with yearlings, single female, or single male), number of offspring, and den type (ground nest, rock, tree, or excavation). Den visits were attempted for all collared bears. Den type was separated into 4 categories based on characteristics of the den site: (1) ground nest: den made with vegetative material from the surrounding area, formed into a large nest on top of the ground; (2) rock: den in a rock

cave/crevice or against a rock outcropping; (3) tree: den in a hollow standing tree, with entrance to the cavity on the side, base, or top of the tree; and (4) excavation: den dug into the ground, may be under fallen tree or brush (Immel et al. 2013). Reproductive status was also separated into 4 categories: female with cubs (pregnant at time of den entrance), female with yearlings, single female (no offspring), or single male.

To analyze the effects of environmental conditions during hibernation, we collected daily temperature and precipitation data from the Oklahoma Mesonet network. We used past data from the Talihina Mesonet station (elevation 204 m) ranging from 2014 through 2021. When analyzing the entirety of the denning period (denning duration), we calculated the average daily minimum temperature (°C), the average daily maximum temperature (°C), and the total rainfall (cm) from October 15th-April 30th. We also assessed how climate may affect the start of hibernation (den entrance) by calculating the average daily minimum temperature (°C), average daily maximum temperature (°C), and total rainfall from October 15th-December 15th, as well as the end of hibernation (den emergence) by calculating the average daily minimum temperature (°C), average daily maximum temperature (°C), and total rainfall from March 1st-April 30th. Dates for climate data were chosen based on typical denning dates of bears in our region.

Defining Den Entry, Emergence, and Duration

To estimate denning chronology, we used GPS locations from transmitters on the bears' radio collars. Den entrance was determined by either the last point before a large gap in the data, meaning the bear was underground or in an area where GPS transmitter signals could not be reached, or by the first point where a bear stayed within an area with a radius of 100m for several consecutive days (Waller et al., 2012). Conversely, den emergence was determined by bears

moving >100 m outside of the denning area for several consecutive days. Camera trap footage was also used as an assist to help determine emergence. We defined denning duration as the number of days between a bear's den entrance in the fall and emergence in the spring (Waller et al., 2012). In cases of bears utilizing multiple dens within one denning season, we estimated denning duration as the interval between the date of entrance at the bear's first den of the season and the date of emergence at the bear's final den of the season (Waller et al., 2012).

Modeling Factors

We used a generalized linear mixed model (GLMM) to investigate the relationship between demographic characteristics (age, reproductive status, and total offspring) and environmental factors (den type, average daily minimum temperature, average daily maximum temperature, and total precipitation) on den entrance, emergence, and duration of hibernation (Table 1). We used Bear ID as a random effect in all models, as many individuals were represented multiple times throughout the data. Our fixed effects for all models were age, reproductive status, number of offspring, and den type. Additionally, average daily minimum temperature, average daily maximum temperature, and total precipitation for each time period (den entrance, den emergence, and denning duration) were used as fixed effects in their respective models (Table 1).

Table 1. Generalized linear mixed models associated with den entrance, den emergence, and denning duration for black bears in southeast Oklahoma, USA 2014-2021. We included individual Bear ID as a random factor in all models.

Model	AIC	K[a]	Deviance	Residual Degrees of Freedom
DenEntrance ~ Age + OffspringType + TotalOffspring + DenType + FallAvgMinTemp + FallAvgMaxTemp + FallTotalPrecip	304.5	7	276.5	12
DenEmergence ~ Age + OffspringType + TotalOffspring + DenType + SpringAveMinTemp + SpringAveMaxTemp + SpringTotalPrecip	255.4	7	227.4	16
DenDuration ~ Age + OffspringType + TotalOffspring + DenType + TotalAvgMinTemp + TotalAvgMaxTemp + TotalPrecip	237	7	209	11

[a] The number of parameters in the model

RESULTS

We analyzed denning chronology data from 37 individual black bears (5 males and 32 females) in southeast Oklahoma from 2014-2021. According to data for 57 denning entrance events from 34 individuals, the median start date of hibernation was 19 November (range: 21 October- 29 December). Based on data for 59 denning emergence events from 34 individuals, the median end date of hibernation was 3 April (range: 20 February-6 May). Median duration of hibernation was 137 days (range 73-197 days) based on full denning duration data for 53 denning events from 31 individuals. Bear ID did not appear to be important in our data set as the random intercept was 0 with a standard deviation of 0.00 for all models.

The timing of den entrance was most strongly associated with reproductive status (Table 2). Compared to pregnant females, single males and single females entered dens later in the fall. Pregnant females and females with yearlings entered winter dens earlier in the fall, with no significant difference in the timing of denning between the two groups. Females with more offspring entered dens later than females with fewer offspring after new cubs were born. Individual bear age, den type, temperature, and precipitation did not show a significant effect on the timing of den entrance.

Changes in the duration of hibernation were associated with average daily minimum temperature, average daily maximum temperature, total precipitation, and den type, as well as reproductive status (Table 3). Individual bear age and number of offspring did not appear to have a significant effect on denning duration. With a greater average daily maximum temperature, denning duration was longer. Similarly, with a lower average daily minimum temperature, denning duration was shorter. In years with greater total precipitation throughout the denning period, denning duration was shorter. Compared to females with cubs, females with yearlings

stayed in their winter dens for a shorter period of time. Single males and single females did not show a significant difference in denning duration compared to females with cubs. Additionally, bears utilizing tree dens had a longer denning duration compared to bears in excavation den types. Bears utilizing other den types (ground nest, rock) did not show a significant difference in denning duration compared to bears in excavation den types.

The timing of den emergence was most strongly associated with average daily maximum temperature and precipitation (Table 4). Den type, age, and reproductive status also had an effect on den emergence. Number of offspring did not appear to have an effect on emergence. With greater average daily maximum temperatures, bears emerge from their dens earlier (Figure 1). Additionally, with greater total precipitation, bears emerge from dens earlier (Figure 2). Average daily minimum temperature did not appear to have an effect on emergence. Compared to bears in excavation dens, bears utilizing ground nest den types emerged from hibernation earlier. There was not a significant difference between excavation dens and other den types (tree, rock). Additionally, older bears emerged from dens later than younger bears. Compared to female bears with cubs, females with yearlings emerged earlier. There was not a significant difference between females with cubs and single males and single females.

Table 2. Beta estimates (β) of all variables for den entrance date by black bears in southeastern Oklahoma, 2014-2021.

Variable	β	SE	Lower Confidence Limit	Upper Confidence Limit
Age	1.34	2.37	-1.04	3.71
Single female (no offspring)[b]	90.36	57.65	32.71	148.01
Single male (no offspring)[b]	104.92	79.75	25.17	184.66
Females with yearlings[b]	3.82	34.05	-30.23	37.88
Number of offspring	33.99	17.64	16.35	51.63
Ground nest den[c]	-20.29	31.55	-51.84	11.27
Rock den[c]	28.07	31.33	-3.26	59.40
Tree den[c]	-4.00	43.87	-47.87	39.87
Fall Average Daily Minimum Temperature	4.48	14.32	-9.83	18.80
Fall Average Daily Maximum Temperature	-3.96	12.36	-16.31	8.40
Fall Total Precipitation	-0.97	1.72	-2.68	0.75

[b] Females with cubs was the reference variable
[c] Excavation den type was the reference variable

Table 3. Beta estimates (β) of all variables for the full denning duration by black bears in southeastern Oklahoma, 2014-2021.

Variable	β	SE	Lower Confidence Limit	Upper Confidence Limit
Age	0.7543	0.7567	0.00	1.51
Single female (no offspring)[b]	-17.3355	20.8466	-38.18	3.51
Single male (no offspring)[b]	-8.8833	28.2396	-37.12	19.36
Females with yearlings[b]	-52.1066	11.6823	-63.79	-40.42
Number of offspring	-0.4309	6.7723	-7.20	6.34
Ground nest den[c]	1.6552	9.6565	-8.00	11.31
Rock den[c]	-0.4993	9.9992	-10.50	9.50
Tree den[c]	26.0044	14.0749	11.93	40.08
Total Average Daily Minimum Temperature	-17.64	9.6924	-27.33	-7.95
Total Average Daily Maximum Temperature	9.1375	6.9437	2.19	16.08
Total Precipitation	-0.3117	0.2815	-0.59	-0.03

[b] Females with cubs was the reference variable
[c] Excavation den type was the reference variable

Table 4. Beta estimates (β) of all variables for den emergence date by black bears in southeastern Oklahoma, 2014-2021.

Variable	β	SE	Lower Confidence Limit	Upper Confidence Limit
Age	0.7631	0.4751	0.29	1.24
Single female (no offspring)[b]	13.3154	13.4084	-26.72	0.09
Single male (no offspring)[b]	10.5743	14.4775	-25.05	3.90
Females with yearlings[b]	22.9822	8.204	-31.19	-14.78
Number of offspring	1.4676	4.4318	-2.96	5.90
Ground nest den[c]	-8.8683	6.5677	-15.44	-2.30
Rock den[c]	-4.7927	6.0831	-10.88	1.29
Tree den[c]	0.425	8.0488	-7.62	8.47
Spring Average Daily Minimum Temperature	3.8707	4.4952	-0.62	8.37
Spring Average Daily Maximum Temperature	-4.5489	4.1032	-8.65	-0.45
Spring Total Precipitation	-0.9756	0.659	-1.63	-0.32

[b] Females with cubs was the reference variable
[c] Excavation den type was the reference variable

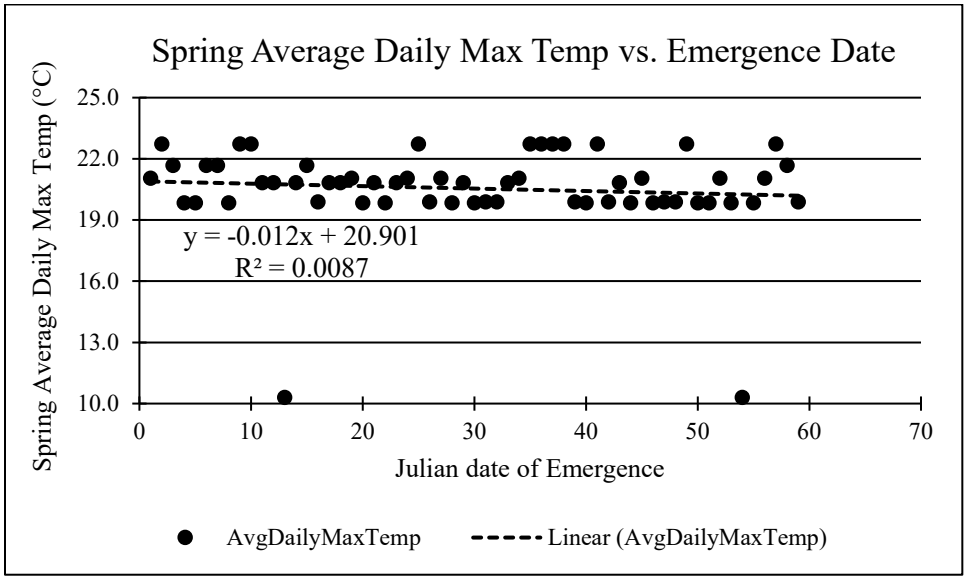

Figure 1. Spring average daily maximum temperature compared to emergence date for black bears in southeast Oklahoma, USA (2014-2021)

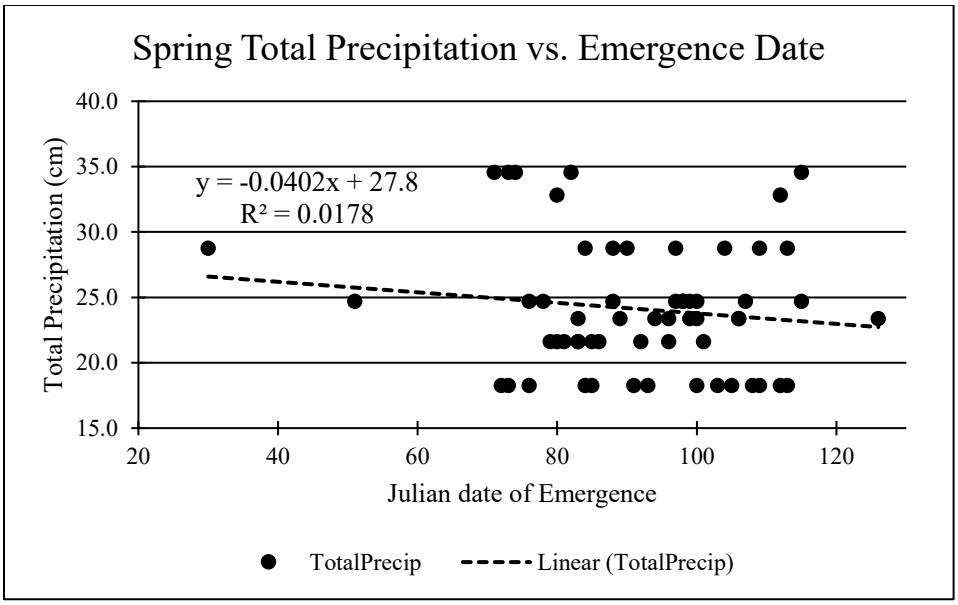

Figure 2. Spring total precipitation compared to emergence date for black bears in southeast Oklahoma, USA (2014-2021)

DISCUSSION

Like many other studies, we found that reproductive status plays a big role in the timing of entrance and emergence (Immel et al. 2013; Johnson & Pelton 1980; Schooley et al. 1994). Pregnant females and females with yearlings enter their winter dens earlier in the fall; single males and females comparatively enter their dens later in the season (Table 2). This may be due to the added vulnerability female bears face with offspring.

In the spring when bears are leaving their dens, females with yearlings were the first to emerge whereas females with new cubs and single males and single females leave their dens later in the spring. This reproductive pattern also matches what other studies have previously found, as females with cubs may spend extra time in their dens given their cubs' vulnerability and limited mobility (Johnson et al. 2017; Johnson & Pelton 1980). Females with yearlings may be influenced to leave their dens earlier than other reproductive classes given their yearlings' need to forage. Denning duration was also shorter for bears with yearlings compared to females with new cubs and single males and single females (Table 3). Moreover, we suspect this may be due to the smaller-bodied yearlings' lower ability to store energy before hibernation and need to forage earlier than adults.

Bears denning in ground nests emerge earlier than bears in all other den types (Table 4). This may be due to the fact that the bears are more exposed to weather conditions in ground nests. Bears in excavations, rock caves, and hollow tree dens are often better insulated and have better coverage from weather (Hayes & Pelton 1994). Bears in hollow tree dens hibernate for a longer period of time compared to other den types (Table 3). Tree dens provide a high degree of cover and are often less accessible than other den types. This may allow bears to remain in dens for longer given the lower degree of vulnerability and perhaps greater isolation from ambient

weather. Though several black bear studies have looked at den site characteristics, use, and suitability (Immel et al. 2013, Hayes & Pelton 1994; Waller et al. 2012) our study is unique for looking into the effect of den type on hibernation chronology.

While weather did not impact den entrance, average daily maximum temperature and total precipitation did appear to be important during spring emergence. With more precipitation, bears emerge from winter dens earlier (Table 4; Figure 2). Other studies have found that this may be due to flooding of dens in the spring (Baldwin & Bender 2010; Waller et al. 2012). Additionally, there is potential that this relationship could be associated with an increase in available forage, as some researchers have used precipitation as a surrogate for vegetative productivity (Baldwin & Bender 2010). Several studies have shown food availability to be an important factor in denning chronology (Immel et al. 2013; Johnson, et al. 2017; Schooley et al. 1994). Though we did not have the vegetation data to investigate this, our precipitation results align with forage condition findings of other studies, citing an association between emergence and vegetative quality. It may be of interest to investigate the relationship between mast years and the timing of black bear emergence in SE Oklahoma in future research.

With greater spring average daily maximum temperatures, bears emerge from winter dens earlier. This may also be related to an increase in food abundance with warmer temperatures and greater precipitation. With a greater average daily maximum temperature, denning duration was longer. Similarly, with a lower average daily minimum temperature, denning duration was shorter. Though this is contradictory to our findings of bears emerging earlier with warmer temperatures, this could be due to bears' metabolism burning through fat reserves more quickly in colder temperatures, therefore needing to emerge earlier to forage. These results are contrasting to those from Johnson (et al. 2017), where changes in the average minimum

temperature during hibernation had the greatest effect on hibernation duration. In the Colorado black bear population, for each 1°C increase in average minimum temperature, hibernation was shortened by an average of 6 days (Johnson et al. 2017). This better aligns with our findings of bears emerging earlier with greater spring average daily maximum temperatures. Though the reason for the disparity is not clear, future data analyses may help us to better understand this.

It was surprising that there was no random effect of Bear ID. We expected this factor to have some effect due to our variability in the number of times individuals were represented in the dataset. In future studies, it may be of interest to include year as a random factor. Given our lack of forage availability data, this may help account for differences in mast years. Because this study has a relatively small sample size, we were limited in the number of parameters we were able to address.

The key findings of this study indicate that as temperatures warm, black bears are emerging from their winter dens earlier in the year. These results serve as a baseline to detect changes in black bear denning behavior in response to environmental conditions. Bears hibernating for shorter periods of time will subject them to greater opportunities for human interaction as they increase their movements to find food. This may lead to greater susceptibility to lethal control measures or vehicle collisions if bears shift their denning behavior. Additionally, this has key implications to help wildlife managers to predict future activity patterns in black bears given the inevitability of a changing climate and expanding wildland-urban interface. Studies such as this one may also better equip managers to mitigate human-bear conflicts.

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