ABSTRACT

FRANCESCHINI, CARA LILY. Denning Chronology of Female American Black Bears in a Temperate Climate and Urban Environment. (Under the direction of Dr. Christopher S. DePerno).

Recent studies of mammal ecology suggest that behaviors may be affected by a changing climate. Specifically, American black bears (*Ursus americanus*) enter dens to compensate for natural winter food shortages and avoid harsh weather. However, in regions with milder temperatures, bears may demonstrate variable behaviors around denning, including den entry, duration, and/or emergence. Rising temperatures may cause bears in regions that historically averaged sub-freezing temperatures to change denning behavior. Also, urbanization is an emerging issue that can impact denning behavior. Our objective was to investigate how weather factors over 7 years impacted the denning chronology of female bears inhabiting the city of Asheville, North Carolina. We attached GPS collars to female bears (n = 70), classified den sites (n = 118), noted reproductive status, and assessed annual mast production in the study area. We evaluated effects of temperature, precipitation, den substrate, reproductive age of the bear, and mast production on den entry, duration, and emergence using linear regression models. Our models determined that for den entry, a 1°C increase influenced bears to enter dens 5.3 days earlier, extended denning duration by 5.7 days, and delayed den emergence by 3 days, and each additional 93.3 mm of precipitation delayed bear entry by 9.7 days and reduced denning duration by 10.7 days. Improved soft mast quality delayed den entry by 14.4 days and improved hard mast quality extended denning duration by 19.8 days. Following trends in other literature, bears with cubs had earlier entry dates, longer duration, and later emergence dates compared to the other reproductive groups. We could not apply our results to other study areas because of Asheville's unique temperate climate and urban setting. We noted counterintuitive trends of

some variables with denning chronology and no definitive denning trigger for our study site. If changes in denning behavior occur, human-bear interactions could increase. Because we studied an urban area with bears, mitigating potential interactions (e.g., reducing bear attractants) and increasing public outreach should be a priority.

Denning Chronology of Female American Black Bears in a Temperate Climate and Urban Environment.

by
Cara Lily Franceschini

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Fisheries, Wildlife, and Conservation Biology

Raleigh, North Carolina
2024

APPROVED BY:

Dr. Christopher S. DePerno
Committee Chair

Dr. Krishna Pacifici

Dr. George Hess

DEDICATION

I dedicate my thesis to my family. They have inspired, motivated, and supported me throughout all my years, but especially these past few years. Their love is unconditional, and I hope they know how blessed I am to have them by my side. I know they are proud of my work hard regardless of the end goal. I have so much love and gratitude in my heart for them!

BIOGRAPHY

Cara Lily Franceschini was born and raised by her loving family in Salem County, New Jersey. She grew up alongside her brother, Antonio, and two loving parents, Felicia and Ralph. The family ended up adding some bonus members along the way who are loved equally. Her family has been extremely involved in her upbringing, always being there to say, “I’m so proud of you.” She developed a love for all animals at a young age because of her time spent outdoors at her grandparents’ house and the Jersey Shore. She continued to pursue her passion of learning about and caring for animals, as she attended North Carolina State University for Animal Science (2019). Not feeling like this major was the right fit, she switched to Fisheries, Wildlife, and Conservation Biology and added Zoology and Environmental Science as minors. As she excelled in school, graduating with her Bachelor of Science degree in just three years (2022), she knew she desired further education. She immediately continued at North Carolina State University in the same major and added Statistics as a minor to obtain her Master of Science degree (2024). Throughout her years, she has gained a plethora of experience involving animals at zoos, beaches, museums, and more! During her journey, she acquired the most fun, loving, and supportive friends that will last a lifetime. Although sad to leave her new “home” she created within the last five years, she cannot wait to see what is in store for her next (hopefully somewhere warm, beautiful, and abundant in wildlife)!

ACKNOWLEDGMENTS

This research was a joint project between the Fisheries, Wildlife, and Conservation Biology Program at North Carolina State University (NCSU) and the North Carolina Wildlife Resource Commission, funded by the Pittman-Robertson Federal Aid to Wildlife Restoration Grant. I want to thank the professors in this program at NCSU for providing me with the knowledge and support to complete this project. Specifically, my committee members (Dr. Christopher DePerno, Dr. Krishna Pacifici, and Dr. George Hess) were undeniably helpful in guiding my ideas for this project and executing them efficiently via planning, writing, analyses, presentations, networking, and more. The members of my committee have been nothing but supportive during this process whilst pushing me to be the smartest version of myself. Dr. DePerno took me under his wing in my quest to obtain my master's degree, and ever since then, he has gone out of his way to meet with me regularly, educate me, and support my hard work. Also, he provided me with the resources to attend my first conference to further my professional knowledge and relationships, which was a vital part of furthering my education. Dr. Pacifici has taken many hours out of his schedule to help me with my data acquisition and analyses, as well as pushing me past my comfort zone by explaining other statistical processes. My growing understanding and passion for statistics stems from my chats and classes with Dr. Pacifici. Moreover, Dr. Hess was crucial for my personal development throughout this process by having kind-hearted talks with me and expanding my knowledge of different branches of the wildlife field that I would not typically explore. His advice was always so thought out and constructive so that my project could improve dramatically.

Next, I thank Colleen Olfenbuttel for her black bear knowledge and expertise. Her feedback was pivotal to advancing my understanding of black bears and improving my scientific writing skills. Additionally, thank you to all the homeowners and businesses who allowed permission to their properties for the data collection process. The reason that I was able to conduct this research was because of the hard work done in the field by Nicholas Gould and Jennifer Strules from their time here at NCSU. These two hardworking individuals conducted all the field work for the black bear data I used in this project. I cannot thank either of them enough for their guidance. With countless emails exchanged, they improved my understanding of their field work, black bear biology, writing, analyses, networking, and more. I thank them for providing me with their data and their endless support and constructive criticism. Thank you to Mike Carraway and Justin McVey for their field support as well. Also, thank you to our friendly reviewers, Eric Teitsworth, Dr. Clyde Sorenson, and Ethan Marburger, for contributing helpful input that strengthened this manuscript.

Fortunately, I was able to be a teaching assistant during my time here at NCSU which helped me afford my expenses. Thank you to Dr. Clyde Sorenson, Dr. Lara Pacifici, Ms. Rachel Freyer, and Dr. Megan Lupek for sparking my love for teaching and helping students through my teaching assistant positions. Throughout my time here at NCSU I have been able to meet many incredible people and create friendships that will last a lifetime. Lastly, thank you to my family as I could not have done this without their constant support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: Denning chronology of female American black bears in a temperate climate and urban environment

ABSTRACT

Recent studies of mammal ecology suggest that behaviors may be affected by a changing climate. Specifically, American black bears (*Ursus americanus*) enter dens to compensate for natural winter food shortages and avoid harsh weather. However, in regions with milder temperatures, bears may demonstrate variable behaviors around denning, including den entry, duration, and/or emergence. Rising temperatures may cause bears in regions that historically averaged sub-freezing temperatures to change denning behavior. Also, urbanization is an emerging issue that can impact denning behavior. Our objective was to investigate how weather factors over 7 years impacted the denning chronology of female bears inhabiting the city of Asheville, North Carolina. We attached GPS collars to female bears (n = 70), classified den sites (n = 118), noted reproductive status, and assessed annual mast production in the study area. We evaluated effects of temperature, precipitation, den substrate, reproductive age of the bear, and mast production on den entry, duration, and emergence using linear regression models. Our models determined that for den entry, a 1°C increase influenced bears to enter dens 5.3 days earlier, extended denning duration by 5.7 days, and delayed den emergence by 3 days, and each additional 93.3 mm of precipitation delayed bear entry by 9.7 days and reduced denning duration by 10.7 days. Improved soft mast quality delayed den entry by 14.4 days and improved hard mast quality extended denning duration by 19.8 days. Following trends in other literature, bears with cubs had earlier entry dates, longer duration, and later emergence dates compared to the other reproductive groups. We could not apply our results to other study areas because of Asheville's unique temperate climate and urban setting. We noted counterintuitive trends of

some variables with denning chronology and no definitive denning trigger for our study site. If changes in denning behavior occur, human-bear interactions could increase. Because we studied an urban area with bears, mitigating potential interactions (e.g., reducing bear attractants) and increasing public outreach should be a priority.

INTRODUCTION

Changes in annual weather factors and rising temperatures caused by increasing greenhouse gases in the atmosphere are a global challenge (Dietz et al., 2020; Honda & Kozakai, 2020; Parmesan, 2006; Zahoor et al., 2021). As urbanization and the urban, suburban, and rural interface expands, greenhouse gases and pollution are predicted to increase, causing habitat alteration and destruction for wildlife through changes to natural climate regimes (Dietz et al., 2020; Honda & Kozakai, 2020; Zahoor et al., 2021). Climate change researchers are often unsure of the future effects on wildlife (Honda & Kozakai, 2020; Johnson et al., 2018; Parmesan, 2006; Zahoor et al., 2021), so it is crucial to conduct research to explore and mitigate potential effects. Recent studies have suggested that wildlife behavior, distribution, population dynamics, and interactions with other species may be affected by a changing climate (Johnson et al., 2018; Parmesan, 2006; Pigeon et al., 2016; Towns et al., 2009; Zahoor et al., 2021). Changing weather factors could alter the timing and growth of natural food for wildlife (Baruch-Mordo et al., 2012; Honda & Kozakai, 2020; Johnson et al., 2015; Johnson et al., 2018; Laufenberg et al., 2018; Parmesan, 2006). Zahoor et al. (2021) predicted future wildlife ranges may be dramatically reduced and fragmented with medium and extreme carbon emission scenarios. Researchers have observed changes in migration behaviors and seasonal timing of animal activity (Honda & Kozakai, 2020; Inouye et al., 2000; Laufenberg et al., 2018). Lane et al. (2012) demonstrated that climate change reduced fitness and population viability in Columbian ground squirrels (*Urocitellus columbianus*), and Honda and Kozakai (2020) noted that human interactions with Asiatic black bears (*Ursus thibetanus*) increased with colder temperatures because bears were attempting to obtain more calories for prolonged denning. A changing climate may create impacts across taxonomic groups, emphasizing the need to investigate how species adapt to alterations in temperatures, resource availability, and environmental conditions.

Species that experience winter torpor may be particularly influenced by changing annual weather factors (Johnson et al., 2018; Lindzey & Meslow, 1976; Miller et al., 2017; O'Pezio et al., 1983; Parmesan, 2006). As researchers explore winter torpor and the correlation with environmental changes, it is essential to focus on denning behavior (i.e., entry, duration, and emergence) of American black bears (*Ursus americanus*) and their response to variations in weather and resource availability, being a species of high management, and whose activities coincide with their surrounding environment (i.e., natural mast and weather conditions). Specifically, in black bears (*hereafter* "bears"), winter torpor is characterized by inactivity in response to natural food shortages and unfavorable ambient conditions, where heart rate, metabolism, and body temperature are reduced to conserve energy (Gaines, 2003; Gould, 2020; Inouye et al., 2000; Nelson et al., 1983; Tøien et al., 2011). Unlike a "true hibernator," the bear's body temperature only drops a few degrees so they can be easily aroused by disturbance to protect themselves and their young (Laske et al., 2011; Nelson et al., 1983; Tøien et al., 2011). Males den on their own, and females can either give birth to young during denning or den with their young born in the previous year (known as "yearlings") (Nelson et al., 1983; Powell et al., 1997). Thus, natural food abundance and reproductive status affect denning chronology in other studies due to bear biology requirements (Bonin et al., 2019; Gaines, 2003; Gray, 2015;

Hightower et al., 2002; Johnson & Pelton, 1980; Laufenberg et al., LeCount, 1983; 2018; Schwartz et al., 1987; Weaver, 1999; Wooding & Hardisky, 1992), which gives us reason to investigate these factors. Given the projected changes to our climate, researchers have attempted to discern the correlation between winter torpor (*hereafter* "denning") and weather cues in various bear species. Pigeon et al. (2016) and Towns et al. (2009) estimated that increased warming may reduce time spent denning by brown bears (*Ursus arctos*) and female polar bears (*Ursus maritimus*), respectively. To den efficiently, bears (and their young, if applicable) need to build fat reserves; so, if temperatures and precipitation levels rise and alter the production of natural food, bears may spend less time denning in areas that experience sub-freezing temperatures (Honda and Kozakai, 2020; Inouye et al., 2000; Lane et al., 2012; Laufenberg et al., 2018; Lindzey and Meslow, 1976; O'Pezio et al., 1983). Changing weather factors are not the only variables to affect denning chronology, as urbanization poses an additional challenge, because human activity can disrupt traditional denning times and alter food availability.

Urbanization, concordant with changing weather, may initiate increases in human-bear interactions and alterations to denning chronology. In years of poor natural mast, bears may expand their home ranges into developed areas and consume anthropogenic foods (e.g., garbage, pet food, bird feeders, and beehives), causing increased potential for human-bear interactions (Beckmann and Berger, 2003; Johnson et al., 2018; Kirby et al., 2016; Laufenberg et al., 2018). Similarly, during hyperphagia, where bears consume approximately 20,000 kcal for up to 20 hours a day to increase their fat reserves (Garshelis et al., 2017; Gould, 2020; Kirby et al., 2016; Nelson et al., 1983), bears could discover anthropogenic, calorie-dense foods in urban areas. Thus, bears may become more habituated to using developed areas (Johnson et al., 2018; Kirby et al., 2016; Miller et al., 2017), leading to increased mortality (vehicle collisions, lethal removal, and illegal take: Baruch-Mordo, 2012; Hostetler et al., 2009; Johnson et al., 2018; Kirby et al., 2016; Laufenberg et al., 2018). The effect of urbanization is important to understand with respect to denning chronology because our study area (Asheville, North Carolina, USA) is in an urban/suburban area where bears are exposed to many anthropogenic foods and activities (J. Strules, unpublished data). Anthropogenic foods being abundant in our study area may also impact den entry, duration, and emergence timings, mimicking the effect of natural mast. Moreover, studies conducted in urban areas are scarce and more focused on regions with severe winters (Hamilton and Marchinton, 1980; Hellgren and Vaughan, 1989), so it is difficult to predict the denning behavior of bears in a temperate-climate and urban setting, such as our study area.

Differences in northern versus southern climates may indicate divergent effects of climate change in den chronology of urban bears. In Durango, Colorado, USA, Johnson et al. (2018) concluded that warming temperature was the strongest factor impacting bear denning ecology where a predicted 1°C increase in winter minimum temperature delayed den entry, reduced den duration by 6 days, and promoted early den emergence. The projected increase in temperature was calculated to have twice the impact on the denning ecology of bears than food availability and development (Johnson et al., 2018). Similarly, weather variables have relatively the same impact on bear denning chronology in other studies taking place in colder climates (Bonin et al., 2019; Gained, 2003; Inouye et al., 2000; Lindzey & Meslow, 1976). Because our study area is in a temperate climate region, bears will likely exhibit differences in den entry, den duration, and den emergence compared to the trends that weather exhibits on bear denning behavior in Johnson et al. (2018). Other research investigates bear individual attributes (i.e., age, weight, sex, reproductive status) and den attributes (i.e., elevation, den substrate, proximity to houses, natural mast, weather) on denning chronology (Hightower et al., 2002; Johnson et al., 2018; Johnson & Pelton, 1980; Lindzey & Meslow, 1976; Parmesan, 2006; Pigeon et al., 2016; Schwartz et al., 1987; Towns et al., 2009; Weaver, 1999; Wooding & Hardisky, 1992; Zahoor et al., 2021). The consensus in research conducted in colder climates is that bears with cubs den the longest (Hightower et al., 2002; Johnson et al., 2018; Johnson & Pelton, 1980; Lindzey & Meslow, 1976; Schwartz et al., 1987; Weaver, 1999; Wooding & Hardisky, 1992), older bears den longer than younger bears (Johnson et al., 2018; Johnson & Pelton, 1980; Schwartz et al., 1987), and warmer temperatures and more precipitation lead to shorter denning durations (Johnson et al., 2018; Parmesan, 2006; Pigeon et al., 2016; Towns et al., 2009; Zahoor et al., 2021). All other variables seem to have variable effects based on the study area.

Bears that inhabit southern areas and experience temperate or warm climates (i.e., Florida, Georgia, Louisiana, North Carolina, South Carolina, Tennessee) undergo different denning behaviors (Hellgren and Vaughan, 1989; Hightower et al., 2002; Johnson and Pelton, 1980; Oli et al., 1997). The duration of denning within the south is about half the time that bears in intense climatic areas experience, with an average of about 3.25 months compared to about 6 months, respectively (Garshelis et al., 2017; Hamilton & Marchinton, 1980; Hardy, 1974; Hellgren & Vaughan, 1989; Johnson & Pelton, 1980; Oli et al., 1997; Weaver, 1999). Because bears in warmer climates do not need to shelter from harsh weather and most natural mast is available year-round (Gray, 2015; Hightower et al., 2002; Inouye et al., 2000; LeCount, 1983; Wooding & Hardisky, 1992), not all bears partake in denning (Garshelis et al., 2017; Gray, 2015; Hardy, 1974; Hightower et al., 2002). Mainly parturient females den so they can give birth in safety, but they den for significantly shorter and more sporadic times than bears in colder climates, with some studies observing that bears may briefly exit and re-enter dens throughout the winter to forage (Garshelis et al., 2017; Gray, 2015; Hightower et al., 2002; LeCount, 1983; Weaver, 1999; Wooding & Hardisky, 1992). Further, it is difficult to estimate bear denning chronology in warmer climate areas because there is no defined trigger to initiate and conclude denning. The limited availability of data on the effect of temperature on denning in warmer climates emphasizes the difficulty in estimating denning chronology.

Our goal was to examine potential differences of denning chronology in bears in a temperate climate and urban setting which has not been explored much. Specifically, our objective was to address bear denning behavior in a temperate climate and urban setting, and to investigate how annual weather factors, reproductive status, natural mast, and den substrate over 7 years impacted the denning chronology of female bears inhabiting the city of Asheville, North Carolina, USA. We performed analyses similar to other studies, to highlight trends between environmental variables and den entry dates, den duration, and den emergence dates (Beckmann & Berger, 2003; Gray, 2015; Hardy, 1974; Hellgren & Vaughan, 1989; Hightower et al., 2002; Johnson et al., 2018; Johnson & Pelton, 1980; LeCount, 1983; Weaver, 1999).

MATERIALS AND METHODS

Study area

Our study was conducted in and around the city of Asheville, North Carolina, USA. Asheville provides important habitat and resources for bears due to being in the southern Appalachian Mountains (Fig. 1; Powell et al., 1997). The region experiences mild winters and cool summers with temperatures ranging from -2 – 28°C (average 15°C), along with substantial precipitation of 130 – 200 cm/year, mainly in the form of rain (Kirk et al., 2012). The area is considered a temperate rainforest consisting of deciduous hardwoods and pine-hardwood mixes.

Areas surrounding Asheville vary in elevation between 500 and 1800 m (Mitchell et al., 2002; Powell et al., 1997). Asheville is 117 km^2 in area and considered a medium-sized city (Kirk et al., 2012; Fig. 1.1 as cited in Gould et al., 2021), with 803 people/km^2 and approximately 40,000 housing units (U.S. Census Bureau, 2022). Asheville is classified as urban due to the population associated with the density of houses, businesses, infrastructure, and recreation (U.S. Census Bureau, 2022; Weeks, 2010). Anthropogenic foods (unsecured garbage, bird seed) are readily available throughout this area (J. Strules, unpublished data).

Data collection

We used homeowner reports of non-nuisance black bears on private property from April 2014 - August 2022 to determine trap sites. We placed culvert traps on private and municipal property in the city of Asheville and checked traps twice daily (Gould, 2020; Gould et al., 2021). We immobilized captured bears with the anesthetic recombination TKX (Telazol®: 5 cc at 100 mg/ml; ketamine hydrochloride: 4.0 cc at 100 mg/ml; and xylazine hydrochloride: 1.0 cc at 100 mg/ml), or BAM™ (butorphanol, azaperone, medetomidine; 0.4 cc/~50 lbs) dosed at 1.0 cc per 45.36 kg by carbon dioxide (CO_2) powered dart pistol (Gould, 2020; Gould et al., 2021). We reversed TKX with yohimbine hydrochloride (0.15 mg/kg) and BAM™ with atipamezole (5 mg/kg metatomidine) and naltrexone (5 mg/kg butorphanol). We released bears from traps when voluntary movement was fully regained (Gould et al., 2021). For more information on bear trapping and immobilization, see Gould et al. (2021).

We attached a numbered identification tag into each ear, tattooed the upper lip, and extracted the first upper premolar to assign an age from bears more than 1 year old via counting cementum annuli (Willey, 1974). We inserted a Passive Integrated Transponder (PIT) tag between the scapulae and attached a GPS collar (Vectronic, Berlin, Germany) weighing no more than ~4% of the bear's body weight. We collected weight, sex, reproductive class, date, and capture location for each bear processed. All data collection was approved by the Institutional Animal Care and Use Committee at North Carolina State University (14-019-O and 16-263-0) and followed the guidelines of the American Society of Mammalogists (Sikes et al., 2016).

We determined den entry dates, den duration (number of days between den entry and den emergence dates), and den emergence dates from GPS collar data. We collected data on bears equipped with GPS collars every 15 minutes inside of Asheville, NC limits and every hour outside city limits. We estimated den entry if locations were clustered for about 2 weeks and classified den emergence as the day that bears left the cluster (Gould et al., 2021; Lindzey & Meslow, 1976). We excluded bears for which we could not identify the den entry date (n = 1) or den emergence date (n = 7). We did not ground truth dens until mid-winter to avoid den abandonment (Gould et al., 2021). Additionally, we collected temperature and precipitation measures from 2014 – 2022 in Buncombe County, North Carolina, USA, from PRISM at Latitude: 35.5868 Longitude: -82.5504 and Elevation: 671 m (4 km resolution: Retrieved [February 5, 2023], from https://www.prism.oregonstate.edu/explorer/). There was only one weather station to measure weather variables at this resolution, so the study area was assumed to experience uniform weather factors throughout. We used average minimum daily temperature and total precipitation over 15-days prior to den entry and den emergence dates of each bear because we wanted to ascertain if weather factors before den entry and/or before den emergence influenced denning chronology. We used the average daily minimum temperature to measure the coldest temperature because it is known to initiate denning in some cases (Ayres et al., 1986; Gaines, 2003; Johnson et al., 2018; Laufenberg et al., 2018). We used 15-days before den entry/emergence dates as a range because bears seem to respond to changes in this amount of time and other studies have used this method (Lindzey & Meslow, 1976). Also, we used the sum of precipitation because it is used in other studies and seen to possibly flood dens (Lane et al., 2012; Lindzey & Meslow, 1976; Schooley et al., 1994). We standardized the values of precipitation (i.e., subtract the mean and divide by standard deviation) due to the extreme range (0 – 167 mm for den entry and 2.8 – 265.8 mm for den emergence), so one scaled unit equated to 93.3 mm.

Data analysis

We collected data from male and female bears (2014 – 2022), but only retained information on females (n = 70) due to the lack of representativeness for males (n = 11). Using data from females' denning events (n = 118), we evaluated variables to influence den entry, duration, and emergence, including weather (average temperature and total precipitation 15 days before den entry and emergence), natural food abundance (hard and soft mast separately: Bonin et al., 2019; Gaines, 2003; Johnson & Pelton, 1980; Laufenberg et al., 2018), bear reproductive status (Schooley et al., 1994; Johnson et al., 2018; O'Pezio et al., 1983), and denning substrate (Gaines, 2003; Schafer et al., 2018) (Tables 1a, b).

We used estimates of hard and soft mast from the North Carolina Wildlife Resource Commission to integrate natural mast in our analyses, as seen in Gould (2020). The percentage of oak (*Quercus* spp.) crowns with acorns was used to determine the hard mast status [failure (0 - 19.4%), poor (19.5 - 39.4%), average (39.5 - 59.4%), good (59.5 - 79.4%), and bumper (79.5 - 100%)]. Soft mast [e.g., pokeberry (*Phytolacca americana*), cherry (*Prunus* spp.), grapes (*Vitis* spp.), blackgum (*Nyssa sylvatica*), blueberry (*Vaccinium* spp.), huckleberry (*Gaylussacia* spp.), blackberry (*Rubus* spp.)] indices were created based on the overall abundance of berries for each for the fall season [0.0 to 2.0 little to no mast (Poor), 2.1 to 4.0 scarce to moderate mast (Fair), 4.1 to 6.0 good to abundant berry production (Good), or 6.1 to 8.0 a bumper crop (Excellent)] (Gould, 2020). We used the categorical indices of hard and soft mast production as covariates to observe how natural mast impacts denning chronology. We did not measure anthropogenic food abundance as a category, but it does not decrease the importance of it due to our urban study area.

We used bear reproductive status as the only individual bear attribute. We measured reproductive status by determining if offspring were present in the den when we conducted physical examinations of the bears in their dens from mid-January to mid-March. Reproductive status was classified into three categories: female who gave birth to cub(s) during denning (COY: known as cub(s) of year), female with yearling(s) in the den (YRLGS), or female not having any young in the den (BARREN). Reproductive status is known to account for variation in denning chronology in prior studies, so including this category was pivotal (Gray, 2015; Hightower et al., 2002; LeCount, 1983; Weaver, 1999; Wooding & Hardisky, 1992). We observed one denning female with a cub and a yearling, so we counted it as COY. Additionally, there were cases where we could not determine if young were in the den or the age of the young for safety reasons (e.g., property owner did not grant permission to enter, and den location being unsafe, such as on a steep slope or snag); these were excluded from all models in our analyses (n = 12).

We classified the denning substrate categorically as anthropogenic, cavity, tree, vegetation, or ground based on insulation properties and bear biology (Gaines, 2003; Schafer et al., 2018). Anthropogenic dens were classified as use of built structures (e.g., residential crawl space, highway berm). Dens in the cavity category were observed as a rock den, natural cavity, or deep excavated cavity. Tree dens were ones in the base of a tree or using any part of a tree.

Ground dens were in open areas, with little excavation, or with little coverage. Vegetation dens were mainly constructed with plants or snags (e.g., dense vegetation, log pile, or under a rootwad). One den was vacated before we could observe the denning substrate, so it was excluded from the analyses.

We used multiple linear regression (lm() function in program R version 4.2.1; R Core Team, 2022) with determined significance at $\alpha = 0.05$ (95% confidence interval: *hereafter* "CI") to construct three global models (Table 2): one for bear den entry ($n = 104$), one for denning duration ($n = 97$), and one for den emergence ($n = 98$). The response variable for the den entry and den emergence models was the day of the year that bears entered/emerged from dens. If a bear entered the den on 10 December and emerged on 10 March, the day of year would be 344 for entry and, so we can measure entry and emergence within the same denning year, 434 (365 + 69) for emergence. The response variable for den duration was the number of days denned (with dates from the previous example, the response would be 90 days because 434 - 344 = 90). The only continuous variables were temperature and precipitation, while all others were categorical. Our global models for den entry and emergence were identical, including temperature, precipitation, reproductive status (reference level = barren), hard mast (reference level = poor), soft mast (reference level = poor), and substrate (reference level = ground). Our global model for den duration included entry temperature, emerge temperature, entry precipitation, emerge precipitation, reproductive status, hard mast, soft mast, and substrate.

Sample sizes for each global model varied because some covariate values were not obtained for certain denning observations because of GPS collar malfunctions, unsafe conditions, or no permission granted, resulting in exclusion of those bears from analysis (Table 1a). We tested for collinearity using Spearman's correlation tests for the continuous variables (one for weather variables before den entry, one for weather variables before den emergence), with correlation coefficients < |0.6| being retained. We used stepwise selection using smallest Akaike Information Criterion (AIC) values on each of our three global models to determine the best fit model for entry, duration, and emergence, applying the step() function in R (Table 2: Burnham & Anderson, 2002; R Core Team, 2022). We had multiple observations of some bears over the study duration (70 different bears were measured, 29 of them had multiple observations) but too few to expect them to bias our results (out of 29 bears with multiple observations, 17 of them were only repeated twice), so they remained independent. Also, we created a kernel density plot to show the distribution of denning duration experienced by all bears (Fig. 2). Lastly, we used the predict() function in R (R Core Team, 2022) using variables in our best fit models to depict the trends in our results on denning chronology. To do this, we manipulated one variable at a time, while we held all other variables as their average value for continuous variables or reference category for categorical variables (Fig. 3).

RESULTS

Den entry

During our 7-year study period, the median date of den entry was 27 December (range 6 October to 26 February: Table 1b). The best fit model for den entry included temperature, precipitation, hard mast, soft mast, and substrate. As no interaction terms were deemed significant, we used an additive model. The variables used in the model accounted for 32.8% of variation in the response (R-squared). The den entry model was primarily influenced by weather factors and soft mast (based on a 95% CI not overlapping 0: Table 3a, Figs 3a, b). The intercept was identified as 358.2 (24 December: p-value < 0.001) with a CI of [-7, -3.6]. For every 1°C increase, den entry was initiated 5.3 days earlier (p-value < 0.001). Because we standardized precipitation to “Scaled Precipitation,” for every additional one scaled unit (93.3 mm), den entry was delayed 9.7 days with a CI of [4.4, 14.9] (p-value < 0.001). As soft mast quality improved (poor to fair), den entry was delayed by 14.4 days with a CI of [2.6, 26.2] (p-value = 0.017). Though not statistically significant, it was predicted that as hard mast quality improves (poor to average), den entry was estimated to be expedited by 10.2 days with a CI of [-21.9, 1.4] (p-value = 0.085). All categories of den substrate were statistically insignificant (anthropogenic p-value = 0.420, cavity p-value = 0.162, tree p-value = 0.878, and vegetation p-value = 0.058).

Den duration

The average den duration was 79.4 days (range 16 to 174 days: Table 1b) but primarily distributed between 50 to 100 days based on the kernel density plot (Fig. 2). The average temperature of the denning duration was 6.98°C (range -13.10°C to 21°C) and there were only 136 out of 1134 total days that denning was below freezing, which shows the temperate climate and mild winters of Asheville. The best fit model for den duration included entry temperature, emerge temperature, entry precipitation, reproductive status, and hard mast, accounting for 48.9% of variation in the response (R-squared). Like the den entry model, there were no interaction terms deemed significant, so we used an additive model. The duration of denning was mostly associated with weather, reproductive status, and hard mast (based on 95% CI not overlapping 0: Table 3b, Figs 3c-h). The intercept was estimated to be 51.2 days denned with a CI of [38.9, 63.6] (p-value < 0.001). For reproductive status, bears with yearling(s) did not differ significantly from the reference level (barren bears), having a denning duration of 3.3 days longer and a CI of [-16.6, 23.1] (p-value = 0.746). Although, bears with cub(s) of year did differ statistically from the reference level, denning for 26.4 days longer with a CI of [10.7, 42.2] (p-value = 0.001). Our results for the impact of weather on den duration suggested that for every 1°C increase in den entry temperatures, there was a 5.7 day increase in den duration with a CI of [3.7, 7.7] (p-value < 0.001). Similarly, for every 1°C increase in den emergence temperatures, there was a 2.6 day increase in den duration with a CI of [0.7, 4.5] (p-value = 0.007). Each scaled unit of entry precipitation (93.3 mm) influenced the den duration to be 10.7 days shorter with a CI of [-17.1, -4.3] (p-value = 0.001). As hard mast quality improved (poor to average), the denning duration was by 19.8 days with a CI of [7.1, 32.6] (p-value = 0.003).

Den emergence

The median date of den emergence was 19 March (range 3 December to 26 April: Table 1b). The variables included in the den emergence best fit model were temperature, reproductive status, and hard mast. The variables used in the model accounted for 45.8% of the variation in the response (R-squared). There were no interaction terms deemed significant, so we used a model with additive terms only. Den emergence was mostly influenced by temperature and reproductive status (based on 95% CI not overlapping 0: Table 3c, Figs 3i and j). The intercept estimated the day of emergence being 409.8 (p-value < 0.001). For reproductive status, bears with yearlings(s) were not significantly different from the reference level (barren bears), having the emergence date be 15 days later with CI of [-0.1, 30] (p-value = 0.052), but bears with cub(s) of year emerged 29 days later than the reference level with a CI of [17.1, 40.9] (p-value < 0.001). To determine the effect of temperature on den emergence, we saw that a 1°C increase in temperatures led to den emergence 3 days later with a CI of [1.5, 4.4] (p-value < 0.001). With hard mast being deemed statistically insignificant, as quality improved (poor to average), the date of emergence was 7 days later with a CI of [2, 16] (p-value = 0.127).

DISCUSSION

We noted a significant relationship between weather variables, reproductive status, and natural mast on denning cues using linear regression models and the predict() function in R (Table 3, Fig. 3; R Core Team, 2022). We determined that warmer temperatures led to earlier den entry, longer denning duration, and later den emergence; more precipitation led to a later den entry and shorter denning duration; more soft mast coincided with later den entry dates; and more hard mast resulted in a longer denning duration. Interestingly, our results present a counterargument to the notion upheld by prior studies that suggest warmer temperatures are correlated with delayed den entry, reduced denning duration, and earlier den emergence (Bonin et al., 2019; Gained, 2003; Inouye et al., 2000; Johnson et al., 2018; Lindzey & Meslow, 1976). We believe the difficulty in not identifying a defined trigger or mechanism for denning is because Asheville is unique to what has been studied, with abundant bear populations experiencing a temperate climate in an urban setting. Typically, most studies investigating weather factor effects on bear denning behavior have been conducted in areas of extreme climates that experience colder temperatures and more snow (Hamilton & Marchinton, 1980; Hellgren & Vaughan, 1989); such as, Alaska (Schwartz et al., 1987), Colorado (Johnson et al., 2018), Maine (Schooley et al., 1994), New York (O'Pezio et al., 1983), and Washington (Lindzey & Meslow, 1976). In areas that are extremely cold, bear denning behavior tends to be very predictable, resulting in a discreet relationship decreasing denning duration as temperatures increase. However, bears in our study area responded differently suggesting that factors driving bear denning and emergence behaviors may be study site specific. Interestingly, limited research on bear denning behavior has been conducted on weather and urban areas combined (Johnson et al., 2018), so it was not unexpected that our results differed from prior results and that a clear trigger to denning behavior was not identified. Importantly, we concluded with the idea that as weather patterns are predicted to be altered, bear denning may be further modified (Bonin et al., 2019; Johnson et al., 2018; Laufenberg et al., 2018; Miller et al., 2017).

Weather variables greatly affected the chronology of den entry, den duration, and den emergence in Asheville, as expected. We speculate that more precipitation leads to delayed den entry dates and less denning durations specifically in Asheville, possibly because of flooding bears out of the den, which is consistent with other literature (Lane et al., 2012; Lindzey & Meslow, 1976; Schooley et al., 1994). Conversely, warmer temperatures in Asheville expedited den entry and delayed den emergence, with a prolonged den duration. The weather in Asheville is temperate and mild, the coldest temperature during our entire study duration was -13.10°C, the average minimum temperature was 6.98°C, and only 12% of days during the entire denning duration were below 0°C. Hence, we expected bears in Asheville, NC to experience unusual denning behavior compared to bears at more northerly latitudes with more intense winters. Hardy (1974) stated that denning bears in Dare County, NC, tended to exit and re-enter dens sporadically for up to 2 weeks, allowing consumption of more calories to sustain longer periods in the den. The random trends of denning may be because of abundance of food sources (natural and anthropogenic) available throughout the winter in warm climates (Garshelis et al., 2017; Gray, 2015; Hightower et al., 2002; Johnson et al., 2015; Johnson et al., 2018; Laske et al., 2011; Laufenberg et al., 2018; LeCount, 1983; Wooding & Hardisky, 1992). Bears in our study area may have exited and re-entered dens during their denning duration in short, sporadic lengths to forage. Further studies could investigate the daily activity and movements of bears in temperate climates to see the extent of them exiting and re-entering dens and how these events adjust denning chronology. Also, Beckmann and Berger (2003) concluded that using developed areas allowed bears to quickly obtain calories and, thus, become less active. Similarly, we speculate that Asheville's temperate climate, urbanization, and abundance of natural and anthropogenic foods may allow bears to forgo denning or den sporadically, causing the observed extreme range in den entry and emergence dates.

The duration and emergence of denning was influenced by reproductive status of bears in Asheville. Our results align with the well documented research of reproductive status influencing denning. As expected, bears with cubs stayed in their dens for significantly longer periods of time than barren bears or bears with yearlings: the average number of days denned for bears with cubs was about 96 days, barren bears was about 52 days, and bears with yearling was about 56 days. In prior research, bears with cubs den longer so they can nurse cubs while avoiding predation (Gray, 2015; Hightower et al., 2002; LeCount, 1983; Weaver, 1999; Wooding & Hardisky, 1992), while bears with yearlings usually tend to den for shorter periods because more outside resources are required for the growing subadults and the care-taking mother (Johnson et al., 2018; Johnson & Pelton, 1980; Powell et al., 1997; Schwartz et al., 1987). Due to mild winter weather in Asheville, we believe we observed variability in den entry and emergence dates because most of the bears were parturient and likely not driven to den by weather events (Johnson et al., 2018; Johnson & Pelton, 1980; LeCount, 1980; Miller et al., 2017; Powell et al., 1997; Schwartz et al., 1987). Denning requirements of pregnant females is likely why the den entry and emergence dates we observed were variable and occurred over an extensive range of time.

Natural mast variables were selected for all three of our best fit models, but only had a significant effect in the den entry and duration models. Specifically, we observed a trend indicating that as soft mast transitioned from poor to fair, den entry was delayed by 2 weeks.

However, as hard mast transitioned from poor to average, the denning duration was extended by almost 3 weeks. With hard mast quality improving, the den entry date was earlier, denning duration was longer, and den emergence date was later. We believe that years with poor hard mast caused bears to den for shorter durations than in years of fair hard mast due to the lack of resources to build needed fat reserves (Bonin et al., 2019; Gaines, 2003; Johnson & Pelton, 1980; Laufenberg et al., 2018; Schwartz et al., 1987). In years of fair soft mast, rural bears may enter dens later than poor soft mast years, so they have more time to forage (O'Pezio et al., 1983). Because our study area was urban and hard and soft mast had contrasting effects on denning chronology, it is difficult to detect a clear relationship or trend in natural mast compared to other areas because an urban setting provides ample human food sources for bears. Gould (2020) reported that urban female yearling bears in Asheville weighed about twice as much as their rural counterparts, allowing them to reproduce at an earlier age. The comparison between urban and rural bears implies that anthropogenic foods provide supplemental, yet crucial, foraging for urban bears and it has been observed that bears in urban areas tend to use human food sources more in poor natural mast conditions (Baruch-Mordo, 2012; Garshelis et al., 2017; Gould et al., 2020; Manville, 1982). Further research should compare rural versus urban bears in a temperate climate, to determine the impacts of anthropogenic food on denning chronology. Because our study area mostly experienced poor mast (hard and soft) conditions, the abundance of anthropogenic foods in our study area (J. Strules, unpublished data) likely negatively influenced the use of natural food. Importantly, additional research quantifying urban food sources will provide a greater understanding of how bears are foraging in Asheville (Gould, 2020).

Den substrates did not have as comparable an influence on denning chronology as weather variables, reproductive status, or mast. The substrates were included in the den entry best fit model but did not have any statistically significant effects. Den sites are readily available in our study area and Gould (2020) did not detect den site selection or avoidance by bears within the study area of Asheville, NC, USA. Similarly, Garshelis et al. (2017) stated that denning sites are rarely limited because of the wide variety of dens that bears use. Better insulated dens and dens further from roads are usually used more frequently and for a longer denning duration, compared to other settings, because of greater protection from disturbance, predation, and harsh weather (Gaines, 2003; Gould, 2020; Schafer et al., 2018), but typically dens in Asheville are relatively similar with respect to insulation and disturbance via the urban surroundings and temperate climate, leading to similar denning chronology amongst bears. Also, Gould (2020) suggested that bears in our study area, or generally urban sites, can easily adjust to anthropogenic disturbances, allowing dens closer to roads or residences to be used for the same length of time as other dens. Thus, the results about den substrate are specifically applicable to bears in urban, temperate climate areas.

We did not find a specific trigger or mechanism that explained bear denning behavior in Asheville, NC, but rather demonstrated how certain variables are correlated with, and can modify, trends of denning. Identifying trends is crucial to further research and understanding of bear denning because it is extremely variable in different environments. Our results indicate that weather variables can impact trends in the timing of bear denning specifically in Asheville; thus, as climate is projected to be altered, future additional management actions could benefit bears and humans. With changing bear den entry and emergence, there can be potential for increasing human and bear interactions, as bears use anthropogenic resources (Baruch-Mordo, 2012; Johnson et al., 2015; Johnson et al., 2018; Miller et al., 2017). Although the bears in our study demonstrated speculated trends of prolonged denning with warmer temperatures, there are possibilities for human-bear interactions. Due to our urban study site providing adequate food, bears may exit and re-enter dens more frequently to forage (Gray, 2015; Hardy, 1974; Hightower et al., 2002; LeCount, 1983; Wooding & Hardisky, 1992), so this could increase the likelihood of future human-bear interactions. As bears have an excellent sense of smell and memory of where they discovered food sources, they may continue searching for food in human areas which is detrimental to our study area, precisely (Baruch-Mordo, 2012; Hostetler et al., 2009; Manville, 1982). More human-bear interactions are thought to be correlated with increased human-bear conflict and bear mortalities as well (Baruch-Mordo, 2012; Hostetler et al., 2009; Johnson et al., 2018; Kirby et al., 2016; Laufenberg et al., 2018).

We suggest increasing public outreach and minimizing bear attractants to avoid bear habituation: securing garbage, bird feeders, pet food, human food, and beehives. Proactive management of bear attractants by residents in urban areas may be the best way for people and bears to coexist with minimal conflict. Because potential climate change is emerging science, more research is required to fully understand the impacts on wildlife and the environment. Future work should focus on how anthropogenic resources and temperate climates impact bear denning chronology, while management efforts should focus on ways to mitigate bear usage of anthropogenic resources and the interactions between humans and bears. Additionally, because studies bears in warm/temperate areas can exit and re-enter dens throughout the winter to forage, future research should focus on activity and movements during the denning period to determine the extent of these events. Comparing our results to bears in a more rural area would be vital to understanding how urbanization impacts bears more directly.

LITERATURE CITED

Ayres L.A., Chow L.S., & Graber D.M. (1986). Black Bear Activity Patterns and Human Induced Modifications in Sequoia National Park. *Bears: Their Biology and Management*, *6*, 151–154. https://doi.org/10.2307/3872819

Baruch-Mordo, S. (2012). *Black bear ecology and human-bear interactions in an urban system.* [Ph.D., Colorado State University]. https://www.proquest.com/docview/1315240514/abstract/63558F17863C4AF4PQ/1

Beckmann, J., & Berger, J. (2003). Rapid ecological and behavioural changes in carnivores: The responses of black bears (*Ursus americanus*) to altered food. *Journal of Zoology*, *261*, 207–212. https://doi.org/10.1017/S0952836903004126

Bonin, M., Dussault, C., & Côté, S. (2019). Increased Trophic Position of Black Bear (*Ursus americanus*) at the Northern Fringe of its Distribution Range. *Canadian Journal of Zoology, 98*. https://doi.org/10.1139/cjz-2019-0062

Burnham, K., & Anderson, D. (2004). Model selection and multi-model inference. *Second. NY: Springer-Verlag, 63*(2020), 10.

Dietz, T., Shwom, R. L., & Whitley, C. T. (2020). Climate Change and Society. *Annual Review of Sociology, 46*(1), 135–158. https://doi.org/10.1146/annurev-soc-121919-054614

Gaines, W. (2003). Black Bear, *Ursus americanus*, Denning Chronology and Den Site Selection in the Northeastern Cascades of Washington. *Canadian Field Naturalist, 117*. https://doi.org/10.22621/cfn.v117i4.833

Garshelis, D.L., Scheick, B.K., Doan-Crider, D.L., Beecham, J.J. & Obbard, M.E. (2017). *Ursus americanus. The IUCN Red List of Threatened Species*. Accessed September 19, 2023, from https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T41687A45034604.en

Gould, N. P. (2020). *Ecology of American Black Bears in an Urban Environment.* [Ph.D., North Carolina State University].

Gould, N. P., Powell, R., Olfenbuttel, C., & DePerno, C. S. (2021). Growth and reproduction by young urban and rural black bears. *Journal of Mammalogy, 102*(4), 1165–1173. https://doi.org/10.1093/jmammal/gyab066

Gray, C. A. (2015). *Reproductive biology and denning ecology of the American black bear (Ursus americanus) in central Georgia* [Ph.D., University of Georgia].

Hamilton, R. J., & Marchinton, R. L. (1980). Denning and Related Activities of Black Bears in the Coastal Plain of North Carolina. *Bears: Their Biology and Management, 4*, 121–126. https://doi.org/10.2307/3872854

Hardy, D. M. (1974). *Habitat requirements of the black bear in Dare County, North Carolina.* [Ph.D., Virginia Polytechnic Institute and State University].

Hellgren, E. C., & Vaughan, M. R. (1989). Denning Ecology of Black Bears in a Southeastern Wetland. *The Journal of Wildlife Management, 53*(2), 347–353. https://doi.org/10.2307/3801136

Hightower, D. A., Wagner, R. O., & Pace, R. M. (2002). Denning Ecology of Female American Black Bears in South Central Louisiana. *Ursus, 13*, 11–17.

Honda, T., & Kozakai, C. (2020). Mechanisms of human-black bear conflicts in Japan: In preparation for climate change. *Science of The Total Environment, 739*, 140028. https://doi.org/10.1016/j.scitotenv.2020.140028

Hostetler, J. A., Walter McCown, J., Garrison, E. P., Neils, A. M., Barrett, M. A., Sunquist, M. E., Simek, S. L., & Oli, M. K. (2009). Demographic consequences of anthropogenic influences: Florida black bears in north-central Florida. *Biological Conservation, 142*(11), 2456–2463. https://doi.org/10.1016/j.biocon.2009.05.029

Inouye D.W., Barr B., Armitage K.B., & Inouye B.D. (2000). Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences, 97*(4), 1630–1633. https://doi.org/10.1073/pnas.97.4.1630

Johnson H.E., Breck S.W., Baruch-Mordo S., Lewis D.L., Lackey C.W., Wilson K.R., Broderick J., Mao J.S., & Beckmann J.P. (2015). Shifting perceptions of risk and reward: Dynamic selection for human development by black bears in the western United States. *Biological Conservation, 187*, 164–172. https://doi.org/10.1016/j.biocon.2015.04.014

Johnson, H. E., Lewis, D. L., Verzuh, T. L., Wallace, C. F., Much, R. M., Willmarth, L. K., & Breck, S. W. (2018). Human development and climate affect hibernation in a large carnivore with implications for human–carnivore conflicts. *Journal of Applied Ecology, 55*(2), 663–672. https://doi.org/10.1111/1365-2664.13021

Johnson, K. G., & Pelton, M. R. (1980). Environmental Relationships and the Denning Period of Black Bears in Tennessee. *Journal of Mammalogy, 61*(4), 653–660. https://doi.org/10.2307/1380310

Kirby, R., Alldredge M. W., & Pauli J. N. (2016). The diet of black bears tracks the human footprint across a rapidly developing landscape. *Biological Conservation, 200*, 51–59. https://doi.org/10.1016/j.biocon.2016.05.012

Kirk R.W., Bolstad P.V., & Manson S.M. (2012). Spatio-temporal trend analysis of long-term development patterns (1900–2030) in a Southern Appalachian County. *Landscape and Urban Planning, 104*(1), 47–58. https://doi.org/10.1016/j.landurbplan.2011.09.008

Lane J.E., Kruuk L.B., Charmantier A., Murie J.O., & Dobson F.S. (2012). Delayed phenology and reduced fitness associated with climate change in a wild hibernator. *Nature, 489*(7417), 554–7. https://doi.org/10.1038/nature11335

Laske T.G., Garshelis D.L., & Iaizzo P.A. (2011). Monitoring the wild black bear's reaction to human and environmental stressors. *BMC Physiology, 11*(1), 13. https://doi.org/10.1186/1472-6793-11-13

Laufenberg, J. S., Johnson, H. E., Doherty, P. F., & Breck, S. W. (2018). Compounding effects of human development and a natural food shortage on a black bear population along a human development-wildland interface. *Biological Conservation, 224*, 188–198. https://doi.org/10.1016/j.biocon.2018.05.004

LeCount, A. L. (1980). Some Aspects of Black Bear Ecology in the Arizona Chaparral. *Bears: Their Biology and Management, 4*, 175–179. https://doi.org/10.2307/3872864

LeCount, A. L. (1983). Denning Ecology of Black Bears in Central Arizona. *Bears: Their Biology and Management, 5*, 71–78. https://doi.org/10.2307/3872521

Lindzey F.G., & Meslow E.C. (1976). Winter Dormancy in Black Bears in Southwestern Washington. *Journal of Wildlife Management, 40*(3), 408–415. https://doi.org/10.2307/3799942.

Manville, A. M., II. (1982*). Human Impact on the Black Bear in Michigan's Lower Peninsula.* [Ph.D., Michigan State University]. https://www.proquest.com/docview/303246953/abstract/B33C33494E84FAEPQ/1

Miller J.A., Smith T.S., Auger J., Black H.L., & Allphin L. (2017). The late-denning activities of the American black bear in Utah. *Ursus, 27*(2), 78–89. https://doi.org/10.2192/URSU-D-15-00035.1

Mitchell M.S., Zimmerman J.W., & Powell R.A. (2002). Test of a Habitat Suitability Index for Black Bears in the Southern Appalachians. *Wildlife Society Bulletin (1973-2006), 30*(3), 794–808. http://www.jstor.org/stable/3784233

Nelson, R. A., Folk, G. E., Pfeiffer, E. W., Craighead, J. J., Jonkel, C. J., & Steiger, D. L. (1983). Behavior, Biochemistry, and Hibernation in Black, Grizzly, and Polar Bears. *Bears: Their Biology and Management, 5*, 284–290. https://doi.org/10.2307/3872551

Oli, M. K., Jacobson, H. A., & Leopold, B. D. (1997). Denning Ecology of Black Bears in the White River National Wildlife Refuge, Arkansas. *The Journal of Wildlife Management, 61*(3), 700–706. https://doi.org/10.2307/3802177

O'Pezio, J., Clarke, S. H., & Hackford, C. (1983). Chronology of Black Bear Denning in the Catskill Region of New York. *Bears: Their Biology and Management, 5*, 87–93. https://doi.org/10.2307/3872523

Parmesan C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics, 37*(1), 637–669. https://doi.org/10.1146/annurev.ecolsys.37.091305.110100

Pigeon, K. E., Stenhouse, G., & Côté, S. D. (2016). Drivers of hibernation: Linking food and weather to denning behaviour of grizzly bears. *Behavioral Ecology and Sociobiology, 70*(10), 1745–1754. https://doi.org/10.1007/s00265-016-2180-5

Powell R.A., Zimmerman J.W., & Seaman D.E. (1997). Ecology and Behaviour of North American Black Bears: Home Ranges, Habitat, and Social Organization. *Springer Science & Business Media, 4*.

PRISM Climate Group at Oregon State University. (2023). Accessed February 5, 2023, from https://www.prism.oregonstate.edu/explorer/

R Core Team. (2022). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. Accessed November 29, 2022, from https://www.R-project.org/.

Schafer, T. L. J., Breck, S. W., Baruch-Mordo, S., Lewis, D. L., Wilson, K. R., Mao, J. S., & Day, T. L. (2018). American black bear den-site selection and characteristics in an urban environment. *Ursus, 29*(1), 25–31. https://doi.org/10.2192/URSUS-D-17-00004.2

Schooley, R. L., McLaughlin, C. R., Matula, G. J., & Krohn, W. B. (1994). Denning Chronology of Female Black Bears: Effects of Food, Weather, and Reproduction. *Journal of Mammalogy, 75*(2), 466–477. https://doi.org/10.2307/1382569

Schwartz, C. C., Miller, S. D., & Franzmann, A. W. (1987). Denning Ecology of Three Black Bear Populations in Alaska. *Bears: Their Biology and Management, 7*, 281–291. https://doi.org/10.2307/3872635

Sikes, R. S., and The Animal Care and Use Committee of the American Society of Mammalogists. (2016). 2016 Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. *Journal of Mammalogy, 97*, 663–688

Tøien, Ø., Blake, J., Edgar, D. M., Grahn, D. A., Heller, H. C., & Barnes, B. M. (2011). Hibernation in Black Bears: Independence of Metabolic Suppression from Body Temperature. *Science, 331*(6019), 906–909. https://doi.org/10.1126/science.1199435

Towns, L., Derocher, A. E., Stirling, I., Lunn, N. J., & Hedman, D. (2009). Spatial and temporal patterns of problem polar bears in Churchill, Manitoba. *Polar Biology, 10*(32), 1529–1537. https://doi.org/10.1007/s00300-009-0653-y

U.S. Census Bureau. (2022). *City of Asheville, NC density estimate and housing units*. Accessed September 23, 2022, from https://www.census.gov/quickfacts/ashevillecitynorthcarolina

Weaver, K. M. (1999). *The ecology and management of black bears in the Tensas River Basin of Louisiana.* [Ph.D., The University of Tennessee].

Weeks J.R. (2010). Defining Urban Areas. In: Rashed T., & Jürgens C., editors. Remote Sensing of Urban and Suburban Areas. Dordrecht: Springer Netherlands. *Remote Sensing and Digital Image Processing.* p. 33–45. [accessed 2022 Sep 23]. https://doi.org/10.1007/978-1-4020-4385-7_3

Willey, C. H. (1974). Aging Black Bears from First Premolar Tooth Sections. *The Journal of Wildlife Management, 38*(1), 97–100. https://doi.org/10.2307/3800203

Wooding, J. B., & Hardisky, T. S. (1992). Denning by Black Bears in Northcentral Florida. *Journal of Mammalogy, 73*(4), 895–898. https://doi.org/10.2307/1382213

Zahoor, B., Liu, X., Ahmad, B., Kumar, L., & Songer, M. (2021). Impact of climate change on Asiatic black bear (*Ursus thibetanus*) and its autumn diet in the northern highlands of Pakistan. *Global Change Biology, 27*(18), 4294–4306. https://doi.org/10.1111/gcb.15743

Table 1. Variables used in the analyses: categorical (a) and numeric (b) variables and their measurements (*N*) for bears in and around Asheville, NC, USA (2014 – 2022). The categorical (a) variables include reproductive status [cub(s) of year, barren, yearling(s)], hard mast (poor, average), soft mast (poor, fair), substrate (anthropogenic, cavity, tree, vegetation, ground). The numeric (b) variables show the mean (or median for dates of entry and emergence), standard deviation, and range of entry temperature, emergence temperature, entry precipitation, emerge precipitation, den entry dates, den duration, and den emergence dates.

a.

Variable	Category	Entry (*N*)	Duration (*N*)	Emergence (*N*)
Reproductive Status	Cub(s) of Year	72	66	67
	Barren	20	19	19
	Yearling(s)	12	12	12
Hard Mast	Poor	69	67	68
	Average	35	30	30
Soft Mast	Poor	49	47	47
	Fair	55	50	51
Substrate	Anthropogenic	13	12	12
	Cavity	12	12	12
	Tree	17	14	14
	Vegetation	28	26	27
	Ground	34	33	33

b.

Variable	Mean	SD	Range
Entry Temperature (°C)	0.1	3.3	-8.7 – 11.98
Emergence Temperature (°C)	1.8	3.3	-7.65 – 10.24
Entry Precipitation (mm)	51.8	38.9	0 – 167.2
Emergence Precipitation (mm)	49.4	35.1	2.78 – 265.83
Den Entry (Date)	12/27 (Median)	–	10/6 – 2/26
Den Emergence (Date)	3/19 (Median)	–	12/3 – 4/26
Den Duration (Number of Days Denned)	79.4	37.4	16 – 174

Table 2. Variables included in each global model to estimate bear denning, NC, USA (2014 – 2022). We constructed a global model for den entry, den duration, and den emergence. The den entry and emergence global models include temperature, reproductive status, hard and soft mast, precipitation, and substrate. The den duration global model includes entry temperature, emerge temperature, reproductive status, hard and soft mast, entry precipitation, emerge precipitation, and substrate. Asterisks (*) denote covariates chosen for each respective best fit model, after stepwise selection using the smallest AIC values.

Type	Global Model Variables
Den Entry	Temperature* Reproductive status Hard mast* Soft mast* Precipitation* Substrate*
Den Duration	Entry temperature* Emerge temperature* Reproductive status* Hard mast* Soft mast Entry precipitation* Emerge precipitation Substrate
Den Emergence	Temperature* Reproductive status* Hard mast* Soft mast Precipitation Substrate

Table 3. Parameter estimates, 95% confidence interval (CI), and p-value associated with selected variables for den entry (a), duration (b), and emergence (c), for bears in and around Asheville, NC, USA (2014 – 2022). Den entry (a) predictors include the intercept [(hard mast (poor), soft mast (poor), substrate (ground)], temperature, precipitation, hard mast (average), soft mast (fair), and substrates. Den duration (b) predictors include the intercept [reproductive status (barren) and hard mast (poor)], reproductive status [cub(s) of year], reproductive status [yearling(s)], temperature of den entry, precipitation of den entry, hard mast (average), and temperature of den emergence. Den emergence (c) predictors include the intercept [reproductive status (barren) and hard mast (poor)], reproductive status [cub(s) of year], reproductive status [yearling(s)], temperature, and hard mast (average). Asterisks (*) denote statistical significance at $\alpha = 0.05$.

a.

Entry Predictor	Estimate	95% CI	P-Value
Intercept [Hard Mast (Poor), Soft Mast (Poor), Substrate (Ground)]	358.21	349.38 – 367.03	< 0.001*
Temperature (°C)	-5.28	-7 – -3.55	< 0.001*
(Scaled) Precipitation (mm)	9.67	4.42 – 14.92	< 0.001*
Hard Mast (Average)	-10.24	-21.91 – 1.44	0.085
Soft Mast (Fair)	14.38	2.6 – 26.17	0.017*
Substrate (Anthropogenic)	5.96	-8.63 – 20.54	0.420
Substrate (Cavity)	-11.05	-26.6 – 4.5	0.162
Substrate (Tree)	1.14	-13.48 – 15.75	0.878
Substrate (Vegetation)	-14.85	-30.24 – 0.54	0.058

b.

Duration Predictor	Estimate	95% CI	P-Value
Intercept [Reproductive Status (Barren), Hard Mast (Poor)]	51.21	38.88 – 63.55	< 0.001*
Cub(s) of Year	26.42	10.66 – 42.18	0.001*
Yearling(s)	3.25	-16.6 – 23.09	0.746
Temperature of Den Entry (°C)	5.71	3.73 – 7.7	< 0.001*
(Scaled) Precipitation of Den Entry (mm)	-10.7	-17.05 – -4.34	0.001*
Hard Mast (Average)	19.81	7.05 – 32.57	0.003*
Temperature of Den Emergence (°C)	2.58	0.71 – 4.45	0.007*

Table 3 (continued).

c.

Emergence Predictor	Estimate	95% CI	P-Value
Intercept [Reproductive Status (Barren), Hard Mast (Poor)]	409.77	400.32 – 419.22	< 0.001*
Cub(s) of Year	28.99	17.08 – 40.90	< 0.001*
Yearling(s)	14.95	-0.11 – 30.02	0.052
Temperature (°C)	2.98	1.55 – 4.41	< 0.001*
Hard Mast (Average)	6.97	2.01 – 15.96	0.127

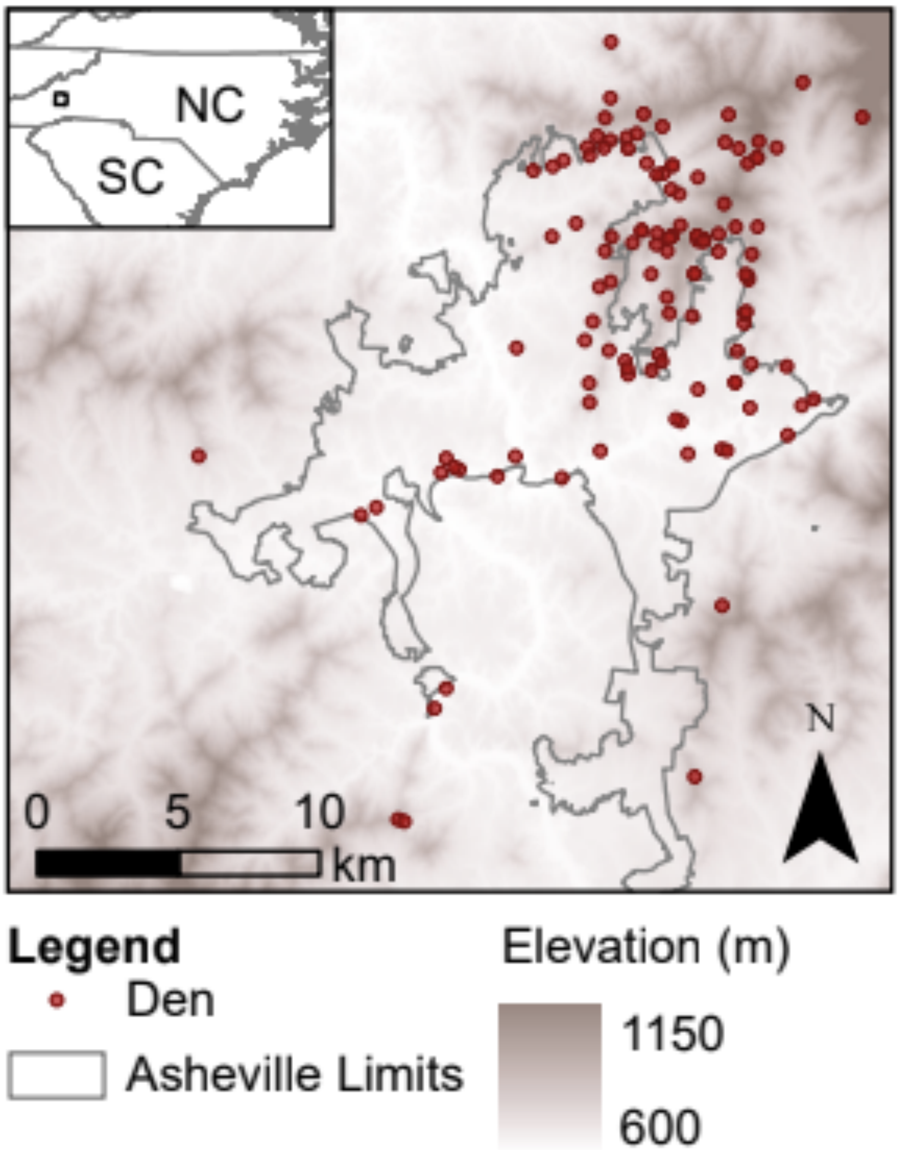


Figure 1. Den locations of black bears (red dots) in and around the city of Asheville, North Carolina, USA (gray outline: 2014 – 2022), overlayed with elevation.

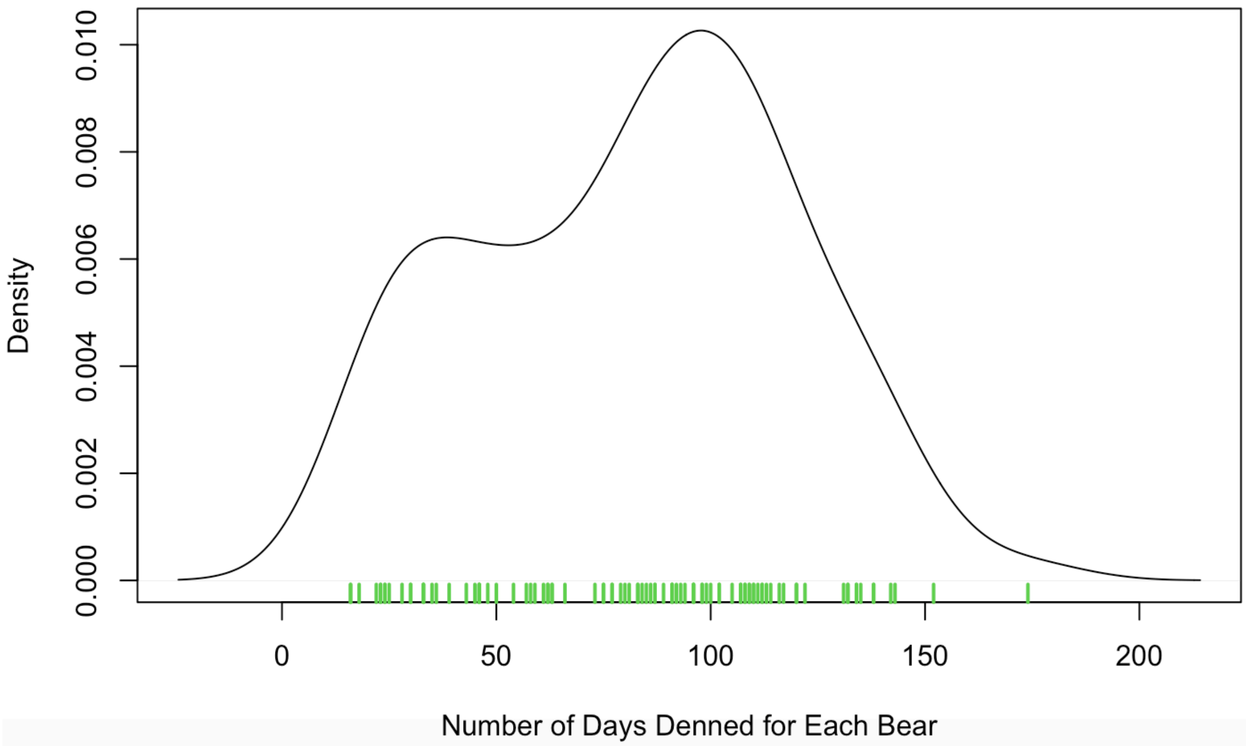
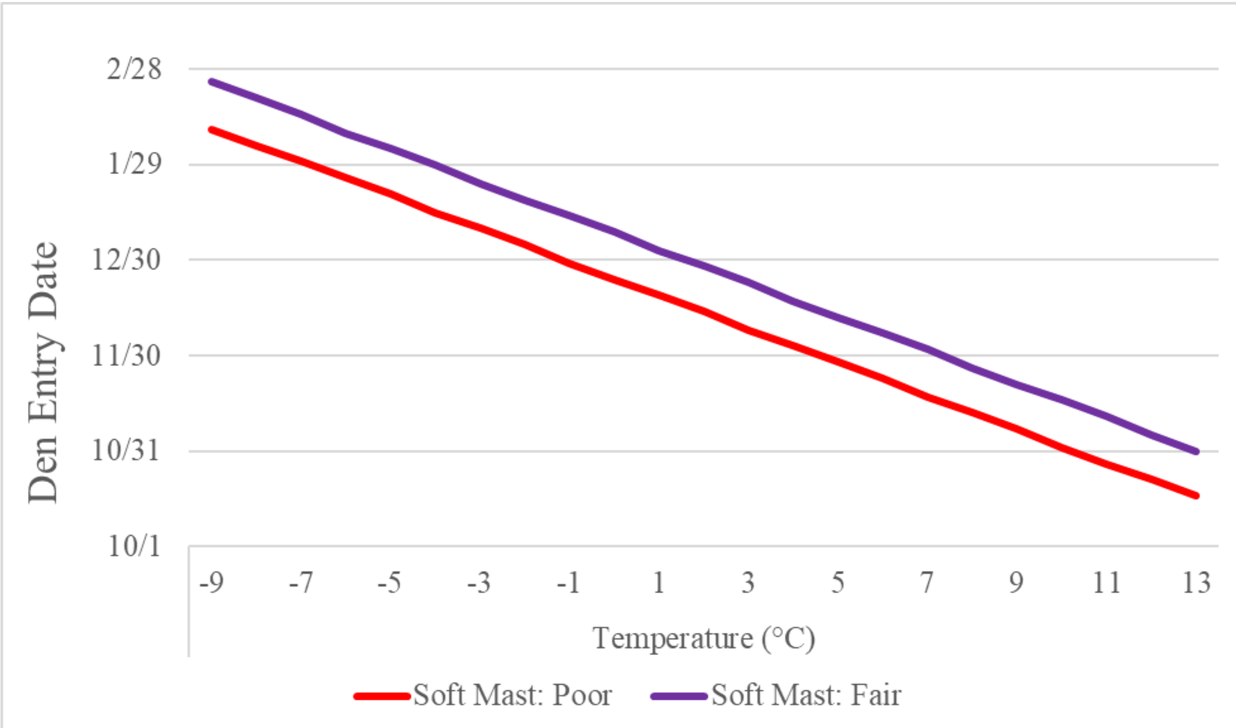


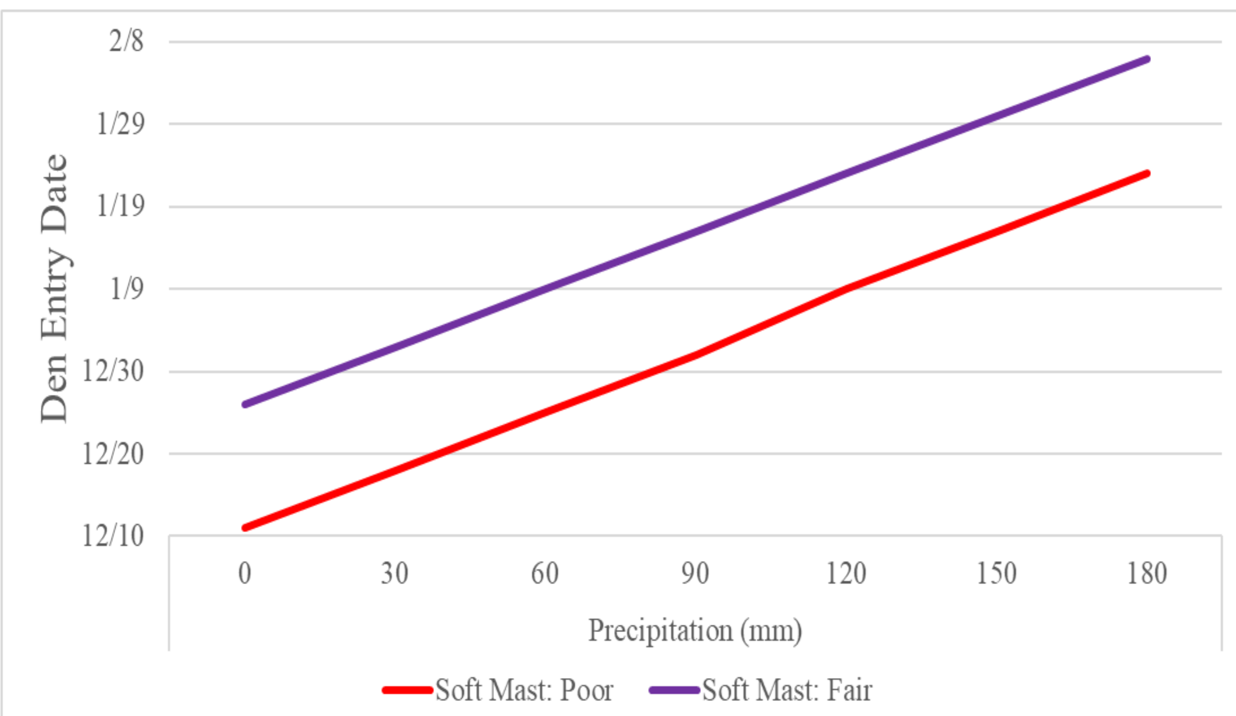
Figure 2. Distribution of the denning duration (days) for all bears' observations (*n* = 97) within a density plot, using kernel density estimation. Each green tick mark represents one bear's observation, Asheville, NC, USA (2014 –2022). Higher values of the density curve denote more bears denning for "x-value" days.

Figure 3. Values of each statistically significant variable plotted in a linear regression line using the "predict" function in R, for denning chronology of bears in Asheville, NC, USA (2014 – 2022). The plots associated with the entry model include a and b. Plots c, d, e, f, g, and h are associated with the duration model. The emergence model is represented by i and j. To show the den entry dates, entry temperature (a) and precipitation (b) were plotted and overlaid by soft mast. To depict the number of days denned, entry temperature (c, f), emergence temperatures (d, g), and entry precipitation (e, h) were plotted and overlaid by reproductive status (c, d, e) and hard mast (f, g, h). To represent the emergence dates, emergence temperature was overlaid by reproductive status (i) and hard mast (j). All other variables were held at their average, if continuous, or their reference level, if categorical.

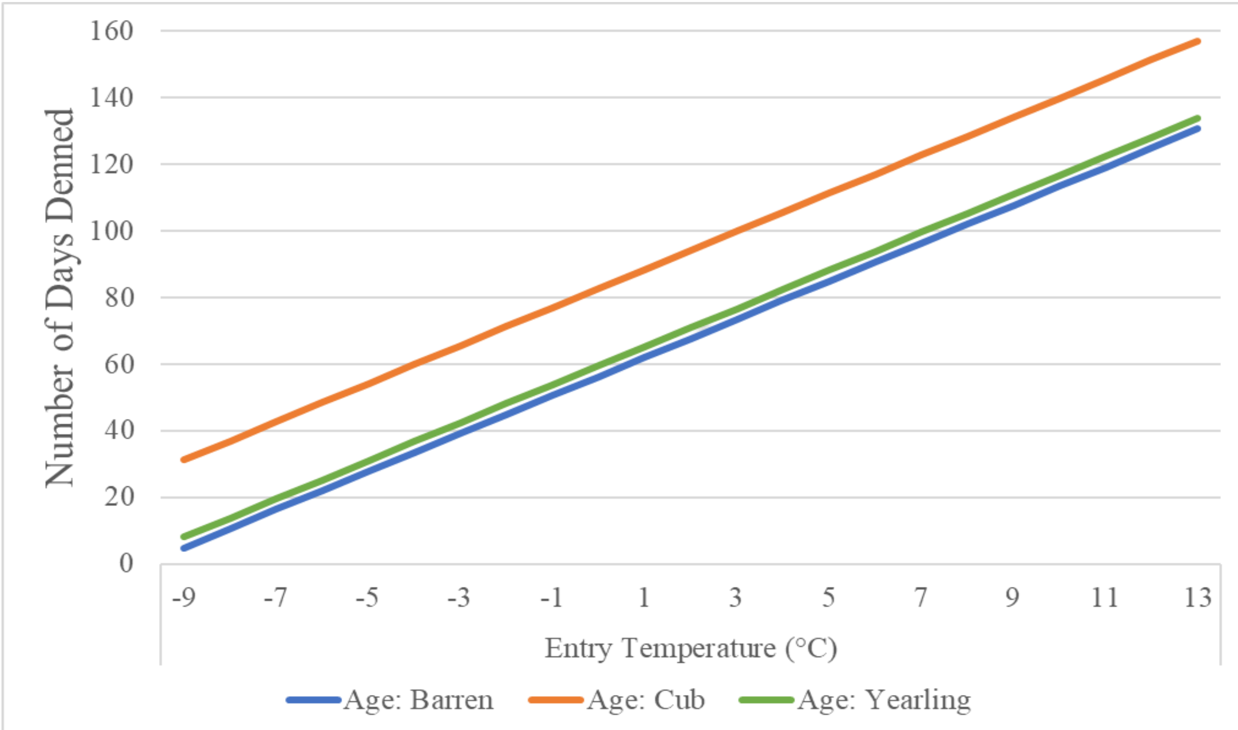
a.


Den Entry Date
2/28
1/29
12/30
11/30
10/31
10/1
-9
-7
-5
-3
-1
1
3
5
7
9
11
13
Temperature (°C)
Soft Mast: Poor
Soft Mast: Fair

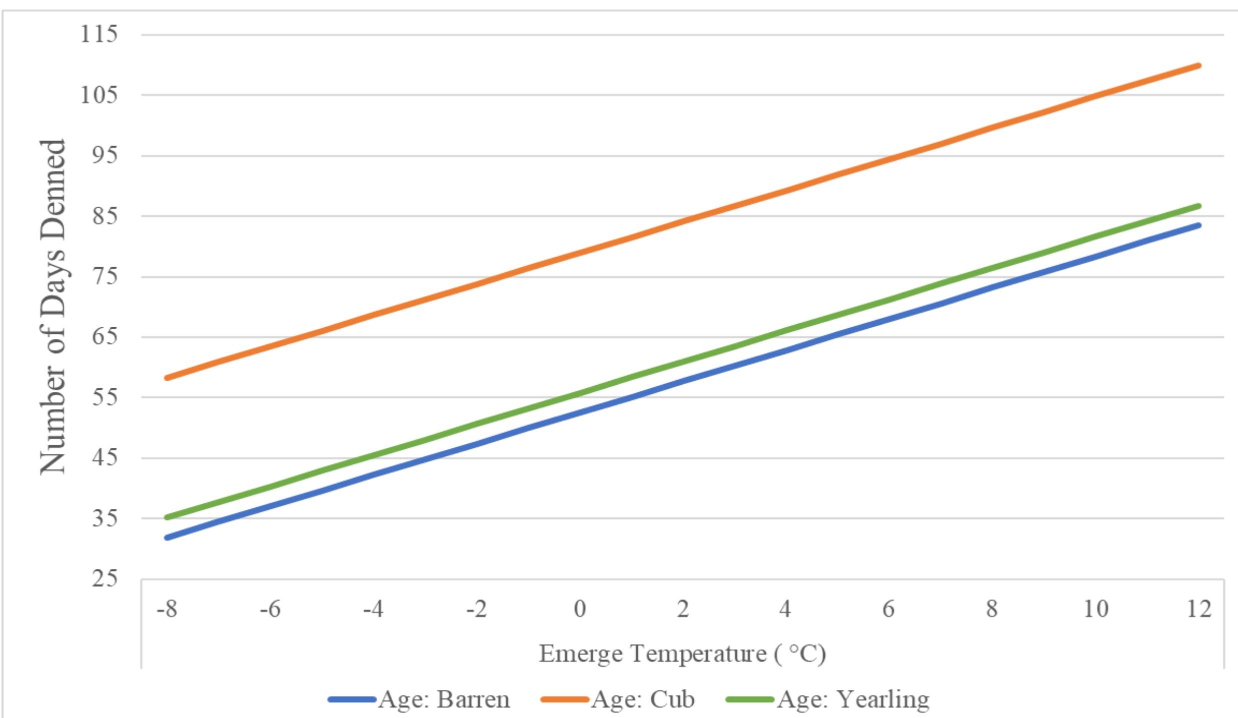
b.


Den Entry Date
2/8
1/29
1/19
1/9
12/30
12/20
12/10
0
30
60
90
120
150
180
Precipitation (mm)
Soft Mast: Poor
Soft Mast: Fair

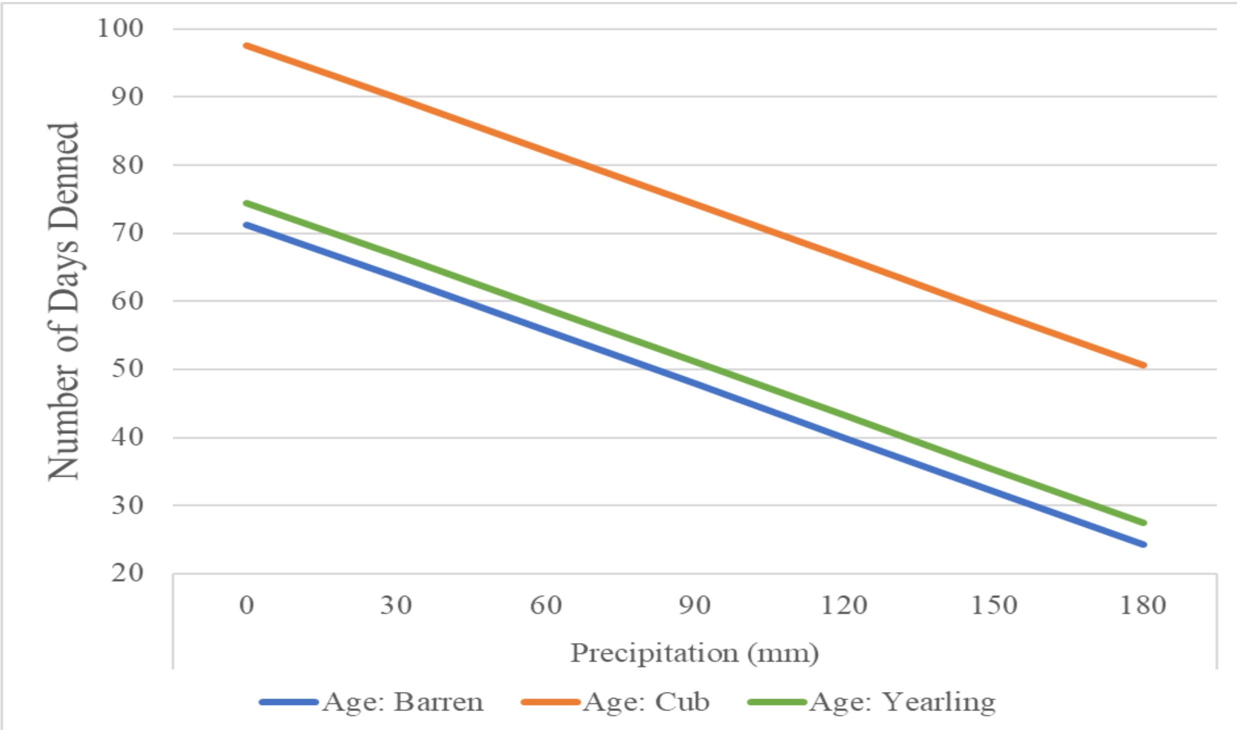
c.


160
140
120
100
80
60
40
20
0
Number of Days Denned
-9
-7
-5
-3
-1
1
3
5
7
9
11
13
Entry Temperature (°C)
Age: Barren
Age: Cub
Age: Yearling

d.

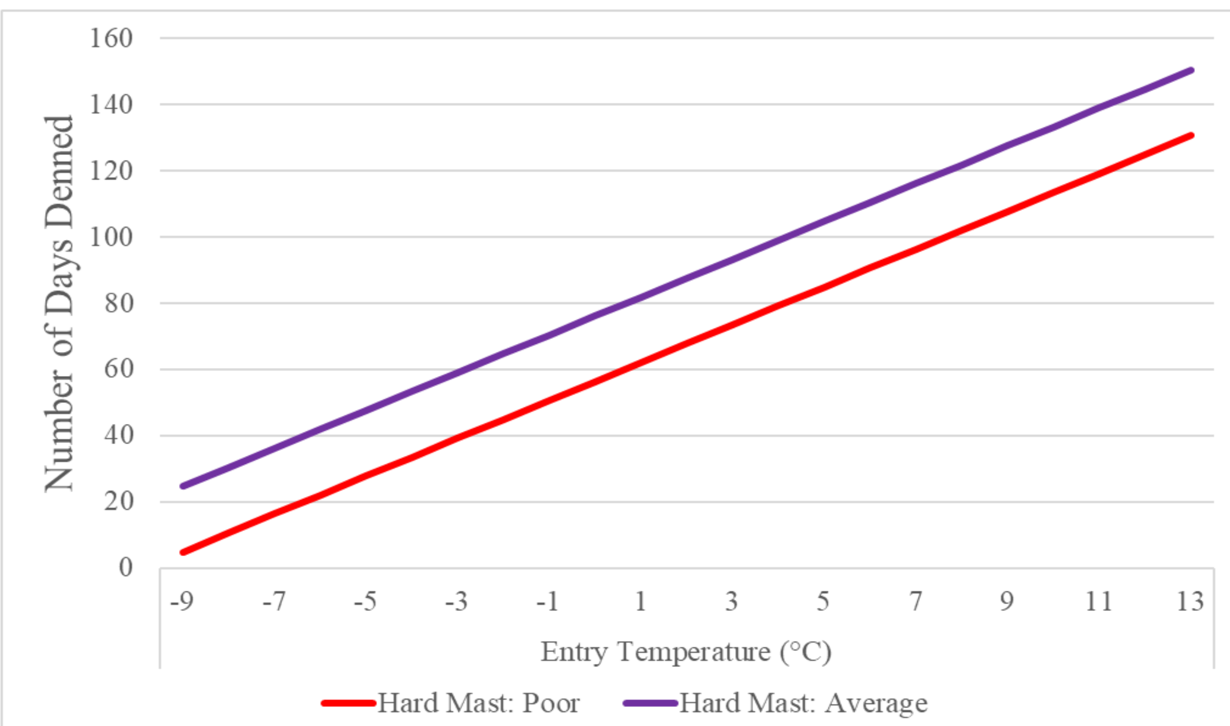

115
105
95
85
75
65
55
45
35
25
Number of Days Denned
-8
-6
-4
-2
0
2
4
6
8
10
12
Emerge Temperature (°C)
Age: Barren
Age: Cub
Age: Yearling

e.



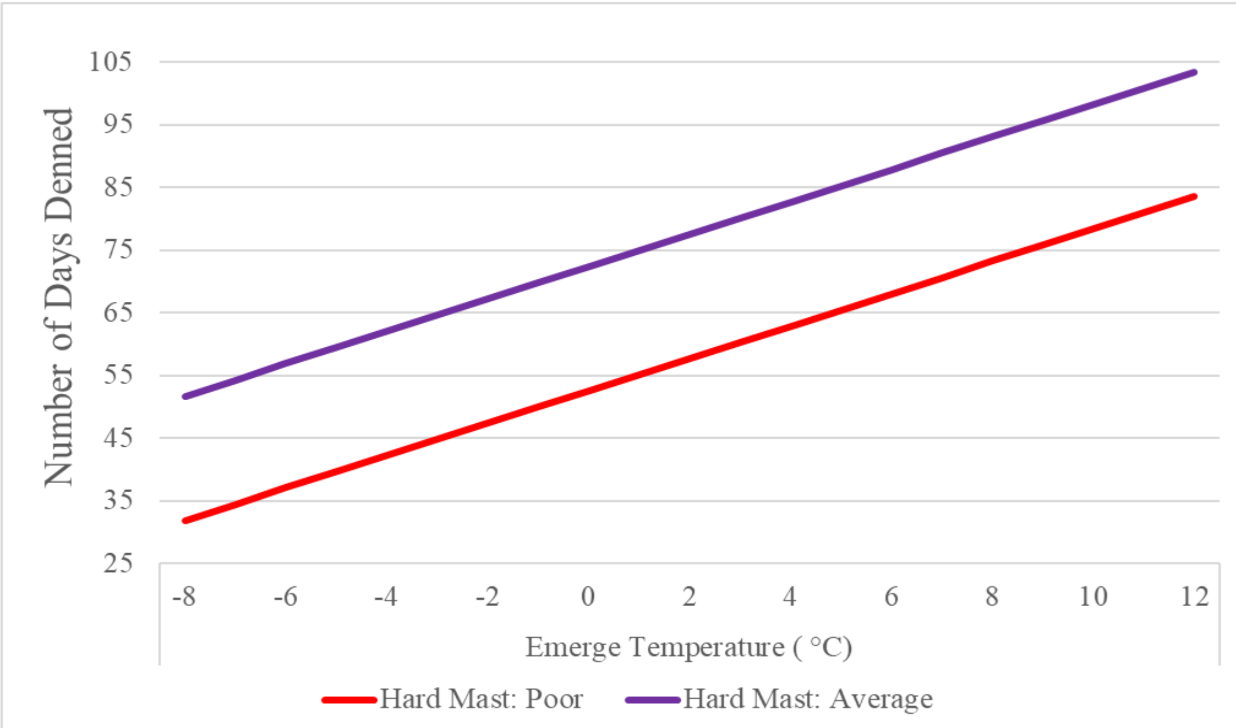
Number of Days Denned
100
90
80
70
60
50
40
30
20
0
30
60
90
120
150
180
Precipitation (mm)
Age: Barren
Age: Cub
Age: Yearling

f.

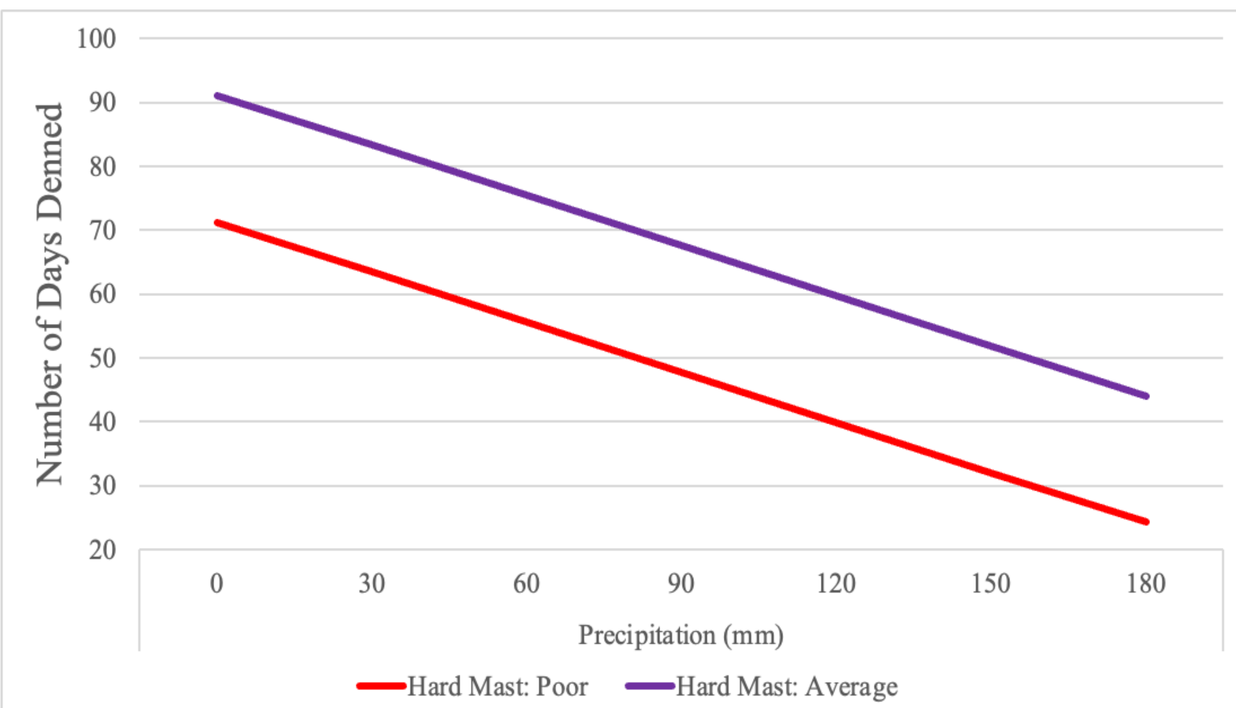


Number of Days Denned
160
140
120
100
80
60
40
20
0
-9
-7
-5
-3
-1
1
3
5
7
9
11
13
Entry Temperature (°C)
Hard Mast: Poor
Hard Mast: Average

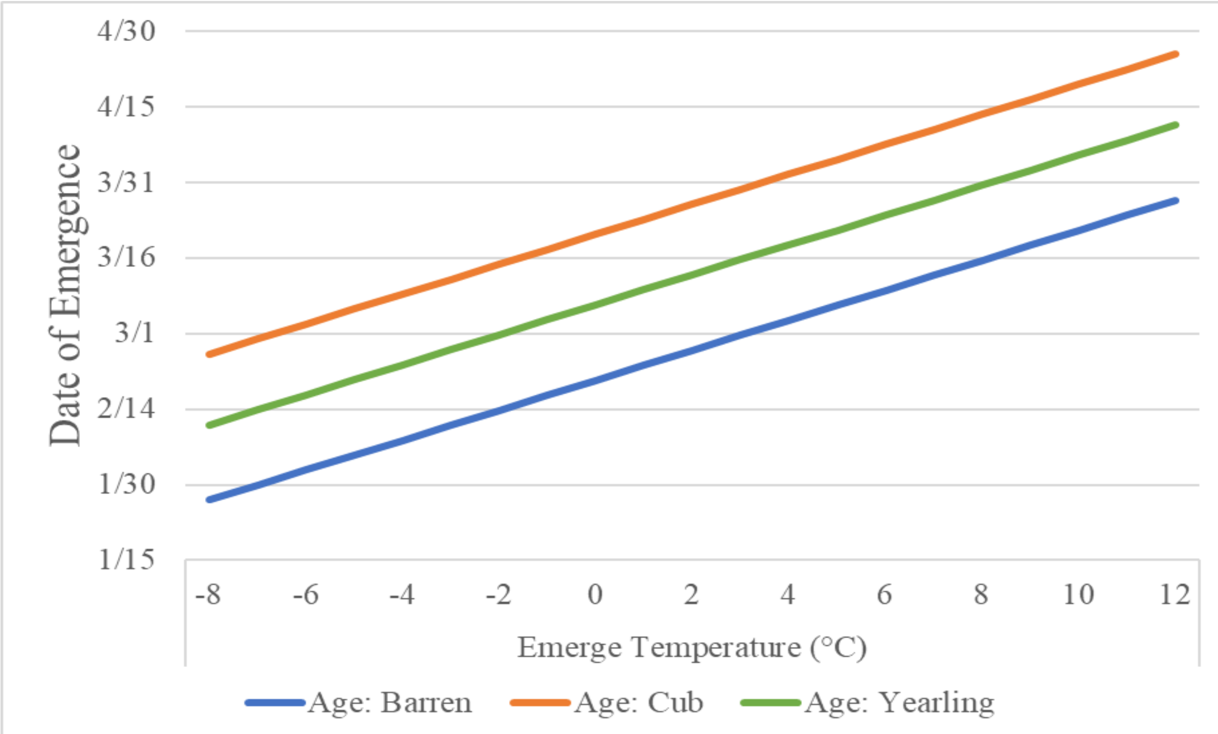
g.


105
95
85
75
65
55
45
35
25
Number of Days Denned
-8
-6
-4
-2
0
2
4
6
8
10
12
Emerge Temperature (°C)
Hard Mast: Poor
Hard Mast: Average

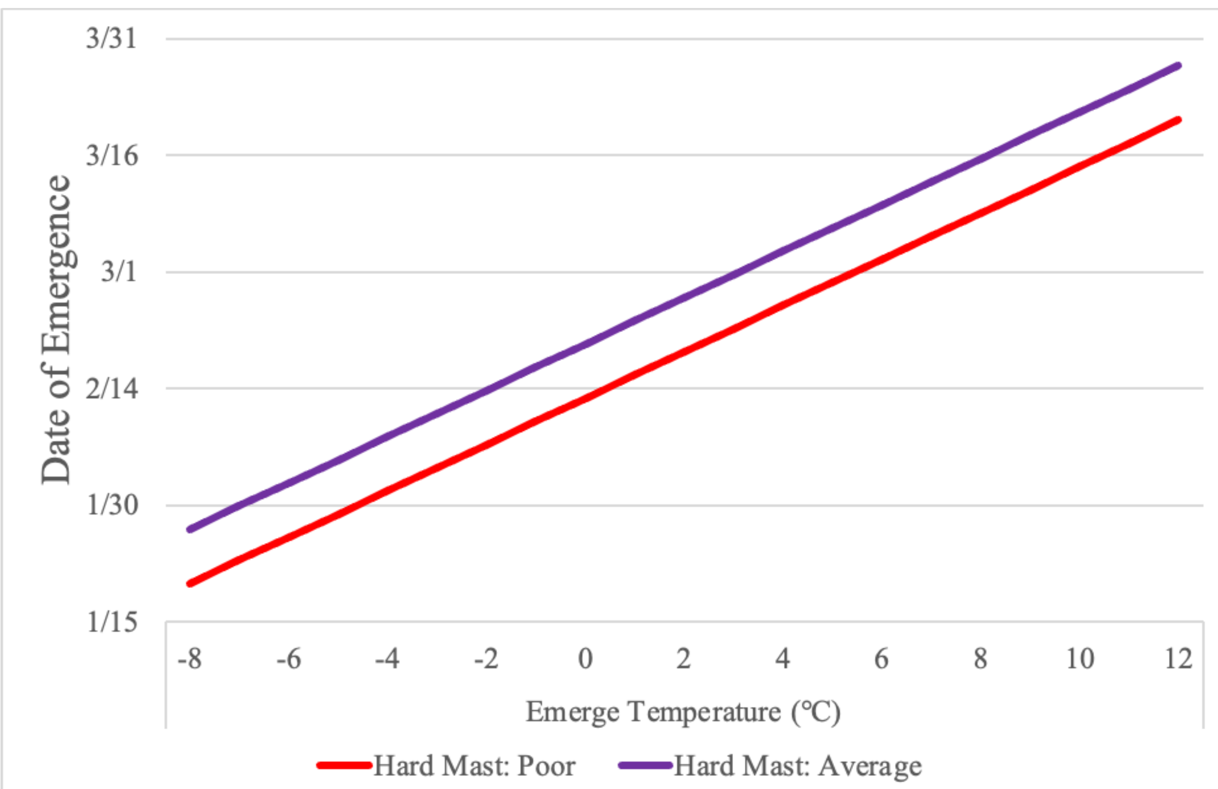
h.


100
90
80
70
60
50
40
30
20
Number of Days Denned
0
30
60
90
120
150
180
Precipitation (mm)
Hard Mast: Poor
Hard Mast: Average

i.


4/30
4/15
3/31
3/16
3/1
2/14
1/30
1/15
Date of Emergence
-8
-6
-4
-2
0
2
4
6
8
10
12
Emerge Temperature (°C)
Age: Barren
Age: Cub
Age: Yearling

j.


3/31
3/16
3/1
2/14
1/30
1/15
Date of Emergence
-8
-6
-4
-2
0
2
4
6
8
10
12
Emerge Temperature (℃)
Hard Mast: Poor
Hard Mast: Average