A Bear's Eye View: Insight on American Black Bear (*Ursus americanus*) Hibernation and Foraging Ecology in Virginia's Central Appalachian Mountains

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Scientific Abstract

Following mass agricultural expansion and deforestation in the late 1800s and early 1900s, American black bear populations (*Ursus americanus*, hereafter black bear) were low across most of Virginia. The Department of Wildlife Resources (VADWR) and the United States Forest Service worked to rebuild wildlife habitat in the state, leading to recovery of bears. While some aspects of black bear hibernation and foraging ecology have been studied, there remain knowledge gaps on key aspects of black bear biology. Hibernation behavior, for example, is understudied with most knowledge stemming from post-hibernation emergence studies. We used a unique dataset with continuous monitoring of mother bears and their cubs from Virginia Tech's Black Bear Research Center in 2015-2016, to better understand hibernation ecology, mother-cub dynamics, and biological-foster cub dynamics. We found that increased black bear activity levels were driven by both higher temperature and photoperiod, but the onset of hibernation was primarily driven by only temperature. Temperature is projected to rise in VA and rising temperatures regionally could be responsible for increased active behaviors in bears, which could lead to increased human-black bear interactions on the landscape, especially during hibernation onset. We also found that mother bears spend similar amounts of time with biological and foster cubs. Biological cubs did not show more dominance behaviors toward fosters than biological siblings, which we also observed with foster, where they did not continuously display these behaviors towards biological cubs. These results are promising for orphan cub fostering programs in VA and other states and indicate that foster cub litter integration can be successful.

Foraging ecology also is challenging to study in black bears because direct observation is generally not possible due to their cryptic nature, closed habitat, or potential danger in observing. We used a dataset from camera collars deployed on 15 bears (8 males, 7 females) in Bath County Virginia in 2018 and 2019 to better understand diet seasonality and to determine habitat and environmental drivers of black bear foraging patterns, particularly on white-tailed deer (*Odocoileus virginianus*) and invasive plant species. We identified 178 unique diet items to family, genus, or species in videos, much higher numbers than previously reported in the literature, and we found high diet overlap between sexes. Diet composition was primarily influenced by season with higher levels of consumption of herbaceous soft mast in spring, fruit and seed soft mast in summer, and hard mast in fall. Females exhibited more hunting events on deer fawns in spring than males, but males and females consumed similar numbers (28 vs. 24, respectively) via hunting and scavenging combined. Males consumed anthropogenic foods more often than females, particularly when closer to human settlements and males more commonly consumed invasive plant species in spring while females more often consumed insect in spring invasive species in summer. Our results highlight strong seasonally- and subtle sex-mediated differences in black bear diets. We provide information on drivers of diet choices by bears, as well as identify where foraging hotspots on species of interest occur, providing information useful to VADWR in managing increased human-wildlife interactions (and mitigating potential for negative interactions), predator-prey relations, and invasive species spread across the landscape.

42 **A Bear's Eye View: Insight on American Black Bear (Ursus americanus) Hibernation and**
43 **Foraging Ecology in Virginia's Central Appalachian Mountains**

44 *General Audience Abstract*
45 American black bears were almost eliminated from Virginia following mass agricultural expansion
46 and deforestation in the late 1800s and early 1900s. The Department of Wildlife Resources
47 (VADWR) and the United States Forest Service worked to rebuild wildlife habitat in the state,
48 leading to recent recovery of bears in VA. However, there are still gaps in our knowledge of black
49 bear ecology and gaining new knowledge will aid in better management of black bears across the
50 state. We used two unique video data sets to study hibernation and foraging (or feeding) ecology
51 to fill important knowledge gaps. To study hibernation behavior, we used a video data set of
52 continuously monitored, temporarily captive mother bears and their cubs held at Virginia Tech's
53 Black Bear Research Center in 2015-2016. We found that black bear activity was driven by both
54 daily temperature and photoperiod (length of daylight), but onset of hibernation was mostly driven
55 by temperature only. With Virginia projected to experience rising, and more variable, temperatures
56 due to climate change, this may mean that bears will stay longer on the landscape in fall, even past
57 the point where vegetation (food) has gone dormant, potentially leading to increased human-black
58 bear interactions as bears seek human foods. We also examined mother-cub interactions and found
59 mother bears did not spend more time with their biological cubs than their fosters (fosters are
60 orphaned black bear cubs arising due to death of mothers) and biological cubs did not show more
61 dominance behaviors (i.e., biting, chasing, or pinning to ground) toward fosters than biological
62 siblings. These are positive results for VADWR's surrogate sow program across the state.

63   Foraging ecology is difficult to study in black bears because direct observation is generally
64 not possible due to their secretive nature, dense habitat, or potential danger in observing. Therefore,
65 traditionally, many studies collect and examine scat (fecal) samples or stomach contents from
66 harvested bears, but these methods may not find diet items that are quickly digested. We used a
67 unique dataset from video camera collars placed on 15 bears in Bath County Virginia in 2018 and
68 2019. We found some important differences from the literature - our spring diets had higher
69 proportions of deer and soft vegetation (leaves), however the unknown diet items in the literature
70 were high, leading to incomplete or incorrect diet profiles. Diet composition was primarily
71 influenced by season with higher levels of consumption of leafy soft mast in spring, fruit and seed
72 soft mast in summer, and hard mast in fall. Males and females had high dietary overlap and we
73 found that females had more hunting events on deer fawns in spring than males, but overall males
74 and females consumed similar numbers (28 vs. 24, respectively) via hunting and scavenging
75 combined. Males more often consumed human foods than females, while females more often
76 consumed insect species than males. Also, males more commonly consumed invasive species in
77 spring, while females did so in summer. Our results highlight differences in diet content caused by
78 season and subtle differences in diets between sexes. We provide information on drivers of feeding
79 choices bears make and we identify foraging hotspots for deer and invasive species, information
80 useful to VADWR in managing potential human-wildlife interactions, predator-prey relations, and
81 invasive species spread across the landscape.

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Chapter 1: Introduction to American Black Bears (*Ursus americanus*) in Virginia's Central Appalachian Mountains

American Black Bear (Ursus americanus) Background

The American black bear (*Ursus americanus,* hereafter black bear) historically ranged across much of North America until the species declined due to unregulated harvest and habitat loss (Fig. 1). In Virginia, this decline was first noted in the mid-1700s as black bears were less commonly found around the state, with continuing declines into the early 1900s as forest resource depletion from timber harvest, human development/expansion persisted across the state, and chestnut blight in the state (Pelton et al. 1999, Scheick and McCown 2014, VADWR 2023*a*). Only recently, starting in the mid-1970s, have black bears begun to reoccupy much of their historic range, due in large part to the success of wildlife management efforts (including better protection efforts and translocations in addition to maturation of mast-bearing forests) across North America (VADWR 2023*a*).

In the 1950s, black bear populations across Virginia, were scarce and they occurred around 25% of Virginia, primarily to the Appalachian Mountains and the Great Dismal Swamp (Fig. 2a, VADWR 2023*a*). Today, black bears have expanded due to harvest regulations by the Virginia Department of Wildlife Resources (VADWR). Presently, black bears are found as established populations or have been sighted across Virginia (Fig. 2b-f). In the Appalachian Mountains, an expanding black bear population now supports both chase and hunting seasons throughout the fall and into the winter, comprising a hound chase season (in specific regions of the state, mid-November to early December, ~14 days), an archery season (early October to mid-November, ~40 days), a muzzleloader season (mid-November, ~7 days), and a firearms season (in specific regions of the state, starting from early October to early December and going until early January, between ~30-90 days), with some regional variation on the dates (VADWR 2023*b*).

212   As the black bear population has increased in size, there has also been an increase in the level

213   of interactions between humans and bears, which has the potential to alter black bear behavior and

214   landscape use (Hertel et al. 2016). In Virginia, the black bear is the largest predator on the landscape

215   (excluding humans). As the geographic range of black bears has expanded, a greater understanding of

216   black bear behavior is important to effectively manage populations and their potential interactions with

217   humans. Thus, a greater understanding of black bear behavior in Virginia's rapidly urbanizing

218   environment is necessary to effective management of the species, especially to avoid or mitigate

219   negative human-black bear interactions as access to human-provided foods increases (Myers and

220   Young 2018).

221   Adult black bears typically reach 1.5-2.0 meters (5.0-6.0 feet) in length; males in Virginia

222   typically weigh 80-180 kg (175-400 lbs.) with some exceeding 225 kg (500 lbs.), whereas females

223   weigh 65-115 kg (150-250 lbs.) and can be smaller than males (VADWR 2023*a*). black bear weights

224   vary considerably within a year as black bears gain large amounts of body mass in preparation for

225   hibernation, but because they do not feed during hibernation, they emerge from the den substantially

226   lighter after having metabolized their accumulated fat reserves during hibernation. Females usually

227   reach sexual maturity by 3-4 years of age, whereas males mature more slowly, reaching maturity

228   between 4-6 years of age (Powell et al. 1997). The mating season for black bears in the Appalachian

229   Mountains spans from mid-late June to late July. A courting pair may remain together from a few hours

230   to several days, mating multiple times over this period (IBA 2020, VADWR 2023*a*). In our study, we

231   documented mating interactions lasting from 1.25 hours to just over 8 days (Kelly and Holcombe,

232   unpublished data).

233   Similar to other black bear species, female black bears experience delayed embryo implantation

234   post-fertilization. During this process, the fertilized egg becomes a blastocyst that remains suspended

2

235   in development for up to several months until implantation into the uterine lining occurs, usually

236   around the time a female enters hibernation in late November to mid-December (Lopes et al. 2004,

237   Mesa-Cruz 2018). Upon onset of hibernation, a denning female carries the pregnancy until giving birth

238   in January or February (Lopes et al. 2004, Mesa-Cruz et al. 2020, VADWR 2023*a*). Litter size

239   typically ranges from one to four cubs (although 6 is the highest recorded), with one to two cubs being

240   the most common in the mountains of Virginia (VADWR 2023*a*) and 2.35 cubs being the average in

241   Virginia (Klenzendorf et al. 2002). Cubs are weaned at 6-8 months but remain with their mother until

242   their second spring (Murphy 2016, VADWR 2023*a*). Because cubs stay with their mother through a

243   second winter, females mate every other year unless they lose their cubs during or shortly after

244   hibernation.

245   Hibernation behavior in black bears is an understudied aspect of black bear ecology, yet a

246   better understanding of the drivers of hibernation could aid in predicting black bear's annual

247   emergence. Both temperature and photoperiod have been proposed as mechanisms influencing onset

248   of, and arousal from hibernation (Pigeon et al. 2016, Johnson et al. 2018; Blumenthal et al. 2011, Ware

249   et al. 2012). If temperature is the prominent driver stimulating arousal from hibernation, human-

250   wildlife interactions may become more common earlier as climate changes continue to result in milder

251   winters in the Appalachian Mountains (Pigeon et al. 2016). However, if hibernation is driven primarily

252   by photoperiod, then climate change should not strongly impact black bear hibernation timing.

253   Additionally, black bear age, body condition, and pregnancy status also may impact hibernation onset

254   and duration (Pigeon et al. 2016, Mesa-Cruz et al. 2020). Thus, studying black bear behaviors

255   surrounding hibernation can provide useful information to allow effective and proactive planning,

256   especially in relation to changing climate.

257   Black bears are omnivorous and opportunistic feeders. Items in their diets include a variety of

258   species, such as berries, vegetation, human-provisioned foods, carrion, and live prey such as white-

259   tailed deer (*Odocoileus virginianus,* hereafter deer) (Morin et al. 2016). Upon den emergence in spring

260   (April to mid-May in the Appalachian Mountains, depending on elevation), black bears immediately

261   search for food, often in a sparse landscape. Items commonly foraged at this time include both natural

262   (e.g., skunk cabbage (*Symplocarpus spp.*), bearcorn (squawroot (*Conopholis americana*), deer, and

263   anthropogenic food sources (VADWR 2023*a*). In the summer months, a bear's diet shifts as various

264   plant species come into season (i.e., fruit) such as blueberries (*Vaccinium corymbosum*), raspberry

265   (*Rubus idaeus*), and pokeweed (*Phytolacca americana*). Toward the end of summer and throughout

266   fall, black bears shift again, relying heavily on hard mast (i.e., acorns, hickory nuts) on the landscape.

267   However, when hard mast availability is low, black bears may seek supplemental anthropogenic food

268   items (e.g., agricultural crops, bird feeders, garbage) to build up their fat stores before hibernation

269   (Gantchoff and Belant 2017, Pereira et al. 2021). Bears in hyperphagia may seek more high-fat and

270   carbohydrate-rich foods, such as agricultural crops or anthropogenic food sources, to build up fat levels

271   in preparation for hibernation (VADWR 2023*a*).

272   Searching for food (i.e., foraging) requires energy, time, and spatial awareness (Breed and

273   Moore 2016, Lincoln and Quinn 2019, Tezuka et al. 2022). Understanding black bear foraging

274   behavior can provide better insight into whether black bears forage on items in proportion to their

275   availability on the landscape or whether they target higher quality food items despite the potentially

276   higher cost (e.g., fawns) or higher risk (e.g., anthropogenic food). Effective management of these food

277   resources is important, given that black bear populations across many parts of Virginia are increasing

278   rapidly (VADWR 2023*a*) and the potential for interactions with humans over food resources is

279   growing. Fine-scale analysis of foraging behavior will increase clarity and yield valuable information

280   for wildlife managers, especially regarding black bear impacts on deer recruitment and the noted recent

281   increases, over two-fold (VWCH, 2023), in human-black bear interactions (VADWR 2023*a*). In

282   addition, knowing how black bears use the landscape, identifying where/if they access and consume

283   anthropogenic foods (and at what rate), and establishing behaviors black bears exhibit at different

284   times of the year will fill knowledge gaps in black bear behavioral, foraging, and hibernation ecology

285   in the Appalachian Mountains.

286   *Thesis Objectives*

287   The objectives of my thesis address two aspects of black bear ecology, partitioned hibernation and

288   foraging. Objective 1 examines black bear hibernation ecology through analysis of video-recorded

289   observations of four hibernating temporarily captive female black bears at the Virginia Tech's Black

290   Bear Research Center to better understand the drivers of hibernation behavior and its implications to

291   management. For this objective, I provide insight into the timing/duration of active and passive

292   behaviors as they relate to the mother's body condition, weather variables, and presence and

293   interactions with biological and foster cubs. I also analyzed timing and duration of cub behaviors

294   relative to the same variables and explored dominance behaviors of biological cubs towards foster

295   cubs.

296   The second objective delves into black bear foraging ecology, specifically through further

297   analysis data obtained from video-enabled camera collars to document and analyze wild black bear

298   foraging activity and resource selection patterns in a predominantly forested landscape to evaluate

299   black bear foraging decisions. Using environmental and habitat variables as predictor variables, I

300   focused on consumption of deer and invasive plant species as those forging items were of particular

301   interest to VADWR. I also constructed diet composition for black bears (separated by males and

females) and compared my video diet analysis to diet composition as recorded in the literature to assess the effectiveness of using this novel method to determine diet of American black bears.

Using advanced technologies, such as camera collars or remote surveillance videos, can allow for previously unseen insight into wildlife ecology. Observing behaviors of elusive and cryptic species, such as those that are nocturnal or live in dense forests, is challenging and often not achievable with traditional methods (Löttker et al. 2009, Jeanniard-du-Dot et al. 2017). These challenges can hinder our ability to evaluate how landscape and climate change affect animal behavior. Novel biologging advancement of video camera collars could help address current limitations of studying wild animal hibernation and foraging behaviors.

Project Study Areas – Background Information
Black Bear Research Center – Blacksburg, VA (Objective 1)

The Black Bear Research Center (BBRC), formerly the Ursid Research Center, was established in 1988 through collaboration between Virginia Tech's Dr. Michael Vaughan and VADWR to study black bear behavior, reproductive and hibernation physiology, and to serve as a place to foster orphaned cubs to females that gave birth at the BBRC. From 1988 to the facility's closing in 2009, when former black bear biologist Dr. Vaughan retired, the BBRC held 111 black bears. The facility was reopened from 2012 until 2016 under Dr. Marcella Kelly, housing 19 black bears during these years. The BBRC housed both male and female (usually pregnant) adult black bears and provided a place to foster orphaned cubs to surrogate mothers. The BBRC offered a unique opportunity to study cub growth and development (Hellgren and Vaughan 1989, Bridges et al. 2011, Mesa-Cruz et al. 2020), maternal effects on cubs, and pseudo-pregnancy, among other research projects (Mesa-Cruz 2018).

Black bears were captured from areas across Virginia in the summer and fall each year and brought to the BBRC by VADWR personnel. Bears kept at the facility underwent hibernation and

arousal, gave birth to cubs, and subsequently were released back into the wild in April or May of the

following year. The BBRC also conducted extensive public outreach that especially focused on

positive aspects of black bear management and highlighted the collaborative research between

VADWR and Virginia Tech. Throughout the 2015-2016 season, five female black bears (four with

cubs; Table 1) at the BBRC were monitored continuously using video cameras mounted above the

holding pens. This data was yet to be analyzed until now.

Appalachian Mountains in Western Virginia – Bath Country, VA (Objectives 2)

The Virginia Appalachian Coyote Study (VACS) was initiated in 2011 as a collaboration between

VADWR (formerly the Department of Game and Inland Fisheries [VDGIF]). This study's objectives

were to examine and evaluate the potential impacts of coyotes (*Canis latrans*) on deer in the

Appalachian Mountains (Kelly et al. 2015). The original VACS project arose due to public and agency

concerns about declining numbers of deer, as noted by decreased hunter harvest data (VDGIF 2015).

Using distance sampling estimation techniques, VACS researchers found relatively low deer

densities in Bath and particularly Rockingham Counties (Montague et al. 2017). An analysis of scats

collected in these counties (Fig. 3) revealed a high relative percent frequency of occurrence (RPO) of

deer (42%) in coyote scats (Fig. 4; Morin et al. 2016). Interestingly, the RPO of deer in bobcat (*Lynx*

rufus, 17%) and black bear (20%) scats also was substantial (Morin et al. 2016). These findings of deer

consumption by all predators gave new insight into Appalachian predator-prey relations (Clevinger

2022, Alonso 2024, Clevinger et al. 2024) and led to a follow-up, expanded project: the Virginia

Appalachian Carnivore Study (VACSII) initiated in 2016. A project goal of VACSII is to better

understand space use, resource selection, and diet of Appalachian carnivores and assess impacts, as a

guild of predators, on deer. VADWR supported continued coyote monitoring and added a focus on

347   bobcats (McNitt et al. 2019, 2020*a*, *b*), whereas the Virginia Deer Hunters Association, Safari Club

348   International, and the Acorn Alcinda Foundation supported the work on black bears.

349   As part of VACSII, a sub-set of black bears was fitted with collars that each contained a video

350   camera, GPS (global positioning system) unit, and accelerometer to track black bear activity as the

351   animals moved across the landscape. Cameras (Vectronic VERTEX PLUS Collars) were set at high

352   resolution (720p resolution) and wide-angle view to document foraging activity and facilitate the

353   search for evidence of fawn predation.

354   In 2018, camera collars were placed on ten black bears (five females, five males; Fig. 5, Table

355   2). All ten cameras were recovered; however, one camera was damaged when the subject black bear

356   was struck by a vehicle, which destroyed the camera and prevented video retrieval. Initially, collars

357   were programmed to take 20-second videos every 20 minutes for 10-14 hours a day for one to three

358   months, coinciding with the peak in fawn births, resulting in a maximum of up to 17.5 hours of video

359   data per black bear (Table 3). After the spring/summer fawning season, the video frequency setting was

360   modified to record one video every 60 minutes, enabling cameras to last longer in the field and

361   extending data collection into early fall. However, due to a programming error, cameras recorded data

362   from time 2:00:00 EST (6:00:00 UTC) to 16:00:00 EST (20:00:00 UTC). Due to other programming

363   errors by the field team in VA, videos in the fall of 2018 were not successfully recorded.

364   In 2019, eight camera collars were placed on three females and five males. Of these eight

365   collared black bears, all were recovered, but one male and one female did not yield data, resulting in

366   six total black bears for the 2019 survey year (Table 3). These collars were initially programmed to

367   take 15-second videos every 20 minutes for 16 hours per day for 1-2 months, followed by 10-second

368   videos every 20 minutes for 16 hours per day for 1-4 weeks. The next interval consists of 8-second

369   videos every 60 minutes for 14 hours a day for 1-2 months, then 8-second videos every 30 minutes for

370   12 hours a day for 3-5 weeks, and finally, 8-second videos every 30 minutes for 12 hours a day for the

371   final 3-5 weeks (Table 2). These variable schedules allowed data collection to extend past the fawning

372   season to determine black bear behaviors in the fall, especially during hunting season.

373   Additionally, at the time of each video recording, a GPS location was recorded to allow cross-

374   referencing between behavior and location. This will allow for analyses of habitat type combined with

375   space and landscape use. Although the GPS fix rate was high, it was not 100%; thus, some videos were

376   not accompanied by a GPS location. However, this rate of missed locations was <3% (Robert Alonso,

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378

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Tables & Figures
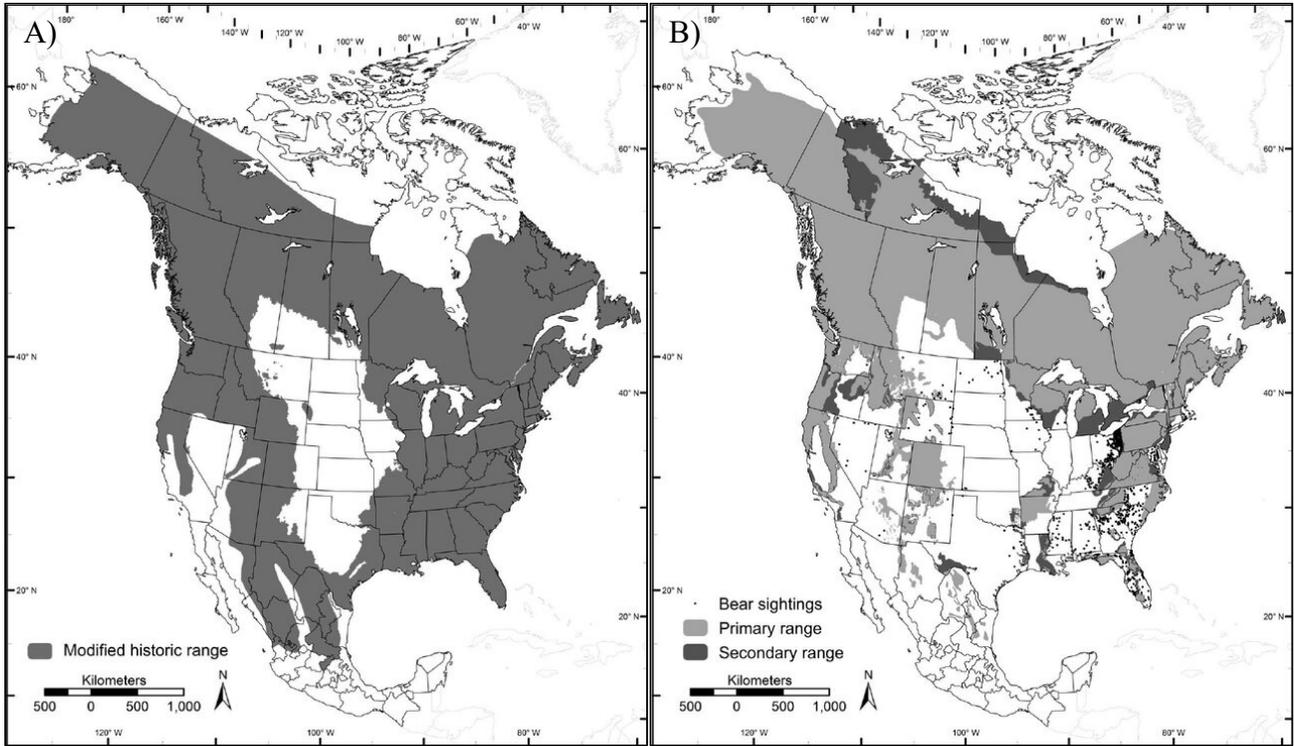
Figure 1. A) The historical range of the American black bears from Pelton et al. (1999), modified to exclude prairies ecoregions, and B) the estimated primary and secondary range for the black bears in North America, 2006-2012 (Pelton et al. 1999, Scheick and McCown 2014).

Legend:
- No black bears
- Ocassional black bear sightings
- Black bear range

A) Distribution of black bears in Virginia in 1950

B) Distribution of black bears in Virginia in 1974

C) Distribution of black bears in Virginia in 1983

D) Distribution of black bears in Virginia in 2001

E) Distribution of black bears in Virginia in 2010

F) Distribution of black bears in Virginia in 2021
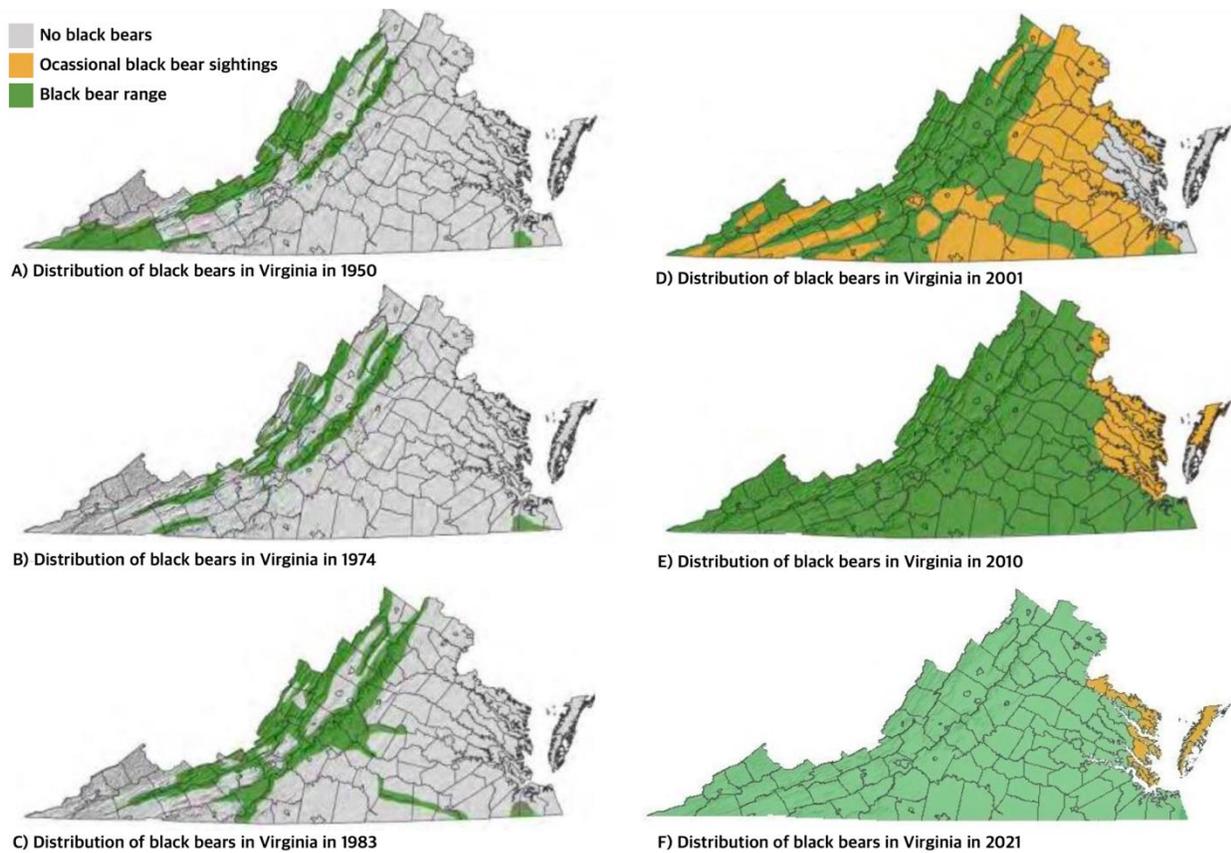
498   A
499   Figure 2. Distribution of American black bears within Virginia starting in A) 1950, occupying around
500   25% of Virginia, particularly in the mountains. Black bears' range diminished throughout the
501   Appalachian Mountains of Virginia around B) 1974 but began spreading again in the mountains and
502   into the Piedmont region in C) 1983. In D) the early 2000s, black bears continued to expand across
503   the state, with occasional sightings across most of the state. Only a decade later, E) black bears
504   expanded their distribution to most areas in the state, except for eastern coastal areas, which only
505   have occasional sightings of black bears. F) Presently, black bears are regularly found in almost all
506   areas of the state, except for the far eastern counties and the Virginia eastern shore. Figure adapted
507   from Virginia Department of Wildlife Resources' black bear Management Plan (VADWR, 2023a).
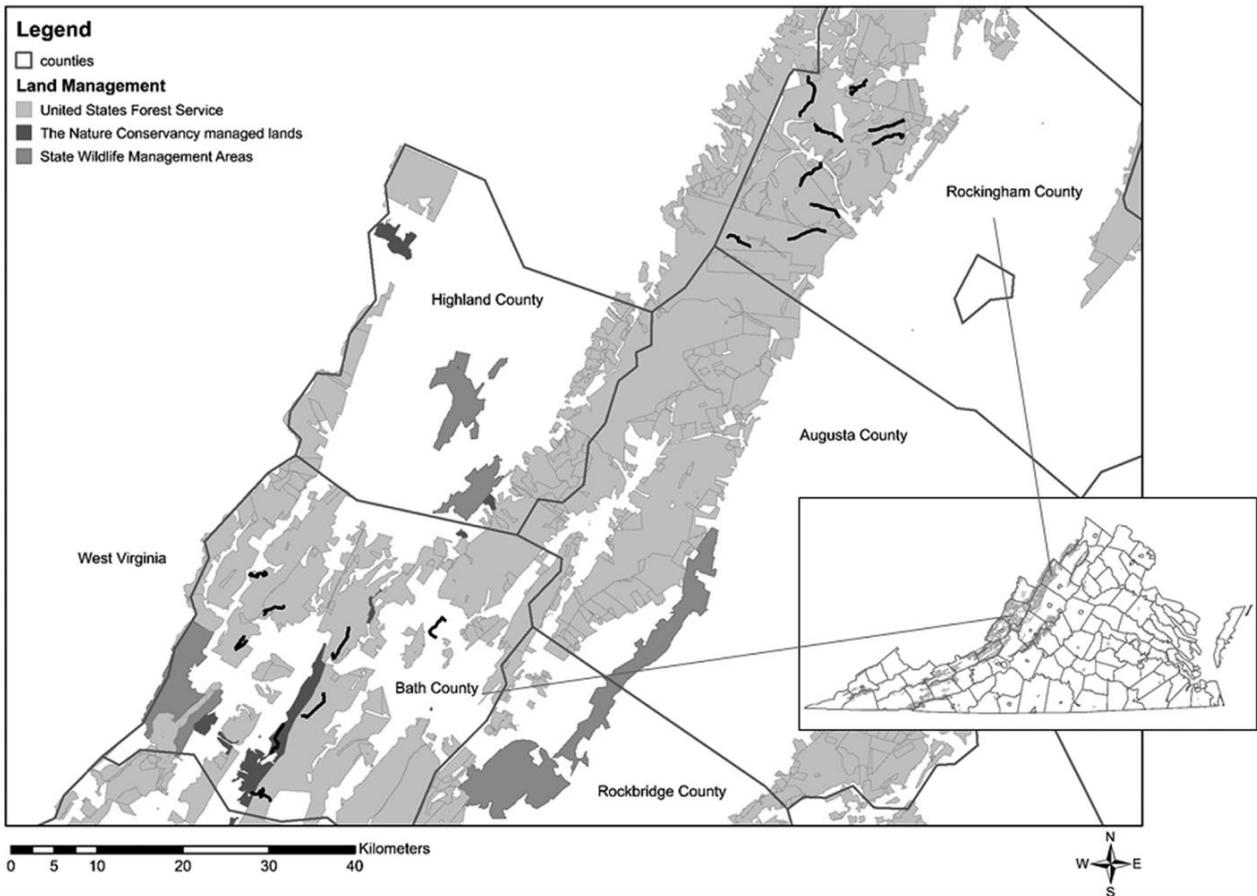
508
509 Figure 3. The original Virginia Appalachian Coyote Study (VACS) occurred in Bath and
510 Rockingham Counties. This current study focuses on collared black bears from Bath
511 County only from data collected in 2018 and 2019. Figure from Morin et al. (2016).
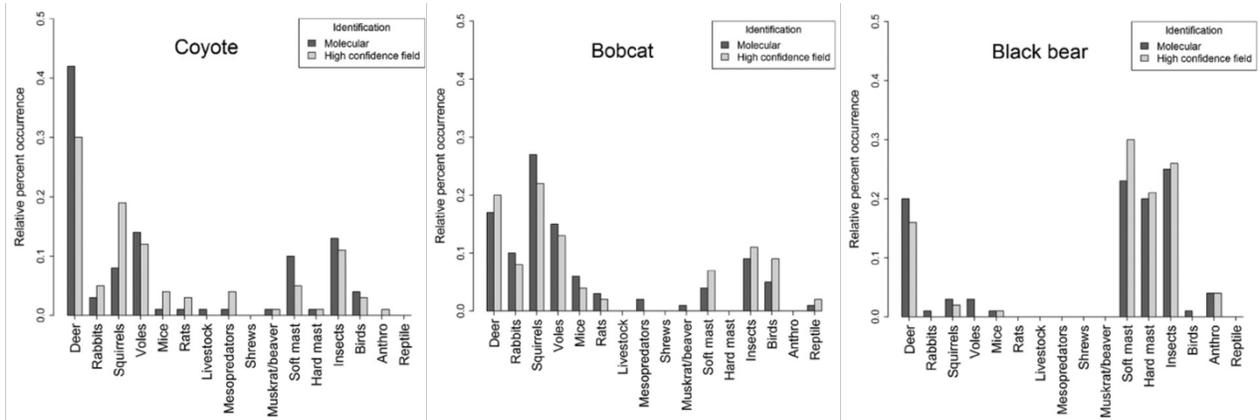
512
513 Figure 4. Relative frequency of occurrence of diet items based on molecular identification and high-
514 confidence field identification for coyotes, bobcats, and black bears scat samples collected in western
515 Virginia, USA, from June 2011 through May 2012. Figure adapted from Morin et al. (2016).
516

Figure 5. A) Dr. Robert Alonso and former MS student David McNitt installing camera collars on black bears in Bath County, VA, in 2018 and 2019, and B) the camera lens and storage box can be seen in the image.

Table 1. Information on female American black bears housed at the Black Bear Research Center (BBRC) in 2015-2016. This includes BBRC assigned black bear number (black bear ID), their entrance date to the BBRC, date of birth of the cub(s), number of biological cub(s), number of fosters cub(s), and status (accepted or rejected by mother), date of emergence from the culvert (i.e., den) for the mother and cub(s), and difference in time between the mother and cub(s) emergence from the culvert.

black bear ID	Entrance Date to BBRC	Cub(s) Date of Birth	Biological Cub(s)	Foster Cub(s)	Mother Emergence Date	Cub(s) Emergence Date	Difference Between Mother & Cub(s) Emergence	Release Date
black bear 126	8/7/15	2/9/16	1 Male, 1 Female	1 Male [Accepted]	4/11/16	4/12/16	9 Hours 2 Minutes	5/4/16
black bear 127	9/24/15	1/20/16	2 Males, 1 Female	1 Male [Accepted]	3/6/16	3/6/16	2 Hours 45 Minutes	5/4/16
black bear 128	9/24/15	1/25/16	2 Females	1 Male [Rejected]	3/19/16	3/19/16	0 Hours 0 Minutes	5/4/16
black bear 129	9/24/15	2/19/16	1 Female	1 Female [Accepted] 1 Male [Rejected]	3/28/16	4/11/16	13 days 15 Hours 50 Minutes	5/24/16
black bear 130	9/24/15	-	-	-	-	-	-	1/5/16

18

529 Table 2. Camera collars settings for black bears collared in Bath County, VA in 2018 and 2019,
530 including programming start date, programming end date, video length, video start time for the day,
531 the video end time for the day, frequency of videos, and GPS point schedule.

Year	Start Date	End Date	Video Length	Start Time (Local)	End time (Local)	Frequency	GPS Schedule
2018	5/15/18	7/31/18	20 sec	2:00*	16:00*	Every 20 min	20 min
2019	5/15/19	7/14/19	15s	5:20	21:20	Every 20 min	20 min
	7/15/19	7/21/19	10s	5:20	21:20	Every 20 min	20 min
	8/1/19	9/30/19	8s	6:00	20:00	Every hour	1 hour
	10/1/19	11/2/19	8s	7:00	19:00	Every 30 min	1 hour
	11/3/19	12/15/19	8s	6:00	18:00	Every 30 min	1 hour

*programming error

532

Table 3. Camera collars for black bears collared in Bath County, VA, in 2018 and 2019 including
black bear camera code (Bear/Cam Code), black bear sex, presence/absence of cubs (if any), black
bear weight in pounds (lbs.) and kilograms (kg) at capture, video camera start date (First Cam
Day), video camera end date (Last Cam Day), total days of video camera collar recordings (Total
Cam Days).

Survey Year	black bear Cam Code	Sex	Cubs	Weight (lbs.)	Weight (kg)	First Cam Day (MM/DD/YY)	Last Cam Day (MM/DD/YY)	Total Cam Days
2018	UAF01	F	None	135	61.24	7/10/18	8/1/18	23
	UAF28	F	None	120	54.43	5/30/18	7/14/18	46
	UAF29	F	None	120	54.43	5/30/18	7/29/18	61
	UAF32	F	Yearling	150	68.04	6/11/18	7/25/18	45
	UAF38	F	None	130	58.97	7/3/18	7/31/18	29
	UAM15	M	-	155	70.31	6/8/18	7/30/18	53
	UAM36	M	-	145	65.77	7/2/18	7/31/18	30
	UAM37	M	-	275	124.74	7/2/18	7/31/18	30
	UAM41	M	-	250	113.40	7/11/18	7/31/18	21
	UAM30	M	-	Hit by car - no video data recovered				
2019	UAF42	F	1 cub	100	45.36	6/5/19	12/15/19	194
	UAF43	F	2 cubs	Hit by car - no video data recovered				
	UAF52	F	None	105	47.63	7/30/19	12/15/19	139
	UAM44	M	-	165	74.84	6/11/19	10/22/19	134
	UAM45	M	-	150	68.04	6/15/19	9/26/19	104
	UAM47	M	-	160	72.58	7/22/19	11/20/19	122
	UAM49	M	-	125	56.70	7/25/19	12/15/19	144
	UAM53	M	-	Malfunction - no video data recovered				

Chapter 2: Factors influencing the duration of behaviors in American black bear (*Ursus americanus*) adult females and their cubs surrounding hibernation and den emergence

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Abstract

Hibernation behavior is understudied in American black bears (*Ursus americanus*), with most knowledge derived from post-hibernation emergence studies. Temperature and photoperiod have been identified as potential drivers of the timing of hibernation, but are also linked to food availability. We explore drivers of black bear hibernation activity using a unique video-recorded data set of four temporarily captive female bears with cubs in a food-controlled environment. We subset 22,000+ hours of video into two interval cycles to 1) analyze adult behavior from September 2015 to May 2016 and 2) analyze mother-cub interactions post-birth, including whether mothers showed bias towards biological versus foster cubs. We consolidated 58 behaviors into three broad classifications (active, passive alert, passive) and found that the hibernation stage, time of day, and interaction between photoperiod and temperature were associated with changes in adults' activity levels. During hyperphagia, post-birth, and emergence stages, increased activity levels were driven by both higher ambient temperature and photoperiod, but the onset of hibernation was primarily driven by only temperature. We further found that mother bears did not spend significantly more time with either cub group, thus not showing bias toward biological versus foster cubs. For the maternal-cub interval, we found cub behaviors were influenced by several different parameters, such as mother and cubs' relative growth rate, time of day, and temperature. Additionally, cubs did not show more dominance behaviors (i.e., biting, chasing, pinning to ground) toward foster than biological siblings. Our analysis of foster cubs' litter integration provides promising results for orphan cub fostering programs. Furthermore, our results indicate that rising temperatures regionally could be responsible for increased active behaviors, which could lead to increased human-black bear interactions on the landscape, especially during hibernation onset. Overall, predicting black bear responses to rising temperatures regionally is likely to depend on multiple factors related to a bear's life stage and condition. Temperature could partially be responsible for increased active behaviors, especially during the onset of hibernation, which is important when managing black bear populations in a changing climate to potentially mitigate increased human-wildlife interactions on the landscape.

Introduction

570

571 Hibernation is common among some mammalian species particularly where food resources or

572 conditions are seasonally limiting (Evans et al. 2016). Hibernating bear species (*Ursidae*) have been

573 studied for their unique physical and physiological responses as they do not ingest nutrients, do not

574 produce urine (i.e., anuria), and decrease body movement (Stenvinkel et al. 2013). American black

575 bears (*Ursus americanus*), hereafter black bears, exert these physical and physiological responses

576 across a majority of their range in North America (Mesa-Cruz 2018). Most knowledge of black bear

577 hibernation behavioral ecology stems from pre- or post-hibernation studies. Hibernation onset appears

578 to be driven by ambient temperature (Hughes 2000, Peñuelas and Filella 2001, Walther et al. 2002,

579 Pigeon et al. 2016, Johnson et al. 2018). It also has been suggested, however, that photoperiod is a key

580 driver of physiological responses in the timing and duration of hibernation in bears (Blumenthal et al.

581 2011, Ware et al. 2012).

582 In many regions, rapid changes in annual ambient temperatures driven by climate change, but

583 without a concomitant change in photoperiod, have resulted in potential disruptions in physiological

584 mechanisms driving hibernation onset and arousal (Walther et al. 2002, Bradshaw and Holzapfel 2010,

585 Evans et al. 2016). Such changes could impact both animals and plants because some species'

586 responses to seasonal changes are in total or partially driven by photoperiod while others respond to

587 environmental temperature cues (Peñuelas and Filella 2001, Walther et al. 2002, Lesser and Fridley

588 2016). This could be problematic if bears den later and emerge earlier and search for food across a

589 landscape where some vegetation is dormant or has had frost damage (Peñuelas and Filella 2001,

590 Bartareau et al. 2012, Hubbard et al. 2022), which may cause bears to seek out anthropogenic food

591 sources (Bartareau et al. 2012, Kirby et al. 2016, Hubbard et al. 2022). Temperature has been

592 documented to be associated with the onset of, and emergence from, dormancy in many annual plants

22

593   (Singh et al. 2017). Studies in temperate and boreal ecosystems around the world have found that

594   photoperiod, temperature, or a combination of the two environmental cues typically drive plant

595   species-specific responses (Basler and Korner 2014, Singh et al. 2017). Changes in temperature,

596   particularly unseasonably cold after a warming period, affect bud emergence and kill off the flowers or

597   young plants (Ghelardini et al. 2010, Augspurger 2013), while other plants respond to the photoperiod

598   as a stronger driver for dormancy or dormancy emergence ((Basler and Korner 2014, Singh et al. 2017,

599   Lang et al. 2024). For example, changes in the environment, compared to historical patterns, include

600   the potential increase in more unpredictable frost dates (Rast and Brisbin 1987, Augspurger 2011). This

601   can cause severe frost damage to the buds of many plant species that bears rely on (Augspurger 2013,

602   Rowland et al. 2013, Muffler et al. 2016). This has been documented in blueberries (*Vaccinium spp.*)

603   and oak species (*Quercus spp.)*, common diet items for bears, which are susceptible to damage from

604   late frosts (Rowland et al. 2013).

605   Thus, environmental and climate changes may have consequential impacts on the activity

606   levels of bears. Populations of bears in sub-tropical climates, such as Florida or Louisiana, do not enter

607   hibernation, except for pregnant females, when food supplies are available throughout the winter

608   season (Wooding and Hardisky 1992, Hellgren et al. 1997). In fact, pregnant females in these warmer

609   areas display similar hibernation patterns to bears in colder climates, entering dens at a similar time as

610   in other areas, and remaining in their dens for 2-4 months (Hellgren and Vaughan 1989, Wooding and

611   Hardisky 1992).

612   Other physiological factors such as pregnancy status, body condition, sex, and bear age are also

613   thought to impact hibernation onset and duration (Tøien et al. 2011, Shimozuru et al. 2013). The

614   mating season for bears in in central the Appalachian Mountains spans from late May to early August.

615   Because female bears display delayed implantation of embryos, embryonic development occurs just

616   prior to hibernation onset, in late-October to mid-December (Lopes et al. 2004, Mesa-Cruz et al. 2020).

617   Thereafter, hibernating females carry the pregnancy alone until giving birth in January or February

618   (Lopes et al. 2004, VDGIF 2011, Mesa-Cruz et al. 2020).

619   During hibernation, bears decrease their metabolism by 50-60%, their heart rate reduces by 40-

620   80%, and they do not eat, drink, defecate, or urinate unless aroused by warmer weather or disturbance

621   (Tøien et al. 2011). Pregnant females typically enter dens around the same time or before males and

622   non-pregnant females, perhaps in preparation to resume embryonic development (Friebe et al. 2014).

623   Black bears in Virginia can enter hibernation as early as October in the central Appalachian Mountains

624   of Virginia, but have been noted entering dens as late as early December, depending on food resources

625   available on the landscape (VADWR 2023). Litter size ranges from 1-5 cubs, with 2 cubs being the

626   average (Bridges et al. 2011, Baruch-Mordo et al. 2014, Gray et al. 2017). Cubs are weaned at 6-8

627   months but remain with their mother until their second spring (VADWR 2023). Because cubs stay with

628   their mother through a second denning season, females mate every other year unless they lose their

629   cubs during or shortly after hibernation (VADWR 2023).

630   Females with yearling cubs entering hibernation potentially have expended more energy over

631   the course of the previous year than males and non-pregnant females as they use their energy to feed

632   their offspring by nursing during the spring and summer and share food resources in the fall in

633   preparation for hibernation (Barboza et al. 1997). Better body condition of mothers going into and

634   throughout hibernation has positively impacts yearling or newborn cub survival and, for pregnant

635   females, can potentially increases litter size at birth (Belant et al. 2006, Bartareau et al. 2012, Mesa-

636   Cruz 2018). To reach a larger body mass, bears experience hyperphagia, where they consume large

637   quantities of high-caloric content foods prior to hibernation. In the wild, hyperphagia can start in mid

638   to late summer and in early fall (Hellgren and Vaughan 1989, Hubbard et al. 2022). Female bears need

639   a proportionally larger quantity of food than males or non-pregnant females during hyperphagia to

640   support pregnancy and birth, or yearling cubs, through hibernation, resulting in the need for extra

641   nutrients and adipose body reserves (Belant et al. 2006, Bartareau et al. 2012, Hubbard et al. 2022).

642   With some historical areas of black bear populations on the rebound, there has been an increase

643   in orphan cub fostering programs to promote natural cub adoption has been increasing in the last few

644   decades, especially as a mechanism to bolster previously decreasing bear populations (Clarke et al.

645   1980*a*, Hashem 2019). However, in areas with large and increasing populations, such as Virginia, the

646   presence of a foster cub could potentially pose constraints imposed on mothers with biological cubs

647   (Clarke et al. 1980*a*, Hashem 2019). Yet, little research has been conducted to investigate impacts on

648   mother bears or the effectiveness of cub fostering programs beyond the acceptance or rejection of a

649   cub, as it is difficult to quantify successful adoption and cub integration into the biological litter

650   (Hashem 2019). Understanding maternal investment in foster cubs is important as it could impact the

651   body condition of the mother and reduce resources for biological cubs (Trivers and Willard 1973,

652   Clutton-Brock et al. 1981, Derocher and Stirling 1998, Koskela et al. 2009). Further, although denning

653   locations and litter sizes can be monitored by bear managers after emergence, it is difficult to monitor

654   behavioral interactions and resource partitioning between mothers and cubs and among cubs (Clarke et

655   al. 1980*b*, Blair et al. 2020).

656   Studying precursors to the onset of, and emergence from, hibernation has proven challenging in

657   the wild. Rogers et al. (2020) utilized den video cameras to study wild bear hibernation to uncover new

658   aspects of mother, cub, and yearling behavior, some of which contradict prevailing perspectives in the

659   literature (See Rogers et al. 2020, Hertel et al. 2021). During live observations in captivity, the

660   presence of humans appeared to alter natural bear behavior, and researchers have missed documenting

661   certain natural behaviors (i.e., foraging, maternal care, sleeping, Johnson and Pelton 1980, Linnell et

662   al. 2000, Tuyttens et al. 2014). Additionally, without rigorous data entry, quality-checking protocols,

663   and detailed ethograms set in place, bias in behavioral studies can lead to inconsistent and

664   uninformative results (Tuyttens et al. 2014).

665   Bear body condition (mass) going into hibernation, changes in body mass, number of embryos

666   developing, and foster cub care could all potentially impact hibernation onset, duration, and den

667   emergence. Thus, there is a need for a better understanding of the drivers of hibernation timing and

668   duration to aid wildlife management agencies in preparation for annual bear emergence and allow for

669   effective and proactive planning, especially in relation to accelerated climate change. These increased

670   temperatures in historically colder months in places such as the Appalachian Mountains of Virginia

671   could lead to changes in hibernation patterns exhibited by bears, especially if the only food that

672   persists on the landscape during critical times periods is anthropogenic, leading to potentially increased

673   human-wildlife interactions (Johnson et al. 2018). However, if hibernation is driven primarily by

674   photoperiod, then climate change may not strongly impact bear hibernation schedules, even if

675   temperature increases.

676   In this study, we implemented a multi-dimensional behavior research approach to explore how

677   physiological and environmental factors relate to changes in bear behavior surrounding the onset of,

678   and arousal from, hibernation. We used a unique data set of 24/7 video-recorded bear observations in a

679   food-controlled and semi-environmental-controlled setting at Virginia Tech's Black Bear Research

680   Center (BBRC). Our objectives were to 1) determine the relationships between adult female bear

681   behaviors and environmental and physiological factors, including hibernation stage; 2) determine the

682   influence of environmental and physiological factors on maternal-offspring interactions; and 3) assess

683   the behavioral effects of orphan cub fostering on mother bears' interactions with offspring.

684   *Methods*

685   *Data Collection & Study Facility*

686   From 2015 to 2016, the Black Bear Research Center (BBRC), located in Blacksburg, Virginia, housed

687   four pregnant female bears (Table 1) from September to May. Bears kept at the BBRC underwent

688   hibernation from onset to arousal with food supplied (dry dog food) to mimic food availability on the

689   landscape as described below and by Hellgren et al. (1990) and Mesa-Cruz et al. (2020). While at the

690   BBRC for the 2015-2016 season, bears were monitored 24/7 via video surveillance from cameras

691   (Night Owl SP, LLC, Night Owl Pro Series 8CH DVR System) placed above the pens to document and

692   categorize behaviors surrounding hibernation. The BBRC facility is covered with a tin roof but

693   otherwise open to ambient weather conditions and temperatures. All bears were released by May 24,

694   2016. Throughout their time at the BBRC, health checks were conducted every 10-14 days, when mass

695   and body measurements were taken (Mesa-Cruz et al. 2020). All procedures were previously approved

696   by the Institutional Animal Care and Use Committee at Virginia Tech under protocols 12-112 and 15-

697   162.

698   Foster cubs were able to distinguish the foster cub by a few different aspects, largely due to the

699   size difference between the biological and foster cubs, with the foster cubs being notably smaller than

700   the biological cubs as well as differences in natural markings (i.e., white fur patches on ears) on the

701   cubs. External labeling (such as collars, paint markings, etc.) were not added to the foster cubs to

702   reduce the potential for bias by the mother bear on the introduced foster cub.

703   *Video Behavioral Data*

704   From the 24/7 monitoring of four bears, we watched and recorded all behaviors in videos on two

705   interval cycles: adult female behavior interval [hereafter, 'adult interval'] and maternal-offspring

706   behavior interval [hereafter, 'maternal-offspring interval']. The adult interval was conducted on female

707 adult bears from their entrance into the BBRC until their release at the conclusion of the study on May

708 4, 2016. We conducted 1-minute behavioral observations on all four bears followed by a 15-minute

709 break such that we recorded 1-minute observations every 16 minutes, resulting in 90 minutes of

710 behavioral observations per day. This interval was chosen after preliminary analysis comparing 1-

711 minute data recording intervals over a 72-hour period that occurred at 2 hours, 1 hour, 90 minutes, 30

712 minutes, and 15 minutes. We found no differences in behavior types at 15- and 30-minute intervals, but

713 at longer intervals, passive and especially active behaviors were overrepresented (ANOVA or t-test

714 results). Therefore, we chose the 15-minute intervals to be more conservative in accurately

715 representing black bear behaviors, despite the more intensive data entry required. For each sub-

716 sampled observation period, we recorded the date, behavior observed and its start time, end time, and

717 duration, as well as location within the pen (open area or den).

718   The maternal interval of behavioral recording was conducted on the mother black bear and her

719 cubs from cub birth at the BBRC to the time of their release. We conducted 1-minute behavioral

720 observations on all adults and cubs on a shorter interval of every 11 minutes resulting in 130 to 131

721 minutes of observations per black bear per day. This interval was set at 11 minutes to prevent missing

722 cub behaviors, which often occurred in relatively short durations (Holcombe, Mesa-Cruzm & Kelly,

723 unpublished data) that may be missed during 15-minute intervals. Within these observations, we

724 recorded the same information as in the adult interval. Additionally, we recorded black bear group

725 identification (mother, biological cub(s), or foster cub) and interaction behaviors that occurred between

726 individuals. The interaction of most interest was mutual play versus dominating play to assess how the

727 introduction of foster cubs may impact the play interactions in the litter and whether biological cubs

728 displayed aggressive or dominating behaviors directed at the foster cubs. We defined dominating

729   behaviors as biting, pinning to the ground, and scratching the other cub (Alt and Beecham 1984,

730   Rogers 1985). Otherwise, observed play behaviors were categorized as mutual.

731   We categorized the 58 observed behaviors from both intervals into three broad behavior

732   classifications: active, passive alert, and passive (Figure 1; Table 2). We defined 36 active behaviors

733   where the individual exhibited movements (i.e., walking, climbing, eating, drinking, etc.). We defined

734   15 passive alert behaviors where the individual exhibited no major movement but still appeared alert

735   (i.e., laying but vigilant, sitting/standing and vigilant). We defined four passive behaviors where the

736   individual was not moving and was in a sedentary, non-alert state (i.e., lying down, sleeping, cub under

737   mother sleeping). We excluded from the analysis human-oriented events, which included: camera

738   malfunctions, health checks, husbandry (cage cleaning and feeding), and when the bear was out of the

739   field of view. We also excluded behaviors 24 hours post health checks to allow adult bear behavioral

740   recovery.

741   To verify the quality and accuracy of behavioral classifications, we conducted continuous

742   quality checks on all entered data with a team of observers familiar with the data and behavioral

743   classifications. We also quality-checked locational data to verify whether bears were truly classified as

744   'out of field' within the pen area. We also verified cub mutual play versus dominance behaviors

745   between cubs and recorded which cub the behavior was directed towards. To verify observer accuracy

746   in entering video data, the data they entered was regularly reviewed and spot checked for accurate

747   entering of observed behaviors. If an observer made several errors in data entry, the recording was

748   deleted and data was re-entered. If continued errors were made on the spot-checked data, that observers

749   total recordings were deleted and data was assigned to another person for re-entry.

Physiological Variables

To determine if bears exhibited what we would consider natural behaviors in captivity, we divided the video data into five stages that bears were likely to exhibit in the wild surrounding the onset of, and arousal from, hibernation. These five physiological stages included hyperphagic, hypophagic, pre-partum, postpartum, and emergence (Nelson et al, 1983), which varied for each black bear depending on birth and emergence dates (Supplementary Table S1).

During hyperphagia, we increased bears' food available for consumption from ~170 kJ/kg/day (at the end of September) to 335-376 kJ/kg/day with proportional adjustments by the body mass of each individual bear. We induced hypophagia, defined as the period of food reduction approaching hibernation, by reducing the food available by 50% per week until the first week of January if the black bear had not already stopped food consumption voluntarily. During hypophagia, food reduction by researchers and by black bears themselves (often voluntarily even if food was available), resulted in reduced food consumption, but occurred during a short window of photoperiod for this stage. During pre-partum and postpartum stages, food was not presented to bears to mimic food availability on the landscape during hibernation. Bears were monitored for parturition using ultrasounds and direct den inspections to note changes in physiological stage from pre- to postpartum (Mesa-Cruz et al. 2020). Towards the end of postpartum and as emergence began, food (~170 kJ/kg/day) was slowly reintroduced to bears arousing from hibernation at the end of March or beginning of April or earlier if bears showed signs of hibernation arousal such as defecation, increased physical activity, and water consumption. During the entirety of this study water was available for bears to consume at any point. While at the BBRC, bears went through typical hibernation stages for the region with similar onset of hibernation timing, giving birth to cubs, and subsequently were released back into the wild in April or May of the following year as described by Hellgren et al. (1990) and Mesa-Cruz et al. (2020).

773 *Environmental Variables*

774 To understand daily mean photoperiod (hours) for the BBRC, we used the R package 'suncalc' to

775 extract the sunlight phases (i.e., times for sunrise and sunset) to use in our analysis (Thieurmel and

776 Elmarhraoui 2022). To understand daily mean temperature and daily mean precipitation at the BBRC,

777 we used the R package 'prism' maintained by The PRISM Climate Group through Oregon State

778 University (Hart and Bell 2015) with 1km resolution raster files from weather stations. This allowed us

779 to extract daily mean temperature (Celsius) and precipitation (mm) values for the BBRC. We plotted

780 temperature and photoperiod by date to visualize changes over time, and we fit a smoothed conditional

781 line of temperature and photoperiod to visualize the relationship.

782 We calculated mother and cub relative growth rates (RGR) using data collected during health

783 checks every 10-14 days (Oftedal et al. 1993, Mesa-Cruz et al. 2020). We used a flat digital scale

784 (Salter Brecknell VD 1000, MN, USA) for the mother's body mass (BM) during health checks while

785 the bear was anesthesia under IACUC handling protocols. To collect cub body mass, each cub was

786 placed on a pediatric digital scale manufactured by Brecknell USA, MS20 ± 10 g sensitivity (Mesa

787 Cruz 2018, Mesa-Cruz et al. 2020). To calculate RGR, we took the weight of bears at each health

788 check minus the weight at the previous health check divided by the number of days between health

789 checks Thus, we assumed RGR was constant per day between these health checks to establish daily

790 RGR for all individuals. Cubs' RGR was calculated the same way and averaged per litter for biological

791 cubs, but not averaged for foster cubs because we did not foster more than one orphan per litter. All

792 covariates used in analyses, their definitions, and sources can be found in Table 3.

793 *Statistical Analysis & Modeling*

794 *Generalized Linear Mixed Models (GLMM) Analysis*

795 We used GLMMs to determine the influence of covariates on the duration of time (in minutes) per day

796 that each black bear group (mother, biological cub, or foster cub) spent in a particular type of behavior

797 (active, passive alert, and passive). We chose to use GLMMs to build additive and interactive models

798 from our *a priori* generalized linear models (GLMs) to account for non-normal data (Breslow and

799 Clayton 1993) and incorporate differences from repeated measures of the same individual by using the

800 individual as a random effect (Zuur et al. 2011). Given the right skew (positive skew) in the data

801 distribution due to the nature of behavior observation duration data, we used a negative binomial

802 distribution to account for the spread (Booth et al. 2003).

803   We added predictor variables with stepwise model selection and used Akaike Information

804 Criterion (AIC) to rank models (Akaike 1973) and considered models competing if the ΔAIC between

805 them was < 2.0 (Burnham and Anderson 2002). We compared with ΔAIC weight model comparison

806 with our *a priori* model sets for date, hibernation stage, time of day, daily precipitation, daily average

807 temperature, photoperiod, RGR of mother, RGR of biological cub, and RGR of foster. All continuous

808 numerical covariates were scaled by z-score to be centered on 0 so that the beta coefficients were

809 comparable (Peterson & Brown, 2005). We then built additive and interactive models based on results

810 from our *a priori* models to build *post hoc* models, where we combined the strongest predictors. Prior

811 to full analysis, we used a Pearson's correlation matrix in base R (R Core Team 2022), and we

812 considered variables highly correlated if $|r| \geq 0.60$. We did not include highly correlated variables in the

813 same models. We calculated confidence intervals (CIs) and considered a variable supported in the

814 analysis if the beta (β) on the scaled covariates did not overlap zero.

Adult Interval

815 We analyzed the adult interval behaviors (active, passive alert, and passive) from September 27, 2015,

816 to May 4, 2016, so the time periods were the same for all four mother bears, excluding camera

817 malfunction dates and the 24-hour immediately after health checks. We also allowed for a 3-day

818 acclimation period for all bears to adjust to being at the BBRC before observations were conducted as

819 this is when we observed similar levels of the three behavior types when compared to later dates in the

820 study. We considered acclimation when bears consumed food and water and frequency of behaviors

821 like passing and climbing were drastically reduced.

822 For cubs, we also analyzed active, passive alert, and passive behaviors from the birth of the

823 biological cubs to their release back into the wild, resulting in slightly different total durations for each

824 cub. We coded the age of cubs as days since birth, given that their birthdays were different, to allow for

825 comparability among litters based on the biological cub ages.

Maternal-Offspring Interval

828 To analyze the maternal interval behaviors and interactions with their cubs from February 1, 2016, to

829 May 4, 2016, we conducted paired *t*-tests to compare potential differences in the daily time allocation

830 of the mother with the different cub types (biological or foster). Litters with multiple biological cubs

831 were averaged for a single daily value for biological cubs. The birth date of each cub was isolated by

832 closely monitored by observers to isolate which date the cubs were born via direct observation of cub

833 calls (see Mesa Cruz (2018) for more details). To allow for comparison between cub groups, the cub

834 age was individualized per cub group, based on this recorded date of birth.

835 We compared the daily duration of maternal interactions with three cub groups: all cubs

836 combined (biological and foster), only biological cubs, and only foster cubs. We used GLMMs of the

837 daily duration of observed time interacting with cubs as the response variable for behavior groups

838 (active, passive alert, passive). We used the same physiological and environmental covariates described

839 above as predictors.

840 *Biological vs. Cub Interactions*

841 We extracted the duration of dominance playing and mutual playing behaviors to isolate these

842 interactions. We used GLMMs of the duration of these behaviors as a response variable using the same

843 covariates as potential predictors of such behaviors. In these models, we also assessed if one cub group

844 exhibited more of one behavior type than the other. We compared the daily duration of play behaviors

845 to determine whether biological or foster cubs exhibited higher levels of dominance behaviors towards

846 a certain cub group.

847 *Results*

848 The 24/7 monitoring of four bears resulted in 22,416 hours of video data. From the adult interval

849 (September 2015 to May 2016), we recorded 86,360 1-minute observations, totaling 1,161 hours

850 across all bears, excluding camera malfunction days. Of these observations, we excluded 5289 'out of

851 field' observations (6.12% across all bears), resulting in 81,071 final observations (1,085 hours) used

852 in this analysis. For the maternal interval (February to May 2016), we recorded 129,091 1-minute

853 observations (1,770 hours), excluding camera malfunction days. Of these observations, we excluded

854 4336 'out of field' observations (3.36% across all bears), resulting in 124,755 final 1-minute

855 observations (1,714 hours) used in this analysis. Bears were only 'out of field' a minimal proportion

856 (0.02 to 0.09) of the entire observational period. We eliminated data for 25 days out of 240 days, 18 of

857 which were from periods of camera malfunctions mid-to-late January (during a power outage caused

858 by a winter storm) when all bears were still in hibernation and another 7 days from late-February to

859 early March, before any bears emerged from hibernation.

860   Mother bears' average RGR ranged from a high of 0.0065 [CIs – 0.0034-0.0097] on November

861   16, 2015, to a low of -0.0043 [⁻0.0050-⁻0.0036] on January 20, 2016 (Figure 2A). Biological cubs'

862   average RGR ranged from a low of 0.0146 [0.0071-0.0221] on May 4, 2016, to a high of 0.0490

863   [0.0153-0.0827] on February 17, 2016 (Figure 3B). Foster cubs' average RGR ranged from a low of

864   0.0075 [⁻0.0022-0.0173] on May 4, 2016, to a high of 0.0211 [single cub at this time] on February 2,

865   2016 (Figure 2B).

866   Temperatures ranged from a low mean daily temperature on February 15, 2016, of -10.74°C to

867   a high on September 30, 2015, of 24.20°C, whereas photoperiod ranged from a low of 9.58 hours of

868   light from December 20-23, 2015, to a high of 13.83 hours of light on the day of release on May 4,

869   2016 (Supplementary Figure S1a). Over the adult interval, temperature and photoperiod were not

870   highly correlated ($r = 0.41$; Supplementary Figure S1b; Table S2a). However, temperature and

871   photoperiod were correlated ($r = 0.63$) during the maternal-offspring interval, as were cub age and

872   photoperiod ($r=0.96$) (Supplementary Table S2b). Therefore, we did not include these correlated

873   variables in the same analysis (Dormann et al. 2013).

874   *Adult Interval Results*

875   In general, we found that bears spent the majority of their time at the BBRC displaying passive

876   behaviors across all physiological stages, averaging 0.90 [range, 0.44-1.00] proportionally per stage,

877   whereas passive alert averaged 0.06 [0.00-0.60] and active averaged 0.05 [0.00-0.47], proportionally

878   per stage, but did change over time (Figure 3).

879   *Active Behaviors*

880   Our two top models during the adult interval included black bear ID as a random effect and the

881   hibernation stage, time of day, and an interactive effect between temperature and photoperiod as the

882   main covariates associated with black bear active behaviors from September to May (Table 4). The

35

883   competing model had an uninformative variable (i.e., CIs on the beta coefficient overlapped 0:

884   Supplementary Table S3) of mother RGR. The highest average daily proportion of active behaviors

885   occurred during emergence (0.09) and hyperphagia (0.05), and relatively low levels of active behaviors

886   occurred in hypophagia (0.03), postpartum (0.03) and, as expected, were lowest in pre-partum

887   hibernation (0.01) (Figure 3). For time of day, bears were more active during the day across all

888   hibernation stages (Figure 4A).

889   Temperature and photoperiod had a strong interaction ($p<0.0001$) in both top models, with

890   impacts on the active behaviors across hibernation stages (Figure 5). The strong drivers of adult

891   activity were photoperiod and temperature during hyperphagia, postpartum, and emergence, while

892   temperature was the main driver for hypophagia (Supplementary Table S3). During hyperphagia

893   (Figure 5A), there was higher activity at longer photoperiods and the highest activity at warmer

894   temperatures and longer photoperiods. During hypophagia (Figure 5B), temperature was the major

895   driver for adult activity, with black bears showing higher levels of activity at warmer temperatures, but

896   no impact from photoperiod. During prepartum (Figure 5C), we observed little to no activity with

897   temperature or photoperiod driving active behaviors. During postpartum (Figure 5D), there was higher

898   activity at warmer temperatures and longer photoperiods, with temperature driving this interaction

899   slightly more than photoperiod. During emergence (Figure 5E), there was higher activity at warmer

900   temperatures and longer photoperiods, again with temperature driving this interaction slightly more

901   than photoperiod.

902   *Passive Alert Behaviors*

903   In our single top model, which included Bear ID as a random effect in the GLMM, we found that the

904   hibernation stage and time of day were mainly associated with passive alert behaviors (Table 4;

905   Supplementary Table S3). The highest average daily proportion of passive alert behaviors occurred

906   during hyperphagia (0.10) and emergence (0.09), with slightly lower levels during hypophagia (0.04)

907   and the lowest levels during pre-partum (0.01) and postpartum (0.02) (Figure 3). For the time of day,

908   we found bears displayed more passive alert behaviors during the day across all hibernation stages

909   (Figure 4B).

910   *Passive Behaviors*

911   Black bear individual ID as a random effect, hibernation stage, day of the year, time of day,

912   photoperiod, and mother RGR were the main factors influencing passive behaviors in our single-top

913   model (Table 4; Supplementary Table S3). As expected, most passive behaviors occurred during

914   hibernation pre-birth (0.98) and hibernation post-birth (0.96), with slightly lower levels of passive

915   behaviors during the pre-hibernation food reduction (0.92) and the lowest levels during the pre-

916   hibernation hyperphagia (0.85) and emergence (0.81) (Figure 3). Passive behaviors tended to occur

917   more at night but generally overlapped in CIs with daytime (Figure 4C). We found a strong negative

918   relationship with longer photoperiod, showing a higher frequency of passive behaviors at shorter

919   photoperiods. We also found a strong negative relationship with mother RGR, showing a higher

920   frequency of passive behaviors at lower RGR.

921   *Maternal-Offspring Interval Results*

922   In this analysis, we excluded Bear 128 as she rejected the foster introduced to her litter. We found that,

923   in general, all bear groups spent the majority of their time at the BBRC displaying passive behaviors

924   (Figure 6). This interval period only included 2 hibernation stages (postpartum and emergence). During

925   postpartum, mothers spent an average daily proportion of 0.92 with cubs in passive behaviors [daily

926   proportion ranging from 0.73-1.00] and 0.78 [0.64-0.96] during emergence. Mothers spent an average

927   daily proportion of observed in passive alert behaviors as 0.04 [0.00-0.16] during postpartum and 0.13

928   [0.00-0.28] during emergence. For active behaviors, mothers spent an average daily proportion of 0.04

929   [0.00-0.14] during postpartum with cubs and 0.08 [0.03-0.16] during emergence.

930   During postpartum, biological cubs spent an average daily proportion of 0.99 [0.94-1.00] in

931   passive behaviors and 0.81 [0.66-0.99] during emergence (Figure 6). Passive alert behaviors for

932   biological cubs spent an average daily proportion of 0.01 [0.00-0.03] during postpartum and 0.04

933   [0.00-0.12] during emergence. Active behaviors for biological cubs during postpartum spent an

934   average daily proportion of 0.02 [0.00-0.06] during and 0.15 [0.00-0.29] during emergence.

935   Foster cubs were similar to biological cubs during postpartum, where they spent an average

936   daily proportion of 0.99 [0.98-1.00] in passive behaviors and during emergence where they averaged

937   0.86 [0.68-1.00] (Figure 6). Passive alert behaviors for foster cubs spent an average daily proportion of

938   0.00 [0.00-0.00] during postpartum and 0.02 [0.00-0.10] during emergence. Active behaviors for

939   biological cubs during postpartum spent an average daily proportion of 0.00 [0.00-0.00] during and

940   0.12 [0.00-0.26] during emergence.

941   *Mother Bears During Maternal-Offspring Interval*

942   We had two competing top models for active behaviors (Table 5) exhibited by mother bears postpartum

943   and emergence when cubs were present from February to May 2016. The top model had Bear ID as a

944   random effect, mother RGR, and biological cub RGR as drivers for active behaviors, while the

945   competing model had an uninformative variable of cub age (Supplementary Table S4). Mother bears'

946   active behaviors decreased as her RGR increased (Figure 7A), and there was a strong, positive

947   influence of biological cub RGR on mothers' active behaviors (Figure 7B).

948   We had one top model that included black bear ID as a random effect, showing a strong

949   positive effect of cub age and mother RGR on mother bears' passive alert behaviors (Table 5;

950   Supplementary Table S5). Temperature had a moderate positive influence on mother bears' passive

951   alert behaviors, which they more often exhibited during the daytime (Figure 7E, 7D).

952   Our single top model indicated a strong decrease in mothers' passive behaviors with cub age

953   (Table 5; Figure 7G; Supplementary Table S5). Mother bears also exhibited higher median passive

954   behaviors at night, however there were high levels of passive behaviors observed, resulting in a large

955   overlap between day and night (Figure 7H). Passive behavior strongly declined as temperature

956   increased (Figure 7I) and moderately declined as biological cub's RGR increased (Supplementary

957   Table S4; Figure 7J).

958   *Biological Cubs*

959   We had a single top model that showed a strong, significant increase in active behaviors as cubs aged

960   and as the temperature decreased, and a moderate decrease as the mother's RGR increased and as their

961   own RGR increased (Table 6; Figure 8A-D). We had a single top model for biological cub passive alert

962   behaviors indicating a moderate effect of time of day with biological cubs exhibiting higher activity

963   during the day (Figure 8E), a relatively strong decrease in passive alert behaviors as the photoperiod

964   lengthened (Figure 8F) and as daily precipitation decreased (Figure 8G). For passive behaviors, our top

965   model included a strong negative effect of cub age (Figure 8H), time of day with more passive

966   behaviors at night (Figure 8I), and a slight positive effect of precipitation Figure (8J). We had a

967   competing model that had an uninformative variable of mother RGR (Supplementary Table S5).

968   *Foster Cubs*

969   For foster cub active behavior, we had a single top model with a marginally competing model (Table 7)

970   that included a strong positive effect of cub age (Figure 9A) and a moderate negative effect of foster

971   cub RGR (Figure 9B), with an uninformative variable of biological cub RGR (Supplementary Table

972   S6). For foster cub passive alert behaviors, the single top model showed a moderately negative effect

39

973   of mother RGR (Table 8; Figure 9C). We had a single top model for foster cubs' passive behaviors,

974   showing a negative effect of cub age (Figure 9D), time of day with higher passive behaviors at night

975   (Figure 7E), and positive effect of biological cub RGR (Figure 9F), while foster cub RGR and mother

976   RGR were uninformative (Table 7; Figure 9D-F; Supplementary Table S6). There was a strong

977   negative effect of foster cub age on passive behaviors (Figure 9D).

978   *Maternal Time Allocation and Interactions*

979   We recorded 8,603 instances of mother bear interactions with cubs over the maternal-offspring interval

980   subset across all bears. We found that the majority of the time that mothers interacted with cubs (0.904

981   [CI = 0.7234-1.000]), they interacted significantly more with both biological and foster cubs

982   simultaneously than with either cub group alone. Mothers spent slightly proportionally more time with

983   only biological cubs on average (0.051 [0.000-0.154]) than only foster cubs (0.044 [0.000-0.197];

984   Figure 10A)). However, there was no significant difference (p=0.73, paired t=0.35, df=88) in time

985   allocation of the mother bear toward biological versus foster cubs.

986   Our single top model for mother bear interactions with their cubs included time of day,

987   behavior group (i.e., active, passive alert, passive), and cub age (Table 8; Supplementary Table S7;

988   Figure 10B-C). Passive interaction behaviors (e.g., sleeping with cubs) were most common

989   proportionally (0.881), followed by passive alert behaviors (e.g., overseeing the cubs play, 0.073) and

990   active behaviors (e.g., climbing with cubs, 0.046) (Figure 10B). Additionally, passive behavior

991   interactions were more often observed in the evening, while passive alert and active behavior were

992   more often exhibited during the day (Figure 10B). As cub age increased, mother interactions with cubs

993   decreased, switching to primarily passive behavior, mainly in the evenings when they were sleeping

994   together or as cubs spent more time in other areas of the pen while the mother watched them from a

995   distance (Figure 10C).

Mutual Play and Dominance Play Interactions

996

997 We recorded 3,696 instances of mutual play behaviors, and 1,166 instances of dominance play

998 behaviors over the maternal-offspring interval subset across all bears. Our single top model indicated

999 that biological cubs exhibited a higher frequency of mutual play behaviors than foster cubs, even when

1000 accounting for litter size (Figure 11A; Table 9; Supplementary Table S7).

1001 We had a single top model for dominance play interactions between biological and foster cubs,

1002 showing influences of cub group (biological or foster cubs), time of day, precipitation, and an

1003 uninformative variable of mother RGR for frequency of dominance play interactions (Table 9;

1004 Supplementary Table S7). Biological cubs exhibited significantly higher dominance behavior than

1005 foster cubs (Figure 11B) and exhibited slightly more dominance interactions in the evening, while

1006 foster cubs had a similar level of dominance play interactions, with slightly more during the day

1007 (Figure 11C). We also found an increase in dominance play interactions when there was higher

1008 precipitation (Figure 11D).

1009 *Discussion*

1010 *Adult Interval*

1011 We used a unique video dataset in a semi-natural, food-controlled environment to examine bear

1012 hibernation ecology, garnering new information on factors influencing behaviors surrounding

1013 hibernation onset and arousal. Our top models included the hibernation stage as a factor, indicating that

1014 bears at the BBRC underwent stages consistent with hibernation that wild bears would experience

1015 (Seger et al. 2013). For example, as expected in the wild (Seger et al. 2013), we found adult female

1016 body mass generally increased during hyperphagia, declined during hypophagia and prepartum, and

1017 increased again at postpartum and emergence for 3 of 4 bears monitored. During emergence (who had

1018 the highest number of cubs) and appeared to lose body mass after emergence (Mesa-Cruz et al. 2020).

1019	This increase during the transition from post-partum to emergence is likely due to the bears emerging

1020	and consuming large amounts of water during the periods surrounding arousal to replenish themselves

1021	at this depleted state while also lactating, which was observed in this study.

1022	Bears were most active and alert in the daytime during hyperphagia and emergence, and all

1023	exhibited consistently high passive behaviors, especially while in the den (end of hypophagia,

1024	prepartum, and postpartum). It is possible that our high levels of overall passive behaviors (especially

1025	in hyperphagia and emergence) could be a function of bears exhibiting less foraging activity while held

1026	in captivity. However, other studies also have found high frequencies of resting behaviors in wild bears

1027	during these stages (Beckmann and Berger 2003, McLellan 2011). In fact, radio-collared bears in the

1028	wild exhibited a proportional daily sleeping/resting rate of 0.51 on average during daylight hours

1029	(Holcombe and Kelly, unpublished data), similar to levels at the BBRC at 0.57 on average. Therefore,

1030	our results are likely to be representative of wild bear behavior, with a potential for slight over-

1031	representation of passive behaviors.

1032	Our top models also found that photoperiod interacted with temperature in predicting duration

1033	of active behaviors in bears, and this varied by hibernation stage. Past research has shown the onset of

1034	hibernation to be influenced by decreasing ambient temperature in an area (Shimozuru et al. 2013,

1035	Pigeon et al. 2016, Johnson et al. 2018), whereas other studies have shown photoperiod to be

1036	influential on physiological responses in timing of onset and arousal from hibernation in black bears

1037	(Blumenthal et al. 2011), in other *Ursidae* species (Ware et al. 2012), and in other wildlife species

1038	(Abbott et al. 1984, Bilenca et al. 1994, Russart and Nelson 2018, Montgomery et al. 2019, Pretorius et

1039	al. 2020, Dagtekin et al. 2023). Yet, few studies on wildlife species have examined the interaction

1040	between these two variables, with the exception of Körtner and Geiser (1995) who found minimal

1041	interaction between the variables on mountain pygmy-possum (*Burramys parvus*), showing instead

1042   that body weight and total daily activity were impacted independently by photoperiod or temperature,

1043   not both simultaneously.

1044   Our study adds important nuance regarding the interaction between temperature and

1045   photoperiod on hibernation stage. Both temperature and photoperiod positively influenced activity in

1046   bears. However, prepartum was weakly influenced by either, but this time period (end of December -

1047   January) coincides with the darkest and coldest months in our study area with little variation in either

1048   variable. By contrast, hypophagia (mid-to-late November - early January), when bears reduce food

1049   intake and prepare for hibernation, was strongly influenced primarily by temperature only. We note that

1050   while food availability also has been seen to impact the onset of hibernation in brown bears (*Ursus*

1051   *arctos*, Rodríguez et al. 2007, Ware et al. 2012, Pigeon et al. 2016, Krofel et al. 2017), and other

1052   mammals that exhibit torpor (Körtner and Geiser 1995, Turner and Geiser 2017), we were able to

1053   control this factor by feeding bears the same amount (calibrated by their body weights). Thus overall,

1054   we found that 4 of 5 hibernation stages were significantly influenced by both temperature and

1055   photoperiod, with similar magnitude of impacts during hyperphagia and prepartum, while temperature

1056   was a slightly stronger driver for activity in postpartum and emergence, and active behavior during

1057   hypophagia was almost entirely driven by temperature. Thus, temperature appears to be a more

1058   important driver in general (in 3 out of 5 stages) of active behaviors in our study.

1059   Climate change has been projected to result in milder winters in the central Appalachian

1060   Mountains, leading to warmer weather later in fall and an earlier start to spring warm weather

1061   (Gaertner et al. 2019, Kutta and Hubbart 2019). In fact, the National Oceanic and Atmospheric

1062   Administration (NOAA 2023, accessed 2023) has projected Virginia to have a 40-50% probability of

1063   being warmer in both December and April (Figure 12A, B). Later warm fall weather and an earlier

1064   onset of spring weather (Van Moorter et al. 2013, Kutta and Hubbart 2019) may lead to both later den

1065 entrance, which we found to be strongly influenced by temperature, and earlier black bear emergence

1066 (Johnson et al. 2018), which we found to be influenced by photoperiod and slightly stronger by

1067 temperature. Earlier emergence has been seen in brown bears (Pigeon et al. 2016) in northern latitudes

1068 as of the globe as they shift their regular emergence patterns to match the changing environment.

1069   The physiological responses during hibernation across bear species appears to be linked to

1070 weather and also to food availability (Baldwin and Bender 2010, Johnson et al. 2018, Kirby et al.

1071 2019). Changes, or lack thereof, in the food present naturally on the landscape when bears emerge, due

1072 to the earlier emergence with increasing ambient temperatures, can cause bears to seek out other food

1073 sources as a subsidy (Hellgren and Vaughan 1987, Krofel et al. 2017, Johnson et al. 2018, Kirby et al.

1074 2019). In the winter months, when traditional food sources such as green leafy plant matter and

1075 available prey, such as deer fawns that are used in early summer, are not present on the landscape,

1076 bears have been seen to seek out 'easy' meals of anthropogenic food subsidies such as unsecured

1077 garbage or pet food kept outdoors (Krofel et al. 2017, Johnson et al. 2018, Kirby et al. 2019), which

1078 can lead to increases in human-bear interactions. Additionally, Kirby et al. (2019) showed that bears

1079 collar in 2011 near Durango, Colorado consumed higher levels of human foods hibernated for shorter

1080 periods, compounding the issue.

1081   Our results have potentially important ramifications for human-bear interactions in the area.

1082 Warming temperatures do not necessarily mean that natural plant species will extend their growing

1083 seasons. For example, Ettinger et al. (2021) found that photoperiod was a common cue and strong

1084 driver of woody plants' (i.e., oaks) spring phenology and growth, citing 87% of the 30 studies

1085 analyzed, which only sometimes interacted with temperature. This could impact species composition

1086 of plant communities available to bears, as certain plant species may emerge on the landscape due to

1087 photoperiod alone, while others do not, resulting in changing plant communities surrounding the time

1088   of den entrance and emergence (Bauerle et al. 2012, Odom & Ford, 2020, Ettinger et al. 2021). Around

1089   the world, plant phenology is linked to fluctuating temperatures when not coinciding with typical

1090   photoperiods (Malyshev et al. 2018), including links to flower production occurring early in many

1091   species in the northern and northeastern part of the United States (Ellwood et al., 2013).

1092   In the Appalachian Mountains, plant phenology for endemic species also has shown these

1093   trends, including for highbush blueberry (*Vaccinium corymbosum*, Spann et al. 2004) in bear summer

1094   diets, with the driver for flower initiation being temperature even if photoperiod has not reached the

1095   initiation day length. Within the fall diet, oak species (Elliott et al. 2015) have been shown to be driven

1096   by both photoperiod and temperature for emerging from dormancy in spring for bud burst. Black bears

1097   in the Appalachian Mountains depend on hard mast (e.g., acorns.) in their seasonally-driven diet (Seger

1098   et al. 2013), particularly with changing levels of mast production, they may seek out alternative,

1099   possibly anthrophonic, food sources (Kirby et al. 2016). Projected increases in temperatures in the

1100   central Appalachian Mountains (Lesser and Fridley 2016) may lead to changes in the species

1101   composition in the area, as potentially different species thrive in changing environments. With

1102   differential responses of plants to photoperiod and temperature (Gaertner et al. 2019), combined with

1103   recent increases in bear population numbers in the area (VADWR 2023) and bears' propensity to seek

1104   out anthropogenic food in times of scarcity, could lead to increased human-bear interactions.

1105   *Maternal-Offspring Interval*

1106   We found that mother bears' active behaviors were driven negatively by the RGR of mothers

1107   themselves and positively by biological cubs' RGR in the periods from birth to release. This has been

1108   found in other bear research; as mother bears provide nutrients to growing cubs via nursing, their body

1109   mass can decrease even when consuming food during emergence, particularly with young cubs

1110   (Hilderbrand et al. 1999, Jenkins et al. 2001, Seger et al. 2013, Mesa-Cruz et al. 2020).

1111   We also found that mother bears' passive alert behaviors increased, and passive behaviors

1112   decreased with cub age and as temperatures increased. As cubs age and gain mobility, they explore

1113   their surroundings, leading to increases in mothers passively watching cubs that are interacting and

1114   playing with each other, in their process of social learning. Social learning from each other, in addition

1115   to other behaviors such as foraging learned from their mother, have been seen in other species,

1116   including bear species (Van Lawick-Goodall 1968, Terkel 1996, Mazur and Seher 2008, Sargeant and

1117   Mann 2009, Fugazza et al. 2018). In the captive facility, mother bears may exhibit more passive-alert

1118   behavior than in the wild, where cubs may wander farther into unfamiliar territory, causing mothers to

1119   exhibit more active and vigilant behaviors to protect their cubs (Dyck and Baydack 2004, Smith et al.

1120   2009, Steyaert et al. 2013*b*, *a*). Such behavior is likely not necessary when confined to a relatively

1121   small area where cubs are completely within view.

1122   Both biological and foster cubs increased active behaviors as they got older and at lower RGR

1123   levels, which is likely due to relative weight gain occurring more rapidly when they are smaller, which

1124   begins to slow as they get larger (Oftedal et al. 1993, Seger et al. 2013). These trends in cub weight

1125   gain in our study were similar to cubs' weight gain in the wild, which sets the foster cubs up well to

1126   allow cubs to be large enough to keep up with, and follow mothers around, in the wild (Robbins et al.

1127   2012). Foster cubs exhibited passive alert behaviors as mothers put on more weight (e.g., at higher

1128   RGR). Biological cubs exhibited more passive behaviors at night and, for both cub groups, at younger

1129   ages, which is not surprising as they are less mobile when very young, and are known to be generally

1130   diurnal (Mansfield et al. 2022). Higher levels of diurnal activity have been seen in wild mother bears

1131   with cubs than for males and females without cubs (Hubbard et al. 2022, Mansfield et al. 2022).

1132   There is little literature on litter integration after the introduction of foster cubs to a surrogate

1133   sow, even though many states (14 states within the eastern black bear range, K. Martin personal

46

1134   communications) practice fostering orphaned cubs to wild bears. Foster cubs showed decreased

1135   passive behaviors as biological cubs' weight gain slowed as they got older, as noted by the foster cub

1136   exploring surroundings with its new siblings as it integrated into the litter. Maternal investment in

1137   foster cubs is also not commonly studied. It is challenging to study investment into biological offspring

1138   in the wild, let alone their physiological investment in both biological and foster cubs (Roulin 2002).

1139   Most studies examining maternal investment across species, including bears, research the impact on

1140   sex-mediated survival and reproductive output of biological offspring (Trivers and Willard 1973,

1141   Clutton-Brock et al. 1981, Pontier et al. 1993, Derocher and Stirling 1998), but not investment in

1142   biological versus foster cubs. We found no information in the literature on the interaction between

1143   foster cubs and biological cubs.

1144   Foster cub adoption, natural and transplanted, has been widely observed in black bear

1145   management efforts (Clarke et al. 1980*b*, Alt 1984, Alt and Beecham 1984, Rogers 1985, Atkinson et

1146   al. 1996, Lunn et al. 2000, Benson and Chamberlain 2006, Hashem 2019), but has also been observed

1147   in other bear species including brown bears (Jonkel et al. 1980, Servheen et al. 1995, Beecham et al.

1148   2016), polar bears (Belikov 1976, Atkinson et al. 1996, Lunn et al. 2000), and Asiatic bears (*Ursus*

1149   *thibetanus;* Skripova 2013). The use of orphan cub fostering programs to foster a natural cub adoption

1150   has been increasing in the last few decades, especially as a mechanism to bolster low bear population

1151   in the recent past (Clarke et al. 1980*b*, Alt 1984, Alt and Beecham 1984, Hashem 2019). However,

1152   there has been litter documentation on work previously conducted to investigate the effectiveness of

1153   such programs beyond initial acceptance or rejection of the cub, as it is difficult to observe and

1154   quantify successful adoption and cub integration into a biological litter (Rogers 1985, Cant 2013,

1155   Hashem 2019). Additionally, while denning and litters can be monitored by bear managers during

1156   hibernation, once bears emerge, it becomes difficult to monitor the foster cubs' interactions with the

1157 mother and their littermates (Clarke et al. 1980*b*, Blair et al. 2020). Studies that have examined success

1158 rates of foster initiatives in bears have shown mixed results, but most note foster cubs to be initially

1159 accepted into the litter and cared for by the mother (Clarke et al. 1980*b*, Rogers 1985, 1986).

1160   In our study, mother bears spent similar amounts of time with biological cubs and foster cubs

1161 alike, appearing to demonstrate no preferential time investment in biological cubs. Most of their time

1162 was spent with both cub groups together in passive behaviors, often sleeping, which decreased in

1163 frequency over time as cubs gained mobility and explored surroundings while the mother bears

1164 watched over them. Other studies have documented mutual play behaviors among cubs in the wild

1165 (Rogers et al. 2020), which we also recorded. We also found that biological cubs more frequently

1166 exhibited mutual play and dominance behaviors than foster cubs, but we did not find that dominance

1167 interactions were directed toward foster cubs more than biological siblings, when present in a litter.

1168 Thus, our analysis of foster cubs' litter integration provides promising results for orphan cub fostering

1169 programs.

1170 *Management Implications*
1171 *Adult Interval*

1172 The interplay between photoperiod and temperature is often not invested in ecological studies.

1173 However, given the rapidly changing ecosystems around the world in response to climate change, and

1174 the expected upward trajectory of temperature in Virginia, it is important to untangle the relative

1175 influence of each, especially for a hibernating species. We documented the interaction between

1176 photoperiod and temperature and highlighted the strong influence of temperature as a driver of active

1177 behavior, particularly at the onset of hibernation. Bears appear to maintain high levels of activity if

1178 temperature remains high, even if plant foods may have already become dormant.

1179   This mismatch in bear activity with plant phenology may to drive bears to seek human foods,

1180   as shown by others (Kirby et al. 2016). In fact, VADWR has already anecdotally noted an increased

1181   presence of black bears on the landscape at the onset of hibernation (i.e., later hibernation dates) and

1182   earlier emergence dates, even if only mobile for short periods during warm spells (K. Martin, VADWR

1183   Deer, Turkey, Bear Biologist, personal communications). Our results of temperature as a potential

1184   driver of changing bear behaviors, provide evidence to support on-the-ground observations.

1185   The potential changes in bear behavior due to temperature may be important to VADWR in

1186   adjusting bear hunting seasons, which currently range from October 1 through January 6 (varying by

1187   county) and from August 1 to December 2 (chase season). Lengthening hunting and chase seasons to

1188   end later may be a possibility, but is likely important to not move up the start date as the current timing

1189   of seasons is designed to protect pregnant females (VADWR 2023). VADWR may also need to better

1190   prepare the public for potential changes in bear activity, which varies across the state depending on the

1191   level of urbanization. VADWR can provide increased information on how to coexist with bears, which

1192   likely will be essential to prevent or mitigate human-wildlife interactions.

1193   *Maternal Interval*

1194   Our results indicate mothers do not preferentially allocate time towards biological cubs and such cubs

1195   do not dominate fosters preferentially. These are promising results for orphan cub fostering programs

1196   (Hedgpeth 2022). However, our experience has shown that foster cubs can be rejected, especially if

1197   done after emergence (Kelly and Holcombe, unpublished data). While we did have two rejections of

1198   foster cubs, these foster cubs were introduced when the biological cubs were almost 100 days old and

1199   44 days after emergence, which is much later than the other foster cubs in the study. In one case, the

1200   foster cub was rejected immediately, while in the other, the rejection occurred 2-3 hours after what

1201   seemed to be a successful introduction. Thus, fostering to wild bears may miss these delayed

1202 rejections. Cub age at the time of introduction has been seen to be important in the successful adoption

1203 of foster cubs in other studies (Clarke et al. 1980*a*, Alt and Beecham 1984, Rogers 1986, Ternent 2006,

1204 VADWR 2023). This emphasizes the important window of increased likelihood of foster cub

1205 acceptance into the litter by conducting introduction before den emergence, or soon thereafter, to allow

1206 for higher chance of acceptance and litter integration (Alt and Beecham 1984, Beecham 2006,

1207 Beecham et al. 2016, Michigan DNR 2016).

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Tables & Figures

Figure 1. A) An example of the observation view from video cameras above each black bear pen at the Black Bear Research Center in Blacksburg, Virginia in 2016. Adult female Bear127 had three biological and one foster cub. Some areas of the circular pen area are not visible to the observer. In this example, black bear 127 is rolling on her back and interacting with Cub 2 and Cub F (foster cub) as they climb on their mother. Cubs 1 and 3 are recorded as mutual playing rather than dominating play. B) black bear 129 and her one biological cub are both recorded as nursing. The mother and cub are noted as interacting with each other in this frame. C) black bear 128 is recorded as back-scratching and her two biological cubs are recorded as lying down sleeping. The mother is noted as not interacting with another black bear and Cub 1 and Cub 2 are noted as interacting with each other.
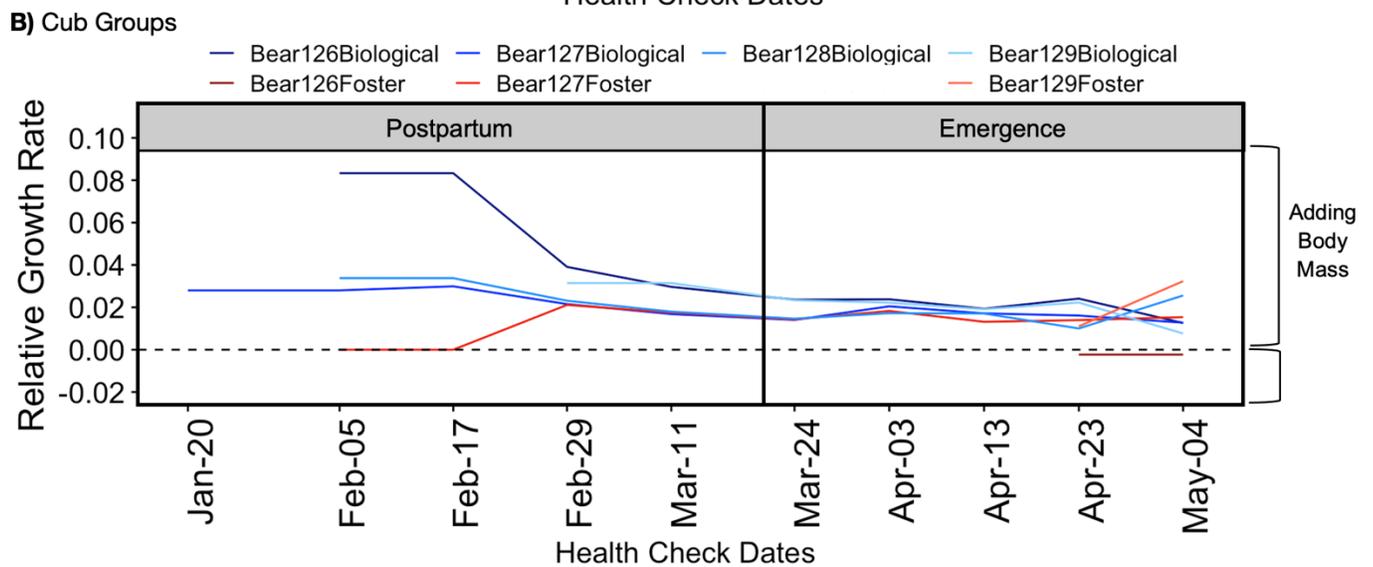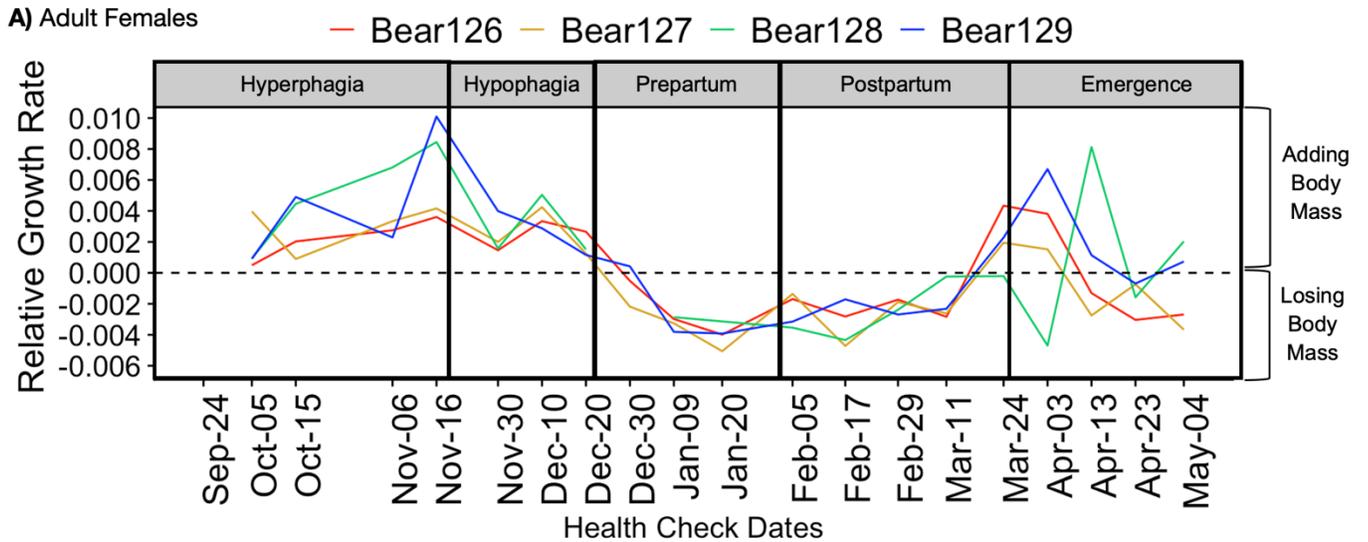
Figure 2. A) The relative growth rate (RGR) of the adult females and B) cubs (averaged for litters with more than one cub) for mothers' biological cubs in blue shades and foster cubs in red shades) calculated using data collected during health checks every 10-14 days. RGR values denote relative changes in growth between health checks, with positive values indicating body mass gains from previous body mass and negative values indicating a decrease in body mass. Data collected at the Black Bear Research Center in Blacksburg, Virginia from September 2015 to May 2016.
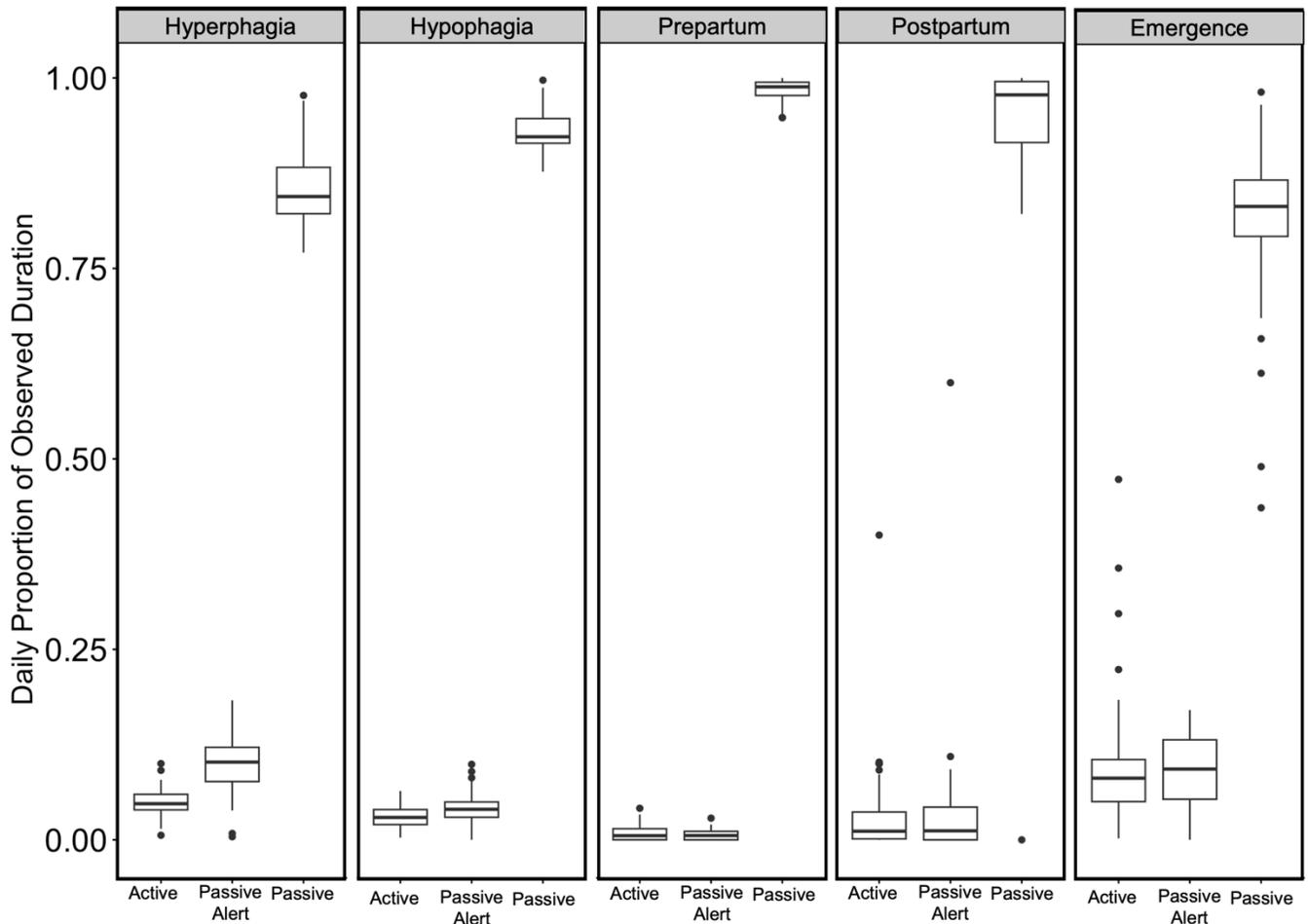
Figure 3. Daily proportion of observed activity in minutes by behavior type (Active, Passive Alert, Passive) and hibernation stage from the adult interval of video data collected at the Black Bear Research Center in Blacksburg, Virginia for female American black bears from September 2015 to May 2016. Plots by behavior type show daily proportion of activity, with the dark middle line showing the mean, the lines through the box showing the minimum and maximum range with the points showing the outliers of those ranges.
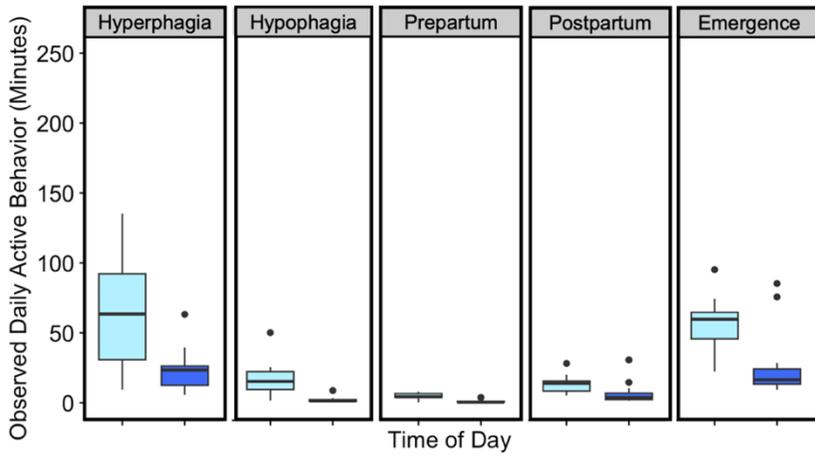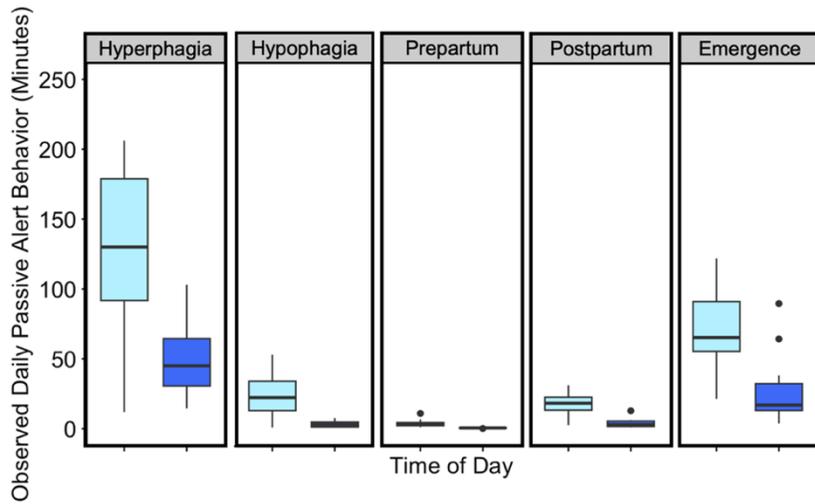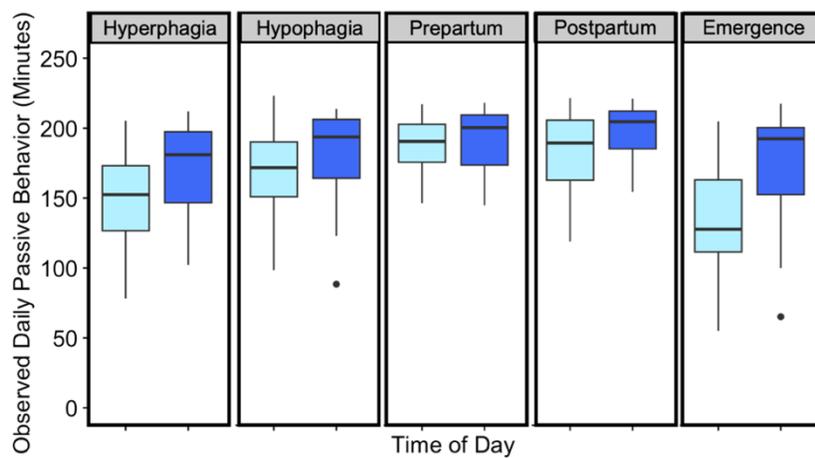
1574
1575 Figure 4. American black bear adult females observed daily behavior (in minutes) during day versus
1576 night for A) active, B) passive alert, and C) passive behaviors during the five hibernation stages from
1577 September 2015 to May 2016 at the Black Bear Research Center in Blacksburg, Virginia.
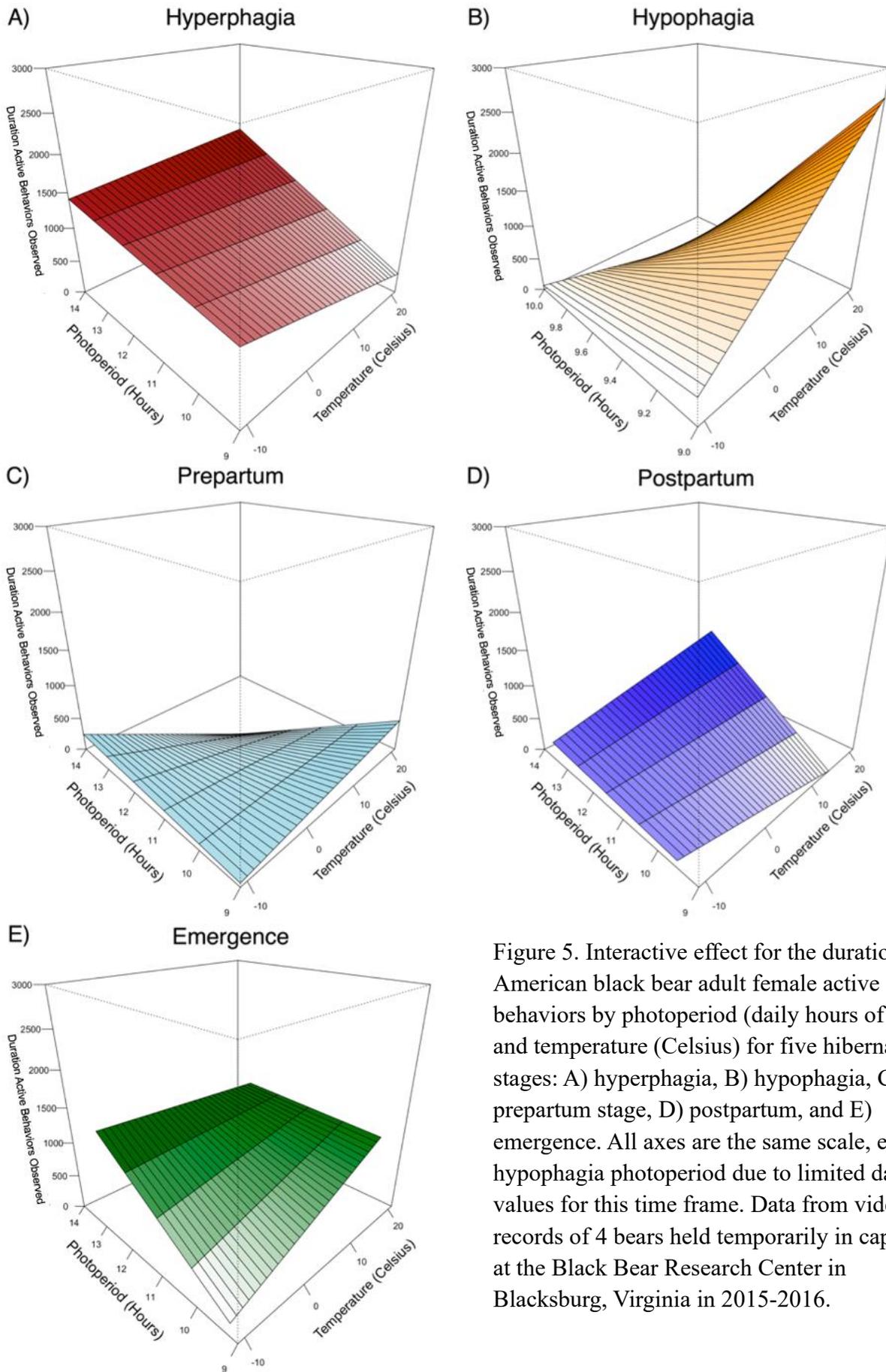
Figure 5. Interactive effect for the duration of American black bear adult female active behaviors by photoperiod (daily hours of light) and temperature (Celsius) for five hibernation stages: A) hyperphagia, B) hypophagia, C) prepartum stage, D) postpartum, and E) emergence. All axes are the same scale, except hypophagia photoperiod due to limited data values for this time frame. Data from video records of 4 bears held temporarily in captivity at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016.

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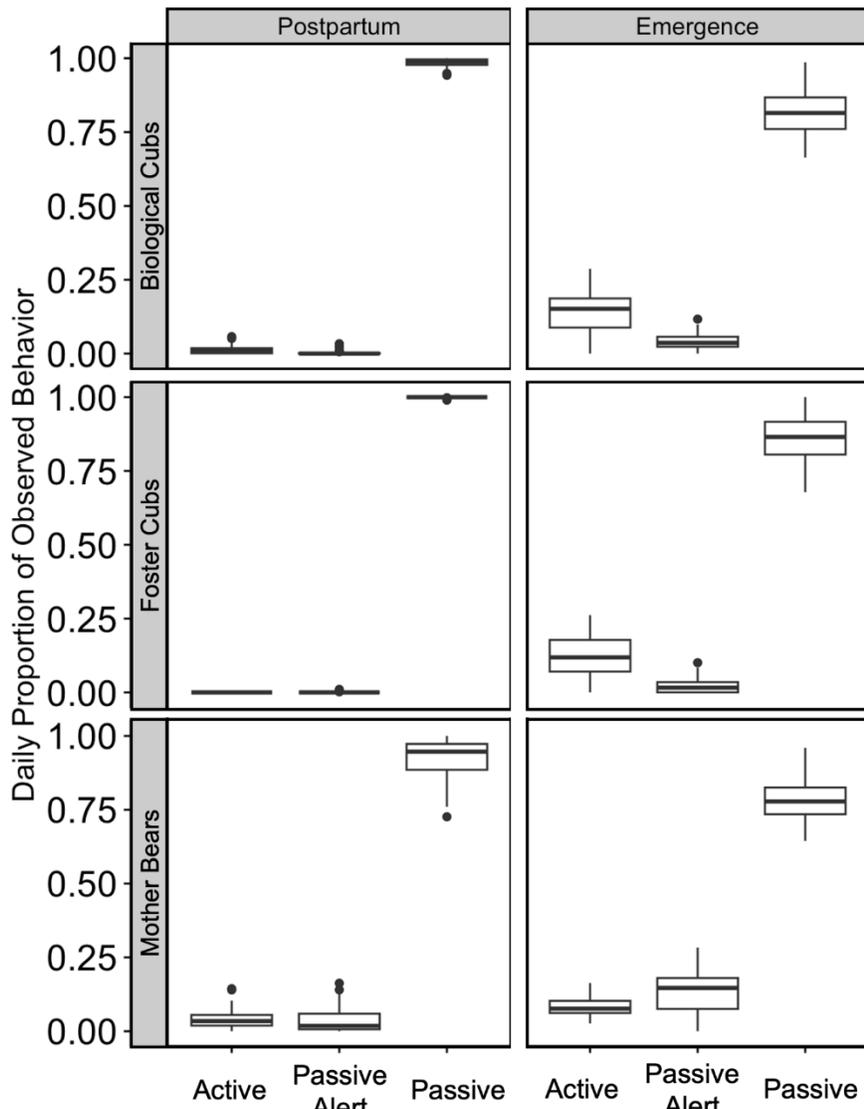
Figure 6. Daily proportion of observed activity in minutes by behavior type (Active, Passive Alert, Passive) and hibernation stage from the maternal-offspring interval of video data collected at the Black Bear Research Center in Blacksburg, Virginia for American black bears from January to May 2016. Plots display middle line as the mean and upper and lower lines of the box are minimum and maximum range, with the points showing the outliers.
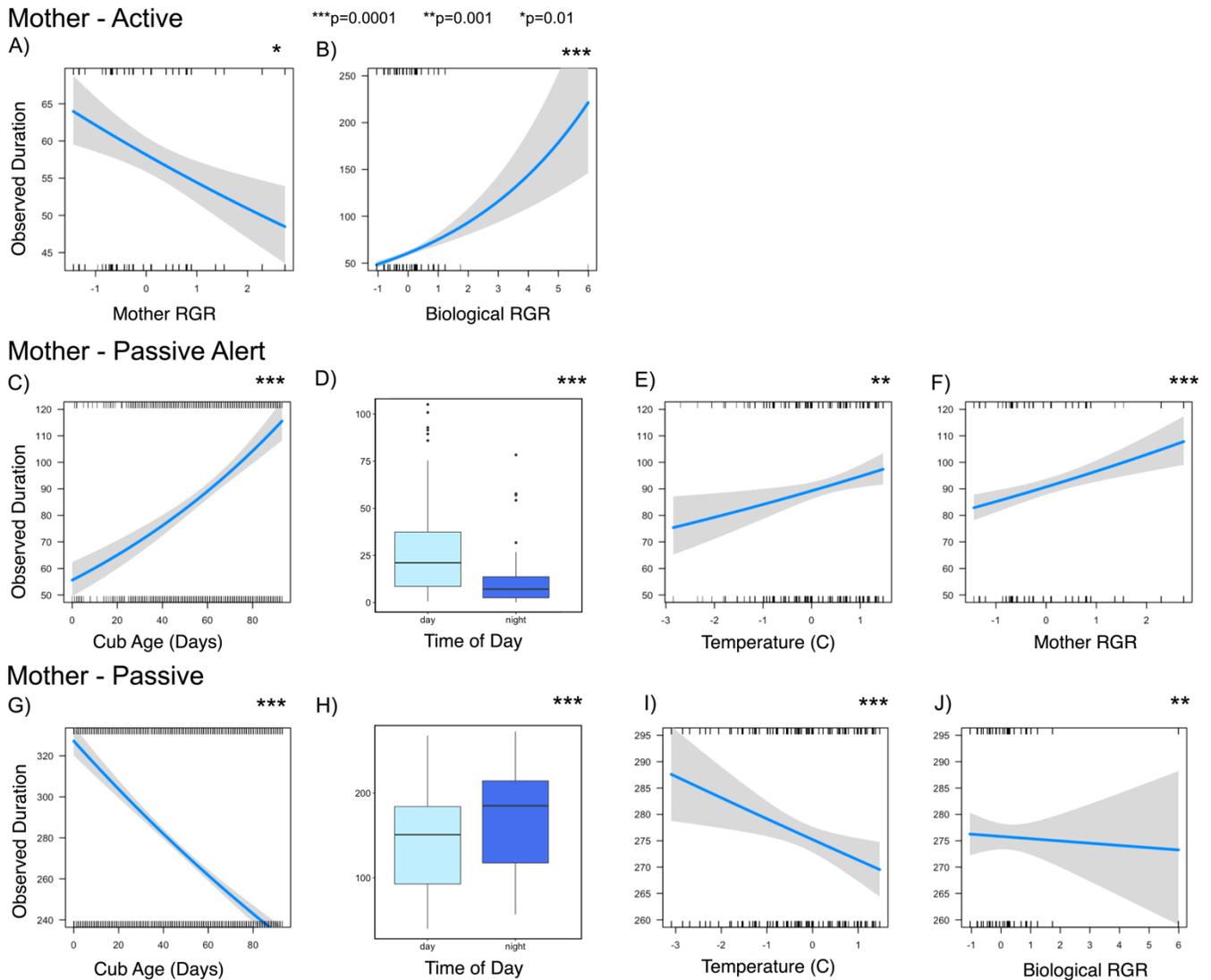
Figure 7. Top models (Generalized Linear Mixed Models) for mother bears when cubs were present for the maternal-offspring interval dataset from January to May 2016. The duration of the mother bears' active behaviors (in seconds) was influenced by A) the mother's RGR [scaled] and B) the biological cub's RGR [scaled]. Duration of mother bears' passive alert behaviors influenced by C) cub age [scaled, plot unscaled], D) time of day [scaled, plot binned for visualization], E) temperature [scaled], and F) mother's RGR [scaled]. Duration of mother bears' passive behaviors influenced by G) cub age [scaled, plotted unscaled], H) time of day, I) temperature [scaled], and J) biological cub's RGR (scaled). P-values are noted at the top for each variable. Behavior data was collected via a remote video recording of 4 black bears temporarily held at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016. Time of day has a different y-axis range as it is displayed as a circular variable instead of a linear regression, with the shading showing 95% confidence intervals for this variable. Y-axis scales vary depending on the range of output.

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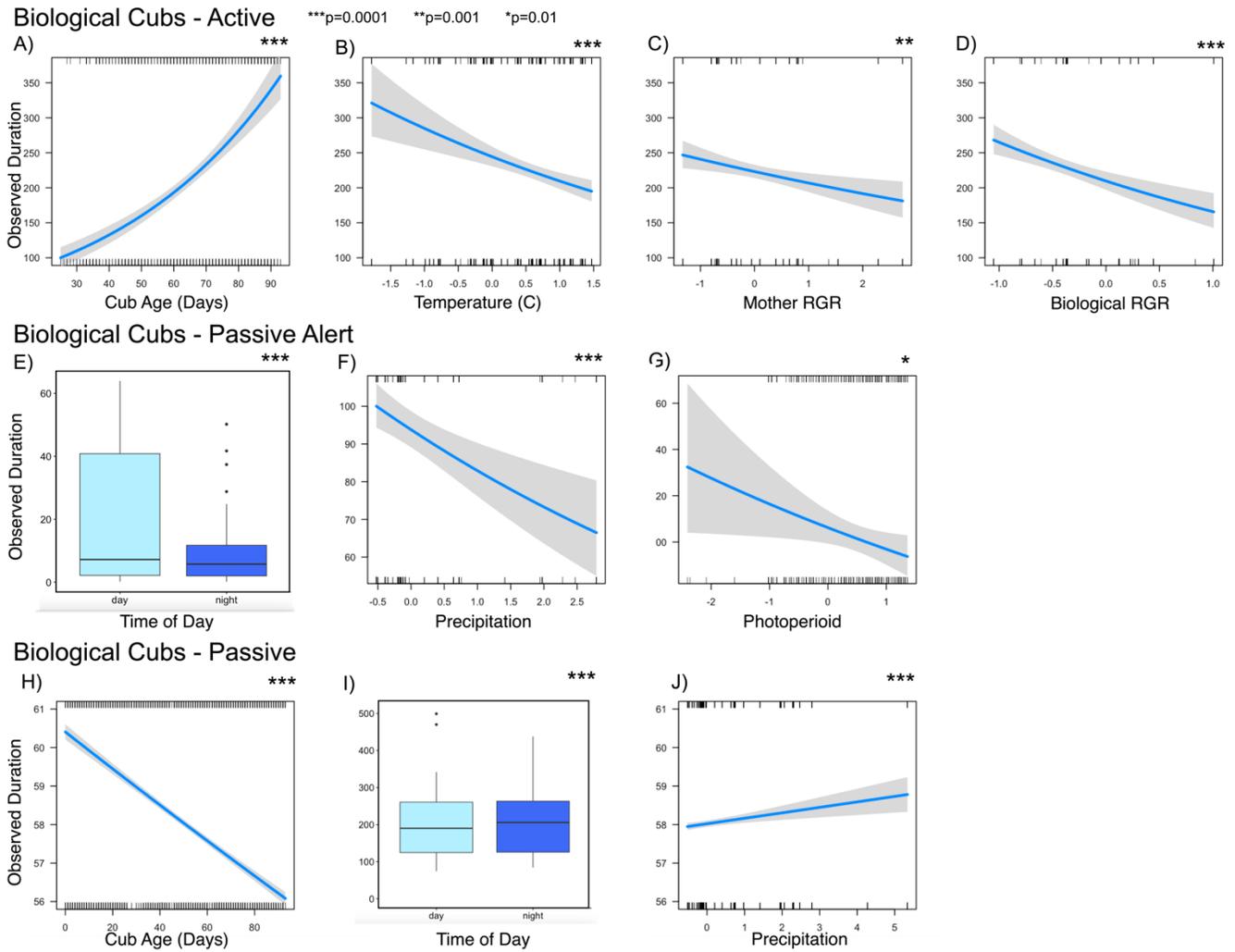
Figure 8. Top models (Generalized Linear Mixed Models) for biological cubs for the maternal-offspring interval from January to May 2016. The duration of the biological cubs' active behaviors (in seconds) was influenced by A) cub age [scaled, plot unscaled], B) photoperiod [scaled], C) temperature [scaled], and D) the mother bear's RGR. Duration of biological cubs' passive alert behaviors influenced by E) time of day [scaled], F) precipitation [scaled], and G) photoperiod [scaled]. Duration of biological cubs' passive behaviors influenced by H) cub age [scaled, plot unscaled], I) time of day [scaled, plot binned for visualization], and J) precipitation [scaled]. Behavior data was collected via a remote video recording of 4 black bears and their cubs temporarily held at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016. Time of day has a different y-axis range as it is displayed as a circular variable instead of a linear regression, with the shading showing 95% confidence intervals for this variable. Y-axis scales vary depending on the range of output.
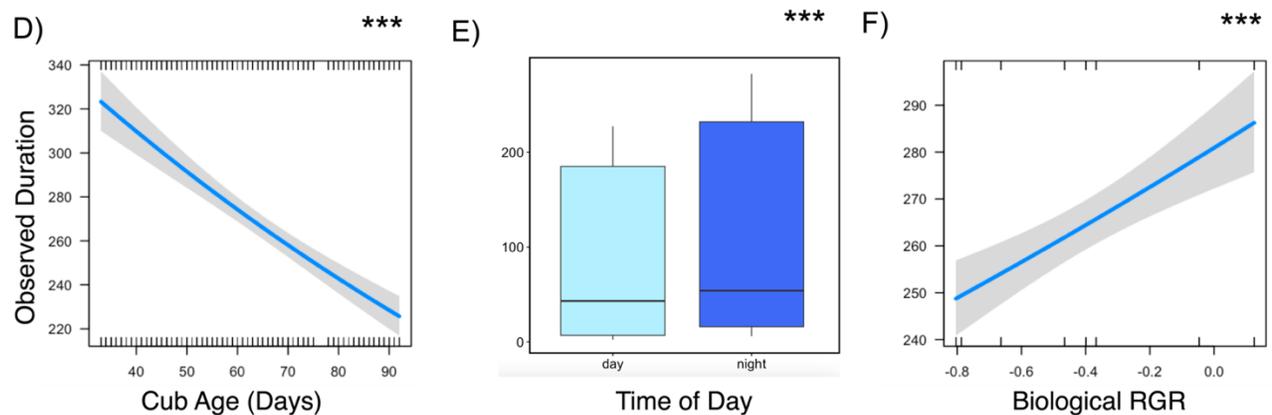
Figure 9. Top models (Generalized Linear Mixed Models) for foster cubs for the maternal interval from February to May 2016. Duration of the foster cubs' active behaviors (in seconds) was influenced by A) cub age [scaled, plot unscaled] and B) the foster cub's RGR [scaled]. Duration of foster cubs' passive alert behaviors influenced by C) mother bear's RGR [scaled]. Duration of foster cubs' passive behaviors influenced by D) cub age [scaled, plot unscaled], E) time of day [scaled, plot binned for visualization], and F) biological cub's RGR [scaled]. Behavior data was collected via a remote video recording of 4 black bears and their cubs temporarily held at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016. Time of day has a different y-axis range as it is displayed as a circular variable instead of a linear regression, with the shading showing 95% confidence intervals for this variable. Y-axis scales vary depending on the range of output.
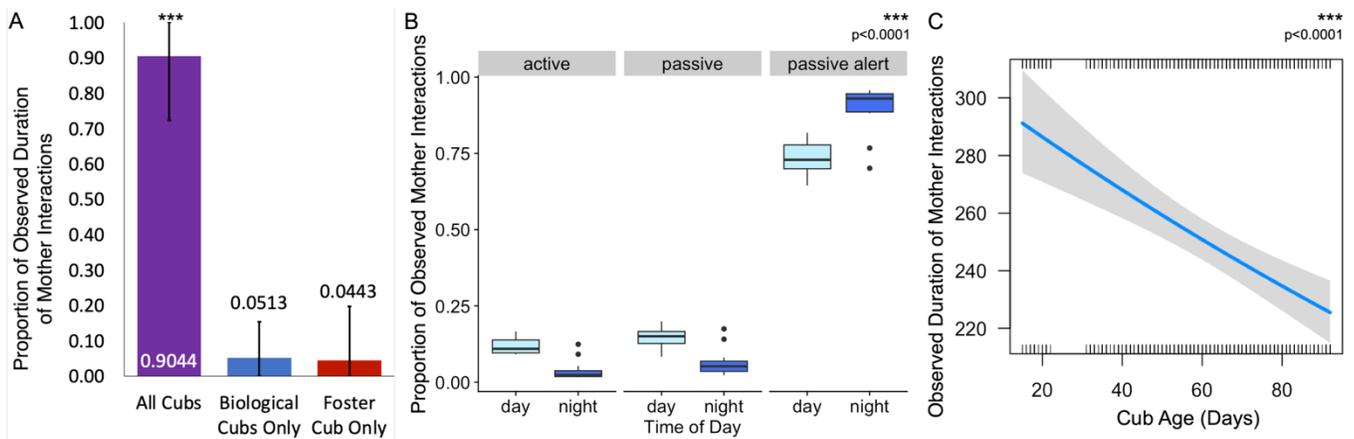
Figure 10. A) Proportion of time mother bears interacted with biological and foster cubs all together
(purple bar), was significantly higher than interactions with only with biological (blue bar), and only
with the foster (red bar, paired two sample t-test). There was no significant difference in time
allocation between biological and foster cubs (p=0.73, paired t=0.35, df=88). B) Top models
(Generalized Linear Mixed Models) indicated that mother bears spent most of their time [scaled, plot
binned for visualization] interacting with cubs passively (i.e., sleeping with them in the evening). C)
Duration of mother bears' interactions with cubs generally decreased with cub age [scaled, plot
unscaled]. Behavior data was collected via a remote video recording of 3 black bears and their cubs
temporarily held at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016. Y-axis
scales vary depending on the range of output.
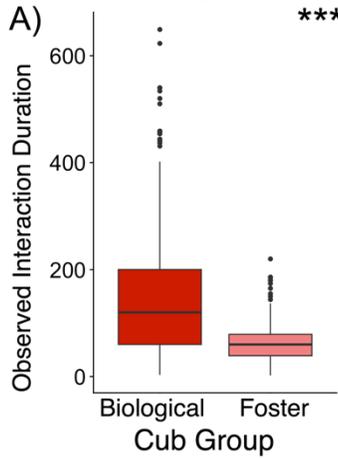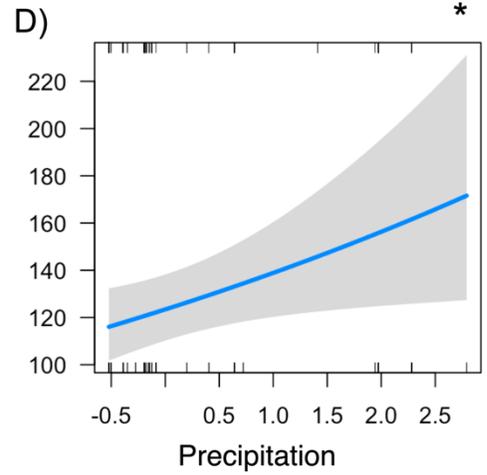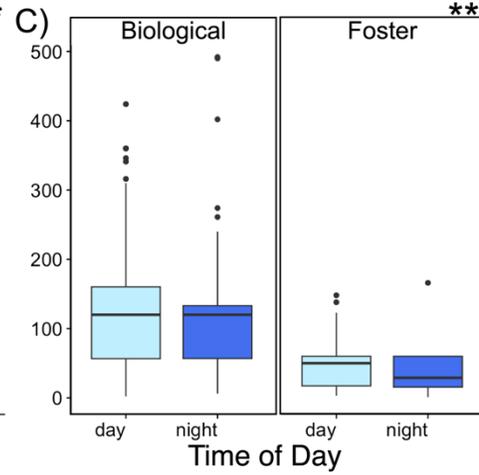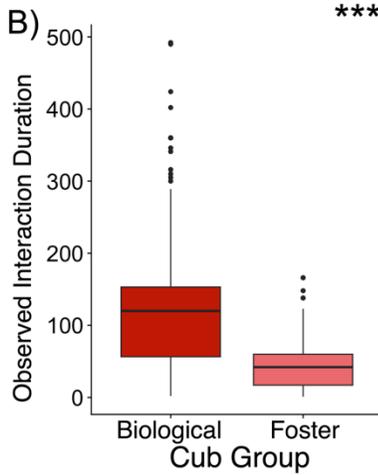
Figure 11. Top models (Generalized Linear Mixed Models) for mutual play and dominance interactions between cub groups (biological and foster). A) Biological cubs showed a higher frequency of play behaviors than foster cubs. B) Biological cubs showed a higher frequency of dominance behaviors than foster cubs. C) Biological cubs had a higher frequency of dominance behavior than fosters, which they exhibited more commonly during the day [time of day scaled, plot binned for visualization]. D) Precipitation [scaled] positively and marginally significantly influenced overall dominance behaviors observed. Behavior data was collected via a remote video recording of 4 black bears and their cubs temporarily held at the Black Bear Research Center in Blacksburg, Virginia in 2015-2016. Box plots show mean (middle line) and 95% CIs plus outliers, while regression shading shows 95% confidence intervals
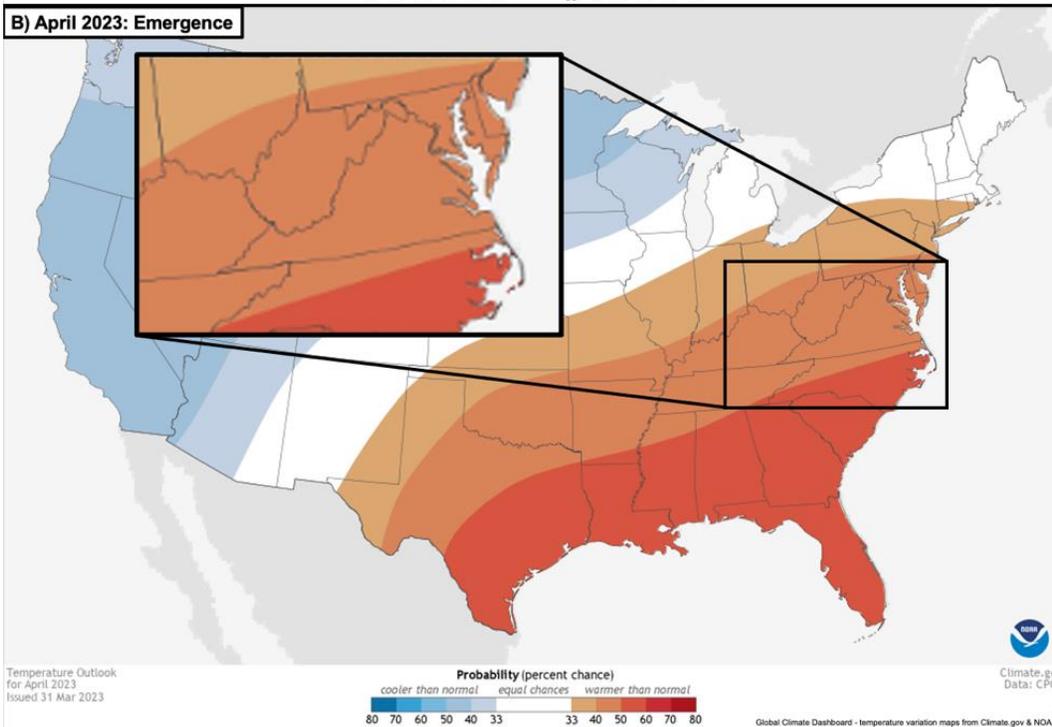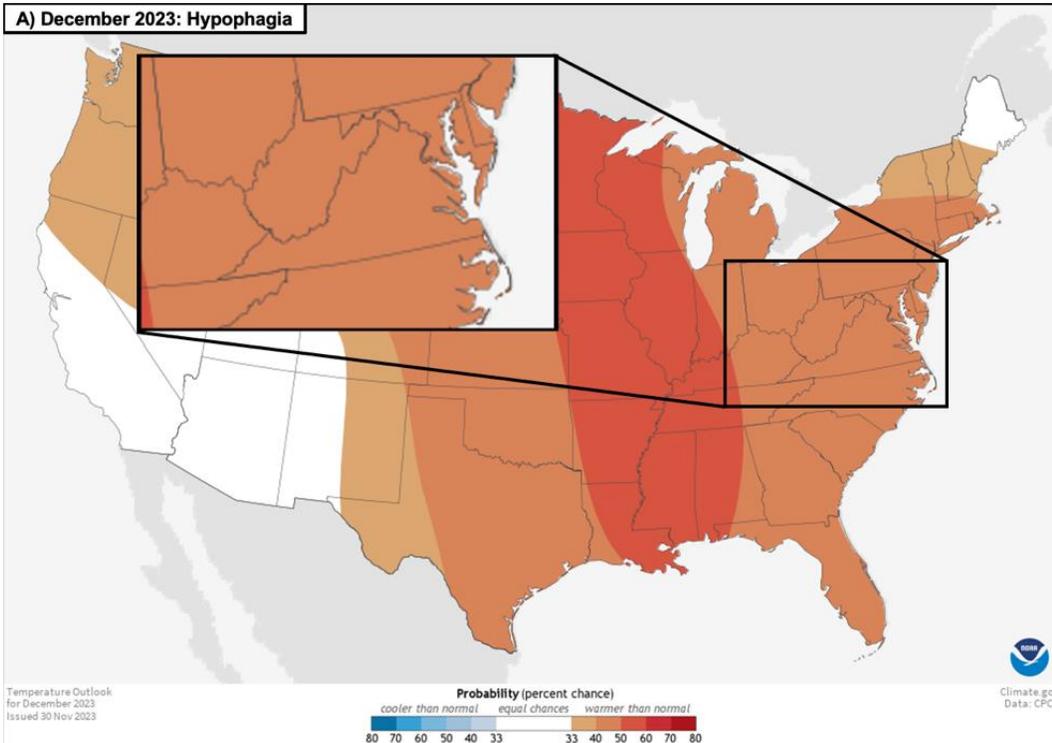
1644
1645 Figure 12. Projected impacts of climate change in the United States from the National Oceanic and
1646 Atmospheric Administration (NOAA 2023, accessed March 2023) displaying the probability of
1647 percent change in temperature, indicating that Virginia has a 40-50% chance to be warmer than normal
1648 in both A) hypophagia period (December) and B) emergence period (April).

71

1649 Table 1. American black bears housed at the Black Bear Research Center (BBRC) in Blacksburg,
1650 Virginia from September 2015 to May 2016, including BBRC assigned black bear number (black bear
1651 ID), entrance date, date of birth of cub(s), number of biological cub(s), number of fosters cub(s) and
1652 status (accepted or rejected), date of the mother emergence from a culvert (den), date of cub(s)
1653 emergence from a culvert (den), and difference in timing of mother and cub emergence noted as the
1654 duration of time between the mother and cub(s) emergence from a culvert (den). For all bears, the
1655 mother emerged first. Bear 130 was not pregnant and was released early due to difficulties acclimating
1656 to captivity.

Bear ID	Entrance Date to BBRC	Cub(s) Date of Birth	Biological Cub(s)	Foster Cub(s)	Mother Emergence Date	Cub(s) Emergence Date	Duration Between Mother & Cub(s) Emergence
Bear 126	8/7/15	2/9/16	1 Male, 1 Female	1 Male [Accepted]	04/11/16	04/12/16	9 Hours 2 Minutes
Bear 127	9/24/15	1/20/16	2 Males, 1 Female	1 Male [Accepted]	03/06/16	03/06/16	2 Hours 45 Minutes
Bear 128	9/24/15	1/25/16	2 Females	1 Male [Rejected]	03/19/16	03/19/16	0 Hours 0 Minutes
Bear 129	9/24/15	2/19/16	1 Female	1 Female [Accepted] 1 Male [Rejected]	03/28/16	04/11/16	13 days 15 Hours 50 Minutes
Bear 130	9/24/15	-	-	-	-	-	-

1657

1658 Table 2. Behavior groups for all 58 behaviors or activities documented. We defined 36 active
1659 behaviors when the individual exhibited movement of various types, passive alert (15 behaviors) as
1660 when the individual exhibited no major movement but still appeared awake/alert, and passive (four
1661 behaviors) when the individual was not moving and was sedentary (i.e., lying down sleeping, cub
1662 under mother sleeping). We excluded human-oriented events (3 behaviors) and when the black bear
1663 was out of a field of view. Data was collected from the Black Bear Research Center in Blacksburg,
1664 Virginia from September 2015 to May 2016.

Behavior Group	Behaviors		
Active Behaviors 36 behaviors	-cubs-moving (culvert) [for the pre-emergence observations] -back scratching -charging -chewing -cleaning cubs -climbing -climbing on mother -defecating -digging -drinking -eating	-grooming cubs -grooming self -licking object -nesting -nursing -pacing -panting -playing -pulling hay -repositioning -rolling on back -running -scratching ground	-scratching objects -scratching self -sniffing -staggering to walk -standing and wiggling -stretching -swaying -transporting cubs -urinating -waddling -walking -wrestling
Passive Alert Behaviors 15 behaviors	-being transported -getting groomed -getting transported -lying down grooming cub -lying down looking around	-lying down sniffing cubs -lying down wiggling -sitting -sitting looking around -sitting sniffing cubs	-standing 2 legs -standing 4 legs -standing looking around -standing sniffing cubs -yawning
Passive Behaviors 4 behaviors	-cubs-still (culvert) [for the pre-emergence observations]	-lying down -lying down sleeping -sleeping under mother	
Human-Oriented 4 behaviors	-camera malfunction -immobilization	-out of field -person cleaning	

1665

1666 Table 3. Abbreviations for covariates (Variable Codes) that were incorporated into AIC model sets with
1667 definitions, explanations, and sources for each covariate. Video data was collected from the Black Bear
1668 Research Center in Blacksburg, Virginia from September 2015 to May 2016.

Variable Codes	Model Set	Variable Definition	Variable Explanation and Sources
HibStage	Mom Dataset	Hibernation Stage	Pre-Hibernation Hyperphagic Pre-Hibernation Food Reduction Hibernation Pre-Birth Hibernation Post-Birth Emergence
BBRCDay	Mom Dataset	Days at BBRC	0 to 270 – number of days at the BBRC to allow for a continuous date
Cub Age	Cub Dataset	Cub's age	Number of days since the biological cubs were born a continuous date comparison
Time of Day	Mom and Cub Datasets	Time of the Observation	Hour, minutes, seconds using 24 hr clock when observations occurred
Precip	Mom and Cub Datasets	Precipitation Precipitation	Total Daily rainfall, R package 'prism'(Hart and Bell 2015)
Temp	Mom and Cub Datasets	Temperature	Daily mean temperature, R package 'prism' (Hart and Bell 2015)
Light	Mom and Cub Datasets	Photoperiod	Daily photoperiod (light for the day), R package 'suncalc' (Thieurmel and Elmarhraoui 2022)
Temp*Light	Mom and Cub Datasets	Temperature*Photoperiod	Daily temperature (mean; Hart and Bell 2015) multiplied by daily photoperiod (light for the day, Thieurmel and Elmarhraoui 2022)
Litter	Mom Dataset	Litter size	Number of biological cubs per mother (excluding fosters) to represent biological toll of having cubs during hibernation
Mwt	Mom and Cub Datasets	Mom's RGR	Mother's RGR (Relative growth rate) in what kilograms (kg) per day.
Bwt	Cub Dataset	Biological Cub's RGR	Biological Cub's RGR (Relative growth rate) in grams (g) per day.
Fwt	Cub Dataset	Foster Cub's RGR	Foster Cub's RGR (Relative growth rate) in grams (g) per day.

1669

1670 Table 4. Models analyzed for the adult behavior interval from September 2015 to May 2016 for active, passive
1671 alert, and passive behaviors, using Akaike Information Criterion (AIC) to rank models. Model definition describes
1672 the variables in the model, ΔAIC represents the difference in AIC between models and the top model, *w*i represents
1673 model weight, K is the number of parameters, and Log(l) is the -2LogLikelihood. Data was collected from the
1674 Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	*wi*	K	Log(*l*)
Adult Interval [September 2015 to May 2016] – Active Behaviors					
Duration Active~(1|Bear) + Hib Stage + TOD + Light + Temp + (Light*Temp)	37808.57	0.00	0.65	11	-18893.29
Duration Active~(1|Bear) + HibStage + TOD + Light + Temp + (Light*Temp) + RGR	37810.44	1.87	0.25	12	-18893.22
Duration Active~(1|Bear) + Day+TOD+Hib Stage+Precip+Temp+(Light*Temp)+RGR	37812.40	3.83	0.10	13	-18893.20
Duration Active~(1|Bear) + Day + Hib Stage + Light + Temp + (Light*Temp)	37818.49	9.91	0.00	10	-18899.24
Duration Active~(1|Bear)+ Hib Stage + Light + Temp + (Light * Temp)	37828.15	19.57	0.00	9	-18905.07
Duration Active~(1|Bear) + Day + Hib Stage	37887.91	79.34	0.00	7	-18936.95
Duration Active~(1|Bear) + Hib Stage	37894.42	85.85	0.00	6	-18941.21
Duration Active~(1|Bear) + Day + TOD	37940.81	132.24	0.00	4	-18966.41
Duration Active~(1|Bear) + Light + Temp + (Light * Temp)	37945.10	136.53	0.00	5	-18967.55
Duration Active~(1|Bear) + Day	37946.65	138.07	0.00	3	-18970.32
Duration Active~(1|Bear) + Light	38022.88	214.30	0.00	3	-19008.44
Duration Active~(1|Bear) + RGR	38109.28	300.70	0.00	3	-19051.64
Duration Active~(1|Bear) + Precip	38129.43	320.86	0.00	3	-19061.72
Duration Active~(1|Bear) + TOD	38136.40	327.83	0.00	3	-19065.20
Duration Active~(1|Bear) + Temp	38138.42	329.84	0.00	3	-19066.21
Duration Active ~ 1	38140.35	331.78	0.00	2	-19068.18
Adult Interval [September 2015 to May 2016] – Passive Alert Behaviors					
Duration Passive Alert~(1|Bear) + TOD + Hib Stage	38069.59	0.00	0.64	7	-19027.80
Duration Passive Alert~(1|Bear) + Hib Stage	38072.92	3.33	0.12	6	-19030.46
Duration Passive Alert~(1|Bear)+ Hib Stage + Temp	38073.01	3.42	0.12	7	-19029.51
Duration Passive Alert~(1|Bear)+ Hib Stage + Light	38073.89	4.30	0.07	7	-19029.94
Duration Passive Alert~(1|Bear)+ Hib Stage + Light + Temp	38074.91	5.32	0.04	8	-19029.46
Duration Passive Alert~(1|Bear) + Light	38102.41	32.82	0.00	3	-19048.21
Duration Passive Alert~(1|Bear) + Light + Temp + (Light * Temp)	38102.60	33.01	0.00	5	-19046.30
Duration Passive Alert~(1|Bear) + Temp	38108.08	38.49	0.00	3	-19051.04
Duration Passive Alert~(1|Bear) + TOD	38114.42	44.83	0.00	3	-19054.21
Duration Passive Alert ~ 1	38118.03	48.44	0.00	2	-19057.01
Duration Passive Alert~(1|Bear) + Day	38118.18	48.59	0.00	3	-19056.09
Duration Passive Alert~(1|Bear) + RGR	38119.72	50.13	0.00	3	-19056.86
Duration Passive Alert~(1|Bear) + Precip	38119.88	50.28	0.00	3	-19056.94
Adult Interval [September 2015 to May 2016] – Passive Behaviors					
Duration Passive~(1|Bear) + Day + TOD + Hib Stage + Light + RGR	179572.63	0.00	0.69	10	-89776.32
Duration Passive~(1|Bear)+Day+TOD+Hib Stage+Precip+Temp+(Light*Temp)+RGR	179575.38	2.75	0.17	13	-89774.69
Duration Passive~(1|Bear) + TOD + Hib Stage + Light + RGR	179575.85	3.21	0.14	9	-89778.92
Duration Passive~(1|Bear) + TOD + Hib Stage + Light	179620.74	48.11	0.00	8	-89802.37
Duration Passive~(1|Bear) + TOD + Hib Stage	179663.32	90.69	0.00	7	-89824.66
Duration Passive~(1|Bear) + Day + Hib Stage + Light + RGR	179737.57	164.94	0.00	9	-89859.79
Duration Passive~(1|Bear) + HibStage + Light + Temp + (Light*Temp) + RGR	179742.74	170.10	0.00	10	-89861.37
Duration Passive~(1|Bear) + Hib Stage + RGR	179760.59	187.96	0.00	7	-89873.30
Duration Passive~(1|Bear)+ Hib Stage + Light + Temp	179782.84	210.21	0.00	8	-89883.42
Duration Passive~(1|Bear) + Hib Stage + Light	179783.35	210.71	0.00	7	-89884.67
Duration Passive~(1|Bear)+ Hib Stage + Light + Temp + (Light * Temp)	179784.33	211.69	0.00	9	-89883.16
Duration Passive~(1|Bear) + Hib Stage	179824.06	251.43	0.00	6	-89906.03
Duration Passive~(1|Bear) + Light + Temp + (Light * Temp)	180229.43	656.80	0.00	5	-90109.72
Duration Passive~(1|Bear) + RGR	180248.37	675.74	0.00	3	-90121.19
Duration Passive~(1|Bear) + Temp	180273.07	700.44	0.00	3	-90133.54
Duration Passive~(1|Bear) + Light	180379.57	806.94	0.00	3	-90186.79
Duration Passive~(1|Bear) + Day + TOD	180385.46	812.82	0.00	4	-90188.73
Duration Passive~(1|Bear) + TOD	180410.00	837.37	0.00	3	-90202.00
Duration Passive~(1|Bear) + Day	180519.31	946.67	0.00	3	-90256.65
Duration Passive~(1|Bear) + Precip	180537.12	964.49	0.00	3	-90265.56
Duration Passive ~ 1	180543.68	971.05	0.00	2	-90269.84

1675 *1|black bear* represents individual black bear as a random effect*, Day* represents Days at the BBRC (September-May), *TOD* represents Time of Day*, Temp*
1676 represents Temperature, *Precip* represents Precipitation, *RGR* represents adult female Relative Growth Rate, *Hib Stage* represents Hibernation Stage, and
1677 *Light* represents Photoperiod.
1678

Table 5. Models analyzed for the second subset of video data (recorded every 11 mins), the maternal-offspring interval dataset, for mother bears from January to May 2016 for active, passive alert, and passive behaviors using the Akaike Information Criterion (AIC) to rank models. Model definition describes the variables in the model, ΔAIC represents the difference in AIC between models and the top model, *w*i represents model weight, K is the number of parameters, and Log(*l*) is the -2LogLikelihood. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	*w*i	K	Log(*l*)
Maternal Interval [January to May 2016] – Mother – Active Behaviors					
Duration Active~(1|BearID) + Mother RGR + Biological RGR	22233.97	0.00	0.66	4	-11112.98
Duration Active~(1|BearID) + Cub Age + Mother RGR + Biological RGR	22235.93	1.97	0.25	5	-11112.97
Duration Active~(1|BearID) + Cub Age + Time of Day + Precip + Temp + Light + Mother RGR + Biological RGR	22238.92	4.95	0.06	9	-11110.46
Duration Active~(1|BearID) + Time of Day + Biological RGR	22241.15	7.18	0.02	4	-11116.57
Duration Active~(1|BearID) + Cub Age + Time of Day + Biological RGR	22242.69	8.73	0.01	5	-11116.35
Duration Active~(1|BearID) + Biological RGR	22243.25	9.28	0.01	3	-11118.62
Duration Active~(1|BearID) + Cub Age + Time of Day	22260.14	26.17	0.00	4	-11126.07
Duration Active~(1|BearID) + Cub Age	22261.65	27.69	0.00	3	-11127.83
Duration Active~(1|BearID) + Cub Age + Time of Day + Temp	22262.12	28.15	0.00	5	-11126.06
Duration Active~(1|BearID) + Light	22263.23	29.26	0.00	3	-11128.61
Duration Active~(1|BearID) + Mother RGR	22268.59	34.62	0.00	3	-11131.29
Duration Active~(1|BearID) + Temp	22269.48	35.51	0.00	3	-11131.74
Maternal Interval [January to May 2016] – Mother – Passive Alert Behaviors					
Duration Passive Alert~(1|BearID) +Cub Age +TOD +Temp +Mother RGR	24820.20	0.00	0.73	6	-12404.10
Duration Passive Alert~(1|BearID) + Cub Age + TOD + Precip + Temp + Light + Mother RGR + Biological RGR	24822.98	2.78	0.18	9	-12402.49
Duration Passive Alert~(1|BearID) + Cub Age + TOD + Mother RGR	24824.92	4.72	0.07	5	-12407.46
Duration Passive Alert~(1|BearID) + Cub Age + Temp + Mother RGR	24827.86	7.66	0.02	5	-12408.93
Duration Passive Alert~(1|BearID) +Cub Age+Mother RGR+Biological RGR	24833.32	13.12	0.00	5	-12411.66
Duration Passive Alert~(1|BearID) + Cub Age+TOD+Temp+Biological RGR	24833.65	13.45	0.00	6	-12410.82
Duration Passive Alert~(1|BearID) + Cub Age	24843.27	23.07	0.00	3	-12418.63
Duration Passive Alert~(1|BearID) + Light	24855.61	35.42	0.00	3	-12424.81
Duration Passive Alert~(1|BearID) + Temp	24917.99	97.79	0.00	3	-12455.99
Duration Passive Alert~(1|BearID) + TOD + Biological RGR	24940.10	119.91	0.00	4	-12466.05
Duration Passive Alert~(1|BearID) + Precip	24946.79	126.59	0.00	3	-12470.39
Duration Passive Alert~(1|BearID) + Biological RGR	24947.46	127.26	0.00	3	-12470.73
Duration Passive Alert~(1|BearID) + TOD	24948.41	128.21	0.00	3	-12471.20
Duration Passive Alert~(1|BearID) + Mother RGR	24952.23	132.03	0.00	3	-12473.12
Duration Passive Alert ~ 1	24956.70	136.51	0.00	2	-12476.35
Maternal Interval [January to May 2016] – Mother – Passive Behaviors					
Duration Passive~(1|BearID) + Cub Age + TOD + Temp	79365.85	0.00	0.51	5	-39677.92
Duration Passive~(1|BearID) + Cub Age + TOD + Temp + Biological RGR	79367.74	1.89	0.20	6	-39677.87
Duration Passive~(1|BearID) + Cub Age + TOD + Temp + Mother RGR + Biological RGR	79368.55	2.71	0.13	7	-39677.28
Duration Passive~(1|BearID) + Cub Age + TOD	79371.07	5.23	0.04	4	-39681.54
Duration Passive~(1|BearID) + Cub Age + TOD + Precip + Temp + Light + Mother RGR + Biological RGR	79371.12	5.28	0.04	9	-39676.56
Duration Passive~(1|BearID) + Cub Age + TOD + Mother RGR	79371.29	5.45	0.03	5	-39680.65
Duration Passive~(1|BearID) + Cub Age + TOD + Precip	79371.36	5.52	0.03	5	-39680.68
Duration Passive~(1|BearID) + Cub Age + TOD + Biological RGR	79373.03	7.19	0.01	5	-39681.52
Duration Passive~(1|BearID) + Cub Age + Temp	79527.81	161.96	0.00	4	-39759.90
Duration Passive~(1|BearID) + Cub Age + Temp + Biological RGR	79529.81	163.96	0.00	5	-39759.90
Duration Passive~(1|BearID) + Cub Age	79532.20	166.35	0.00	3	-39763.10
Duration Passive~(1|BearID) + Light	79558.80	192.95	0.00	3	-39776.40
Duration Passive~(1|BearID) + Temp	79780.86	415.01	0.00	3	-39887.43
Duration Passive~(1|BearID) + Biological RGR	79840.87	475.02	0.00	3	-39917.43
Duration Passive~(1|BearID) + TOD	79915.45	549.61	0.00	3	-39954.73

1\|black bear represents individual mother black bear as a random effect, *RGR* is Relative Growth Rate, *Precip* is Precipitation, *Temp* is Temperature, and *Light* represents Photoperiod.

Table 6. Models analyzed for the second subset of video data (recorded every 11 minutes), the maternal-offspring dataset, for biological cubs from January to May 2016 for active, passive alert, and passive behaviors using Akaike Information Criterion (AIC) to rank models,. Model definition describes the variables in the model, ΔAIC represents the difference in AIC between the model and the top model, *w*i represents model weight, K is the number of parameters, and Log(*l*) is the -2LogLikelihood. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	*w*i	K	Log(*l*)
Maternal Interval [January to May 2016] – Biological Cubs – Active Behaviors					
Duration Active~(1|BearID) + Cub Age+Temp+Mother RGR+Biological RGR	21389.37	0.00	0.96	6	-10688.69
Duration Active~(1|BearID) + Cub Age + Temp + Biological RGR	21395.57	6.20	0.04	5	-10692.79
Duration Active~(1|BearID) + Cub Age + Temp + Mother RGR	21406.24	16.87	0.00	5	-10698.12
Duration Active~(1|BearID) + Cub Age + Temp	21427.15	37.78	0.00	4	-10709.58
Duration Active~(1|BearID) + Cub Age + Mother RGR	21435.46	46.09	0.00	4	-10713.73
Duration Active~(1|BearID) + Cub Age	21440.55	51.17	0.00	3	-10717.27
Duration Active~(1|BearID) + Light + Temp + Biological RGR	21504.64	115.27	0.00	5	-10747.32
Duration Active~(1|BearID) + Light + Temp	21513.84	124.47	0.00	4	-10752.92
Duration Active~(1|BearID) + Light	21515.07	125.70	0.00	3	-10754.54
Duration Active~(1|BearID) + Biological RGR	21515.65	126.28	0.00	3	-10754.83
Duration Active~(1|BearID) + Precip	21541.25	151.88	0.00	3	-10767.63
Duration Active~(1|BearID) + Time of Day	21553.77	164.40	0.00	3	-10773.89
Duration Active~(1|BearID) + Temp	21554.06	164.69	0.00	3	-10774.03
Duration Active~(1|BearID) + Mother RGR	21554.79	165.42	0.00	3	-10774.39
Duration Active ~ 1	21555.44	166.07	0.00	2	-10775.72
Maternal Interval [January to May 2016] – Biological Cubs – Passive Alert Behaviors					
Duration Passive Alert~(1|BearID) + Time of Day + Precip + Light	11509.74	0.00	0.91	5	-5749.87
Duration Passive Alert~(1|BearID) + Cub Age + Time of Day + Precip	11514.53	4.78	0.08	5	-5752.26
Duration Passive Alert~(1|BearID) + Light + Temp	11521.15	11.41	0.00	4	-5756.57
Duration Passive Alert~(1|BearID) + Precip	11523.02	13.28	0.00	3	-5758.51
Duration Passive Alert~(1|BearID) + Time of Day	11530.06	20.32	0.00	3	-5762.03
Duration Passive Alert~(1|BearID) + Cub Age + Time of Day	11530.68	20.93	0.00	4	-5761.34
Duration Passive Alert~(1|BearID) + Light	11532.27	22.52	0.00	3	-5763.13
Duration Passive Alert~(1|BearID) + Biological RGR	11539.06	29.32	0.00	3	-5766.53
Duration Passive Alert~(1|BearID) + Temp	11539.18	29.44	0.00	3	-5766.59
Duration Passive Alert ~ 1	11540.13	30.39	0.00	2	-5768.07
Duration Passive Alert~(1|BearID) + Cub Age	11541.09	31.35	0.00	3	-5767.55
Duration Passive Alert~(1|BearID) + Mother RGR	11541.73	31.99	0.00	3	-5767.87
Maternal Interval [January to May 2016] – Biological Cubs – Passive Behaviors					
Duration Passive~(1|BearID) + Cub Age + Time of Day + Precip	387158.91	0.00	0.65	5	-193574.46
Duration Passive~(1|BearID) + Cub Age +Time of Day +Precip+Mother RGR	387160.23	1.32	0.34	6	-193574.12
Duration Passive~(1|BearID) + Cub Age + Time of Day	387168.40	9.49	0.01	4	-193580.20
Duration Passive~(1|BearID) + Cub Age + Time of Day + Mother RGR	387170.00	11.09	0.00	5	-193580.00
Duration Passive~(1|BearID) + Cub Age	387328.94	170.03	0.00	3	-193661.47
Duration Passive~(1|BearID) + Time of Day + Precip + Light + Mother RGR	387340.17	181.26	0.00	6	-193664.09
Duration Passive~(1|BearID) + Time of Day + Precip + Light	387340.55	181.64	0.00	5	-193665.28
Duration Passive~(1|BearID) + Time of Day + Light	387349.81	190.90	0.00	4	-193670.90
Duration Passive~(1|BearID) + Light	387502.24	343.33	0.00	3	-193748.12
Duration Passive~(1|BearID) + Light + Mother RGR	387502.82	343.91	0.00	4	-193747.41
Duration Passive~(1|BearID) + Biological RGR	387664.74	505.83	0.00	3	-193829.37
Duration Passive~(1|BearID) + Temp	387838.35	679.44	0.00	3	-193916.17
Duration Passive~(1|BearID) + Time of Day	387905.14	746.23	0.00	3	-193949.57
Duration Passive~(1|BearID) + Mother RGR	387993.35	834.44	0.00	3	-193993.68
Duration Passive~(1|BearID) + Rainfall	388006.62	847.71	0.00	3	-194000.31
Duration Passive ~ 1	388028.59	869.68	0.00	2	-194012.29

1\black bear represents individual mother black bear as a random effect; *RGR* is Relative Growth Rate, *Precip* is Precipitation, *Temp* is Temperature, and *Light* represents Photoperiod.

Table 7. Models analyzed for the second subset of video data (recorded every 11 minutes), the maternal-offspring dataset, for foster cubs from January to May 2016 for active, passive alert, and passive behaviors using the Akaike Information Criterion (AIC) to rank models. Model definition describes the variables in the model, ΔAIC represents the difference in AIC between the model and the top model, *w*i represents model weight, K is the number of parameters, and Log(*l*) is -2LogLikelihood. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	*wi*	K	Log(*l*)
Maternal Interval [January to May 2016] – Foster Cubs – Active Behaviors					
Duration Active~(1|BearID) + Cub Age + Foster RGR	6751.62	0.00	0.48	4	-3371.81
Duration Active~(1|BearID) + Cub Age + Biological RGR + Foster RGR	6752.70	1.09	0.28	5	-3371.35
Duration Active~(1|BearID) + Cub Age + TOD + Precip + Temp + Light + Mother RGR + Biological RGR + Foster RGR	6754.56	2.94	0.11	10	-3367.28
Duration Active~(1|BearID) + Cub Age + Biological RGR	6755.96	4.34	0.05	4	-3373.98
Duration Active~(1|BearID) + Cub Age + Mother RGR + Biological RGR	6756.42	4.80	0.04	5	-3373.21
Duration Active~(1|BearID) + Light + Biological RGR + Foster RGR	6757.48	5.86	0.03	5	-3373.74
Duration Active~(1|BearID) + Light + Biological RGR	6761.57	9.95	0.00	4	-3376.78
Duration Active~(1|BearID) + Cub Age	6764.46	12.84	0.00	3	-3379.23
Duration Active~(1|BearID) + Cub Age + Mother RGR	6766.45	14.83	0.00	4	-3379.22
Duration Active~(1|BearID) + Mother RGR + Biological RGR	6768.23	16.61	0.00	4	-3380.11
Duration Active~(1|BearID) + Biological RGR	6770.21	18.60	0.00	3	-3382.11
Duration Active~(1|BearID) + Foster RGR	6776.62	25.00	0.00	3	-3385.31
Duration Active~(1|BearID) + Light	6778.30	26.68	0.00	3	-3386.15
Duration Active~(1|BearID) + Precip	6790.07	38.46	0.00	3	-3392.04
Duration Active~(1|BearID) + Temp	6793.31	41.70	0.00	3	-3393.66
Duration Active ~ 1	6796.80	45.18	0.00	2	-3396.40
Duration Active~(1|BearID) + TOD	6798.01	46.39	0.00	3	-3396.00
Duration Active~(1|BearID) + Mother RGR	6798.77	47.15	0.00	3	-3396.38
Maternal Interval [January to May 2016] – Foster Cubs – Passive Alert Behaviors					
Duration Passive Alert~(1|BearID) + Mother RGR	2242.11	0.00	0.36	3	-1118.05
Duration Passive Alert~(1|BearID) + Precip + Mother RGR	2243.32	1.21	0.20	4	-1117.66
Duration Passive Alert~(1|BearID) + Cub Age + Mother RGR	2243.48	1.37	0.18	4	-1117.74
Duration Passive Alert~(1|BearID) + Cub Age + Precip + Mother RGR	2245.09	2.98	0.08	5	-1117.55
Duration Passive Alert~(1|BearID) + CubAge +Precip +MotherRGR +FosterRGR	2246.13	4.02	0.05	6	-1117.06
Duration Passive Alert~(1|BearID) + Biological RGR	2247.22	5.12	0.03	3	-1120.61
Duration Passive Alert ~ 1	2247.84	5.73	0.02	2	-1121.92
Duration Passive Alert~(1|BearID) + Cub Age	2248.23	6.12	0.02	3	-1121.12
Duration Passive Alert~(1|BearID) + Temp	2248.33	6.23	0.02	3	-1121.17
Duration Passive Alert~(1|BearID) + Foster RGR	2248.50	6.39	0.01	3	-1121.25
Duration Passive Alert~(1|BearID) + TOD	2248.62	6.51	0.01	3	-1121.31
Duration Passive Alert~(1|BearID) + Light	2248.83	6.72	0.01	3	-1121.41
Duration Passive Alert~(1|BearID) + Precip	2249.82	7.71	0.01	3	-1121.91
Maternal Interval [January to May 2016] – Foster Cubs – Passive Behaviors					
Duration Passive~(1|BearID) + Cub Age + TOD + Biological RGR	18190.19	0.00	0.59	5	-9090.10
Duration Passive~(1|BearID)+TOD + Mother RGR + Biological RGR + Foster RGR	18191.84	1.64	0.26	6	-9089.92
Duration Passive~(1|BearID) + Cub Age + TOD + Mother RGR + Biological RGR + Foster RGR	18192.82	2.63	0.16	7	-9089.41
Duration Passive~(1|BearID) + Cub Age + TOD	18211.70	21.51	0.00	4	-9101.85
Duration Passive~(1|BearID) + Cub Age + TOD + Mother RGR	18211.73	21.53	0.00	5	-9100.86
Duration Passive~(1|BearID) + Cub Age + Biological RGR	18215.20	25.01	0.00	4	-9103.60
Duration Passive~(1|BearID)+Cub Age+Mother RGR+BiologicalRGR+FosterRGR	18217.76	27.57	0.00	6	-9102.88
Duration Passive~(1|BearID) + Cub Age	18235.58	45.39	0.00	3	-9114.79
Duration Passive~(1|BearID) + Cub Age + Mother RGR	18236.07	45.88	0.00	4	-9114.04
Duration Passive~(1|BearID) + Light	18271.01	80.82	0.00	3	-9132.50
Duration Passive~(1|BearID) + Mother RGR + Biological RGR + Foster RGR	18283.08	92.89	0.00	5	-9136.54
Duration Passive~(1|BearID) + Biological RGR	18301.50	111.31	0.00	3	-9147.75
Duration Passive~(1|BearID) + TOD	18310.31	120.11	0.00	3	-9152.15
Duration Passive~(1|BearID) + Foster RGR	18310.86	120.67	0.00	3	-9152.43
Duration Passive~(1|BearID) + Temp	18317.42	127.23	0.00	3	-9155.71
Duration Passive~(1|BearID) + Mother RGR	18321.45	131.25	0.00	3	-9157.72
Duration Passive~(1|BearID) + Precip	18326.28	136.08	0.00	3	-9160.14

1\black bear represents individual mother black bear as a random effect, *RGR* is Relative Growth Rate, *Precip* is Precipitation, *Temp* is Temperature, *Light* represents Photoperiod, *TOD* is time of day

Table 8. Models analyzed for the second subset of video data (recorded every 11 minutes), the maternal-offspring dataset for interactions between mother and cubs (biological and foster) from January to May 2016 for active, passive alert, and passive behaviors using Akaike Information Criterion (AIC) to rank models. Model definition describes the variables in the model, ΔAIC represents the difference in AIC between the model and the top model, *w*i represents model weight, K is the number of parameters, and Log(l) is the -2LogLikelihood. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	*w*i	K	Log(*l*)
Maternal Interval [January to May 2016] – Mother Interactions					
Duration Interaction~(1|BearID) + Cub Age + TOD + Behavior Type	46311.94	0.00	1.00	6	-23149.97
Duration Interaction~(1|BearID) + TOD + Behavior Type + Mother RGR + Biological RGR	46323.79	11.85	0.00	7	-23154.90
Duration Interaction~(1|BearID) + TOD + Behavior Type + Mother RGR	46334.58	22.64	0.00	6	-23161.29
Duration Interaction~(1|BearID) + TOD + Behavior Type	46339.38	27.44	0.00	5	-23164.69
Duration Interaction~(1|BearID) + TOD + Behavior Type + Precip	46340.49	28.55	0.00	6	-23164.25
Duration Interaction~(1|BearID) + Behavior Type	46341.18	29.24	0.00	4	-23166.59
Duration Interaction~(1|BearID) + Cub Age	48984.21	2672.27	0.00	3	-24489.10
Duration Interaction~(1|BearID) + Light	48998.95	2687.01	0.00	3	-24496.48
Duration Interaction~(1|BearID) + TOD	49003.49	2691.55	0.00	3	-24498.75
Duration Interaction~(1|BearID) + Biological RGR	49022.81	2710.86	0.00	3	-24508.40
Duration Interaction~(1|BearID) + Temp	49030.56	2718.62	0.00	3	-24512.28
Duration Interaction~(1|BearID) + Mother RGR	49048.61	2736.67	0.00	3	-24521.31
Duration Interaction~(1|BearID) + Precip	49056.90	2744.96	0.00	3	-24525.45
Duration Interaction ~ 1	49059.53	2747.59	0.00	2	-24527.76
Duration Interaction~(1|BearID) + Foster RGR	49061.16	2749.22	0.00	3	-24527.58

1|BearID represents individual mother black bear as a random effect, *TOD* is time of day, *Behavior Type* is Active, Passive Alert, and Passive, *Precip* is Precipitation, *RGR* is Relative Growth Rate, *Temp* is Temperature, and *Light* represents Photoperiod.

1711   Table 9. Models analyzed for the second subset of video data (recorded every 11 minutes), the mother black
1712   bear & cubs' dataset, play, and dominance interactions between biological and foster cubs from January to May
1713   2016 for active, passive alert, and passive behaviors. Using Akaike Information Criterion (AIC) to rank models,
1714   top model(s) noted with (ΔAIC>2.0).). Model definition describes the variables in the model, AIC represents
1715   the Akaike Information Criterion for model comparison, ΔAIC represents the difference in AIC between
1716   models, wi represents model weight, K presents the number of parameters, and Log(l) represents -
1717   2LogLikelihood. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Maternal Interval [January to May 2016] – Mutual Play Interactions					
Duration Play~(1|BearID) + black bear Group	7585.59	0.00	0.56	3	-3789.80
Duration Play~(1|BearID) + Cub Age + black bear Group	7587.59	2.00	0.20	4	-3789.79
Duration Play~(1|BearID) + Cub Age + black bear Group + Precip	7588.99	3.39	0.10	5	-3789.49
Duration Play~(1|BearID) + black bear Group + Foster RGR	7589.22	3.63	0.09	5	-3789.61
Duration Play~(1|BearID) + Cub Age + black bear Group + Precip + Foster RGR	7590.58	4.99	0.05	6	-3789.29
Duration Play~(1|BearID) + Foster RGR	7744.27	158.67	0.00	3	-3869.13
Duration Play ~ 1	7744.28	158.69	0.00	2	-3870.14
Duration Play~(1|BearID) + Light	7744.63	159.04	0.00	3	-3869.32
Duration Play~(1|BearID) + Biological RGR	7745.11	159.52	0.00	3	-3869.56
Duration Play~(1|BearID) + TOD	7745.52	159.93	0.00	3	-3869.76
Duration Play~(1|BearID) + Temp	7745.58	159.98	0.00	3	-3869.79
Duration Play~(1|BearID) + Mother RGR	7746.26	160.67	0.00	3	-3870.13
Duration Play~(1|BearID) + Cub Age	7746.27	160.68	0.00	3	-3870.13
Duration Play~(1|BearID) + Precip	7746.28	160.69	0.00	3	-3870.14
Maternal Interval [January to May 2016] – Dominance Play Interactions					
Duration Dominance~(1|BearID) + TOD + black bear Group + Precip + Mother RGR	3680.89	0.00	0.69	6	-1834.45
Duration Dominance~(1|BearID) + TOD + black bear Group + Mother RGR	3683.89	3.00	0.15	5	-1836.95
Duration Dominance~(1|BearID) + black bear Group + Precip	3685.25	4.36	0.08	4	-1838.63
Duration Dominance~(1|BearID) + black bear Group + Mother RGR	3685.58	4.69	0.07	4	-1838.79
Duration Dominance~(1|BearID) + TOD + black bear Group	3688.59	7.70	0.01	4	-1840.29
Duration Dominance~(1|BearID) + black bear Group	3692.21	11.32	0.00	3	-1843.10
Duration Dominance~(1|BearID) + Mother RGR	3764.01	83.12	0.00	3	-1879.01
Duration Dominance~(1|BearID) + Precip	3766.72	85.83	0.00	3	-1880.36
Duration Dominance~(1|BearID) + TOD	3770.99	90.10	0.00	3	-1882.49
Duration Dominance~(1|BearID) + Temp	3772.16	91.27	0.00	3	-1883.08
Duration Dominance~(1|BearID) + Biological RGR	3772.17	91.28	0.00	3	-1883.08
Duration Dominance ~ 1	3772.35	91.46	0.00	2	-1884.17
Duration Dominance~(1|BearID) + Foster RGR	3773.40	92.51	0.00	3	-1883.70
Duration Dominance~(1|BearID) + Cub Age	3773.69	92.80	0.00	3	-1883.84
Duration Dominance~(1|BearID) + Light	3774.17	93.28	0.00	3	-1884.09

1718   *1\black bear* represents individual mother black bear as a random effect, *black bear Group* represents Cub Groups of Biological
1719   or Foster, *RGR* is Relative Growth Rate, *Precip* is Precipitation, *Temp* is Temperature, and *Light* represents Photoperiod.

Supplementary Material
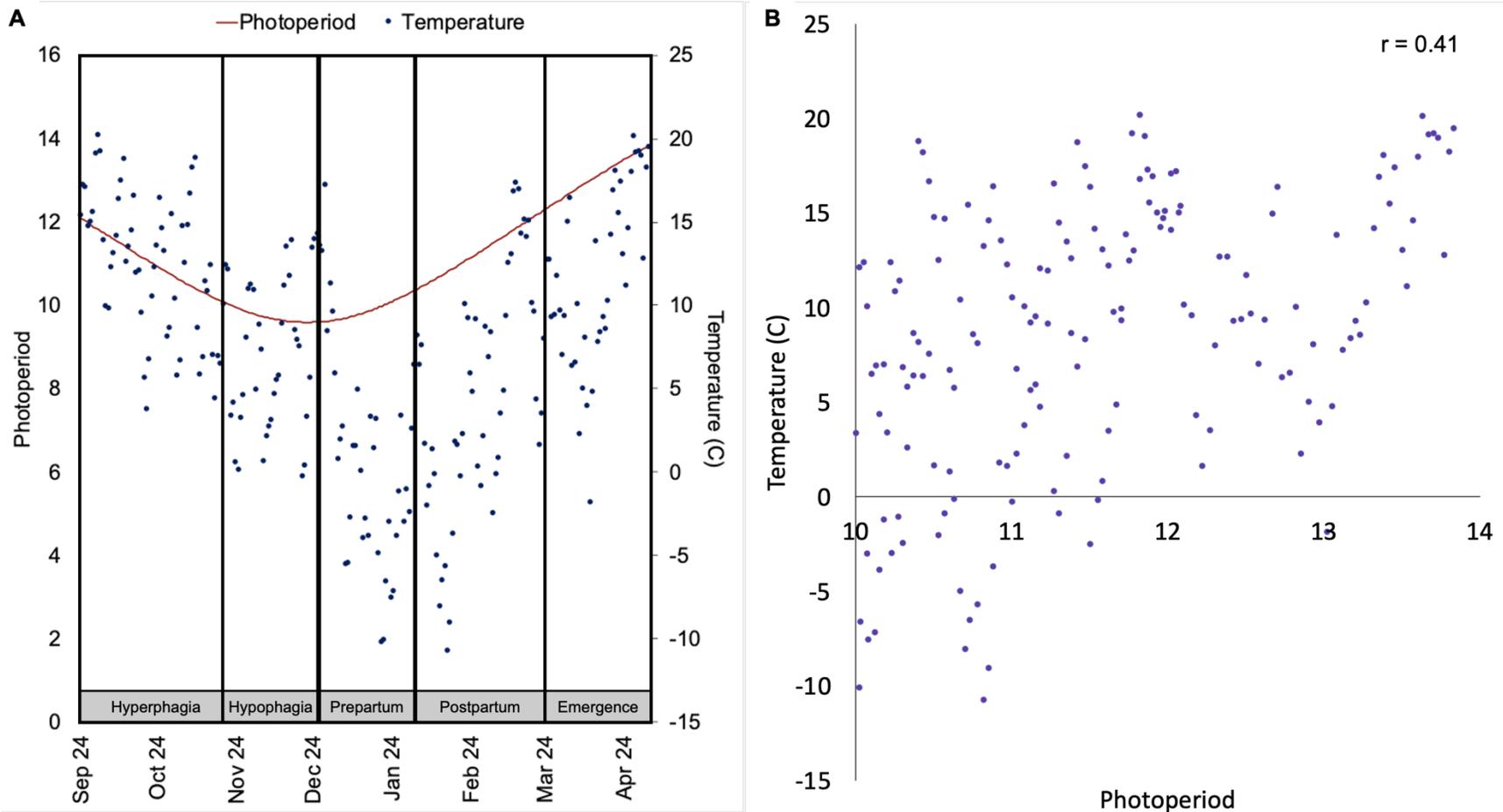
Supplementary Figure S1. A) Photoperiod (hours of light per day, left axis, red line) and mean daily temperature (Celsius, blue points, right axis) and over time during the survey period of September to May 2015-2016 as extracted from R package 'suncalc' (Thieurmel and Elmarhraoui 2022) for the area surrounding the BBRC. B) Pearson's correlation of photoperiod (Hours) and temperature (Celsius) in the adult interval showed weak correlation (r-value = 0.41), below our correlation threshold of 0.6 thus, we kept these in the same model. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

727 Supplementary Table S1. We established five hibernation stages for black bears housed at the BBRC: 1) pre-hibernation hyperphagic stage, when
728 black bears eat increased amounts of food to build up fat reserves for hibernation, 2) pre-hibernation food reduction stage, when food was reduced to
729 simulate natural conditions, 3) hibernation pre-birth stage, when females decreased activity and metabolic activity but had not given birth, 4)
730 hibernation post-birth stage, when females gave birth and were nursing but had not emerged from the den, and 5) emergence stage when mothers and
731 cubs emerge from dens and mothers begin eating and drinking, until their release date. Data was collected from the Black Bear Research Center in
732 Blacksburg, Virginia.

black bear ID	Hyperphagia		Hypophagia		Prepartum		Postpartum		Emergence	
	Start	End	Start	End	Start	End	Start	End	Start	End
Bear 126	08/07/15	12/06/15	12/07/15	1/08/16	01/09/16	02/08/16	02/09/16	04/10/16	04/11/16	05/04/16
Bear 127	09/24/15	12/06/15	12/07/15	12/25/15	12/26/15	01/19/16	01/20/16	03/05/16	03/06/16	05/04/16
Bear 128	09/24/15	12/06/15	12/07/15	12/23/15	12/24/15	01/24/16	01/25/16	03/18/16	03/19/16	05/04/16
Bear 129	09/24/15	12/06/15	12/07/15	01/07/16	01/08/16	02/18/16	02/19/16	03/27/16	03/28/16	05/04/16

733

734 Supplementary Table S2.
735 A) Pearson's correlation matrix presenting correlation coefficients between variables for the first subset of video data (one-minute observation
736 recorded every 16 minutes) for the adult female black bear dataset from September 2015 to May 2016. Moderate to highly correlated (≥0.6) variables
737 are bolded.

Variables for Adult Interval	Time of Day	Litter size	Date	Precipitation	Temperature	Photoperiod	Mom's RGR
Time of Day	1.00						
Litter size	0.00	1.00					
Date	-0.01	0.00	1.00				
Precipitation	0.01	0.00	-0.16	1.00			
Temperature	0.02	0.02	-0.06	0.20	1.00		
Photoperiod	0.02	0.02	**0.62**	0.03	0.41	1.00	
Mom's RGR	0.01	-0.09	-0.48	0.03	0.18	-0.24	1.00

738 B) Pearson's correlation matrix presenting correlation coefficients between for the second subset of video data (recorded every 11 minutes) for the
739 maternal-offspring dataset from January to May 2016. Moderately correlated (≥0.6) variables are bolded, and highly correlated (≥0.8) variables are
740 bolded and underlined.

Variables for Maternal Interval	Cub Age	Time of Day	Precipitation	Temperature	Photoperiod	Mom's RGR	Biological's RGR	Foster's RGR
Cub Age	1.00							
Time of Day	0.02	1.00						
Precipitation	0.04	-0.01	1.00					
Temperature	0.59	0.01	0.12	1.00				
Photoperiod	**_0.96_**	0.02	0.05	**0.63**	1.00			
Mom's RGR	0.26	0.00	-0.16	0.07	0.31	1.00		
Biological's RGR	0.51	0.02	0.07	0.27	0.46	-0.05	1.00	
Foster's RGR	0.31	0.01	-0.05	0.08	0.23	-0.06	0.26	1.00

741

Supplementary Table S3. A) Estimates and B) plots of β coefficients for the top models (ΔAIC< 2.0), for the adult female black bear video dataset (recording every 16 minutes) from September 2015 to May 2016 for active, passive alert, and passive behaviors. black bear ID was used as a random effect. β is the beta coefficient depicting the magnitude and direction of covariate influence in the top model(s). CI represents the 95% confidence interval for each beta coefficient. Models in shaded gray represent non-supported effects on observed behavior type (95% CIs include 0). Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Set	β_{Day} [CI]	$\beta_{HS\text{-}Hyper}$ [CI]	$\beta_{HS\text{-}Hypo}$ [CI]	$\beta_{HS\text{-}Pre}$ [CI]	$\beta_{HS\text{-}Post}$ [CI]	$\beta_{HS\text{-}Emerge}$ [CI]	β_{Light} [CI]	β_{Temp} [CI]	$\beta_{Light*Temp}$ [CI]	β_{TOD} [CI]	β_{RGR} [CI]
Active Behaviors	-0.004^ [-0.006--0.002]	-1.48 [-1.88--1.08]	-1.47 [-1.83--1.11]	-1.38 [-1.73--1.03]	0.37 [-0.51-0.23]	4.89^ [4.45-5.34]	-0.15 [-1.23--0.07]	-0.05 [-0.05--0.01]	-0.09 [-0.13--0.05]	0.11 [0.01-0.02]	0.11 [0.01-0.02]
Passive Alert Behaviors	—	-0.04 [-0.09-0.02]	-0.22 [-0.31--0.14]	-0.51 [-0.67--0.33]	-0.09 [-1.19--0.01]	4.15^ [4.07-4.23]	—	—	—	0.005 [0.001-0.010]	—s
Passive Behaviors	-0.004^ [-0.001-0.001]	0.07 [0.01-0.12]	0.10 [0.05-0.15]	0.13 [0.09-0.17]	0.15 [0.13-0.17]	5.22^ [5.15-5.29]	-0.03 [-0.04--0.02]	—	—	-0.005 [-0.005--0.004]	-0.03 [-0.03--0.02]

^ represents the intercept, *Day* represents Days at the BBRC (September-May), *HS* represents the Hibernation Stage [*HS-Hyper* is the pre-hibernation hyperphagia stage, *HS-Hypo* is the pre-hibernation food reduction stage, *HS-Pre* is the hibernation pre-birth stage, *HS-Post* is the hibernation post-birth stage, *HS-Emerge* is the emergence stage], *Light* represents Daily Photoperiod, *Temp* represents mean Daily Temperature, *Light*Temp* represents Daily Photoperiod and Daily Temperature Interaction, *TOD* represents Time of Day, and *RGR* represents Relative Growth Rate.
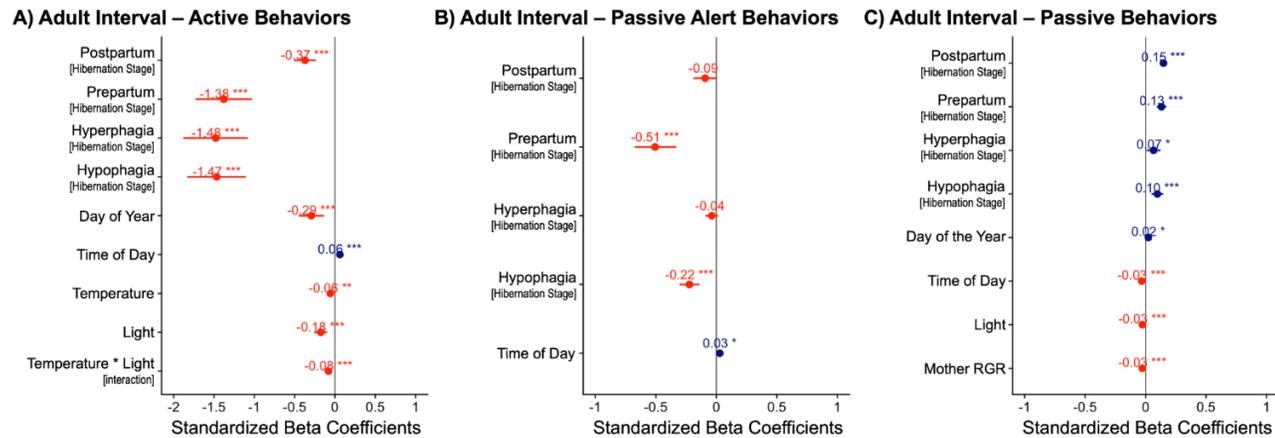
Supplementary Figure S2. Beta values and 95% confidence intervals for A) active, B) passive-alert, and C) passive behaviors for the adult interval are plotted in Table S3 above, with red indicating negative beta coefficients and blue indicating positive beta coefficients. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

84

Supplementary Table S4. Estimates of β coefficients for the top models (ΔAIC< 2.0) for the maternal-offspring video data set (recording every 11 minutes), for mother bears when cubs were present from January to May 2016 for active, passive alert, and passive behaviors. β is the beta coefficient depicting the magnitude and direction of covariate influence in the top model(s). CI represents the 95% confidence interval for each beta coefficient. Models in shaded gray represent non-supported effects on observed behavior type (95% CIs include 0). Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Set	Intercept [CI]	β_{CA} [CI]	β_{BRGR} [CI]	β_{MRGR} [CI]	β_{TOD} [CI]	β_{Temp} [CI]
Active Behaviors	4.11 [4.06-4.14]	—	0.22 [0.15-0.29]	-0.07 [-0.11--0.03]	—	—
Passive Alert Behaviors	3.81 [3.67-3.96]	0.009 [0.007-0.011]	0.06 [-0.01-0.13]	—	0.010 [0.004-0.016]	0.04 [-0.01-0.08]
Passive Behaviors	5.88 [5.85-5.91]	-0.004 [-0.005--0.003]	-0.002 [-0.011-0.001]	—	-0.015 [-0.025--0.003]	-0.007 [-0.009--0.006]

CA represents Cub Age, *BRGR* represents Biological Cub's Relative Growth Rate, *MRGR* represents Mother Bear's Relative Growth Rate, *TOD* represents Time of Day, *Light* represents Daily Photoperiod, and *Temp* represents mean Daily Temperature.

Supplementary Figure S3. Beta values and 95% confidence intervals for A) active, B) passive-alert, and C) passive behaviors for the mother interval for mother bears are plotted in Table S4 above, with red indicating negative beta coefficients and blue indicating positive beta coefficients. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Set	Intercept [CI]	β_{Light} [CI]	β_{Temp} [CI]	β_{CA} [CI]	β_{Precip} [CI]	β_{TOD} [CI]	B_{MRGR} [CI]
Active Behaviors	5.29 [5.24-5.35]	0.26 [0.18-0.34]	-0.06 [-0.12-0.01]	—	—	—	—
Passive Alert Behaviors	4.33 [4.07-4.59]	—	—	0.000 [⁻0.003-0.003]	-0.14 [⁻0.21-⁻0.08]	0.02 [0.01-0.03]	—
Passive Behaviors	4.12 [4.11-4.13]	—	—	0.000 [⁻0.001-0.000]	0.003 [0.001-0.004]	-0.001 [⁻0.002-⁻0.001]	0.001 [⁻0.001-0.002]

772 *Light* represents Daily Photoperiod, *Temp* represents Daily Temperature, *CA* represents Cub Age, *Precip* represents Daily Precipitation, *TOD* represents Time of Day, and *MRGR*
773 represents Mother's Relative Growth Rate.
774
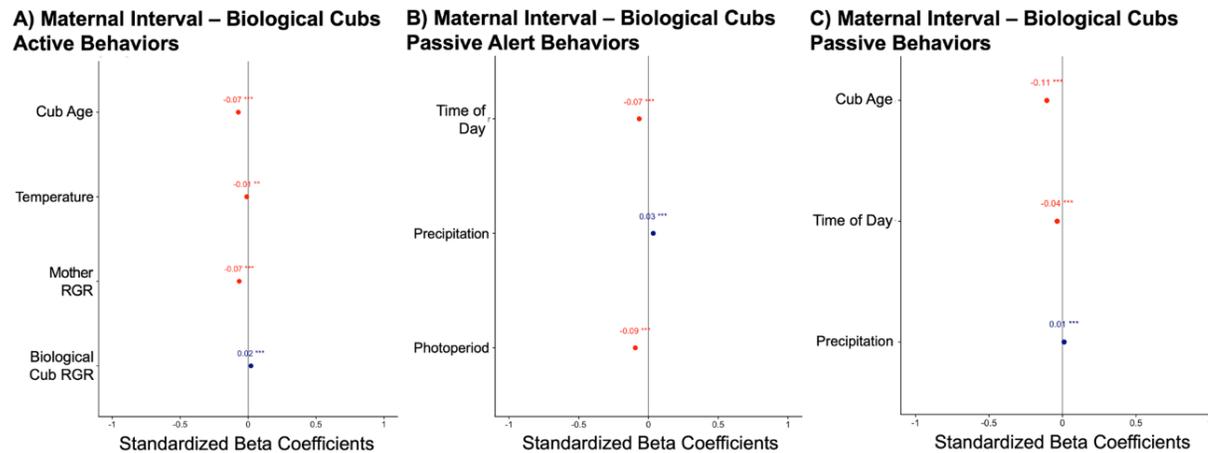
776 Supplementary Figure S4. Beta values and 95% confidence intervals for A) active, B) passive-alert, and C) passive behaviors for the mother interval
777 for biological cubs are plotted in Table S5 above, with red indicating negative beta coefficients and blue indicating positive beta coefficients. Data was
778 collected from the Black Bear Research Center in Blacksburg, Virginia.

Supplementary Table S6. Estimates of β coefficients for the top models (ΔAIC< 2.0), for the maternal-offspring video data set (recording every 11 minutes) for foster cubs from January to May 2016 for active, passive alert, and passive behaviors. β is the beta coefficient depicting the magnitude and direction of covariate influence in the top model. CI represents the 95% confidence intervals for each beta coefficient. Models in shaded gray represent non-supported effects on observed behaviors (95% CI including 0). Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Set	Intercept [CI]	β_{CA} [CI]	β_{MRGR} [CI]	β_{BRGR} [CI]	β_{FRGR} [CI]	β_{TOD} [CI]
Active Behaviors	4.02 [3.77-4.27]	0.009 [0.005-0.012]	—	-0.12 [-0.38--0.13]	-0.11 [-0.20--0.02]	—
Passive Alert Behaviors	3.88 [3.77-3.98]	—	-0.21 [-0.36--0.06]	—	—	—
Passive Behaviors	6.11 [6.02-6.20]	-0.006 [-0.007--0.005]	-0.01 [-0.04--0.02]	0.16 [0.09-0.23]	—	-0.007 [-0.009--0.004]

CA represents Cub Age, *MRGR* represents Mother Bear's Relative Growth Rate, *BRGR* represents Biological Cub's Relative Growth Rate, *FRGR* represents Foster Cub's Relative Growth Rate, and *TOD* represents Time of Day.
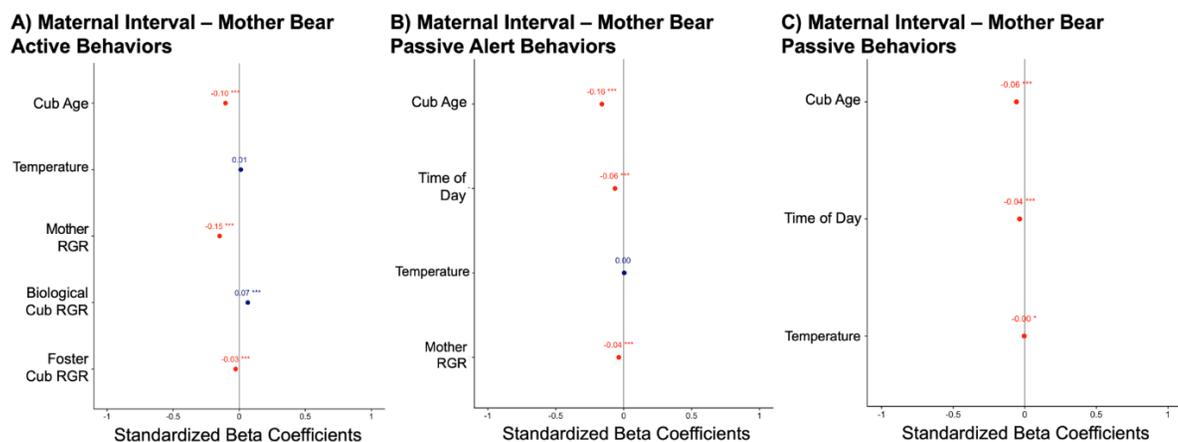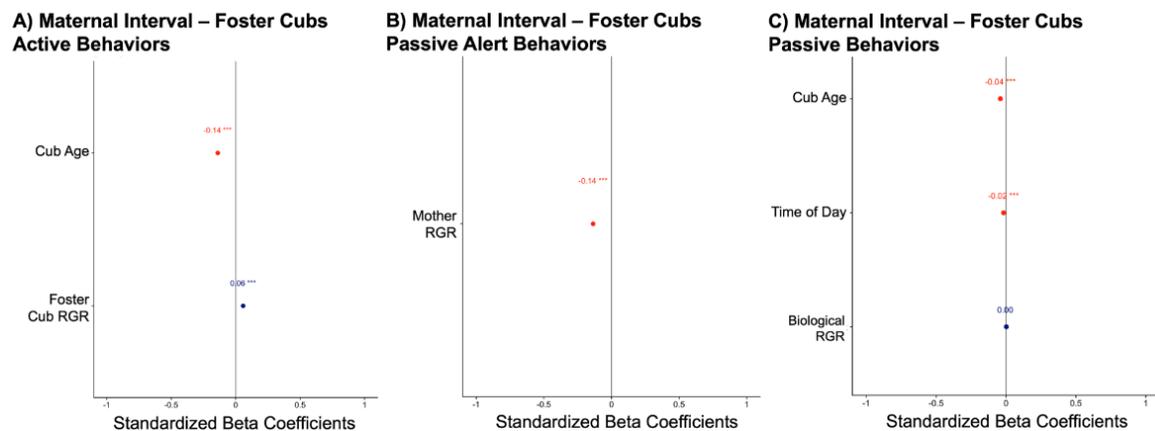

Supplementary Figure S5. Beta values and 95% confidence intervals for A) active, B) passive-alert, and C) passive behaviors for the mother interval for foster cubs are plotted in Table S6 above, with red indicating negative beta coefficients and blue indicating positive beta coefficients. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Supplementary Table S7. Estimates of β coefficients for the top models, (ΔAIC< 2.0) for the maternal-offspring video data set (recorded every 11 minutes) for interactions between mother and cubs (first row), mutual play between cub groups (second row), and dominance play between cub groups (biological and fosters) from January to May 2016. β is the beta coefficient for these interactions depicting the magnitude and direction of covariate influence in the top model. CI represents the 95% confidence intervals for each beta coefficient. Models in shaded gray represent non-supported effects on observed behaviors (95% CI including 0). Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

Model Set	β_{BT-A} [CI]	β_{BT-PA} [CI]	β_{BT-P} [CI]	β_{TOD} [CI]	β_{CA} [CI]	β_{BG-B} [CI]	β_{BG-F} [CI]	β_{MRGR} [CI]	β_{Precip} [CI]
Mother Interactions	4.24^ [4.15-4.34]	0.32 [0.26-0.39]	1.54 [1.47-1.57]	-0.003 [⁻0.005-⁻0.002]	—	—	—	—	—
Mutual Play Interactions	—	—	—	—	0.001 [⁻0.005-0.005]	5.01^ [4.62-5.40]	-0.85 [⁻0.97-⁻0.73]	—	—
Dominance Interactions	—	—	—	0.02 [⁻0.01-0.03]	—	4.55^ [4.31-4.79]	-0.97 [⁻1.16-⁻0.79]	0.14 [0.01-0.27]	0.12 [0.02-0.23]

^ represent the intercept, *BT* represents Behavior Type [*BT-A* is for Behavior Type Active, *BT-PA* is for Behavior Type Passive Alert, *BT-P* is for Behavior Type Passive], *TOD* represents Time of Day, *CA* represents Cub Age, *BG* represents black bear Group [*BG-B* is for Biological Cub black bear Group, *BG-F* is for Foster Cub black bear Group], *MRGR* represents Mother Bear's Relative Growth Rate, and *Precip* represents Daily Precipitation.
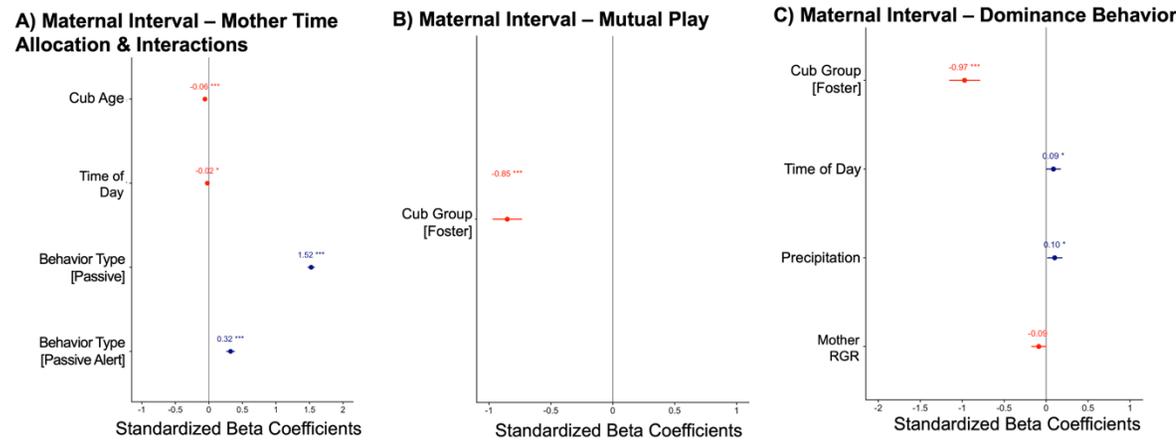
Supplementary Figure S6. Beta values and 95% confidence intervals for the maternal-offspring video data set (recorded every 11 minutes) for A) interactions between mother and cubs (first row), B) mutual play between cub groups (second row), and C) dominance play between cub groups (biological and fosters) are plotted in Table S7 above, with red indicating negative beta coefficients and blue indicating positive beta coefficients. Data was collected from the Black Bear Research Center in Blacksburg, Virginia.

1811 **Chapter 3: Foraging behaviors, diet composition, and literature comparative analysis of**

1812 **wild American black bears (*Ursus americanus*) via camera collars**

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1821 *Abstract*

1822 Foraging ecology studies for many species are traditionally conducted through scat or stomach

1823 content sampling and, more recently, stable isotope analysis to better understand diet profiles and

1824 food availability on the landscape. Although scat sampling is effective for studying obligate

1825 carnivores, these methods likely are less accurate for omnivores such as American black bears

1826 (*Ursus americanus*), because soft mast, tubers, leaves, and fungi are more completely digested,

1827 likely producing incomplete diet profiles. We utilized a unique dataset from camera collars

1828 deployed on 15 bears (8 males, 7 females) in Bath County Virginia in 2018 and 2019 to better

1829 understand seasonal diet patterns and to determine habitat and environmental drivers of black

1830 bear foraging patterns. We found that our diet composition patterns were similar that reported in

1831 the previous literature, although with a few key differences. Previous studies had significantly

1832 and substantially higher unknown diet items across all seasons. We also found high dietary

1833 overlap between males and females, but females tended to have higher diet breadth in spring and

1834 summer than males. Bears had higher levels of consumption of herbaceous soft mast in the

1835 spring that occurred closer to human development/land use for males and closer to mesic forest

1836 for females. Fruit and seed soft mast dominated summer diets (especially farther away from

1837 livestock pastures for males and xeric forests for females), whereas fall diets consisted of hard

1838 mast (closer to croplands for males). Females exhibited more hunting events on white-tailed deer

1839 (*Odocoileus virginianus*) fawns (8) than males (1), especially in spring, yet males still consumed

1840 similar numbers of deer fawns and adults (28) as females (24) in our observations. Duration of

1841 deer consumption events was longer when bears hunted versus scavenged deer and deer

1842 consumption events were more often occurred farther from humans, but closer to croplands.

1843 Males consumed anthropogenic foods more often than females, particularly in the spring, and

1844 closer to human development, whereas females more often consumed insect species, especially

1845 earlier in the year and at minimal to moderate understory density. Males more commonly

1846 consumed invasive species in the spring months, closer to croplands, whereas females more

1847   often consumed invasive species in summer months, closer to pastures. Our results highlight

1848   seasonally- and sex-mediated differences in black bear diets and provide information on drivers

1849   of diet choices by bears, as well as identify where foraging hotspots on species of interest occur,

1850   providing information useful to managing potential human-wildlife interactions, predator-prey

1851   relations, and invasive species spread across the landscape.

Introduction

1853 Foraging ecology is the study of various aspects of searching for and consuming food resources

1854 and can aid in understanding a species' diet and decisions in choosing diet items (Koy and

1855 Plotnick 2007). Foraging behavior has two broad biological drivers: gaining energy to support

1856 growth/development and survival, and devoting time to seeking out nutrients based on the effort

1857 required (Breed and Moore 2016). Such behavior is often discussed in terms of the tradeoff

1858 between time and energy, or as optimizing payoff from foraging decisions (Hughes 1990,

1859 Danchin et al. 2008). The guild in which animals reside (i.e., carnivore, omnivore, herbivore)

1860 determines how animals meet nutritional needs (Jeschke 2007, Stephens et al. 2007, Elbroch et

1861 al. 2015, Breed and Moore 2016, Allen et al. 2021) because, for example, a prey species may

1862 deviate from typical foraging behavior when balancing risk from predation (Howeth and Leibold

1863 2010, Roch et al. 2018).

1864 Direct observation in the field/lab or indirect observation via scat sampling or animal

1865 collection are commonly methods to conduct foraging ecology research (Hilborn et al. 2018,

1866 Dawson et al. 2021) or in a laboratory setting (Dehghani et al. 2016), noting food choices and,

1867 where possible, caloric intake (Inman 1997, Van Den Berg et al. 2016). However, direct

1868 observation is not possible for many wildlife species due to their cryptic nature, closed habitat, or

1869 danger in observing (Brown et al. 2013, Tuyttens et al. 2014). Such is the case for American

1870 black bears (*Ursus americanus*, hereafter 'black bears'), which are typically difficult to observe

1871 in natural environments and could pose risks to observers. Therefore, other techniques must be

1872 used to obtain information on their diets and food choices.

1873 Studies of black bear feeding ecology to understand diet profiles and to relate diet to

1874 landscape conditions primarily have relied on analysis of stomach contents and scat samples

1875   (Cottam et al. 1939, Beeman and Pelton 1980*a*, Eagle and Pelton 1983, Hellgren et al. 1989).

1876   Although scat/stomach sampling often is an effective method for understanding carnivorous

1877   species' diet, these methods are potentially inaccurate for omnivores such as black bears that eat

1878   vegetation, hard and soft mast, in addition to animal matter (Kindschuh et al. 2016, Morin et al.

1879   2019, Bard and Cain 2020, Dawson et al. 2021). Accordingly for omnivores, these

1880   methodologies likely do not fully account for vegetation and other soft mast species (digestible

1881   leaves, tubers and the fleshy component of fruits) that are digested quickly and, therefore, may

1882   not appear in scat or stomach samples (Merkle et al. 2013, Breed and Moore 2016, Lincoln and

1883   Quinn 2019, Dawson et al. 2021). Conversely, indigestible components of soft mast species (e.g.,

1884   fruits, seeds, hereafter "fruit and seed soft-mast") can pass through the digestive track and appear

1885   in scat (Auger et al. 2002), leading to under- or overestimates of the importance of particular diet

1886   items for bears (Koy and Plotnick 2007, Morin et al. 2016).

1887   Previous research examining the importance of different food items in the black bear's diets

1888   have found varying levels of plant matter in fecal samples, and such data commonly are recorded

1889   using only coarse scales such as grasses, stem/leaves and fruit rather than identifying specific

1890   food items (Bull et al. 2001, Di Domenico et al. 2012). Other studies have used Global

1891   Positioning System (GPS) collar locations to identify sites where black bears fed; researchers

1892   then visited the sites indicated by GPS locations to assess potential food items the black bear

1893   may have consumed and collect black bear scats found at these sites for further diet analyses

1894   (Lesmerises et al. 2015, Tezuka et al. 2023). These studies typically report the percent frequency

1895   of food items in the environment to establish a base level of availability available to foraging

1896   bears. However, researcher are rarely able to establish exactly what food items the black bear ate

1897 when present at the site (Merkle et al. 2013), and scats deposited at the site may represent food

1898 that was eaten hours or days before at a different location.

1899 Further, much of the behavioral research on black bears relative to foraging ecology often

1900 involves the relationship to human-wildlife interactions (Lewis et al. 2015, Kirby et al. 2016).

1901 Lewis et al. (2015) analyzed anthropogenic and natural foraging of the black bear in Colorado

1902 and found that bears in urban and suburban areas spend >75% of time feeding on anthropogenic

1903 food sources, especially when natural food production is low. Increased consumption of

1904 anthropomorphic foods by bears led to increased interactions with humans (Lewis et al. 2015).

1905 Questions related to black bear foraging ecology also can provide insights in to black bear

1906 behavioral components such as spatial awareness and memory. Little work has been done with

1907 wild black bears to determine if they return to specific foraging areas as part of their natural

1908 routine (Fies et al. 1987, Mitchell and Powell 2012). Black bears have been tested for spatial

1909 memory in foraging behaviors, but most studies, if not all, have been conducted on captive bears

1910 (Zamisch and Vonk 2012).

1911 In this study, we used a novel approach to investigate black bear diet composition foraging

1912 locations. We use GPS collars fitted with video cameras to directly watch what bears ate and to

1913 identify all species and durations of times bears spent foraging and consuming all diet items. Of

1914 the few past similar studies, Herbert et al. (2020) in Australia, placed camera collars on

1915 kangaroos to assess space use and diet and found that camera collars provided an effective

1916 method to identify plants (down to family) that kangaroos consumed. They also were able to

1917 associate foraging events with GPS locations, which allowed them to evaluate site selection at a

1918 fine (i.e., a single patch) and a broad (i.e., landscape) scale (Herbert et al. 2020). Camera collars

1919 were used to study kill rates of brown bears (*Ursus arctos*) in regulating other species in Alaska

1920 (Brockman et al. 2017), allowing more accurate estimates of brown bears' impacts in this area.

1921 Tezuka et al. (2023) had a similar foraging analysis on Asiatic black bears (*Ursus thibetanus*) to

1922 this study using camera collars to build a diet composition while comparing scat sampling results

1923 to assess differences between the methodologies.

1924   Black bears are often considered a generalist species (Bastille-Rousseau et al. 2011, Bonin et

1925 al. 2020), that should select low-profit items if search time is low and such items are widely

1926 available. However, in the central Appalachians and elsewhere in their distribution, black bears

1927 can exhibit a more specialist omnivore role in spring thru early summer months as they emerge

1928 from hibernation to replenish their body condition by consuming a higher proportion of high

1929 caloric, protein-rich foods such as meat. In the central Appalachians, this is primarily white-

1930 tailed deer (*Odocoileus virginianus,* hereafter deer) consumption (Clevinger 2022, Clevinger et

1931 al. 2024) than in later summer and fall diets, where they resume a more generalist role.

1932   Foraging strategies and food availability within their area of use for many species have been

1933 linked to better understanding a species' resource selection (Mitchell and Powell 2012). Thus,

1934 understanding how bears use the landscape across various habitat types, such as interior forests,

1935 agricultural lands or other landscape features, such proximity to human habitation that can

1936 provide information for managing black bear populations (Escobar et al. 2015, Connor et al.

1937 2019). Further, incorporating environmental variables, such as temperature, precipitation, and

1938 vegetation indices, can allow further insight into the dynamics of foraging species (Pigeon et al.

1939 2016). For example, Pigeon et al. (2016) found that ambient temperature was a driver for brown

1940 bears habitat selection and their spatiotemporal adjustments with altered temperatures on the

1941 landscape.

1942   We utilized GPS points paired with known foraging and non-foraging events observed via

1943   camera collars to better understand foraging and diet dynamics of bears across seasons. Our

1944   objectives were to 1) identify all unique diet items via video collars and compare to diet from the

1945   literature via scats/stomachs and stable isotope analyses; 2) explore seasonal niche breadth and

1946   niche overlap in diet for all bears and separated by sex; 3) determine impacts of covariates (i.e.,

1947   sex, season, landscape variables, and environmental variables) on black bear foraging decisions

1948   and diet consumption timing; and 4) identify if there were specific high-utilization areas within

1949   the landscape where bears foraged on particular species of interest, such as deer or invasive plant

1950   species.

1951   *Methods*

1952   *Study Site – Appalachian Mountains in Western Virginia – Bath Country, VA*

1953   Our study site was located in Bath County, Virginia, within the Valley and Ridge Physiographic

1954   Province of the central Appalachian Mountains (Figure 1). This region is characterized by long

1955   linear ridges and relatively broad valleys (Alonso 2024). This area was originally initiated as the

1956   Virginia Appalachian Carnivore Study (VACS) to study carnivore impacts on deer, due to public

1957   and agency concern about declining deer numbers as noted by decreased hunter harvest data

1958   (VDGIF 2015). The area is composed of a small amount of anthropogenic development and

1959   agricultural land uses embedded within large sections of mature hardwood forest, as well as

1960   mature mixed hardwood/conifer forest, which collectively comprise 85% of the study area. Land

1961   within the county is 56% publicly owned, with 51% as the George Washington National Forest

1962   (GWNF) managed by the UDSA Forest Service (USFS), and 5% under state management,

1963   including the Gathright Wildlife Management Area managed by the Virginia Department of

1964   Wildlife Resources (VADWR), and Douthat State Park managed by the Virginia Department of

1965   Conservation and Recreation (DCR). In addition to these publicly owned lands, there is also a

1966   large preserve managed by The Nature Conservancy in collaboration with the USFS that

1967   accounts for just under 3% of the land area (see Alonso 2024 for more detail).

1968   *Data Collection – Virginia Appalachian Carnivore Study (VACS)*

1969   Through VACS (VACS, Alonso 2024) bears were collared for the purpose of searching GPS

1970   (global positioning system) clusters to document deer predation versus scavenging. However,

1971   cluster searches for bears were inefficient in documenting predation events, especially for fawns,

1972   which were eaten too quickly if death was a result of predation by bears or if the fawn was

1973   scavenged by a black bear (i.e., road-kill). Thus, a sub-set of black bears was fitted with

1974   Vectronic Aerospace, Berlin, Germany, VERTEX PLUS Collars that each contained a video

1975   camera, GPS unit, and accelerometer to track black bear locations and activity as the animals

1976   moved across the landscape. Cameras were set at high resolution (720p resolution) and wide-

1977   angle view on preset intervals to record videos over an extended period (Table 1) to document

1978   foraging activity and facilitate the search for evidence of fawn predation and/or scavenging by

1979   black bears (Figure 2A-2D).

1980   In 2018, camera collars were placed on ten black bears (five females, five males; Table

1981   2). All ten cameras were recovered; however, one camera was damaged when the black bear was

1982   struck by a vehicle, destroying the camera and preventing video retrieval. In 2018, collars were

1983   programmed to take 20-second videos every 20 minutes for 10-14 hours a day for one to three

1984   months, coinciding with the peak in fawn births, resulting in a maximum of up to 17.5 hours of

1985   video data per black bear (Table1).

1986   In 2019, eight camera collars were placed on three females and five males and all were

1987   recovered, but one male and one female did not yield data due to malfunctions, resulting in six

1988   total black bears for the 2019 survey year. These collars were programmed to take 15-second

1989   videos every 20 minutes for 16 hours per day for 1-2 months, followed by 10-second videos

1990   every 20 minutes for 16 hours per day for 1-4 weeks. The next interval consists of 8-second

1991   videos every 60 minutes for 14 hours a day for 1-2 months, then 8-second videos every 30

1992   minutes for 12 hours a day for 3-5 weeks, and finally, 8-second videos every 30 minutes for 12

1993   hours a day for the final 3-5 weeks. These variable schedules (Table 1) allowed data collection to

1994   extend past the summer season to determine black bear behaviors in the fall, especially during

1995   hunting season.

1996   *Video Entry Methods*

1997   We recorded all food species bears interacted with (i.e., investigated, but not ingested by black

1998   bears) or consumed. We recorded duration of time spent foraging and consuming, foraging

1999   source (i.e., finding acorns in leaf litter, consuming a live plant), species consumed, interactions

2000   with the environment (including objects/material sniffed and licked), and inter- and intraspecies

2001   interactions. We categorized food items consumed into 5 broad diet categories, with some

2002   subgroupings, to allow comparison of diet composition between our study and the literature. Our

2003   categories were: animal (deer and other species), anthropogenic, insects, vegetation (fungus, hard

2004   mast, herbaceous soft mast, and fruit and seed soft mast), and unknown.

2005   *Identification and Verification*

2006   For each foraging or consumption video, an observer would identify the plant/animal/fungus

2007   species and the part interacted with or consumed. To ensure we had accurate identification, we

2008   had a team of observers familiar with Virginia species verify all plant and animal species

2009   consumed by black bears. For each foraging and consumption event of plants specifically, an

2010   initial observer identified species, genus, or family of the plant, and two additional observers,

2011   knowledgeable about Virginia plants, would verify species, genus, or family of the plant on the

2012   video. These were then cross validated and if there was any disagreement in the identification of

2013   species, the identification of the plant was moved to a genus or family level. If there was no

2014   consensus of the plant identification, it would be marked as an unknown species, which only

2015   occurred for 0.97% of the total observations.

2016   *Environmental & Landscape Variables*

2017   To relate black bear movement and foraging to environmental conditions, we downloaded daily

2018   mean temperature and precipitation from R package 'prism' maintained by The PRISM Climate

2019   Group through Oregon State University (Hart and Bell 2015) from grid cells at 1 km resolution

2020   raster files from 'a wide range of monitoring networks, applies sophisticated quality control

2021   measures, and develops spatial climate datasets to reveal short- and long-term climate patterns'

2022   (PRISM Climate Group 2024). We extracted the topographic position index (TPI), which is a

2023   method of terrain classification where the altitude of each data point is evaluated against its

2024   surrounding areas to better understand the ruggedness or exposure of a given terrain (U.S.

2025   Geological Survey, 2019). These values were extracted through the R package "raster" using the

2026   extract function (Hijmans 2022).

2027   We extracted habitat variables for each GPS point location of bears where video was

2028   taken and extracted distance to habitat type variables by integrating raster layers from the

2029   National Land Cover Database (NLCD) , the US Forest Service, and ground-truthing by the field

2030   team (Alonso 2024). This resulted in eight broad habitat types for this data set: croplands (corn

2031   (*Zea spp.*) fields, apple (*Malus spp.*) orchards, and other agriculture), mesic forest, herbaceous

2032   areas, forest edge, xeric forest, prescribed burn areas, and successional forest. Because

2033   anthropogenic areas comprise such a small portion of the landscape, we used distance to human

2034   settlements. We found a correlation between distance to apple orchard and corn crop layers of the

2035 cropland rasters, which resulted in us merging these two into one raster to have a single cropland

2036 layer for all analyses. We used Euclidean distance instead of a categorical variable for this

2037 analysis to reduce the number of categorical variables in models and to account for the home

2038 ranges of each black bear not having the same habitat composition and potentially inducing bias

2039 in our analysis (Conner et al. 2003).

2040   To assess distance to anthropogenic structures, we plotted structures within the county

2041 and surrounding area using physical addresses obtained from the Virginia Geographic

2042 Information Network (VGIN) database for Virginia and the West Virginia GIS Data Request

2043 database for West Virginia addresses (West Virginia GIS Technical Center 2022, Virginia

2044 Geographic Information Network Advisory Board 2023). Once all the points were plotted, we

2045 used nearest neighbor methods to extract distances from human settlements to collar points in

2046 meters in ArcGIS.

2047   We also recorded habitat characteristics seen directly in the videos, including the

2048 approximate understory density. Path type used was noted as no path (e.g., often pushing through

2049 vegetation), water edge, creek bed, emergent rocks, forest edge, game trail, hiking trail, gravel

2050 road/trail, old logging roads, and paved roads. For approximate understory density, we used a

2051 Daubenmire scale (Daubenmire 1959) with the following categories based on what we saw on

2052 the video open (0-5% cover), minimal (5-25% cover), moderate (25-50% cover), thick (50-75%

2053 cover), dense (75-95% cover), complete (95%+ cover), with the addition of in water or in a tree

2054 when this occurred on the videos (Supplemental Figure S1).

2055   We divided seasons into 4 groups: late spring, summer, fall, and early winter. Late spring

2056 began at the earliest camera collar start date of May 30 until June 21, which coincided with the

2057 summer vegetation coming into season as seen on videos, and is after the peak fawning date in

2058   the area of June 17th (Clevinger 2022, Clevinger et al. 2024). We categorized summer as June 22

2059   to August 31, because the first signs of hard mast appeared in the last week of August. September

2060   1 until November 30 was categorized as Fall, as this is when the black bears began to decrease in

2061   activity during this time period as food reduced on the landscape. Early winter was defined as

2062   December 1 to 15, which is when the camera collars were programmed to stop recording videos

2063   during the hibernation period when bears largely are inactive.

2064   *Literature Review*

2065   Through August of 2023, we searched Google Scholar for literature on black bear diets with

2066   terms including: *Ursus americanus*, black bear, diet composition. Our results aimed to create a

2067   profile of the 'established' black bear diet composition based on previous studies using stable

2068   isotopes, scat analysis, stomach contents, or direct observation. This resulted in over 8,400

2069   records, few of which were met our restrictions to the eastern range of black bears with a similar

2070   predator guild (i.e., no gray wolves (*Canis lupus*) or brown bear (*Ursus arctos*) species, where

2071   black bears were the largest predator in the landscape) and similar ungulate guild (i.e., no moose,

2072   caribou, and deer as the only ungulate). We composed a diet composition of black bear studies

2073   meeting our criteria from this literature review to compare to our diet composition from videos

2074   with the diet classifications described below (Fedriani et al. 2000, Melville et al. 2015).

2075   *Data Analysis*

2076   *Diet Breadth and Niche Overlap Analysis*

2077   To assess overlap in dietary overlap withing the population, we used Levin's diet breadth (Levins

2078   1974) to understand the diversity or number of different diet items consumed by individuals or

2079   groups. Levin's diet breath is often categorized in broad classifications (Krebs 2021), we

2080   calculated Levin's diet breadth by individual, and then averaged those across season and sex to

2081   identify trends in diet composition for our study area (Feinsinger et al. 1981). We used the

2082   following formula (Krebs 2021):

2083 $$Levin's\ Diet\ Breadth\ = \frac{1}{\Sigma[N]^2}$$

2084 $$N\ =\ Number\ of\ diet\ items\ found\ in\ each\ individual's\ diet$$

2085   This equation takes the sum of number of unique diet items consumed by each individual

2086   for the nine potential diet item classifications in this study. From this, the reciprocal of the sum

2087   of squares is used to normalize the values for comparison between the groups of interest. For

2088   example, if a Levin's diet breadth value is high, then the individual or group would have a large

2089   variety in their diet, whereas if the value is low (relative to others in the group), then the

2090   individual or group has a narrower diet breadth with less variety.

2091   Next, to assess overlap in diet niche we calculated Pianka's niche overlap (Pianka 1974)

2092   is commonly used to assess overlap in diet niche, usually between 2 species or within a species

2093   by season, but can be applied to assess overlap between sexes and individuals. We calculated

2094   Pianka's niche overlap between sexes and between the literature diet composition and the diet

2095   composition from our study. This method takes the product of the proportion of each diet item

2096   for each species, out of the total diet items consumed by both species combined, and sums these

2097   products for each diet item, then divides by all available diet items used by both species (i.e.

2098   sums of each proportional diet item for species 1 times that of species 2). To calculate this, we

2099   used the following formula (Krebs 2021).

2100 $$Pianka's\ Niche\ Overlap\ = \frac{\Sigma_i^n\ p_{ij}\ p_{ik}}{\sqrt{\Sigma_i^n\ p_{ij}^2\ \Sigma_i^n\ p_{ik}^2}}$$

2101 $$p_{ij}\ =\ Proportion\ resource\ [i]\ out\ of\ the\ total\ resources\ used\ by\ group\ 1$$
2102 $$p_{ik}\ =\ Proportion\ resource\ [i]\ out\ of\ the\ total\ resources\ used\ by\ group\ 2$$

2103 $$n = Total\ number\ of\ resources\ found\ used\ by\ both\ groups$$

2104 Pianka's overlap values are bounded by 0-1 such that 0 is no overlap and 1 is 100% overlap. We

2105 compared our average niche overlap by season and sex to identify whether males and females

2106 utilized different food resources and if that varied seasonally.

2107 *Foraging and Consumption Analyses*

2108 To analyze the duration of the duration of time bears spent foraging/consuming a particular diet

2109 item or the presence of a particular diet item as response variables using predictor covariates, we

2110 used generalized linear mixed models (GLMMs). The GLMM approach allowed us to determine

2111 the influence of covariates including date, time of day, daily rainfall (mm), daily average

2112 temperature (Celsius), sex, understory density, elevation, distance to human settlement, Landsat

2113 Enhanced Vegetation Index (EVI), Landsat Normalized Difference Vegetation Index (NDVI),

2114 distance to habitat types (listed above), and season, while using individual black bear as a

2115 random effect to account for individual differences. All continuous numerical covariates were

2116 scaled by z-score to be centered on 0 so that the beta values of the coefficients were comparable.

2117 We added predictor variables one at a time in a forward-based step-wise framework and used the

2118 Akaike Information Criterion (AIC) to rank models (Akaike 1973) and considered models

2119 competing if the ΔAIC between them was < 2.00 (Burnham and Anderson 2002). We used a

2120 correlation matrix to test for correlation between variables and did not include any correlated

2121 variables ($|r|$=0.60) in the same model.

2122 We use all bears in the analyses and also separated the data set by sex to determine if

2123 males and females had different patterns of foraging or consumption. We used a binomial

2124 distribution to code GPS points as foraging or consumption events (1) or other non-foraging

2125 behavior events (0) to allow a true comparison of points used for known foraging or

2126 consumption behaviors and known non-foraging or non-consumption behaviors (Keating and

2127 Cherry 2004, Johnson et al. 2006).

2128   We built a set of *a priori* models of hypothesized impacts and direction of covariates

2129 effects that we thought would influence black bear foraging ecology based on the black bear

2130 biology and findings of previous studies (Supplemental Table S1). For example, we expected to

2131 see higher levels of foraging on vegetation in higher understory densities, and higher

2132 consumption of deer fawns in moderate to dense understory as bears consumed fawns in habitats

2133 used as fawn bedding sites (Gray et al. 2017, Clevinger 2022, Edge et al. 2023). Because bears

2134 respond to seasonal food availability (citation), we expected seasonal changes in proportions of

2135 major diet types, with higher herbaceous soft mast and deer proportions in spring, higher fruit

2136 and seed soft mast in summer, and hard mast proportions highest in fall (Beeman and Pelton

2137 1980*a*, Hellgren et al. 1989, Romain et al. 2013, Hubbard et al. 2022). We also anticipated

2138 anthropogenic food consumption such as garbage, corn, or bird seed, to increase closer human

2139 settlements, pastures or croplands, due to higher presence of these foods near humans (Kirby et

2140 al. 2016, 2019, Gillman et al. 2022). We constructed additive and interactive models based on

2141 results from our *a priori* models to build *post hoc* mixed models, where we combined the

2142 strongest predictors from our best models with stepwise selection. For complete list of *a priori*

2143 hypotheses, see Supplemental Table S1).

2144 *Diet Classification GLMM Analysis*

2145 To understand how black bears are consuming diet items on the landscape, we conducted the

2146 GLMM analysis on diet items that had a large sample sizes of video observation events. This

2147 resulted in analyses broken down by sex for all diet item classifications except deer consumption

2148 where we combined all bears. We had large enough sample sizes to analyze male anthropogenic

2149   food consumption (but not females), female insect consumption (but not males), and to break

2150   into different sexes for all vegetation types except for fungus due to low sample size.

2151   For deer consumption events, we often obtained multiple videos that occurred one after

2152   another in a series and therefore we used duration of deer consumption events as our response

2153   variable assess potential correlates to deer consumption by bears, as these were not particularly

2154   common. Additionally, for all other animal consumption events, we recorded species consumed

2155   (deer, bear, bird, raccoon (*Procyon lotor*), or unknown), part consumed (muscle, organs, bone,

2156   skin, head, or unknown), carcass state (including scavenged, killed, fresh, or stillborn), likely

2157   method of acquiring deer for consumption (hunted, kleptoparasitism, or scavenging), and

2158   whether events were verified kill seen in video or suspected kill. We used negative binomial

2159   GLMMs, given the right skew in the data distribution, to account for the spread (Booth et al.

2160   2003).

2161   *Invasive Species GLMM Analysis*

2162   To understand how black bears are consuming invasive species on the landscape, we used

2163   GLMMs on this data set by sex to determine if there were differences in male versus female

2164   consumption of invasive plant species. On our study area, these invasive plant species largely

2165   consisted of autumn olive (*Elaeagnus umbellata*) and wineberry (*Rubus phoenicolasius*). We

2166   used a binomial distribution coding GPS point of bears with invasive species in their diet (1) or

2167   GPS points for any other plant consumption events (0) with the same covariates used as

2168   predictors of duration of foraging as in previous modeling sets.

2169   *Seasonal Plant Consumption and Landscape Hotspot of Target Species*

2170   To better understand seasonal plant consumption, we took the top 16 plant species and calculated

2171   the proportion of the 15 bears that had the species in their diets, as well as the proportion of the

104

2172 diet that plant species comprised and plotted them against each other to visualize trends in plant

2173 species consumption by season by bears. For assessing presence of species on the landscape, we

2174 noted the daily presence of a species was observed to graphically illustrate the presence of

2175 species in black bear consumption diets. To look at the presence of the food item in the diet, we

2176 calculated the daily proportion of this species as it was observed in the diet to denote 'Average

2177 Presence of Species in black bear Consumption Diet' on the graph.

2178   Lastly, to understand consumption events of deer and invasive species across all bears,

2179 we overlayed on their home ranges, 95% AKDE home ranges created by Alonso 2024, in the

2180 study area. To do this, we used heat maps generated in ArcGIS Pro through inputting the number

2181 of foraging events for each observed event. We used the heat map geoprocessing tool in ArcGIS

2182 Pro with the value to index it as the number of observations for the given food items. For

2183 example, if there was only one occurrence of a species being consume in an area, it would have a

2184 low intensity on the heat scale, where if there were 100 occurrences there it would have a high

2185 intensity on the heat scale.

2186 *Results*

2187 Across 15 bears with camera collars, we accumulated 78.87 hours of video in 2018 (May-

2188 August) ranging from 4.90 to 14.23 hours per black bear across nine black bears, while in 2019

2189 (May-December) we accumulated 56.85 hours of video, ranging 5.89 to 16.11 hours of video per

2190 black bear across six black bears. In total, we analyzed 135.72 hours of recorded video data

2191 across the 15 bears in this study. Due to a programming error, 23.11 hours of videos were

2192 recorded in the dark were unusable, resulting in final analysis of 112.61 hours of video that

2193 recorded a total of 40,587 camera collar events. Of these observed events, 10,535 (26%) were

2194 foraging or consumption events (29.88 hours). The duration of time bears spent their foraging

and consuming was similar at 26.5%. There were 2,225 foraging events that were unsuccessful (21.1%) and 8,310 successful (78.9%) foraging events resulting in consumption.

We observed foraging and consumption events in all four seasons. However, in the winter season, we only had 19 total foraging and consumption events, composing 0.18%, that was insufficient data to model. In the spring, we observed 1,004 foraging and consumption events, 9.53% of all foraging and consumption events observed. In the summer, we observed 7,346 (69.73%) and in the fall, we observed 2,166 (20.56%) foraging and consumption events, of all foraging and consumption events observed.

For understory density, there were 430 foraging and consumption events excluded from the analyses as they occurred in trees (429) and water (1) habitats. These 430 events composed 4.08% of the foraging and consumption events observed throughout the study. Of these, 249 events occurred in open understory (2.36%), 2,255 events were in a minimal understory (21.40%), 3,016 events were in a moderate understory (28.63%), 2,825 events were in a thick understory (26.82%), and 603 events observed were in a complete understory cover (5.72%).

Of the 430 events in trees or water, there were 58 unsuccessful (13.49%, 57 in a tree, 1 in the water) foraging events yielding no food consumed and 372 successful (86.51%) consumption events that occurred in trees, and no consumption occurred in the single water event. The consumption events in trees were composed of 238 events of hard mast, 87 events of fruit and seed soft-mast, 45 events of anthropogenic foods (mostly consumed in orchards), and two events of herbaceous soft-mast. These were excluded from our GLMM analyses as the understory classification could not be assigned, leaving 10,105 total understory data points for foraging and consumption events in the analyses.

2217   Average precipitation was 3.04 cm (range 0.00 to 44.06 cm) over both years for foraging

2218   and consumption events, with most rainfall in the summer season including the high on June 23,

2219   2018. Average daily temperature was 19.71°C (range -6.37°C to 26.40°C) over both years for

2220   foraging and consumption events, with the highest temperature in summer on July 4, 2018, and

2221   the lowest in the late fall season on November 14, 2019. Average NDVI was 0.7720 (range

2222   0.1415 to 0.9798) over both years, with highest NDVI recorded in the summer season on July 4,

2223   2018, and the lowest NDVI value in the fall season (October 6, 2019). Average EVI was 0.5408

2224   (range 0.0827 to 0.8810) over both years, with the highest EVI in the summer season (July 21,

2225   2018) and lowest EVI value in fall (October 23. 2019).

2226   *Diet Composition Comparison*
2227   *VACS Diet Composition*

2228   We observed bears consuming 183 unique diet items in videos composed of 159 fungal or

2229   vascular plant species (including invasives), seven unique insect types, six unique animal

2230   species, and six unique anthropogenic food items (including four plant species), and five types of

2231   unknown (Supplementary Table S2). Dividing the 159 fungal and vascular plant species, we

2232   observed 97 soft mast plant species with herbaceous components consumed, 54 soft mast plant

2233   species with fruit and seed components consumed, six hard mast species, four anthropogenic

2234   plants, and two fungal species.

2235   The majority of bears' diets were composed of fruit and seed (indigestible) soft mast

2236   (0.68, [95% CI – 0.55-0.81]), followed by herbaceous (digestible) soft mast (0.12 [0.08-0.17]),

2237   insects (0.08 [0.01-0.14]), hard mast (i.e., acorns, hickory nuts, 0.06 [0.00-0.13]), deer (0.03

2238   [0.00-0.05]), anthropogenic foods (0.02 [0.01-0.04]), unknown food items (0.01 [0.00-0.01]),

2239   other animal species (0.003 [0.00-0.01], and fungus species (0.00 [0.00-0.01]); Figure 3). In the

107

2240   spring, across 7 bears (3 females and 4 males), herbaceous soft mast made up the largest

2241   proportion of the spring diet at 0.56 [0.39-0.73], whereas in the summer across all 15 bears, fruit

2242   and seed soft mast was the highest at 0.68 [0.53-0.83]. In fall, across 6 bears (2 female and 4

2243   male), fruit and seed soft mast again comprised the highest level of consumption at 0.52 [0.19-

2244   0.85], followed by hard mast at 0.38 [0.06-0.69].

2245   We found significantly higher herbaceous soft mast in the spring compared to summer

2246   (t=5.90, p<0.00), and fall (t=7.02, p<0.00), and in the summer compared to fall (t=4.64, p<0.00)

2247   (Figure 3). We also found significantly lower fruit and seed soft mast (t=-7.05, p<0.00)

2248   proportions in spring versus summer diet and marginally significant lower fruit and seed soft

2249   mast in spring compared to fall (t=-2.85, p=0.05). We found marginally significantly higher

2250   insects in the diet in summer compared to fall (t=2.26, p=0.04). We also found higher hard mast

2251   in the diet in fall compared to spring (t=2.75, p=0.03) and summer (t=2.71, p=0.04). In general,

2252   black bear diet in spring consisted of herbaceous soft mast, deer, insects, anthropogenic foods,

2253   and some fruit and seed soft mast, then switched in summer to primarily fruit and seed soft mast,

2254   insects, and some herbaceous soft mast, and then switched in fall to hard mast and fruit and seed

2255   soft mast, with small components of all other diet item types (Figure 3).

2256   *VACS Animal Matter Diet Composition*

2257   Deer consumption was highest in the spring (0.13 [0.00-0.25]) as expected, with other animal

2258   species being consumed at similar low lower levels across summer and fall. The 'other animal'

2259   diet class included four species and four animal 'parts' that were not identifiable to species. The

2260   four animal species included: bears (13 videos composing 3 unique series of different black bear

2261   consumption events of cannibalism), a raccoon (1 video composing 1 series), an Eastern wild

2262   turkey (*Meleagris gallopavo*, 1 video composing 1 series), and one identifiable bird species

2263   (suspected to be a mid-size game bird [grouse, woodcock, or snipe], 1 video composing 1 series).

2264   There were 10 instances of unknown animal bones consumed and 3 instances of unknown

2265   portions of meat consumed.

2266   *Literature Diet Composition*

2267   We found 26 articles and reports that met our criteria of similarity in region and predator-prey

2268   community. Of those articles, only nine (eight articles, one report) had information on

2269   proportions of diet item classes that could be used for comparison to our study. Of those, four of

2270   the articles grouped all vegetation diet items together (Dykstra 2015, Ditmer et al. 2016, Kirby et

2271   al. 2016, Kirby et al. 2017), and for those, we had to compile our vegetation classes into a single

2272   class to compare. These four articles were also all stable isotope analyses, while the other five

2273   articles were scat or stomach collection and subsequent macroscopic analysis.

2274   *Diet Composition Comparison – VACS vs. Literature*

2275   Stable isotope studies had five diet classifications consisting of: all animal species,

2276   anthropogenic foods, insects, unknown food items, and vegetation (Figure 4A). These studies

2277   found that the majority of bears' diet was vegetation (0.66, [95% CI – 0.49-0.84]), followed by

2278   anthropogenic foods (0.28, [0.12-0.45]), animal matter (0.04, [0.00-0.08]), insects (0.01, [0.00-

2279   0.04]), and unknown food items (0.01, [0.00-0.01]). We found significantly lower levels

2280   anthropogenic food in our VACS diet (0.02 [0.0-0.04], p=0.05), while the remaining diet class

2281   confidence intervals overlapped (Figure 4A).

2282   We found that scat and stomach content papers matched more closely to our observations

2283   in item classifications. The majority of bears' diets had similar trends to VACS diet composition

2284   with fruit and seed soft mast (0.37, [95% CI – 0.19-0.54]), followed by herbaceous soft mast

2285   (0.2451, [0.1336-0.3567]) as the two largest components of the diet (Figure 4B). However, black

2286   bear diets in our study had significantly higher fruit and seed soft mast (p=0.05; Figure 4B) in

2287   the diet. The remaining diet items, had overlapping confidence intervals between our study and

2288   the literature.

2289   *Seasonal Diet Comparison – VACS vs. Literature*

2290   Of the five scat or stomach collection and subsequent macroscopic analysis papers from the

2291   literature review, four of them (Beeman and Pelton 1980*b*, Hellgren et al. 1989, Stratman and

2292   Pelton 1999, Benson and Chamberlain 2006) partitioned diet compositions by season to allow

2293   comparison to our nine diet item classifications (Figure 5). In spring the majority of bears' diets

2294   were herbaceous soft mast (0.40 [95% – 0.18-0.62]), which was lower than what we found in

2295   VACS, but CIs did overlap (Figure 5A). The literature results also showed much lower deer

2296   consumption in spring than we found, but CIs were wide for our study resulting in no significant

2297   difference. Most other diet items occurred in similar amounts with the exception of unknown

2298   food items, which were substantially and significantly (t=7.17; p=0.02) higher (0.35 [0.25-0.44])

2299   in the literature than what we found.

2300   From the literature, the majority of black bear summer diet was fruit and seed soft mast

2301   (0.44 [0.30-0.58]), but it was significantly lower (t=6.07, p<0.001) than what we found for fruit

2302   and seed soft mast (Figure 5B). In contrast, the literature reported much higher levels of

2303   anthropogenic foods (0.17 [0.03-0.32]), in summer than our study. All other diet items were

2304   found in similar amounts, except for unknown food items, which were again significantly higher

2305   (t=3.19; p=0.04) than in our study (Figure 5B).

2306   The literature records showed the majority of the fall diet was hard mast (0.40 [0.20-

2307   0.60]), similar to levels found in our study (Figure 5C). However, we did find higher levels of

2308   fruits and seeds compared to hard mast and compared to fruit and seeds from the review, but CIs

2309 overlapped. Anthropogenic foods (0.12 [0.00-0.25]) were again much higher in the literature than

2310 our findings, but CIs overlapped (Figure 5C). As for spring and summer, there were again

2311 significantly higher (t=3.77; p=0.03) in unknown food items in the literature fall diet than in our

2312 study.

2313   Although we only had 19 foraging events for winter months precluding statistical

2314 analyses, all of those were hard mast, which appeared to differ from literature results. The

2315 literature winter diet composition showed the majority of the diet was fruit and seed soft mast

2316 (0.36 [0.04-0.68]), followed by herbaceous soft mast (0.29 [0.00-0.62]), other animal species

2317 (0.12 [0.00-0.34]), insects (0.08 [0.00-0.18]), unknown food items (0.07 [0.00-0.16]), hard mast

2318 (0.06, [0.00-0.18]), anthropogenic foods (0.02, [0.00-0.03]), and deer (0.01, [0.00-0.01]). There

2319 was no fungus consumption observed in the winter literature results.

2320 *VACS Levin's Diet Breadth*

2321 For all VACS bears combined, the average annual diet breadth across the 9 diet categories we

2322 used was 2.01 (95% CI – 1.60-2.420; Figure 6) across the 15 bears. Spring average annual diet

2323 breadth had the highest value at 2.37 (0.63-3.00), followed by summer average diet breadth at

2324 1.82 (0.36-2.18), and fall with the lowest diet breadth at 1.53 (0.29-1.83). For all bears combined

2325 diet breadths all had overlapping CIs across seasons. Male black bear average annual diet

2326 breadth was 1.75 (0.45-2.20), with spring again being highest in diet breadth at 2.20 (0.74-2.94),

2327 followed by fall at 1.64 (0.41-2.05), and summer as lowest at 1.43 (0.14-1.57), with no

2328 statistically significant differences across seasons (Figure 6). Female black bear average annual

2329 diet breadth was 2.31 (0.69-2.99), with spring again having highest in diet breadth at 2.49 (1.03-

2330 3.53), followed by summer at 2.26 (0.62-2.88), and fall being lowest at 1.32 (0.21-1.53). We

2331 found statically significant higher diet breadths in summer compared to fall (t=2.84, p=0.03) for

2332   females and females also had significantly higher summer diet breadths than males (t= -2.59,

2333   p=0.04, Figure 6)

2334   *VACS Pianka's Niche Overlap*

2335   For all VACS bears combined, we found lowest overlap between spring and fall diets (0.21), low

2336   overlap between spring and summer diets (0.33), and high overlap between summer and fall diets

2337   (0.82, Figure 7A). Male VACS bears exhibited similar seasonal trends, but exhibited lower

2338   spring and summer (0.17), and spring and fall (0.12) diet overlap than annual trends (Figure 7B).

2339   Female bears had much more dietary overlap in their spring and summer diets (0.45), and spring

2340   and fall diets (0.26) than males, and also higher overlap between summer and fall diets (0.93)

2341   than males (Figure 7C). We found 0.96-0.98 dietary overlap between the sexes across all seasons

2342   (Figure 7D).

2343   *VACS Diet Composition*

2344   *Animal Consumption*

2345   We had a total of 159 animal consumption videos composing 71 unique consumption events, and

2346   three foraging-only (i.e., unsuccessful bird nest searches due to no eggs) series across 14 bears

2347   (one male black bear was not observed consuming animal matter). There were not enough non-

2348   deer animal consumption events to model, but the majority of these were from a single male

2349   black bear that was responsible for all black bear cannibalism events (3 unique events), as well

2350   as the only raccoon predation event, and the majority of the unknown bone or meat events

2351   (60.0% unknown bones events, 66.7% unknown meat events).

2352   *Deer Predation*

2353   There were 52 unique deer consumption events for all bears combined across 2018 and 2019

2354   (Figure 8A). Males had 28 and females had 24 unique consumption events overall. Seasonally,

2355 17 unique fawns total were consumed in the spring. Of these 17 fawns, male bears consumed 4,

2356 with 3 of those scavenged and an additional 1 scavenged from a bobcat cache (i.e.,

2357 kleptoparasitism). Female bears consumed at 13 of the 17 unique fawns in spring, 5 of which

2358 were likely hunted, 1 confirmed as hunted on video, 5 scavenged, and 2 more scavenged by

2359 kleptoparasitism from bobcat caches. Only 2 adult deer were consumed in the spring, with 1

2360 scavenged by a male black bear (unknown mortality source) and 1 scavenged from roadkill by a

2361 female bear. In summer, 18 fawns were consumed (9 by males and 9 by females). For male

2362 bears, 7 of the 9 were scavenged, plus 1 confirmed as kleptoparasitism, and 1 confirmed as

2363 hunted. Of the 9 fawns consumed by female bears, 6 were scavenged (including 1 shared with a

2364 male black bear during a mating series), 1 was confirmed as kleptoparasitism, and 2 were likely

2365 hunted. There were 10 adult deer consumed in summer, 9 by male bears and 1 by female bears.

2366 All of which were scavenged. In the fall, no fawns were consumed, and only 5 adult deer were

2367 consumed by male black bears only, all of which were scavenged.

2368   There was also considerable variation in the number of different deer that each black bear

2369 consumed (range 0-10 unique deer per bear). We observed 13 of the 15 bears consuming deer at

2370 some point during the study. For males, 7 out of 8 bears consumed between 1 and 10 unique

2371 deer, with the average being 3.5 deer per male black bear (1 male black bear did not consume

2372 any deer). For females, 6 out of 7 consumed between 1 and 9 unique deer, averaging 3.4 deer per

2373 female black bear (1 female black bear did not consume any deer). For fawn consumption events

2374 only, 4 out of 8 bears consumed fawns, with those bears consuming between 1 and 5 fawns each,

2375 averaging 1.63 fawns per male bear, and 4 male bears did not consume any fawns. For females, 6

2376 of 7 consumed between 1 and 9 fawns, averaging 3.14 fawns per female bear, and 1 female black

2377 bear did not consume any fawns.

2378   For the duration of deer predation, we had a single top GLMM for both sexes analyzed

2379   together that included carcass state of scavenged vs. hunted, temperature, distance to human

2380   settlements, distance to mesic forests, and distance to croplands (Table 3, Supplemental Table

2381   S3). Longer duration of feeding on deer carcasses was associated with hunting behavior and

2382   shorter time spent feeding associated with scavenging carcasses (Figure 8B). We also found

2383   moderate effects such that longer feeding duration occurred further from human settlements,

2384   closer to mesic forests, with slightly stronger effects of occurring closer to croplands. Beta

2385   coefficients for temperature and distance to xeric crossed zero and were not significant.

2386   *Anthropogenic Food Item Consumption [Males Only]*

2387   For anthropogenic consumption events for male bears, we had a single top model that included

2388   season, understory density, temperature, and distances to human settlements, mesic forests, and

2389   herbaceous pastureland (Table 4, Supplemental Table S4). Males consumed fewer anthropogenic

2390   food summer months compared to fall, whereby spring months overlapped the others (Figure 9A,

2391   9B). We found strongest support for males consuming significantly more anthropogenic foods

2392   closer to human settlements (< 1,000m) and also at lower understory densities. We had weak to

2393   moderate support for consumption at warmer temperatures, closer to herbaceous pasturelands

2394   and farther from mesic forest (Figure 9B).

2395   *Insect Consumption [Females Only]*

2396   For insect consumption events for female bears, we had a single top model that included the day

2397   of the year, time of day, understory density, and distances to human settlements, croplands, mesic

2398   forests, and xeric forests as drivers (Table 5, Supplemental Table S4). We found females

2399   consumed significantly more insects (most commonly ant and termite species) earlier in the year.

2400   The strongest two drivers included insect consumption at lower understory densities (1-5% and

2401   5-25%) and closer to xeric forests (Figure 9C, 9D), whereas there were weaker effects driving

2402   insect consumption closer to human settlements, and farther from mesic and croplands areas

2403   (Figure 9D). Weak effects also indicated females consuming more insects more often later in the

2404   day.

2405   *Herbaceous Soft Mast Species*

2406   Preliminary analysis of foraging events revealed sex-mediated differences and therefore we

2407   modeled sexes separately for the remainder of the diet items. For herbaceous soft mast

2408   consumption events for male bears, we had a single top model that included season, day of the

2409   year, understory density, TPI, temperature, and distances to human settlements and forest edge as

2410   drivers (Table 6, Supplemental Table S4). Males consumed more herbaceous soft mast in spring

2411   compared to fall (Figure 10A). Additionally, males foraged on soft mast closer to human

2412   settlements, with all other covariates only having weak influence (Figure 10B).

2413   For herbaceous soft mast consumption by female bears, our single top model included

2414   day of the year, understory density, rainfall, NDVI, and distances to human settlements and forest

2415   edge as drivers (Table 4, Supplemental Table S2). Females consumed significantly more

2416   herbaceous soft mast earlier in the year (June and July; Figure 10C). Other moderate to weak

2417   influences included consuming soft mast at higher NDVI, lower understory density, and closer to

2418   human settlements, mesic forests, herbaceous pasturelands, and xeric forests (Figure 10D).

2419   Effects of more herbaceous soft mast consumption at higher rainfall, was not supported as beta

2420   coefficients crossed zero.

2421   *Fruit & Seed Soft Mast Species*

2422   For fruit and seed soft mast consumption events for male bears, we had a single top model that

2423   included season, day of the year, understory density, TPI, temperature, and distances to human

2424 settlements, agriculture cropland, herbaceous pastureland, forest edge, and xeric forests as

2425 drivers for fruit and seed soft mast consumption (Table 7, Supplemental Table S4). We found

2426 season to be the strongest driver and that males consumed lower fruit and seed soft mast in

2427 spring compared to fall (Figure 11A). Moderate effects included males consuming more fruit and

2428 seed soft mast at higher understory densities, higher temperatures, and farther way from human

2429 settlements (Figure 11B). All other effects were weak as indicated by the magnitude of the betas

2430 (Figure 11B).

2431 For female black bear fruit and seed soft mast consumption, we had a single top model

2432 that included season, day of the year, time of day, understory density, seasons, TPI, EVI, and

2433 distances to cropland, mesic forests, herbaceous pastureland, forest edge, early-to-middle

2434 successional forests, and xeric forests as drivers (Table 7; Supplemental Table S4). Females

2435 consumed more fruit and seed soft mast in summer, with spring and fall overlapping each other

2436 (Figure 11C). Moderately strong effects included more fruit and seed soft mast consumption

2437 farther from pastures and from xeric forests (Figure 11D), whereas all other effect sizes were

2438 relatively small.

2439 *Hard Mast Species*

2440 For male black bear hard mast consumption events, we had a single top model that included day

2441 of the year, NDVI, and distances to human settlements, agriculture cropland, and xeric forests as

2442 drivers (Table 8; Supplemental Table S4). Males consumed significantly more hard mast toward

2443 the end of the year in October and November (Figure 12A). Moderately strong effects included

2444 higher consumption of hard mast closer to cropland and farther from humans, while weaker

2445 effects were consumption at a higher NDVI, and closer to xeric forests (Figure 12D).

2446   The single top model for hard mast consumption for female bears, included season, day

2447   of the year, understory density, temperature, and distances to human settlements, mesic forests,

2448   herbaceous pastureland, and early-to-middle successional forests as drivers (Table 8;

2449   Supplemental Table S4). Females consumed significantly more hard mast food sources towards

2450   the end of the year and specifically in fall months compared to summer, with spring months

2451   overlapping (Figure 12C, 12D). Several covariates had moderate effects including consuming

2452   hard mast at lower understory densities, at higher temperatures, further from human settlements,

2453   and closer to mesic forests (Figure 12D). We also found a small effects sizes for distance to the

2454   herbaceous pasturelands and minimal effects of distance to early-to-middle successional forests.

2455   *Invasive Species*

2456   We found 1275 instances of invasive species consumption, which composed 12.11% of black

2457   bears' total diets. Seasonally, summer had the highest occurrence of invasive species

2458   consumption at 1006 observations (419 by males, 587 by females), while in spring we had 135

2459   observations (81 by males, 54 by females) and in fall 134 observations (99 by males, 35 by

2460   females).

2461   For male bears invasive species consumption events, we had a single top model that

2462   included day of the year, understory density, seasons, TPI, EVI, temperature, and distances to

2463   agriculture cropland, herbaceous pastureland, forest edge, early-to-middle successional forests,

2464   and xeric forests as drivers (Table 9, Supplementary Table S4). Males consumed significantly

2465   higher invasive species in spring and summer compared to fall (Figure 13A). Other strong effects

2466   included males consuming more invasive species closer to agriculture croplands and

2467   pasturelands, while moderate effects included consumption at higher understory density and

2468   closer to successional forest (Figure 13B).

2469   For females, we had a single top model that included day of the year, time of day,

2470   understory density, season, TPI, precipitation, EVI, temperature, and distances to human

2471   settlements, agriculture cropland, herbaceous pastureland, early-to-middle successional forests,

2472   and xeric forests as drivers of invasive species consumption by female bears (Table 9,

2473   Supplementary Table S4). Females consumed significantly more invasive species later in the

2474   year and in spring and especially summer months, compared to fall (Figure 13C). Covariates

2475   with strong effects including consuming more invasive species closer to herbaceous pasturelands

2476   and to croplands and at higher temperatures and higher understory densities (Figure 13D).

2477   *Seasonal Plant Consumption and Landscape Hotspot of Target Species*

2478   The top 16 plant species in black bear diets included 11 natives, four invasive, and one

2479   anthropogenic species (Figure 14). In late spring and early summer, black bear diets were

2480   dominated by three native species (nettle species [*Urtica spp.*], jewelweed (*Impatiens capensis*))

2481   and one invasive (Spanish needles (*Bidens alba*)). The summer diet was dominated by three

2482   native species (raspberry species [*Rubus spp.*], blueberry and huckleberry [*Vaccinium spp.*]), one

2483   anthropogenic species (apples [*Malus spp.*]) and one invasive species (wineberry [*Rubus*

2484   *phoenicolasius*]) at the start to middle of the summer months, with the end of summer

2485   transitioning to fall, which was dominated by two native species (cherry species [*Prunus* spp.],

2486   pokeweed [*Phytolacca americana*]) and one invasive species (autumn olive). The fall diet was

2487   dominated by four native species (magnolia [*Magnolia spp.*], hickory mast [*Carya spp.*], black

2488   walnut mast [*Juglans nigra*], and oak mast [*Quercus spp.*]).

2489   Of the invasive species Autumn olive and wineberry where the most commonly observed

2490   species consumed, and invasive species consumption was most commonly observed in the

2491   southern portion of the county, and was observed throughout the home ranges of 14 out of the 15

2492 bears in this study (Figure 15). Deer consumption showed hotspots in south central Bath County

2493 on a mix of public and private lands, and was observed in 13 out of the 15 bears in this study

2494 (Figure 16).

2495 *Discussion*
2496 *Diet Composition Discussion*
2497 *Diet vs. Literature Composition Comparison*

2498 From our camera collars, we ultimately identified 178 items to unique species, genus, or family.

2499 This total is much higher than other previously published studies, where the highest number of

2500 unique diet items was 71 (Beeman and Pelton 1980*b*), thus providing increased resolution in diet

2501 composition for black bears. Loss of specificity in diet item identification from scats has been

2502 previously noted, particularly with plant matter in the diet (Klare et al. 2011, Morin et al. 2016,

2503 Dawson et al. 2021). Nonetheless, we found fruit and seed soft mast comprised the largest

2504 composition of bears' diet (except in spring), which has been in shown in some scat sampling

2505 studies (Beeman and Pelton 1980*b*, Hellgren et al. 1989, Stratman and Pelton 1999). Other

2506 studies, however, found the majority of the diet was hard mast (Carlock et al. 1983) or a mix of

2507 anthropogenic foods and herbaceous soft mast (Benson and Chamberlain 2006), which could be

2508 due to easier identification in scats or stomachs for these diet items and variability in levels of

2509 human presence across different study areas.

2510 To compare our diet classifications more directly to the literature, we had to collapse our

2511 large number of items and categories into only 9 broad classifications to match categories in the

2512 literature, potentially resulting in loss of substantial information and resolution on black bear

2513 diets. Nonetheless, these broad diet classifications revealed that isotope studies had high

2514 vegetation the diet, but vegetation could not be partitioned into types (e.g., hard mast, herbaceous

2515 soft mast, fruit and seed soft mast), thereby severely limiting inference from stable isotope

2516   studies (Bonin et al. 2020). Additionally, two stable isotope studies had significantly higher

2517   anthropogenic foods than ours (Dykstra et al. 2015, Kirby et al. 2016), which is expected as these

2518   studies were conducted in areas with higher human population levels, while another had similar

2519   compositions (Ditmer et al. 2016). Stable isotope techniques recently have been advancing in

2520   diet item identification capabilities (Crawford et al. 2008), but still often do not yield specific

2521   results unless items have a distinct stable isotope reading (Hatch et al. 2011), thus potentially

2522   leading to incomplete diet profiles (Teunissen van Manen et al. 2014, Merkle et al. 2017). An

2523   advantage of isotope studies, though, is identifying anthropogenic foods (Kirby et al. 2016). Our

2524   low levels of such food items more likely resulted from the rural nature of our study area as bears

2525   appeared to rarely have the opportunity to consume such foods, rather than from missing such

2526   events on video. In fact, the anthropogenic food sources in our study were mostly from hunter

2527   bait sites and human-provided foods, whereas few were from typically observed anthropogenic

2528   food sources such as garbage cans or crops (Merkle et al. 2013, Murray et al. 2015). We did find

2529   higher fruit and seed soft mast use than other studies, but error bars overlapped for both isotope

2530   and scat/stomach literature, likely due to substantial individual differences we found across bears

2531   in our study.

2532   Herbaceous soft mast was the largest component of the spring diet as expected during

2533   spring green-up as it is the most available food on the landscape when bears emerge from

2534   hibernation (Norman et al. 2017). Only one of the three scat sampling studies found a similar

2535   result (Hellgren et al. 1989), whereas the two other studies had unidentifiable food items as

2536   highest in spring (Beeman and Pelton 1980*a*, Stratman and Pelton 1999), likely due to inability

2537   to identify soft mast species in scats/stomachs. We found more similarities in summer diet with

2538   the literature compared to our video analysis with fruit and seed soft mast as the largest

2539   component, but two scat/stomach studies found similarly high anthropogenic food perhaps due to

2540   being in more human dominated landscape (Benson and Chamberlain 2006) and high herbaceous

2541   soft mast (Hellgren et al. 1989). However, there were significantly higher unknown food items in

2542   the literature, particularly in spring in other studies compared to ours.

2543   In fall, fruit and seed was the largest diet component in our study, followed closely by

2544   hard mast. In general, fall diets from the literature were most similar to our findings, with some

2545   having highest fruit and seed, and anthropogenic (Benson and Chamberlain 2006) or hard mast

2546   as the primary food source (Stratman and Pelton 1999). The dominant food source for bears in

2547   fall is typically thought to be hard mast, but can be variable by season and annual mast crop

2548   (Beeman and Pelton 1980a, Vaughan 2009), and our study points to the continued importance of

2549   fruit and seed well into fall. We could not compare our winter diet to the literature due to sample

2550   size, but all 19 videos were bears eating hard mast past November 30th. Literature studies showed

2551   more variation than what we found, but that could be due to sample size.

2552   We expected to find an underestimation of herbaceous soft mast in the literature,

2553   particularly in spring, as such foods are easily digested (Dawson et al. 2021), but most of the

2554   times our CIs overlapped the literature. However, there were significantly more unknown food

2555   items in all 3 seasons (spring, summer, fall) in the literature, calling into question the reliability

2556   of diet studies from isotopes and scats/stomachs to resolutely describe diets, especially in spring

2557   when unknown food items comprised a major portion of black bear diets in the literature. Fruit

2558   and seed soft mast is unlikely to be missed as it has been widely documented that seeds pass

2559   through the digestive tracks of animals with a single-compartment stomachs, resulting in seeds

2560   being deposited in scats (Auger et al. 2002, Berezin 2009, Tezuka et al. 2023). Not surprisingly,

2561   we found similar levels of fruit and seed in our study as the literature.

2562   We found notably more deer consumption in spring, but our wide error bars (due to

2563 individual differences among bears) did not prove to be significantly different than what was

2564 found in the literature. Using scat sampling to understand predator animal matter consumption is

2565 challenging (Murphy et al. 2017) and potentially biased by underrepresentation of diet items

2566 such as when only meat/intestines are eaten without ingesting hair or bones (Godbois et al. 2005,

2567 Morin et al. 2019). Tezuka et al. (2023) used camera collars on Asiatic black bears to compare

2568 diet composition to scat samples collected at the same time and similarly found more evidence of

2569 animal matter and herbaceous soft mast through video observation compared to scat sampling. It

2570 should be noted, however, that while we found evidence in our study of higher deer consumption

2571 in spring, yet the majority of all bears' diets, even in spring, was still plant/fungus matter.

2572 *VACS Diet Breadth and Niche Overlap*

2573 Black bear diet breadth estimates were highest in spring for both males and females, indicating

2574 that bears do not appear to become specialists on one diet item such as deer, but rather, they

2575 likely take advantage of multiple food resources including fawns as a short-duration resource

2576 pulse on the landscape in spring. This corroborates the literature describing bears as

2577 opportunistic omnivores (Bastille-Rousseau et al. 2011) and confirms our observations via

2578 videos that bears appear to encounter deer as they forage on other items and take advantage of

2579 the opportunity to hunt them when it arises (Holcomb and Kelly, personal observation). Other

2580 studies have also shown black bear to exhibit the widest diet breadths in the spring (Ben-David et

2581 al. 2004, Merkle et al. 2017, Klees van Bommel et al. 2022).

2582   We found wider diet breadths for females than males in both spring and summer, and

2583 narrower diet breadths than males in fall, but these breadths were highly variable, and CIs

2584 overlapped. Within females, though, the fall diet was significantly narrower than other seasons,

2585   indicating a more constricted diet in fall for females. Other studies have shown diet breadth to be

2586   variable within populations, sometimes being higher for males including polar bears (*Ursus*

2587   *maritimus*, King 2023) and Asiatic black bears (Naganuma et al. 2020), whereas other times

2588   female diets are more variable, such as with brown bears (Ben-David et al. 2004).

2589   Pianka's niche overlap values indicated substantial dietary overlap between males and

2590   females across all seasons. Dietary overlap between sexes has been commonly documented for

2591   omnivore species (Bianchi et al. 2014), but that does not necessarily indicate high levels of

2592   competition for resources within the species (Pianka 1974, Platt et al. 2016), but instead could

2593   reflect widely available resources on the landscape (Duquette et al. 2017).

2594   Further, we observed that the consumption of invasive species was most frequent for

2595   wineberry, which we found clustered in certain areas of the study site, and autumn olive, which

2596   we found was more widespread across the landscape for consumption events. For both of these

2597   species, black bears were consuming the fruit, and thus seeds, which can potentially lead to

2598   increased spread of these invasive species through seed dispersal (Rogers and Applegate, 1983).

2599   We documented strong seasonal diet changes within sexes from season to season, more

2600   so for males than females, likely in repose to resource availability, which can be seen in our

2601   visualization of black bear diets and plant phenology for the 16 more common plant consumed

2602   across the landscape. Those species known to ripen in summer (*Rubus* spp., apple, blueberry,

2603   huckleberry) are highly represented in summer diets while those known to fruit in fall (walnut,

2604   hickory, oak) are highly represented in fall, as noted in other black bear diet studies (Merkle et al.

2605   2017, Klees van Bommel et al. 2022). Thus, we provide further evidence of bears' opportunistic

2606   foraging strategies that appear to align with frequency of occurrence on the landscape, and we

2607   provide dates and timing of foraging changes for the 16 most common plant species, including

2608   12 native and 4 invasive species.

2609   *Deer Consumption Discussion*

2610   We found that both male and female black bears consumed similar overall numbers of deer.

2611   Scavenging (including kleptoparasitism, or the stealing of food acquired by another predator)

2612   was the most common method of acquiring deer for consumption (83.0% of the 52 deer

2613   consumed), with the majority (73.6%) of these scavenged events from other kills, natural death,

2614   or roadkill events, and a small amount (9.4%), from stealing from bobcat caches. Although we

2615   could not find studies documenting kleptoparasitism in the eastern US, it has been documented

2616   by brown bears in other systems, including taking prey from felids (i.e., Eurasian lynx (*Lynx*

2617   *lynx,* Ordiz et al. 2020) in Europe and, in the United States, black bears stealing from mountain

2618   lion (*Puma concolor*) caches or kill sites(Elbroch et al. 2015, Allen et al. 2021), potentially

2619   linked to bears' opportunistic foraging behaviors. Further, kleptoparasitism by bears may

2620   increase overall predation, as bears indirectly cause other predators to hunt more prey individuals

2621   when their cache or kill sites are raided by bears (Krofel and Kos 2010, Elbroch et al. 2015).

2622   We also documented 12 consumption events on bones or antlers (a.k.a. ostephagy) of

2623   adult deer, which has not been commonly documented in black bears. Ostephagy on cervid

2624   antlers or bones is common among mammals as a source of minerals, especially if minerals are

2625   lacking in their diet (Gambín et al. 2017). This phenomenon has been documented in brown

2626   bears consuming/chewing moose antlers (Wald 2011) and bones of many ungulates, rodents, and

2627   domestic livestock (Gambín et al. 2017), but to date, has not been documented in black bear

2628   diets.

2629   We found that black bears did hunt deer but at a much lower rate than scavenging. The

2630   majority of these hunting events were on fawns in spring, primarily by female bears. However,

2631   young, relatively immobile fawns are common on the landscape in spring (Clevinger et al. 2024)

2632   and bears are likely taking advantage of this seasonal resource. Seasonal shifts away from

2633   ungulate neonates and herbaceous soft mast in spring, to fruit, seed, and other seasonally-driven

2634   diet items, has been documented in other bear species (Ben-David et al. 2004, Ordiz et al. 2020)

2635   as well as in black bears (Merkle et al. 2017). This is likely because later in the season as

2636   neonates grow in size, gain mobility, and can remain with their mother, black bears become

2637   inefficient predators on older fawns.

2638   Although black bears consume deer, other predators on the landscape have been shown to

2639   have impacts on neonate predation (Clevinger et al 2024, Alonso 2024), indicating that complex

2640   predator-prey dynamics likely impact deer populations across the ecosystem. Other ecosystems

2641   with ungulates as a common diet item among bears, felids, and canids also have been shown to

2642   have impacts on prey populations (Elbroch et al. 2015, Allen et al. 2021). However, a recent

2643   study in our study area showed that fawn predation by bears or other mammalian predators was

2644   not, at present, a limit to deer population growth (Clevinger et al. 2024). Additionally, this

2645   ecosystem has experienced substantial changes in habitat, including general forest mesophication

2646   (increasingly wet conditions supporting moisture-loving plants/trees), and now contains large

2647   swathes of the mature forest not generally supportive of deer preferred habitat across the

2648   landscape (Lafon et al. 2017). This may lead to changes in the vegetation composition in an

2649   area, which may result in less palatable species comprising the understory (Russel et al. 2017).

2650   Plotting the distribution of observed deer consumption across the landscape, we found

2651   that there were 'hotspots' for deer consumption across the bear's home ranges in some areas, but

2652 overall, it was observed across the landscape. These events occurred closer to human settlements

2653 but further away from edge forests, which may be a function of where the deer are often found in

2654 this area. This could be due to the favorable habitat types of these locations for white-tailed deer

2655 (Clevinger et al. 2024) and/or the opportunistic nature of black bears' foraging strategies

2656 (Bastille-Rousseau et al. 2011).

2657   Camera collars provide unique insight into black bear behavior that can be observed and

2658 documented in finer detail than from GPS locational points alone. Our study, as well as those

2659 examining Asiatic black bears (Tezuka et al. 2023) and brown bears (Brockman et al. 2017),

2660 show video collars allow better understanding of diet composition and more insight into the

2661 seasonal dynamics of ungulate consumption. Further, the use of heat maps to understand bears'

2662 impact on the deer population allows rare insight into the locations of these consumption events,

2663 which is often not possible without field ground-truthing (Kindschuh et al. 2016). Emerging

2664 technologies such as camera collars provide new insight into aspects of species' behavior and

2665 ecology previously unavailable in studies conducted on wild species, and thus represent valuable

2666 assets to researchers and natural resource managers.

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Tables & Figures
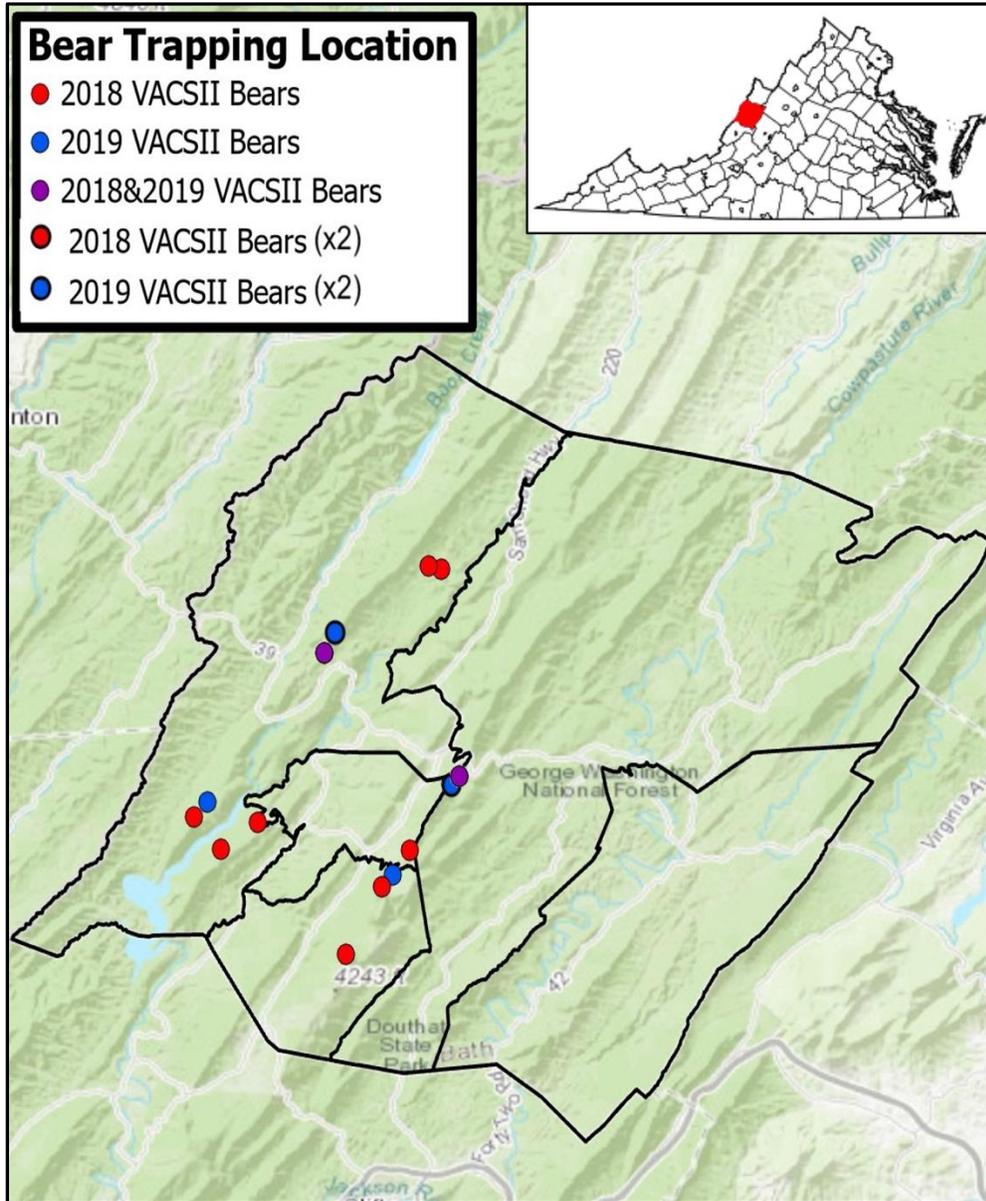
2975

2976 Figure 1. Trap locations within Bath County, Virginia (red shading in inset),
2977 in 2018 and 2019, where 15 American black bears were fitted with camera
2978 collars. Points with a bold outline are where two different bears were trapped
2979 (x2) in one year.

2980

Figure 2. View from high-resolution, camera collars, used to identify species consumed by 15 black bears: A) white-tailed deer (*Odocoileus virginianus*) fawn, B) pokeweed (*Phytolacca decandra*), C) anthropogenic foods (corn - *Zea mays*), and D) invasive species - autumn olive (*Elaeagnus umbellata*). Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.
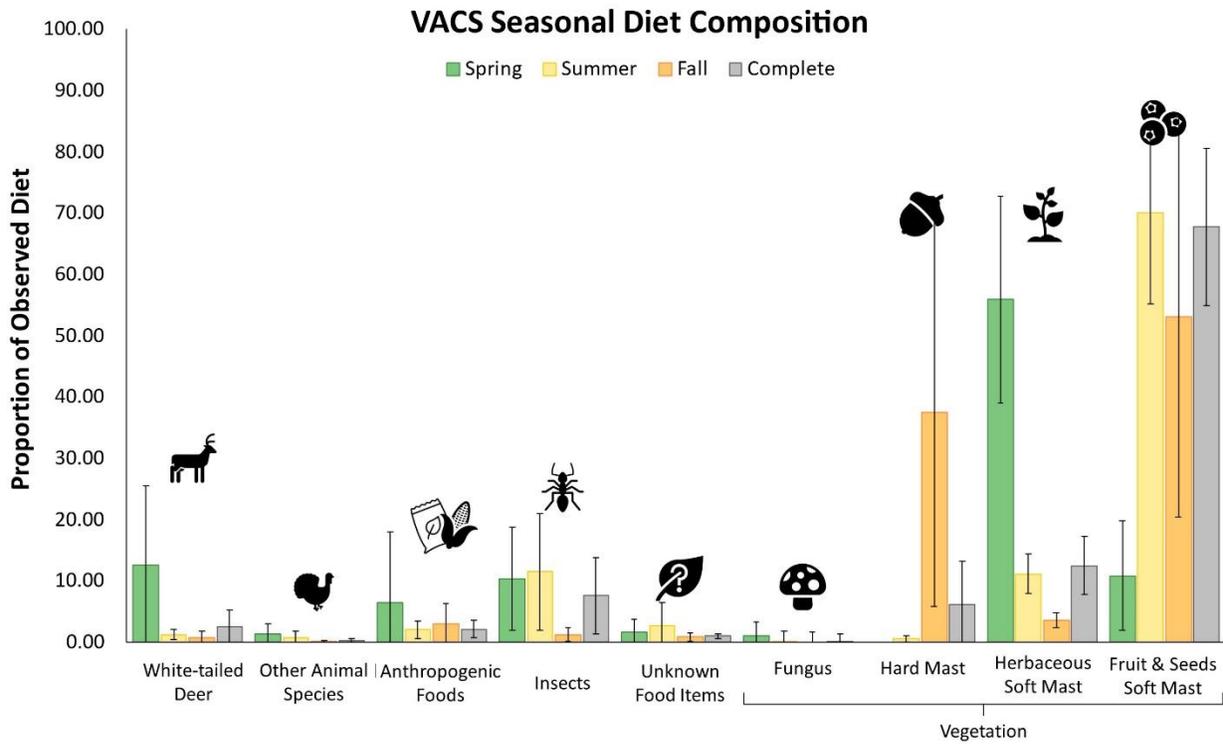
Figure 3. American black bear (n=15) diet composition by season and with seasons combined from the Virginia Appalachian Carnivore Study in 2018 and 2019 in Bath County, through video observation via camera collars. Winter is excluded due to the low sample size.
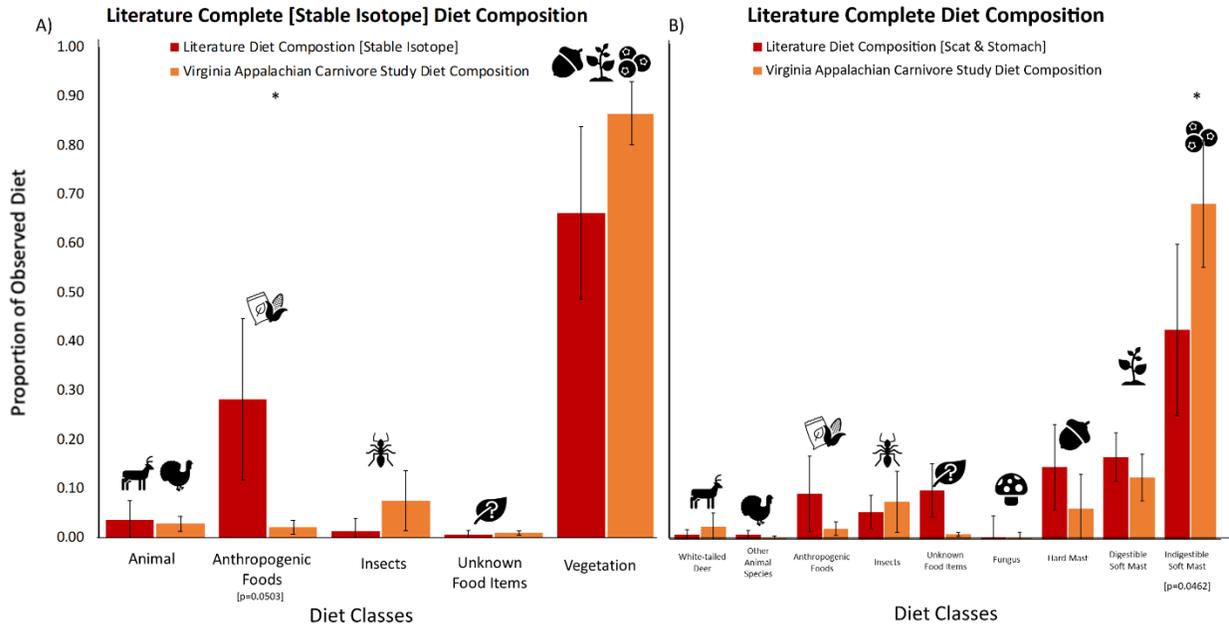
Figure 4. Comparison of overall American black bear (n=15) diet composition from the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018 and 2019, through video observation via camera collars, compared to a literature review of eastern American black bear diet composition from previous studies. A) Diet items were identified from stable isotope analysis, whereas in B) diet items were from scat and stomach contents. Asterisks indicate significant differences.
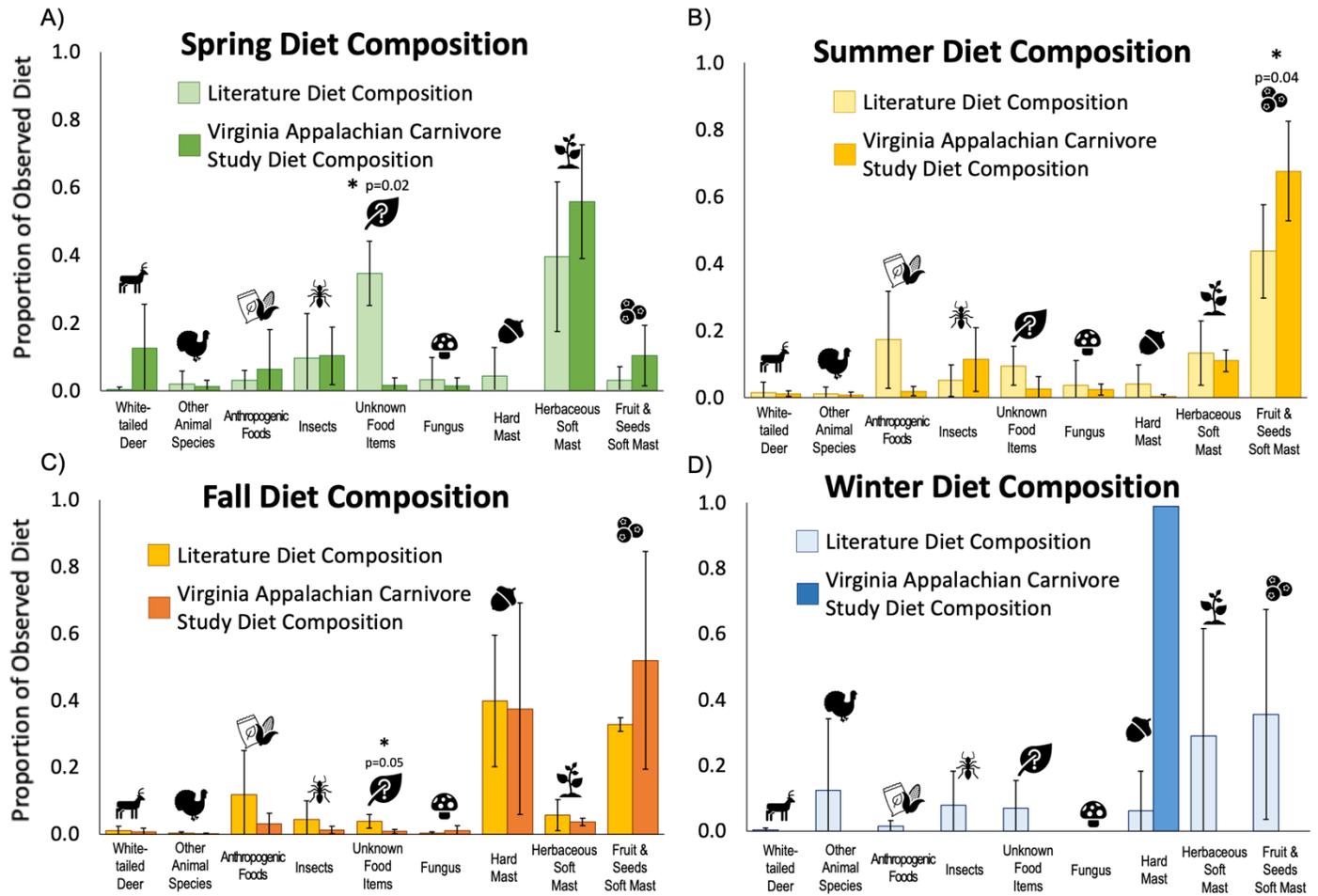
Figure 5. American black bear (n=15) diet composition from the Virginia Appalachian Carnivore Study (VACS) in Bath County, Virginia in 2018 and 2019 through video observations via camera collars (darker shades) compared to literature review from scat and stomach publications (lighter shades). A) Spring diets had three literature studies with seasonal breakdown, B) summer diets had four literature studies with seasonal breakdown, C) fall diets had three literature studies with seasonal breakdown, and D) winter diets had three literature review studies with seasonal breakdown, but for VACS in winter, we note small sample size of only 19 foraging videos that were all hard mast. Asterisks indicate significant differences.

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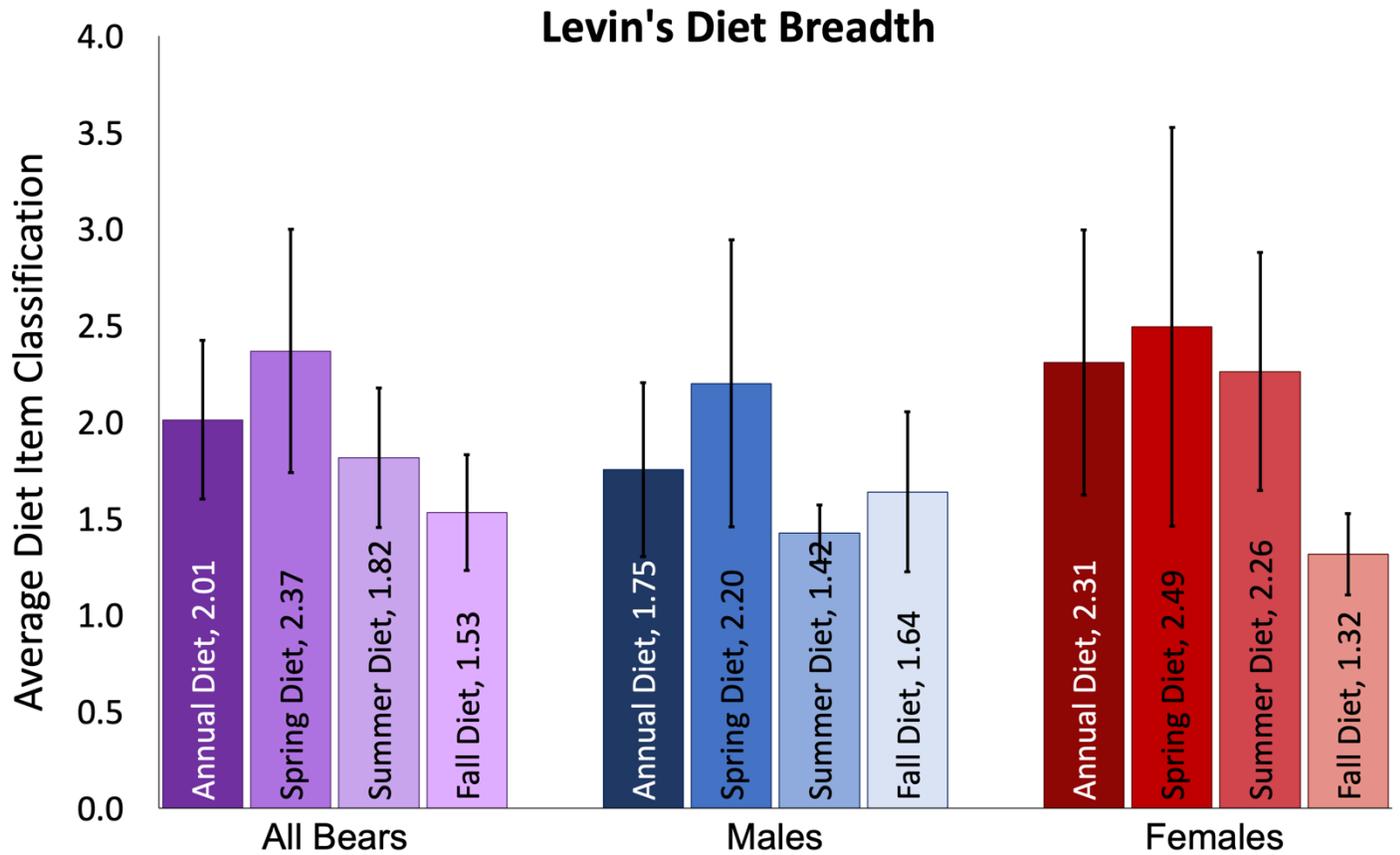
Figure 6. Levin's diet breadths (Levins 1974) for American black bears (*Ursus americanus*) from the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018 and 2019. All bears combined (shades of purple) had the lowest diet breadth in the fall and the highest in the spring across the 9 diet item classifications we had. Male bears (shades of blue) also had the lowest diet breadth in summer and the highest diet breadth in spring. Female bears (shades of red) had the lowest diet breadth in fall and the highest diet breadth in spring. Error bars represent 95% CIs.
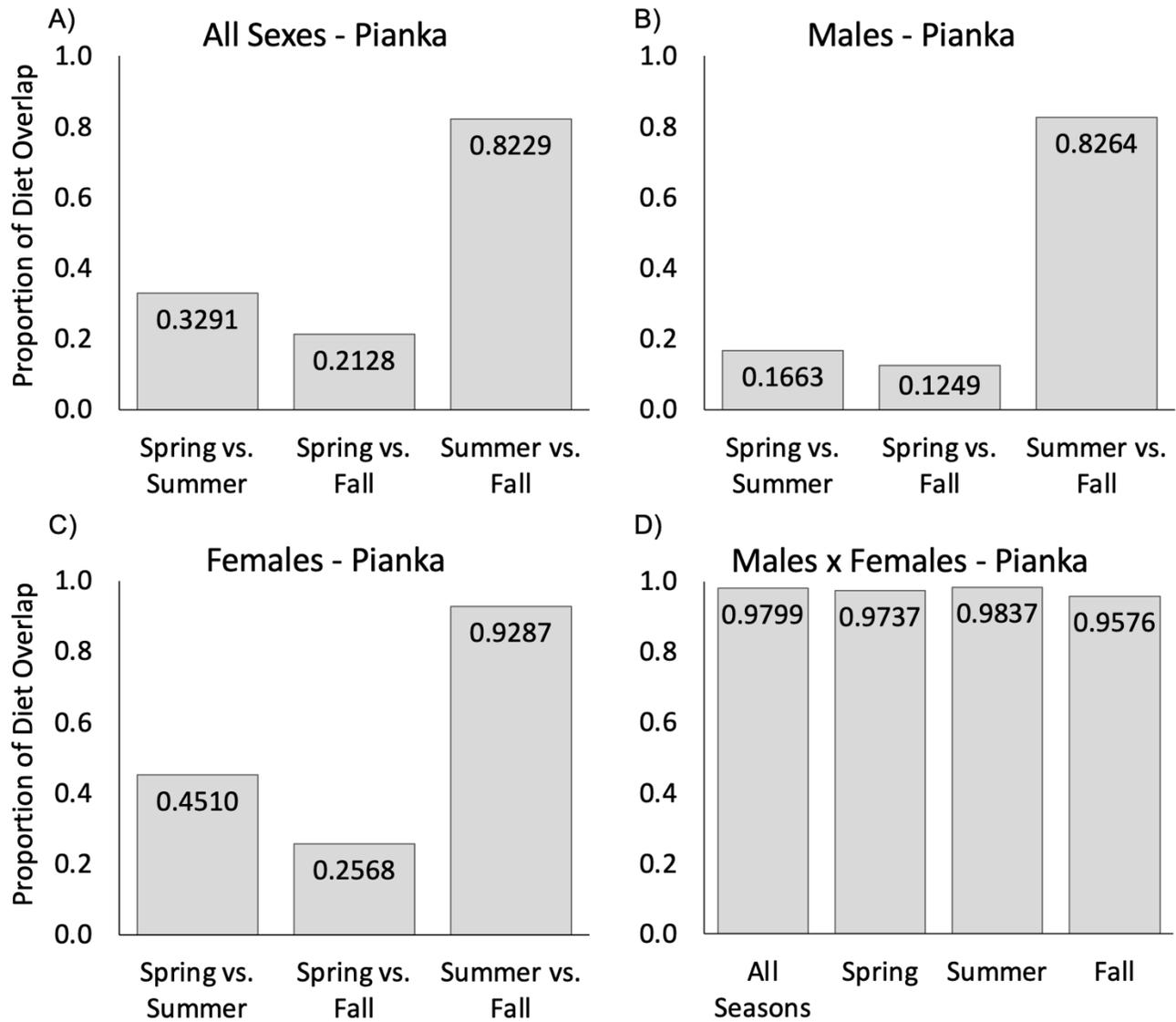
Figure 7. Pianka's niche overlap (Pianka 1974) for American black bears (*Ursus americanus*) from the Virginia Appalachian Carnivore Study in Bath County in 2018 and 2019. A) All bears combined and B) male bears show low dietary overlap between spring vs. summer and spring vs. fall but high dietary overlap between summer vs. fall. C) Female bears show moderate diet overlap between spring vs. summer, low dietary overlap between spring vs. fall, and high dietary overlap between summer vs. fall. D) Within each season and across all seasons combined, males and females had almost complete dietary overlap.
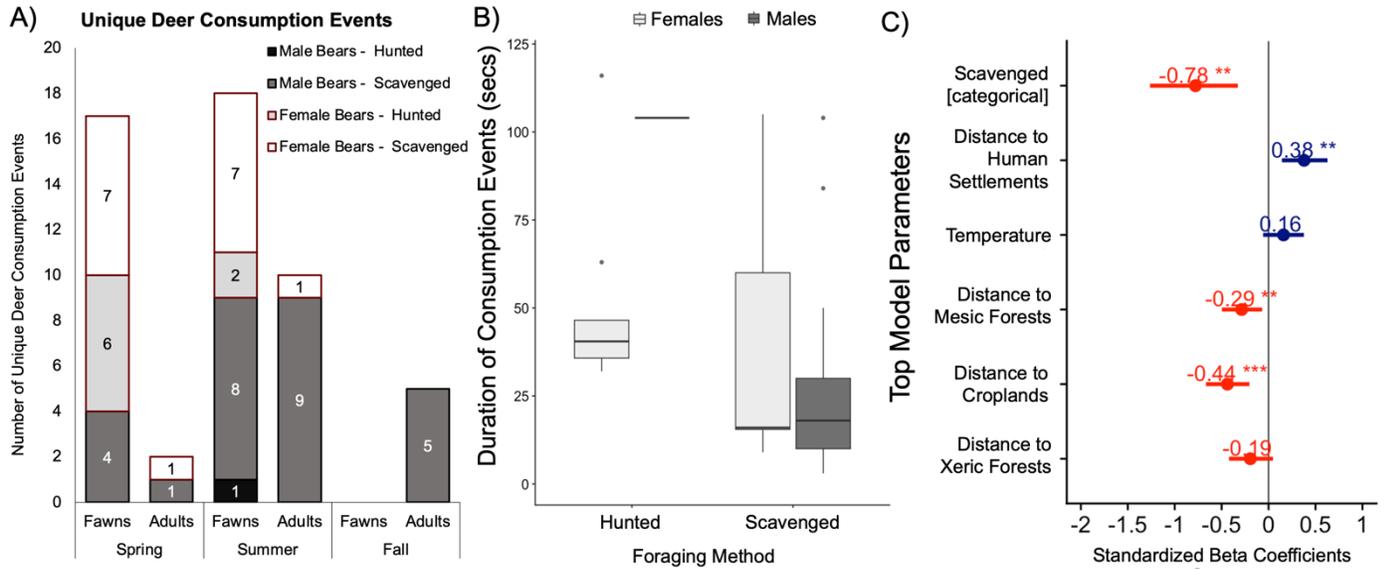
Figure 8. A) Unique deer consumption events of white-tailed deer (*Odocoileus virginianus*) fawns and adults by male (darker shades) and female (lighter shades, outlines in red) black bears divided by season during the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018 and 2019. Data come from video camera collars worn by 15 black bears. B) Our top model (Generalized Linear Mixed Models) for deer consumption duration showed there were longer consumption events when hunting compared to scavenging. C) Top model (Generalized Linear Mixed Models) for deer consumption events in 2018 and 2019, with duration of time feeding on animal matter as the response variable. Red indicates negative beta coefficients, and blue, positive beta coefficients, with asterisks indicating support in the top model.

Male Anthropogenic Food Consumption

A) [scatter/curve plot: Proportion of Foraging Events Observed vs Distance to Human Settlements (meters)]

B) [forest plot: Standardized Beta Coefficients]
- Spring [categorical]: -0.55
- Summer [categorical]: -1.50 ***
- Understory Density: -1.78 ***
- Temperature: 0.68 ***
- Distance to Human Settlements: -2.46 ***
- Distance to Mesic Forests: 0.45 **
- Distance to Pasture: -0.83 *

Female Insect Consumption

C) [boxplot: Proportion of Foraging Events Observed vs Understory Density [Daubenmire Scale]]

D) [forest plot: Standardized Beta Coefficients]
- Day of Year: -0.60 ***
- Time of Day: 0.23 **
- Understory Density: -1.29 ***
- Distance to Human Settlements: -0.27 *
- Distance to Croplands: 0.26 **
- Distance to Mesic Forests: 0.40 ***
- Distance to Xeric Forests: -0.65 ***

3030
3031 Figure 9. Top model (Generalized Linear Mixed Models) using binomial
3032 distribution for male consumption of anthropogenic foods indicating that A)
3033 highest consumption of anthropogenic foods occurs closer to (within 1000 meters)
3034 human settlements (scaled in model, unscaled for display) and B) red beta
3035 coefficients indicate negative relationships and blue indicate positive relationships
3036 for each covariate. Females not included due to small sample size. Top model
3037 using binomial distribution for female consumption of insects indicating that C)
3038 highest consumption was in minimal to moderate (2 -3 on Daubenmire scale)
3039 understory density and D) red beta coefficients indicate negative relationships,
3040 and blue indicate positive relationships for each covariate. Males were not
3041 included in this analysis due to low sample size. Data as part of the Virginia
3042 Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

144

Male Herbaceous Consumption

A)

B)
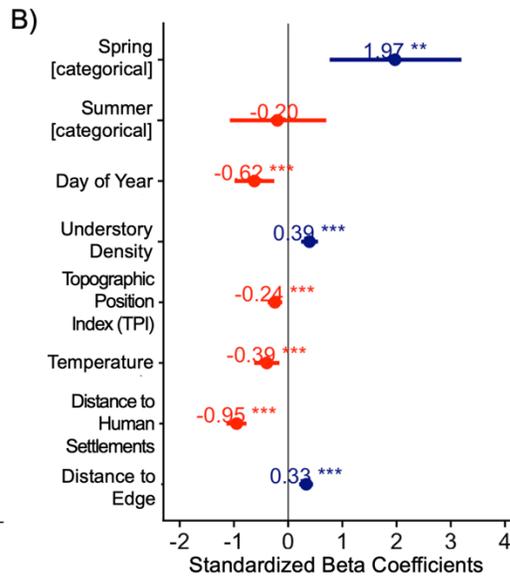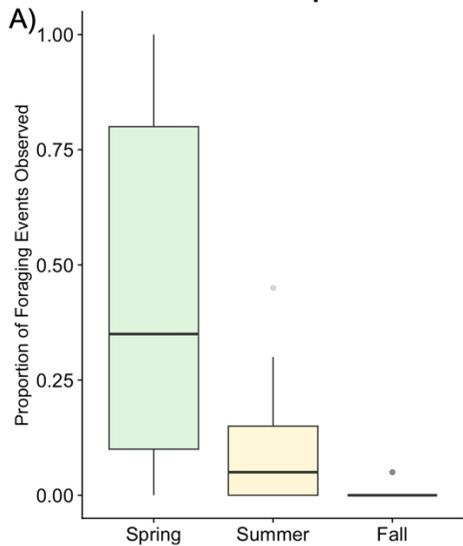
Female Herbaceous Consumption

C)

D)
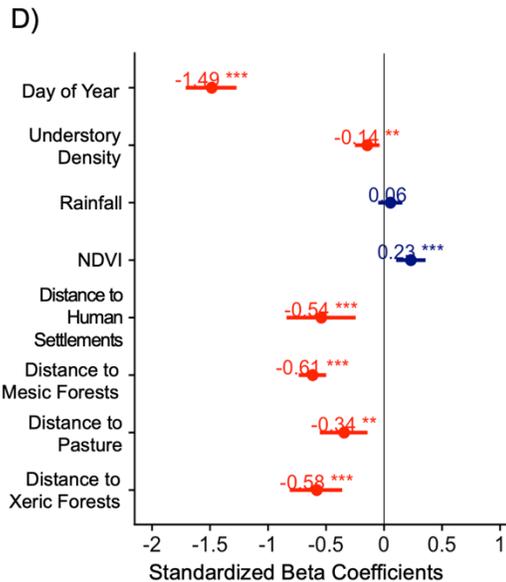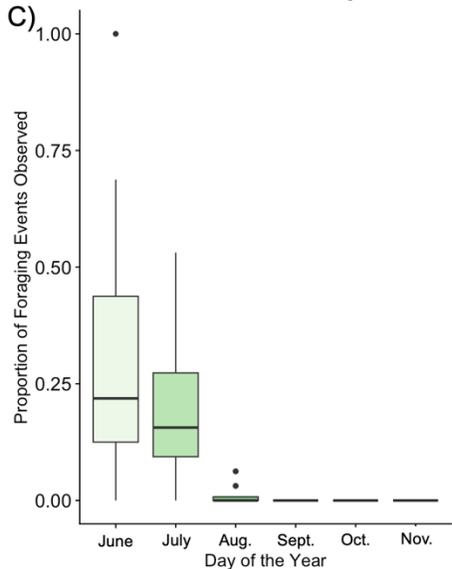
3043
3044 Figure 10. Top model (Generalized Linear Mixed Models) using binomial
3045 distribution for male consumption of herbaceous soft mast indicated that A)
3046 highest consumption was in spring and B) red beta coefficients indicate
3047 negative relationships, and blue indicate positive relationships for each
3048 covariate. Top model for female consumption of herbaceous soft mast
3049 indicated that C) highest consumption was in early months (June and July) of
3050 the year and D) red beta coefficients indicate negative relationships and blue
3051 indicating positive relationships for each covariate. Data as part of the
3052 Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

3053

Male Fruit & Seed Consumption
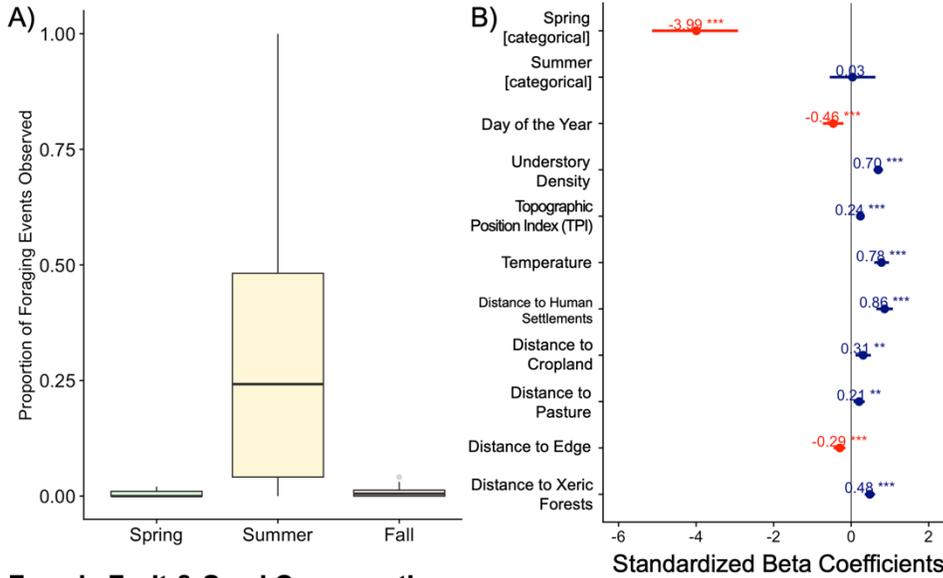
Female Fruit & Seed Consumption
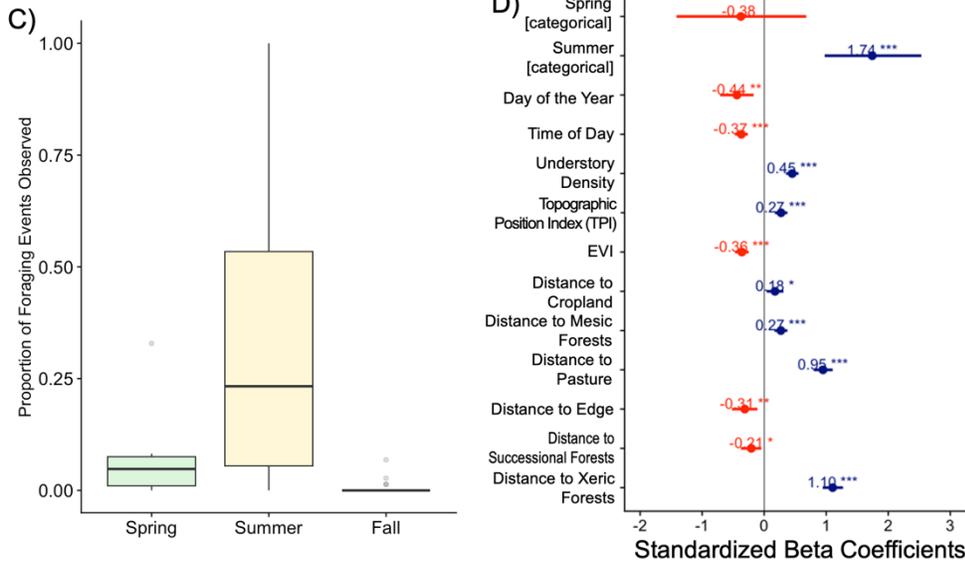
3054
3055 Figure 11. Top model (Generalized Linear Mixed Models) using binomial
3056 distribution for male consumption of fruit and seed soft mast indicated that
3057 A) highest consumption was in summer and B) red beta coefficients indicate
3058 negative relationships and blue indicate positive relationships for each
3059 covariate. Top model for female consumption of fruit and seed soft mast
3060 indicated that C) highest consumption was in summer and D) red beta
3061 coefficients indicate negative relationships and blue indicating positive
3062 relationships for each covariate. Data as part of the Virginia Appalachian
3063 Carnivore Study in Bath County, Virginia in 2018-2019.

146

Figure 12. Top model (Generalized Linear Mixed Models) using binomial distribution for male consumption of hard mast indicated that A) highest consumption was in fall months, particularly October and November, and B) red beta coefficients indicate negative relationships and blue indicate positive relationships for each covariate. Top model for female consumption of hard mast indicated that C) highest consumption was in end of the summer (August) into the start of fall (September) and D) red beta coefficients indicate negative relationships and blue indicate positive relationships for each covariate. Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

Male Invasive Species Consumption
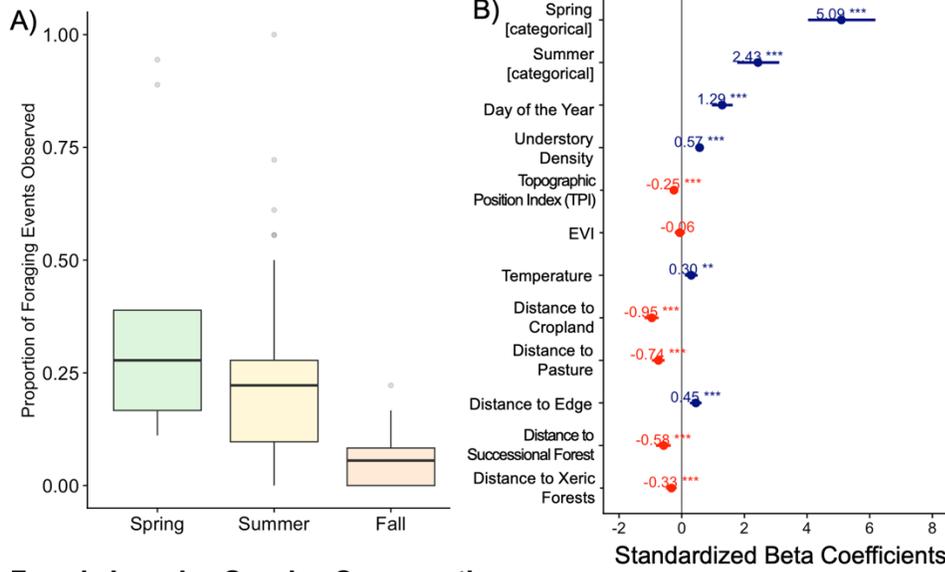
A)

B)

Female Invasive Species Consumption

C)

D)
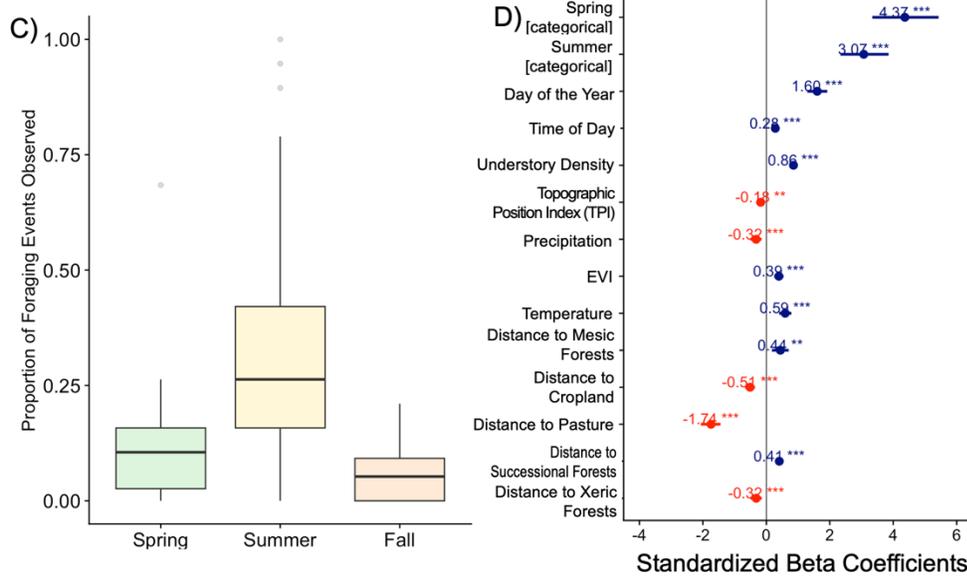
Figure 13. Top model (Generalized Linear Mixed Models) using binomial distribution of male consumption of invasive species indicated that A) highest consumption was in spring and B) red beta coefficients indicate negative relationships and blue indicate positive relationships for each covariate. Top model using binomial distribution of female consumption of invasive species indicated that C) highest consumption was in summer and D) red beta coefficients indicate negative relationships and blue indicate positive relationships for each covariate. Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.
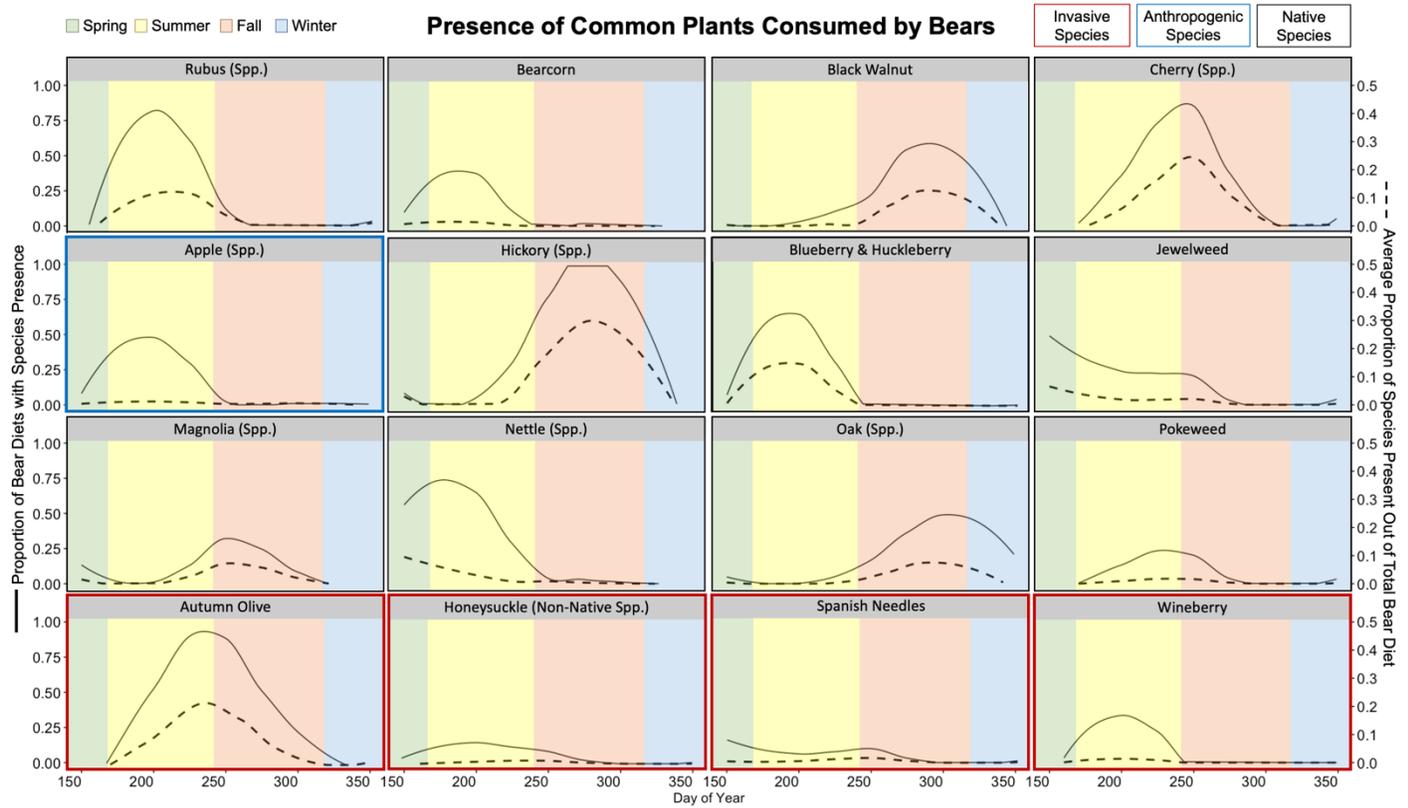
Figure 14. Seasonal depiction of the 16 most commonly observed genus/species in black bears' diets, with solid lines indicating the proportion (out of the 15 bears) with the plant species present in the diet (left y-axis) and dashed lines indicating to the average proportion out of the total diet that the plant species comprised (right y-axis). Red boxes in bottom row indicate consumption of invasive species in the region. Data come from species seen consumed in videos from camera collars on 15 black bears in Bath County, VA in 2018 and 2019.
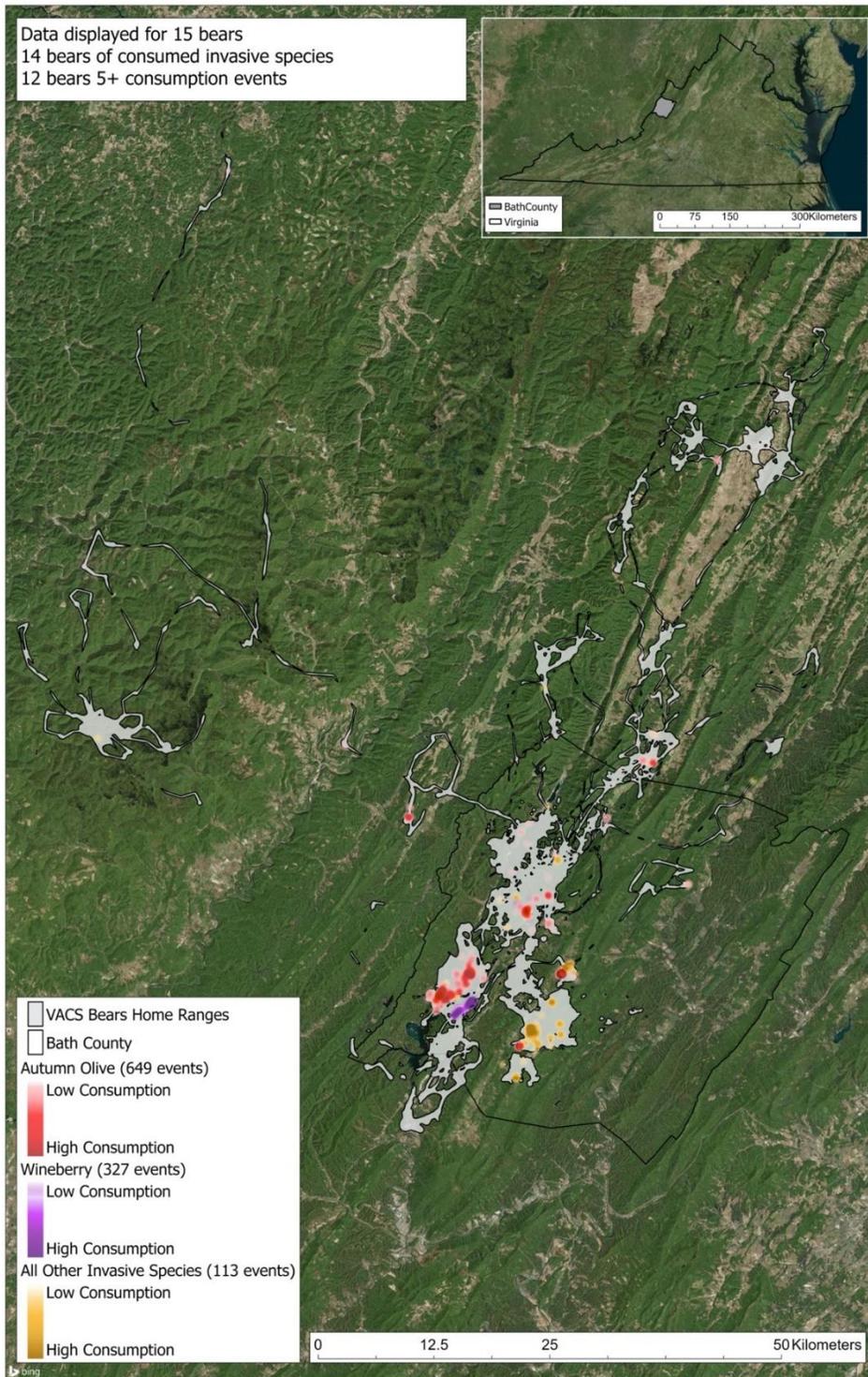
Figure 15. Distribution of locations of invasive species consumption across all 15 bears in 2018 and 2019 in Bath County, Virginia (inset in gray), with red gradient denoting autumn olive consumption (*Elaeagnus umbellata*), purple gradient denoting wineberry consumption (*Rubus phoenicolasius*), and orange gradient denoting remaining invasive species consumed, which occurred at lower frequencies, from within bears' home ranges.
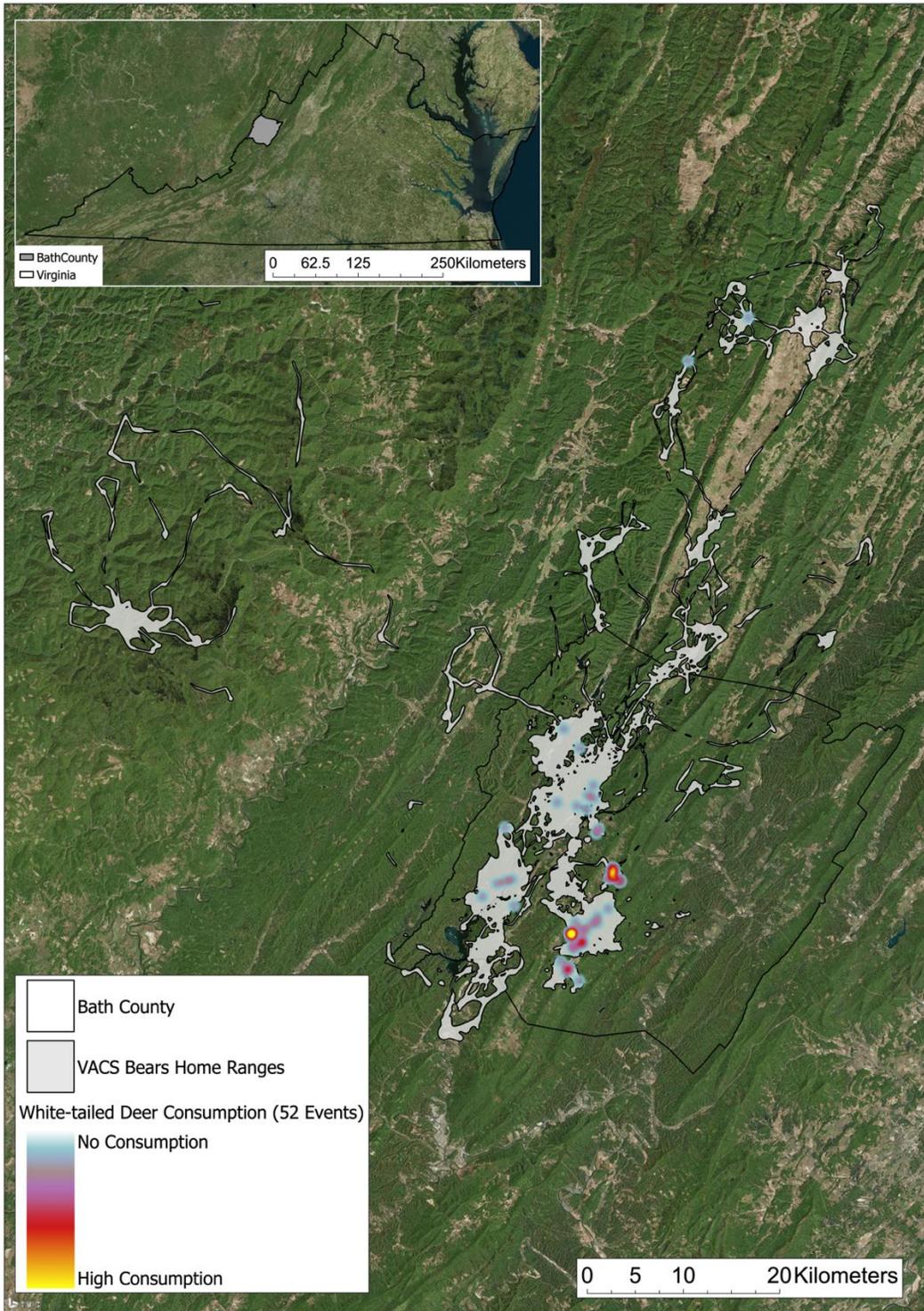
Figure 16. Distribution of white-tailed deer (*Odocoileus virginianus*) consumption across all 15 bears in 2018 and 2019 in Bath County, VA (inset in gray). Data are from videos via camera collars documenting deer consumed within bears' home ranges.

3106 Table 1. Camera collar settings for black bears collared in Bath County, VA, in 2018
3107 and 2019, including programming start date, programming end date, video length,
3108 video start time for the day, the video end time for the day, frequency of videos, and
3109 GPS point schedule.

Year	Start Date	End Date	Video Length	Start Time (Local)	End time (Local)	Frequency	GPS Schedule
2018	05/15/18	07/31/18	20 s	2:00*	16:00*	Every 20 min	20 min
2019	05/15/19	07/14/19	15s	5:20	21:20	Every 20 min	20 min
	07/15/19	07/21/19	10s	5:20	21:20	Every 20 min	20 min
	08/01/19	09/30/19	08s	6:00	20:00	Every 60 min	60 min
	10/01/19	11/02/19	08s	7:00	19:00	Every 30 min	60 min
	11/03/19	12/15/19	08s	6:00	18:00	Every 30 min	60 min

*programming error

3110

3111 Table 2. Camera collars for black bears collared in Bath County, VA, in 2018 and 2019 including
3112 black bear camera code (black bear Cam Code), black bear sex, presence/absence of cubs (Cubs),
3113 black bear weight in pounds (Weight (lbs)) and kilograms (Weight (kg)) at capture, video camera
3114 start date (First Cam Day), video camera end date (Last Cam Day), total days of video camera
3115 collar recordings (Total Cam Days).

Survey Year	black bear Cam Code	Sex	Cubs	Weight (lbs)	Weight (kg)	First Cam Day (MM/DD/YY)	Last Cam Day (MM/DD/YY)	Total Cam Days
2018	UAF01	F	None	135	61.24	07/10/18	08/01/18	23
	UAF28	F	None	120	54.43	05/30/18	07/14/18	46
	UAF29	F	None	120	54.43	05/30/18	07/29/18	61
	UAF32	F	Yearling	150	68.04	06/11/18	07/25/18	45
	UAF38	F	None	130	58.97	07/03/18	07/31/18	29
	UAM15	M	-	155	70.31	06/08/18	07/30/18	53
	UAM36	M	-	145	65.77	07/02/18	07/31/18	30
	UAM37	M	-	275	124.74	07/02/18	07/31/18	30
	UAM41	M	-	250	113.40	07/11/18	07/31/18	21
	UAM30	M	-	Hit by car – no video data recovered				
2019	UAF42	F	1 cub	100	45.36	06/05/19	12/15/19	194
	UAF43	F	2 cubs	Hit by car – no video data recovered				
	UAF52	F	None	105	47.63	07/30/19	12/15/19	139
	UAM44	M	-	165	74.84	06/11/19	10/22/19	134
	UAM45	M	-	150	68.04	06/15/19	9/26/19	104
	UAM47	M	-	160	72.58	07/22/19	11/20/19	122
	UAM49	M	-	125	56.70	07/25/19	12/15/19	144
	UAM53	M	-	Malfunction – no video data recovered				

3116 UAF = *Ursus americanus* female; UAF = *Ursus americanus* male

3117 Table 3. Foraging analysis using generalized linear mixed models with a negative binomial
3118 distribution for duration (in seconds) of deer consumption events by black bears in 2018 and 2019
3119 in Bath County, Virginia. Model definition describes covariates used in model (defined in
3120 footnotes), AIC represents the Akaike Information Criterion, ΔAIC is the difference in AIC
3121 between a model and the top model, wi is the model weight, K is the number of parameters, and
3122 Log(l) is the Log-likelihood. black bear ID was used as a random effect.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Deer Consump. ~ Forage Method + Dist. Humans + Temp. + Dist. Mesic + Dist. Crop	452.50	0.00	0.91	8	-218.25
Deer Consump. ~ *Global*	458.69	6.20	0.04	18	-211.35
Deer Consump. ~ Forage Method + Dist. Humans + Temp. + Dist. Mesic	460.36	7.86	0.02	6	-224.18
Deer Consump. ~ DOY	461.18	8.68	0.01	3	-227.59
Deer Consump. ~ Forage Method + (DOY * Dist. Humans) + DOY + Dist. Humans	462.16	9.66	0.01	6	-225.08
Deer Consump. ~ Forage Method	464.25	11.75	0.00	3	-229.12
Deer Consump. ~ (DOY * Dist. Humans) + DOY + Dist. Humans	464.88	12.39	0.00	5	-227.44
Deer Consump. ~ Scavenged vs. Hunted + Dist. Humans	466.03	13.54	0.00	4	-229.02
Deer Consump. ~ Deer Age	466.39	13.89	0.00	3	-230.19
Deer Consump. ~ Dist. Crop.	466.80	14.30	0.00	3	-230.40
Deer Consump. ~ Deer Age + (DOY * Dist. Humans) + DOY + Dist. Humans	466.85	14.35	0.00	6	-227.42
Deer Consump. ~ Dist. Mesic	467.11	14.62	0.00	3	-230.56
Deer Consump. ~ Dist. Xeric	467.52	15.03	0.00	3	-230.76
Deer Consump. ~ Deer Age + Dist. Humans	468.39	15.89	0.00	4	-230.19
Deer Consump. ~ Sex	468.43	15.93	0.00	3	-231.21
Deer Consump. ~ 1	468.69	16.19	0.00	2	-232.35
Deer Consump. ~ Temp.	469.49	16.99	0.00	3	-231.74
Deer Consump. ~ Dist. Herb.	469.54	17.05	0.00	3	-231.77
Deer Consump. ~ Under.	470.05	17.55	0.00	3	-232.02
Deer Consump. ~ Dist. Succ.	470.57	18.07	0.00	3	-232.28

3123 *Deer Consump.* Is the duration of time bears spent consuming deer, *Forage Method* represents a video series of a consumption
3124 event classified as Scavenged or Hunted as a categorical variable, *Dist. Human* represents the distance to human settlements, *Temp*
3125 represents average daily temperature, *Dist. Mesic* represents the distance to the mesic forest, *Dist. Crop* represents the distance to
3126 agricultural or cropland, *DOY* represents the day of the year, *Dist. Xeric* represents the distance to the xeric forest, *Deer Age* is
3127 whether the carcass being consumed was an adult deer or fawn, *Sex* is the sex of the bear, *Dist. Herb*. Represents the distance to
3128 herbaceous fields or pastureland, *Under.* Represents understory density observed via camera collar video on the Daubenmire scale,
3129 *Dist. Succ.* Represents the distance to the early to mid-successional forest, ~1 is constant model and *Global* represents the model
3130 with all uncorrelated variables.
3131

3132 Table 4. Foraging analysis using generalized linear mixed models with a binomial distribution for
3133 presence of anthropogenic food consumption events for black bears in 2018 and 2019 in Bath
3134 County, Virginia. Females were not included in analysis due to small sample size. Model definition
3135 describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion,
3136 ΔAIC is the difference in AIC between a model and the top model, wi is model weight, K is the
3137 number of parameters, and Log(l) is Log-likelihood. black bear ID was used as a random effect.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Anthropogenic Consump. ~ Under. + Season + Temp. + Dist. Human + Dist. Mesic + Dist. Herb.	386.95	0.00	0.80	8	-185.48
Anthropogenic Consump. ~ Under. + Season + Temp. + Dist. Human + Dist. Herb.	391.07	4.12	0.10	7	-188.54
Anthropogenic Consump. ~ *Global*	391.14	4.18	0.10	18	-177.57
Anthropogenic Consump. ~ Under. + Season + Dist. Human	402.87	15.91	0.00	5	-196.43
Anthropogenic Consump. ~ Under. + Season + Dist. Human + Dist. Herb.	404.57	17.62	0.00	6	-196.29
Anthropogenic Consump. ~ Under. + Dist. Human	404.86	17.90	0.00	3	-199.43
Anthropogenic Consump. ~ Under. + Season	491.18	104.23	0.00	4	-241.59
Anthropogenic Consump. ~ Under.	501.07	114.11	0.00	2	-248.53
Anthropogenic Consump. ~ Under. + Temp.	502.46	115.51	0.00	3	-248.23
Anthropogenic Consump. ~ Dist. Human	510.09	123.14	0.00	2	-253.05
Anthropogenic Consump. ~ Dist. Herb.	587.84	200.89	0.00	2	-291.92
Anthropogenic Consump. ~ Dist. Crop	604.81	217.85	0.00	2	-300.40
Anthropogenic Consump. ~ Season	610.51	223.55	0.00	3	-302.25
Anthropogenic Consump. ~ Dist. Xeric	625.33	238.37	0.00	2	-310.66
Anthropogenic Consump. ~ DOY	625.60	238.64	0.00	2	-310.80
Anthropogenic Consump. ~ Precip.	642.35	255.40	0.00	2	-319.18
Anthropogenic Consump. ~ Dist. Succ.	643.41	256.46	0.00	2	-319.71
Anthropogenic Consump. ~ EVI	649.14	262.19	0.00	2	-322.57
Anthropogenic Consump. ~ Dist. Mesic	649.89	262.94	0.00	2	-322.95
Anthropogenic Consump. ~ NDVI	650.53	263.58	0.00	2	-323.27
Anthropogenic Consump. ~ 1	651.60	264.64	0.00	1	-324.80
Anthropogenic Consump. ~ Dist. Edge	652.03	265.07	0.00	2	-324.01
Anthropogenic Consump. ~ TOD	653.18	266.22	0.00	2	-324.59
Anthropogenic Consump. ~ TPI	653.18	266.23	0.00	2	-324.59
Anthropogenic Consump. ~ Temp.	653.39	266.44	0.00	2	-324.69

3138 *Under.* represents understory density observed in the camera collar video on a Daubenmire scale, *Season* represents the season
3139 assessed by the date, *Temp* represents average daily temperature, *Dist. Human* represents the distance to human settlements, *Dist.*
3140 *Mesic* represents the distance to the mesic forest, *Dist. Herb.* represents the distance to herbaceous fields or pastureland, *Global*
3141 represents the model with all uncorrelated variables included, ~1 is constant or null model, *Dist. Crop* represents the distance to
3142 agricultural or cropland, *Dist. Xeric* represents the distance to the xeric forest, *DOY* represents the day of the year, *Precip* is daily
3143 precipitation, *Dist. Succ.* represents the distance to the early to mid-successional forest, *EVI* represents the enhanced vegetation
3144 index, *NDVI* represents the normalized difference vegetation index, *Dist. Edge* represents the distance to the forest edge, *TOD*
3145 represents the time of day, and *TPI* represents the topographic position index (TPI).
3146

Table 5. Generalized linear mixed models with a binomial distribution foraging/consumption event and consumption of insects for female black bears in 2018 and 2019 in Bath County, Virginia. Males were not included due to small sample size. Model definition describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion , ΔAIC is the difference in AIC between a model and the top model, wi is model weight, K is the number of parameters, and Log(l) is Log-likelihood. black bear ID was used as a random effect.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Insect Consump. ~ DOY + TOD + Under. + Dist. Human + Dist. Crop + Dist. Mesic + Dist. Xeric	1266.66	0.00	0.77	8	-625.33
Insect Consump. ~ DOY + TOD + Under. + Dist. Crop + Dist. Mesic + Dist. Xeric	1269.33	2.68	0.20	7	-627.67
Insect Consump. ~ DOY + Under. + Dist. Human + Dist. Crop + Dist. Mesic + Dist. Xeric	1272.96	6.30	0.03	7	-629.48
Insect Consump. ~ DOY + TOD + Under. + Dist. Human + Dist. Crop + Dist. Xeric	1296.20	29.54	0.00	7	-641.10
Insect Consump. ~ DOY + Under. + Dist. Human + Dist. Crop + Dist. Xeric	1302.93	36.27	0.00	6	-645.46
Insect Consump. ~ DOY + Under. + Dist. Crop + Dist. Xeric	1315.16	48.50	0.00	5	-652.58
Insect Consump. ~ DOY + Under. + Dist. Xeric	1333.00	66.34	0.00	4	-662.50
Insect Consump. ~ DOY + Under. + Dist. Human	1355.20	88.54	0.00	4	-673.60
Insect Consump. ~ DOY + Under.	1379.45	112.79	0.00	3	-686.73
Insect Consump. ~ Under.	1444.87	178.21	0.00	2	-720.43
Insect Consump. ~ DOY + TOD	1595.29	328.64	0.00	3	-794.65
Insect Consump. ~ DOY	1611.53	344.88	0.00	2	-803.77
Insect Consump. ~ Dist. Human	1614.61	347.95	0.00	2	-805.30
Insect Consump. ~ Dist. Xeric	1619.86	353.20	0.00	2	-807.93
Insect Consump. ~ Season	1644.17	377.51	0.00	3	-819.08
Insect Consump. ~ Dist. Crop	1657.23	390.57	0.00	2	-826.61
Insect Consump. ~ Dist. Mesic	1658.72	392.06	0.00	2	-827.36
Insect Consump. ~ Temp.	1662.42	395.76	0.00	2	-829.21
Insect Consump. ~ Dist. Herb.	1666.12	399.47	0.00	2	-831.06
Insect Consump. ~ TOD	1674.10	407.45	0.00	2	-835.05
Insect Consump. ~ Dist. Edge	1676.54	409.88	0.00	2	-836.27
Insect Consump. ~ Dist. Succ.	1679.92	413.26	0.00	2	-837.96
Insect Consump. ~ 1	1681.17	414.51	0.00	1	-839.58
Insect Consump. ~ Precip.	1681.96	415.31	0.00	2	-838.98
Insect Consump. ~ NDVI	1682.11	415.45	0.00	2	-839.05
Insect Consump. ~ EVI	1682.72	416.06	0.00	2	-839.36
Insect Consump. ~ TPI	1682.94	416.28	0.00	2	-839.47

DOY represents the day of the year, *TOD* represents the time of day, *Under. represents* understory density observed in the camera collar video on a Daubenmire scale, *Dist. Human* represents the distance to human settlements, *Dist. Crop* represents the distance to agricultural or cropland, *Dist. Mesic* represents the distance to the mesic forest, *Dist. Xeric* represents the distance to the xeric forest, *Season* represents the Season, *Temp* represents average daily temperature, *Dist. Herb*. represents the distance to herbaceous fields or pastureland, *Dist. Edge* represents the distance to the forest edge, *Dist. Succ.* represents the distance to the early to mid-successional forest, *Precip* represents precipitation, *NDVI* represents the normalized difference vegetation index (NDVI), *EVI* represents the enhanced vegetation index (EVI), and *TPI* represents the topographic position index (TPI).

Table 6. Generalized linear mixed models with a binomial distribution for consumption of herbaceous soft mast (1 for herbaceous soft mast consumption and 0 for other consumption events). Model definition describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion , ΔAIC is the difference in AIC between a model and the top model, wi is model weight, K is the number of parameters, and Log(l) is Log-likelihood. black bear ID was used as a random effect. Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Males – Herbaceous Soft Mast Consumption					
Herb. Consump. ~ DOY + Under. + Season + Temp + TPI + Dist. Human + Dist. Edge	1329.24	0.00	0.76	9	-655.62
Herb. Consump. ~ *Global*	1331.63	2.39	0.23	18	-647.82
Herb. Consump. ~ DOY + Under. + Season + TPI + Dist. Human + Dist. Edge	1338.20	8.95	0.01	8	-661.10
Herb. Consump. ~ DOY + Under. + Season + TPI + Dist. Human	1362.15	32.91	0.00	7	-674.07
Herb. Consump. ~ DOY + Under. + Temp + TPI + Dist. Human + Dist. Edge	1402.57	73.32	0.00	7	-694.28
Herb. Consump. ~ DOY + Under. + Season + TPI	1465.35	136.10	0.00	6	-726.67
Herb. Consump. ~ DOY + Under. + Season	1480.45	151.20	0.00	5	-735.22
Herb. Consump. ~ Season	1490.79	161.55	0.00	3	-742.40
Herb. Consump. ~ DOY + Under. + TPI	1756.06	426.81	0.00	4	-874.03
Herb. Consump. ~ Dist. Human	1767.70	438.46	0.00	2	-881.85
Herb. Consump. ~ DOY	1818.86	489.62	0.00	2	-907.43
Herb. Consump. ~ Dist. Xeric	1837.21	507.97	0.00	2	-916.60
Herb. Consump. ~ Under.	1875.54	546.30	0.00	2	-935.77
Herb. Consump. ~ Dist. Crop	1880.29	551.05	0.00	2	-938.15
Herb. Consump. ~ Dist. Edge	1885.13	555.89	0.00	2	-940.57
Herb. Consump. ~ TPI	1890.11	560.87	0.00	2	-943.06
Herb. Consump. ~ EVI	1893.91	564.67	0.00	2	-944.95
Herb. Consump. ~ Dist. Succ.	1901.52	572.28	0.00	2	-948.76
Herb. Consump. ~ Dist. Mesic	1907.91	578.67	0.00	2	-951.96
Herb. Consump. ~ Temp.	1913.36	584.12	0.00	2	-954.68
Herb. Consump. ~ NDVI	1917.92	588.68	0.00	2	-956.96
Herb. Consump. ~ TOD	1924.01	594.76	0.00	2	-960.00
Herb. Consump. ~ 1	1924.27	595.03	0.00	1	-961.14
Herb. Consump. ~ Dist. Herb.	1924.33	595.08	0.00	2	-960.16
Herb. Consump. ~ Precip.	1924.57	595.33	0.00	2	-960.29
Females – Herbaceous Soft Mast Consumption					
Herb. Consump. ~ DOY + Under. + Precip. + NDVI + Dist. Human + Dist. Mesic + Dist. Herb. + Dist. Xeric	2086.72	0.00	0.99	9	-1034.36
Herb. Consump. ~ DOY + Under. + Precip. + NDVI + Dist. Mesic + Dist. Herb. + Dist. Xeric	2097.15	10.43	0.01	8	-1040.57
Herb. Consump. ~ DOY + Under. + Precip. + Dist. Mesic + Dist. Herb. + Dist. Xeric	2099.67	12.95	0.00	7	-1042.84
Herb. Consump. ~ DOY + Under. + NDVI + Dist. Mesic + Dist. Herb.	2155.97	69.25	0.00	6	-1071.98
Herb. Consump. ~ DOY + Under. + Precip. + Dist. Mesic	2250.27	163.56	0.00	5	-1120.14
Herb. Consump. ~ Season	2366.06	279.34	0.00	3	-1180.03
Herb. Consump. ~ DOY + Under.	2426.79	340.08	0.00	3	-1210.40
Herb. Consump. ~ DOY + Under. + Precip.	2428.20	341.48	0.00	4	-1210.10
Herb. Consump. ~ DOY	2449.49	362.77	0.00	2	-1222.75
Herb. Consump. ~ Dist. Human	2614.51	527.79	0.00	2	-1305.26
Herb. Consump. ~ Dist. Herb.	2768.42	681.71	0.00	2	-1382.21
Herb. Consump. ~ Dist. Xeric	2797.19	710.47	0.00	2	-1396.59
Herb. Consump. ~ Dist. Mesic	2839.58	752.86	0.00	2	-1417.79
Herb. Consump. ~ TPI	2902.83	816.11	0.00	2	-1449.42
Herb. Consump. ~ Under.	2909.77	823.05	0.00	2	-1452.88
Herb. Consump. ~ Dist. Succ.	2938.78	852.06	0.00	2	-1467.39
Herb. Consump. ~ NDVI	2939.63	852.91	0.00	2	-1467.81
Herb. Consump. ~ Dist. Edge	2940.90	854.18	0.00	2	-1468.45
Herb. Consump. ~ Dist. Crop	2943.90	857.18	0.00	2	-1469.95
Herb. Consump. ~ 1	2946.90	860.18	0.00	1	-1472.45
Herb. Consump. ~ Precip.	2947.23	860.51	0.00	2	-1471.61
Herb. Consump. ~ Temp.	2947.71	860.99	0.00	2	-1471.85
Herb. Consump. ~ EVI	2948.48	861.76	0.00	2	-1472.24
Herb. Consump. ~ TOD	2948.90	862.18	0.00	2	-1472.45

DOY represents the day of the year, *Under. represents* understory density observed in the camera collar video on a Daubenmire scale, *Season* represents the Season, *Temp* represents average daily temperature, *TPI* represents the topographic position index (TPI), *Dist. Human* represents the distance to human settlements, *Dist. Edge* represents the distance to the forest edge, *Global* represents the model with all variables included so long as no correlated variables are significant. *Dist. Xeric* represents the distance to the xeric forest, *Dist. Crop* represents the distance to agricultural or cropland, *EVI* represents the enhanced vegetation index (EVI), *Dist. Succ.* represents the distance to the early to mid-successional forest, *Dist. Mesic* represents the distance to the mesic forest, *NDVI* represents the normalized difference vegetation index (NDVI), *TOD* represents the time of day, *Dist. Herb.* represents the distance to herbaceous fields or pastureland, and *Precip* represents precipitation.

3176 Table 7. Generalized linear mixed models with a binomial distribution for consumption of fruit and seed soft mast.
3177 Model definition describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion,
3178 ΔAIC is the difference in AIC between a model and the top model, *w*i is model weight, K is the number of parameters,
3179 and Log(*l*) is Log-likelihood. black bear ID was used as a random effect. Data as part of the Virginia Appalachian
3180 Carnivore Study in Bath County, Virginia in 2018-2019.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Males – Fruit & Seed Soft Mast Consumption					
Fruit/Seed Consump. ~ DOY + Under. + Season + TPI + Temp. + Dist. Human + Dist. Crop + Dist. Herb. + Dist. Edge + Dist. Xeric	2304.97	0.00	0.94	12	-1140.48
Fruit/Seed Consump. ~ *Global*	2310.52	5.55	0.06	18	-1137.26
Fruit/Seed Consump. ~ DOY + Under. + Season + TPI + Temp. + Dist. Human + Dist. Crop + Dist. Herb. + Dist. Edge	2355.30	50.33	0.00	11	-1166.65
Fruit/Seed Consump. ~ DOY + Under. + Season + TPI +Temp. +Dist. Human +Dist. Crop	2379.23	74.26	0.00	9	-1180.62
Fruit/Seed Consump. ~ DOY + Under. + Season + TPI + Temp.	2872.48	567.51	0.00	7	-1429.24
Fruit/Seed Consump. ~ DOY + Under. + Season	2948.33	643.36	0.00	5	-1469.16
Fruit/Seed Consump. ~ Dist. Human	3257.83	952.86	0.00	2	-1626.91
Fruit/Seed Consump. ~ Season	3442.02	1137.05	0.00	3	-1718.01
Fruit/Seed Consump. ~ Dist. Succ.	3450.07	1145.10	0.00	2	-1723.03
Fruit/Seed Consump. ~ DOY + Under.	3678.99	1374.02	0.00	3	-1836.49
Fruit/Seed Consump. ~ Temp.	3753.85	1448.88	0.00	2	-1874.93
Fruit/Seed Consump. ~ DOY	3800.03	1495.06	0.00	2	-1898.01
Fruit/Seed Consump. ~ Dist. Crop	3905.55	1600.58	0.00	2	-1950.77
Fruit/Seed Consump. ~ Dist. Xeric	3967.95	1662.98	0.00	2	-1981.97
Fruit/Seed Consump. ~ Dist. Edge	4013.14	1708.17	0.00	2	-2004.57
Fruit/Seed Consump. ~ Under.	4036.08	1731.11	0.00	2	-2016.04
Fruit/Seed Consump. ~ Dist. Herb.	4058.26	1753.29	0.00	2	-2027.13
Fruit/Seed Consump. ~ Dist. Mesic	4132.38	1827.41	0.00	2	-2064.19
Fruit/Seed Consump. ~ NDVI	4161.81	1856.84	0.00	2	-2078.91
Fruit/Seed Consump. ~ EVI	4256.43	1951.46	0.00	2	-2126.21
Fruit/Seed Consump. ~ TPI	4286.19	1981.22	0.00	2	-2141.10
Fruit/Seed Consump. ~ TOD	4325.71	2020.74	0.00	2	-2160.86
Fruit/Seed Consump. ~ Precip.	4328.05	2023.08	0.00	2	-2162.02
Fruit/Seed Consump. ~ 1	4338.05	2033.09	0.00	1	-2168.03
Females – Fruit & Seed Soft Mast Consumption					
Fruit/Seed Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Dist. Crop + Dist. Mesic + Dist. Herb. + Dist. Edge + Dist. Succ. + Dist. Xeric	2592.98	0.00	0.88	14	-1282.49
Fruit/Seed Consump. ~ *Global*	2596.92	3.94	0.12	18	-1280.46
Fruit/Seed Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Dist. Crop + Dist. Mesic + Dist. Herb. + Dist. Edge	2878.58	285.60	0.00	12	-1427.29
Fruit/Seed Consump. ~ DOY+TOD +Under. +Season +TPI +EVI+Dist. Crop+Dist. Mesic	3326.30	733.32	0.00	10	-1653.15
Fruit/Seed Consump. ~ DOY + TOD + Under. + Season + TPI + EVI	3405.78	812.80	0.00	8	-1694.89
Fruit/Seed Consump. ~ Dist. Xeric	3454.77	861.80	0.00	2	-1725.39
Fruit/Seed Consump. ~ DOY + Under. + Season	3554.31	961.33	0.00	5	-1772.16
Fruit/Seed Consump. ~ Season	3727.67	1134.69	0.00	3	-1860.83
Fruit/Seed Consump. ~ Dist. Succ.	3747.82	1154.84	0.00	2	-1871.91
Fruit/Seed Consump. ~ DOY + TOD + Under.	3854.50	1261.52	0.00	4	-1923.25
Fruit/Seed Consump. ~ Temp.	4036.18	1443.20	0.00	2	-2016.09
Fruit/Seed Consump. ~ Dist. Mesic	4056.23	1463.25	0.00	2	-2026.11
Fruit/Seed Consump. ~ Dist. Herb.	4092.73	1499.75	0.00	2	-2044.36
Fruit/Seed Consump. ~ Under.	4101.65	1508.68	0.00	2	-2048.83
Fruit/Seed Consump. ~ TOD	4148.29	1555.32	0.00	2	-2072.15
Fruit/Seed Consump. ~ DOY	4149.96	1556.98	0.00	2	-2072.98
Fruit/Seed Consump. ~ Dist. Crop	4187.01	1594.03	0.00	2	-2091.50
Fruit/Seed Consump. ~ EVI	4188.87	1595.89	0.00	2	-2092.43
Fruit/Seed Consump. ~ NDVI	4211.02	1618.04	0.00	2	-2103.51
Fruit/Seed Consump. ~ Dist. Human	4223.15	1630.17	0.00	2	-2109.58
Fruit/Seed Consump. ~ Dist. Edge	4223.96	1630.98	0.00	2	-2109.98
Fruit/Seed Consump. ~ TPI	4241.82	1648.84	0.00	2	-2118.91
Fruit/Seed Consump. ~ 1	4318.80	1725.82	0.00	1	-2158.40
Fruit/Seed Consump. ~ Precip.	4320.72	1727.74	0.00	2	-2158.36

3181 *DOY* represents the day of the year, *Under. represents* understory density observed in the camera collar video on a Daubenmire scale, *Season*
3182 represents the Season, *TPI* represents the topographic position index (TPI), *Temp* represents average daily temperature, *Dist. Human* represents
3183 the distance to human settlements, *Dist. Crop* represents the distance to agricultural or cropland, *Dist. Herb.* represents the distance to herbaceous
3184 fields or pastureland, *Dist. Edge* represents the distance to the forest edge, *Dist. Xeric* represents the distance to the xeric forest, *Global* represents
3185 the model with all variables included so long as no correlated variables are significant, *Dist. Succ.* represents the distance to the early to mid-
3186 successional forest, *Dist. Mesic* represents the distance to the mesic forest, *NDVI* represents the normalized difference vegetation index (NDVI),
3187 *EVI* represents the enhanced vegetation index (EVI), *TOD* represents the time of day, and *Precip* represents precipitation.

Table 8. Generalized linear mixed models with a binomial distribution for consumption of hard mast. Model definition describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion, ΔAIC is the difference in AIC between a model and the top model, wi is model weight, K is the number of parameters, and Log(l) is Log-likelihood. black bear ID was used as a random effect. Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Males – Hard Mast Consumption					
Hard Mast Consump. ~ DOY + NDVI + Dist. Human + Dist. Crop + Dist. Xeric	611.21	0.00	0.97	6	-299.60
Hard Mast Consump. ~ DOY + NDVI + Dist. Human + Dist. Crop	618.44	7.23	0.03	5	-304.22
Hard Mast Consump. ~ *Global*	621.30	10.09	0.01	18	-292.65
Hard Mast Consump. ~ DOY + NDVI	631.35	20.14	0.00	3	-312.67
Hard Mast Consump. ~ DOY + NDVI + Dist. Human	633.12	21.91	0.00	4	-312.56
Hard Mast Consump. ~ DOY + Dist. Human	645.70	34.49	0.00	3	-319.85
Hard Mast Consump. ~ DOY	646.30	35.09	0.00	2	-321.15
Hard Mast Consump. ~ Season	796.16	184.95	0.00	3	-395.08
Hard Mast Consump. ~ Temp.	1103.56	492.35	0.00	2	-549.78
Hard Mast Consump. ~ EVI	1514.28	903.07	0.00	2	-755.14
Hard Mast Consump. ~ NDVI	1553.87	942.66	0.00	2	-774.93
Hard Mast Consump. ~ Dist. Succ.	1566.52	955.31	0.00	2	-781.26
Hard Mast Consump. ~ Under.	1779.60	1168.39	0.00	2	-887.80
Hard Mast Consump. ~ Dist. Mesic	1846.36	1235.15	0.00	2	-921.18
Hard Mast Consump. ~ Dist. Edge	1910.07	1298.87	0.00	2	-953.04
Hard Mast Consump. ~ Dist. Human	1941.59	1330.38	0.00	2	-968.79
Hard Mast Consump. ~ Dist. Herb.	1959.00	1347.79	0.00	2	-977.50
Hard Mast Consump. ~ Dist. Xeric	1982.91	1371.71	0.00	2	-989.46
Hard Mast Consump. ~ TOD	2008.11	1396.90	0.00	2	-1002.06
Hard Mast Consump. ~ Dist. Crop	2030.43	1419.22	0.00	2	-1013.22
Hard Mast Consump. ~ Precip.	2034.96	1423.75	0.00	2	-1015.48
Hard Mast Consump. ~ 1	2037.56	1426.35	0.00	1	-1017.78
Hard Mast Consump. ~ TPI	2039.53	1428.32	0.00	2	-1017.77
Females – Hard Mast Consumption					
Hard Mast Consump. ~ DOY + Under. + Season + Temp. + Dist. Human + Dist. Mesic + Dist. Herb. + Dist. Succ.	649.68	0.00	0.78	10	-314.84
Hard Mast Consump. ~ DOY+Under.+Season+Temp.+Dist. Human +Dist. Mesic +Dist. Herb.	652.48	2.81	0.19	9	-317.24
Hard Mast Consump. ~ *Global*	657.45	7.77	0.02	18	-310.72
Hard Mast Consump. ~ DOY + Under. + Season + Temp. + Dist. Human + Dist. Mesic	657.90	8.22	0.01	8	-320.95
Hard Mast Consump. ~ DOY + Under. + Season + Temp.	709.34	59.66	0.00	6	-348.67
Hard Mast Consump. ~ Season	747.60	97.92	0.00	3	-370.80
Hard Mast Consump. ~ DOY + Under.	929.33	279.66	0.00	3	-461.67
Hard Mast Consump. ~ DOY	980.50	330.83	0.00	2	-488.25
Hard Mast Consump. ~ Dist. Human	1261.12	611.44	0.00	2	-628.56
Hard Mast Consump. ~ Dist. Edge	1385.28	735.60	0.00	2	-690.64
Hard Mast Consump. ~ Temp.	1397.42	747.74	0.00	2	-696.71
Hard Mast Consump. ~ Dist. Mesic	1399.96	750.28	0.00	2	-697.98
Hard Mast Consump. ~ Dist. Crop	1400.65	750.97	0.00	2	-698.32
Hard Mast Consump. ~ Dist. Herb.	1528.91	879.24	0.00	2	-762.46
Hard Mast Consump. ~ Dist. Xeric	1549.34	899.66	0.00	2	-772.67
Hard Mast Consump. ~ Dist. Succ.	1565.95	916.27	0.00	2	-780.97
Hard Mast Consump. ~ EVI	1609.08	959.40	0.00	2	-802.54
Hard Mast Consump. ~ Understory	1612.30	962.62	0.00	2	-804.15
Hard Mast Consump. ~ TOD	1637.68	988.00	0.00	2	-816.84
Hard Mast Consump. ~ NDVI	1683.51	1033.84	0.00	2	-839.76
Hard Mast Consump. ~ 1	1686.23	1036.55	0.00	1	-842.11
Hard Mast Consump. ~ Precip.	1686.80	1037.12	0.00	2	-841.40
Hard Mast Consump. ~ TPI	1688.11	1038.44	0.00	2	-842.06

DOY represents the day of the year, *NDVI* represents the normalized difference vegetation index (NDVI), *Dist. Human* represents the distance to human settlements, *Dist. Crop* represents the distance to agricultural or cropland, *Dist. Xeric* represents the distance to the xeric forest, *Global* represents the model with all variables included so long as no correlated variables are significant, *Season* represents the Season, *Temp* represents average daily temperature, *EVI* represents the enhanced vegetation index (EVI), *Dist. Succ.* represents the distance to the early to mid-successional forest, *Under.* represents understory density observed in the camera collar video on a Daubenmire scale, *Dist. Mesic* represents the distance to the mesic forest, *Dist. Edge* represents the distance to the forest edge, *Dist. Herb.* represents the distance to herbaceous fields or pastureland, *TOD* represents the time of day, *Precip* represents precipitation, and *TPI* represents the topographic position index (TPI).

Table 9. Generalized linear mixed models with a binomial distribution for consumption of invasive species. Model definition describes variables in the models (defined in footnotes), AIC is the Akaike Information Criterion, ΔAIC is the difference in AIC between a model and the top model, *w*i is model weight, K is the number of parameters, and Log(*l*) is Log-likelihood. black bear ID was used as a random effect. Data as part of the Virginia Appalachian Carnivore Study in Bath County, Virginia in 2018-2019.

Model Definition	AIC	ΔAIC	wi	K	Log(l)
Males – Invasive Species Consumption					
Invasive Consump. ~ DOY + Under. + Season + TPI + Temp. + EVI + Dist. Crop + Dist. Herb. + Dist. Edge + Dist. Succ. + Dist. Xeric	1738.45	0.00	0.97	13	-856.23
Invasive Consump. ~ DOY+Under.+Season+TPI+EVI+Dist. Crop+Dist. Herb.+Dist. Edge+Dist.Succ.+Dist.Xeric	1745.19	6.74	0.03	12	-860.60
Invasive Consump. ~ DOY + Under. + Season + TPI + EVI + Dist. Crop + Dist. Herb. + Dist. Edge + Dist. Succ.	1759.05	20.60	0.00	11	-868.53
Invasive Consump. ~ DOY + Under. + Season + TPI + EVI + Dist. Crop + Dist. Herb. + Dist. Edge	1794.92	56.47	0.00	10	-887.46
Invasive Consump. ~ DOY + Under. + Season + TPI + EVI + Dist. Crop + Dist. Herb.	1806.81	68.36	0.00	9	-894.41
Invasive Consump. ~ DOY + Under. + Season + TPI + EVI + Dist. Crop	1855.76	117.31	0.00	8	-919.88
Invasive Consump. ~ Dist. Human	2005.34	266.89	0.00	2	-1000.67
Invasive Consump. ~ DOY + Under. + Season + TPI + EVI	2028.51	290.06	0.00	7	-1007.26
Invasive Consump. ~ DOY + Under. + Season	2060.74	322.29	0.00	5	-1025.37
Invasive Consump. ~ Dist. Crop	2107.08	368.63	0.00	2	-1051.54
Invasive Consump. ~ Dist. Herb.	2175.87	437.42	0.00	2	-1085.94
Invasive Consump. ~ Season	2219.18	480.73	0.00	3	-1106.59
Invasive Consump. ~ Dist. Xeric	2262.89	524.44	0.00	2	-1129.45
Invasive Consump. ~ DOY + Under.	2268.20	529.75	0.00	3	-1131.10
Invasive Consump. ~ Understory	2277.06	538.61	0.00	2	-1136.53
Invasive Consump. ~ Precip.	2283.58	545.13	0.00	2	-1139.79
Invasive Consump. ~ TPI	2283.92	545.47	0.00	2	-1139.96
Invasive Consump. ~ NDVI	2311.75	573.30	0.00	2	-1153.88
Invasive Consump. ~ Dist. Mesic	2312.77	574.32	0.00	2	-1154.39
Invasive Consump. ~ EVI	2314.97	576.52	0.00	2	-1155.49
Invasive Consump. ~ 1	2316.24	577.79	0.00	1	-1157.12
Invasive Consump. ~ Dist. Edge	2316.50	578.05	0.00	2	-1156.25
Invasive Consump. ~ TOD	2316.71	578.26	0.00	2	-1156.35
Invasive Consump. ~ Dist. Succ.	2316.82	578.37	0.00	2	-1156.41
Invasive Consump. ~ Temp.	2317.47	579.02	0.00	2	-1156.73
Invasive Consump. ~ DOY	2317.60	579.15	0.00	2	-1156.80
Females – Invasive Species Consumption					
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Rainfall + Temp. + Dist. Human + Dist. Crop + Dist. Herb + Dist. Succ. + Dist. Xeric	2103.50	0.00	0.98	15	-1036.75
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + NDVI + Rainfall + Temp. + Dist. Human + Dist. Crop + Dist. Herb + Dist. Succ. + Dist. Xeric	2111.80	8.30	0.02	15	-1040.90
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Rainfall + Temp. + Dist. Human + Dist. Crop + Dist. Herb	2161.18	57.69	0.00	13	-1067.59
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Rainfall + Temp. + Dist. Human +Dist. Crop	2345.58	242.08	0.00	12	-1160.79
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + EVI + Rainfall + Temp.	2543.31	439.81	0.00	10	-1261.66
Invasive Consump. ~ DOY + TOD + Under. + Season + TPI + Rainfall	2608.42	504.92	0.00	8	-1296.21
Invasive Consump. ~ DOY + Under. + Season	2670.94	567.44	0.00	5	-1330.47
Invasive Consump. ~ Dist. Herb.	2841.23	737.74	0.00	2	-1418.62
Invasive Consump. ~ Understory	2940.98	837.48	0.00	2	-1468.49
Invasive Consump. ~ Dist. Edge	3189.37	1085.87	0.00	2	-1592.68
Invasive Consump. ~ Dist. Crop	3199.40	1095.91	0.00	2	-1597.70
Invasive Consump. ~ Season	3238.33	1134.83	0.00	3	-1616.16
Invasive Consump. ~ Dist. Human	3258.94	1155.45	0.00	2	-1627.47
Invasive Consump. ~ Temp.	3265.67	1162.18	0.00	2	-1630.84
Invasive Consump. ~ Precip.	3279.24	1175.74	0.00	2	-1637.62
Invasive Consump. ~ Dist. Xeric	3280.15	1176.65	0.00	2	-1638.07
Invasive Consump. ~ TPI	3287.20	1183.70	0.00	2	-1641.60
Invasive Consump. ~ EVI	3290.11	1186.62	0.00	2	-1643.06
Invasive Consump. ~ Dist. Succ.	3290.80	1187.31	0.00	2	-1643.40
Invasive Consump. ~ TOD	3300.23	1196.74	0.00	2	-1648.12
Invasive Consump. ~ DOY	3301.85	1198.36	0.00	2	-1648.93
Invasive Consump. ~ NDVI	3301.92	1198.42	0.00	2	-1648.96
Invasive Consump. ~ 1	3306.64	1203.15	0.00	1	-1652.32
Invasive Consump. ~ Dist. Mesic	3308.42	1204.93	0.00	2	-1652.21

DOY represents the day of the year, *Under.* represents understory density observed in the camera collar video on a Daubenmire scale, *Season* represents the Season, *TPI* represents the topographic position index (TPI), *Temp* represents average daily temperature, *EVI* represents the enhanced vegetation index (EVI), *Dist. Crop* represents the distance to agricultural or cropland, *Dist. Herb.* represents the distance to herbaceous fields or pastureland, *Dist. Edge* represents the distance to the forest edge, *Dist. Succ.* represents the distance to the early to mid-successional forest, *Dist. Xeric* represents the distance to the xeric forest, *Dist. Human* represents the distance to human settlements, *Precip* represents precipitation, *NDVI* represents the normalized difference vegetation index (NDVI), *TOD* represents the time of day, and *Dist. Mesic* represents the distance to the mesic forest.

Supplementary Materials
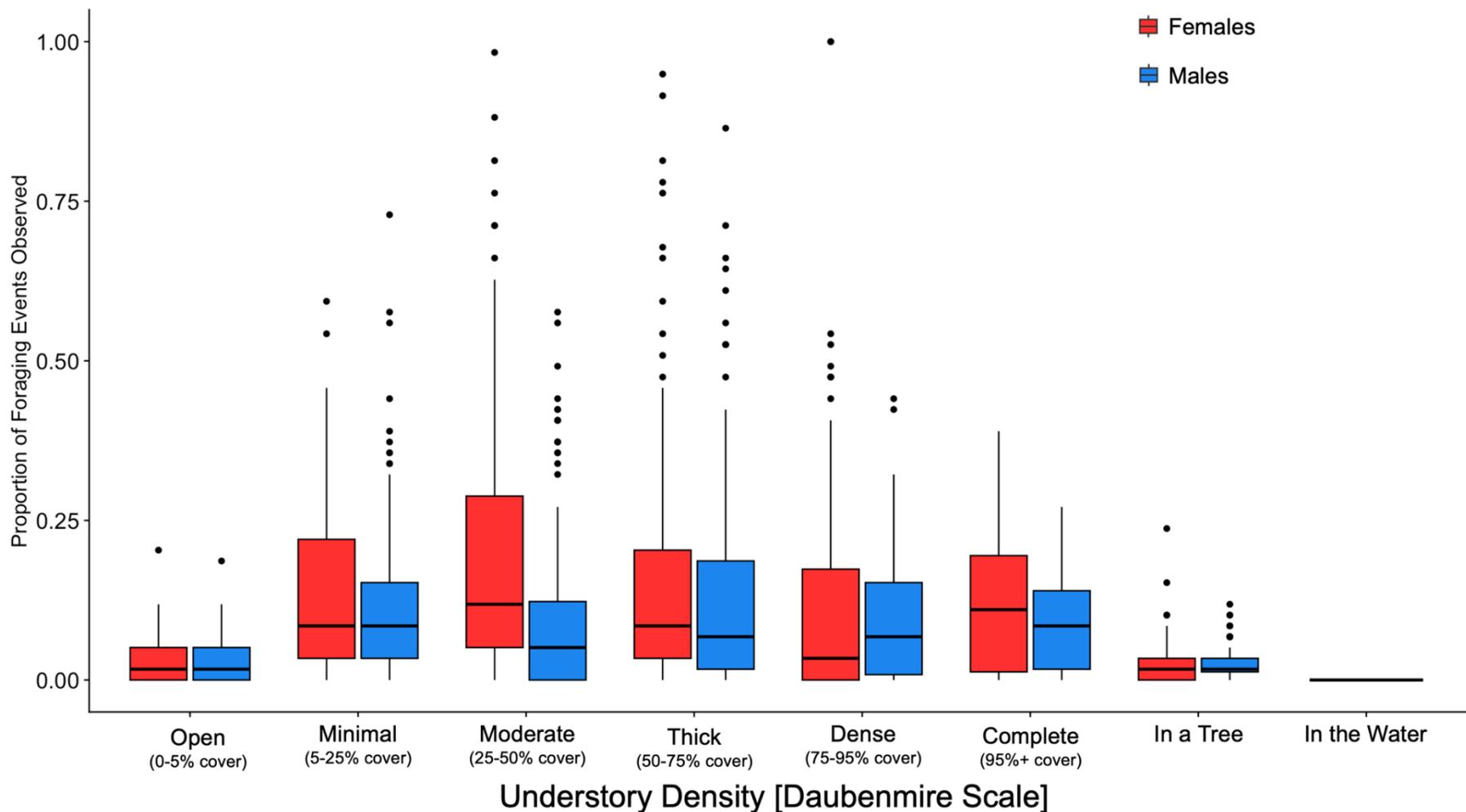
212
213   Supplemental Figure S1. Distribution understory density on a Daubenmire scale (Daubenmire 1959) with the following categories based on what we
214   saw on the video open (0-5% cover), minimal (5-25% cover), moderate (25-50% cover), thick (50-75% cover), dense (75-95% cover), complete
215   (95%+ cover), with the addition of in water or in a tree when this occurred on the videos. Data come from species seen consumed in videos from
216   camera collars on 15 black bears in Bath County, VA in 2018 and 2019.
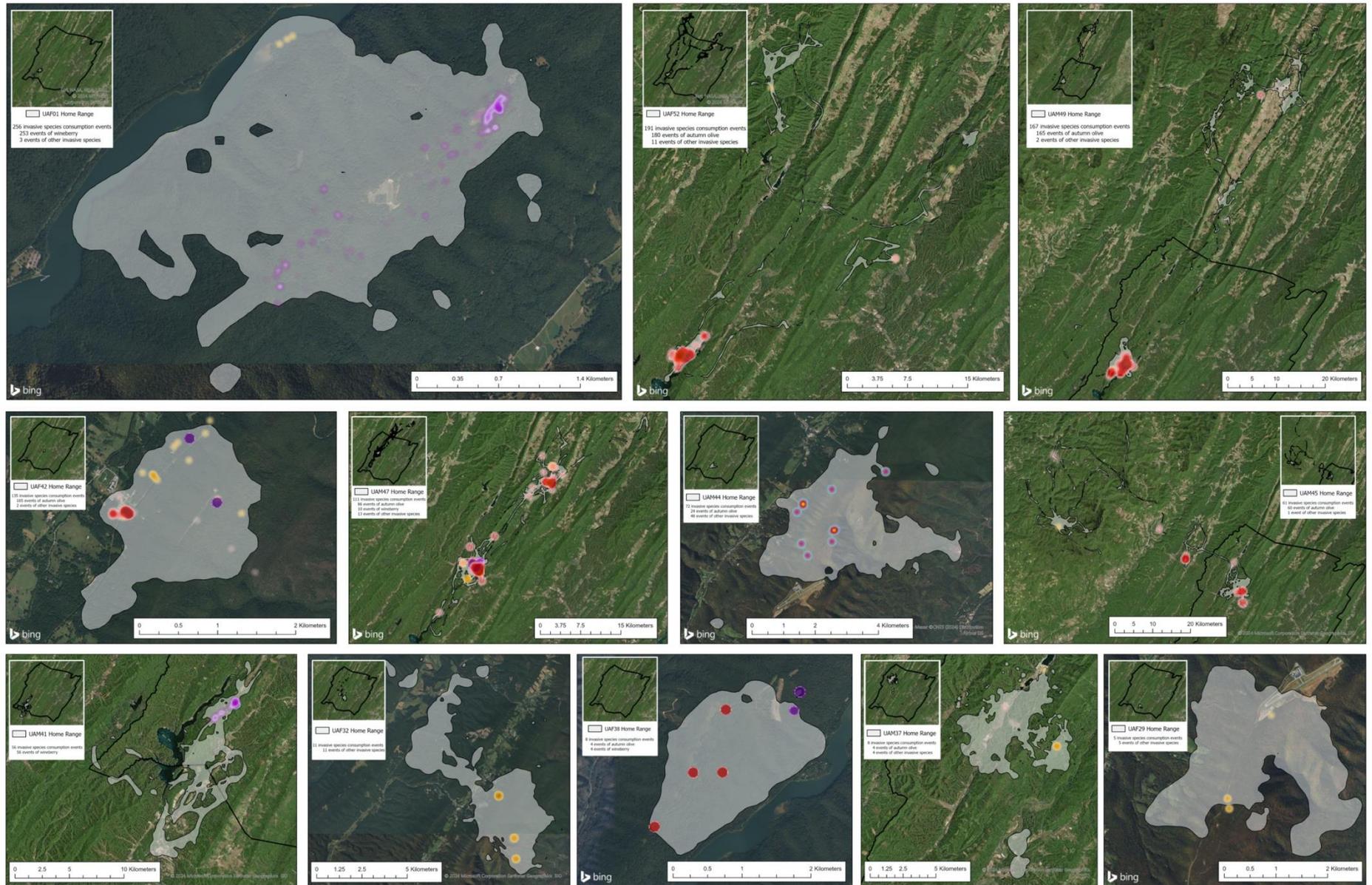
Figure S2. Map displaying of locations of invasive species consumption by across all 15 bears in 2018 and 2019 in Bath County, Virginia (inset in gray), with the red gradient denoting autumn olive consumption (*Elaeagnus umbellata*), the purple gradient denoting wineberry consumption (*Rubus phoenicolasius*), and orange gradient denoting the remaining invasive species consumed, which occurred at lower frequencies.

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221 Supplemental Table S1. Covariates used in foraging analyses with source of covariate, covariate rationale and expected direction and impact, and
222 references to support the expected impacts on foraging of American black bears in 2018 and 2019, in Bath County, Virginia.

Covariates Used In Analyses	Covariate Rationale	Source	Expected & Impact Rationale	Reference
~ Day Of Year	Day of the year was utilized to understand potential changes in foraging over time at a potentially smaller scale than seasons	Collected from video camera collars	We expected shifts in diet items eaten by bears with season, which could be captured by day of the year, such that herbaceous soft mast and white-tailed deer (*Odocoileus virginianus*) would be higher in spring, fruit and seed soft mast being highest in the summer, and hard mast highest in fall.	Eagle and Pelton 1983, Hellgren et al. 1989, Hilderbrand et al. 1999, Mazur et al. 2013, Clevinger 2022, Alonso, 2023
~ Time Of Day	Time of day was utilized to isolate potential foraging trends that occurred by times of the day	Collected from video camera collars	We expected higher levels of foraging activity throughout the day (i.e., diurnal) especially in the fall months in preparation for hibernation during hyperphagia (increased food intake).	Hubbard et al. 2022
~ Understory Density	Understory Density was utilized to isolate if certain diet items were consistently consumed in specific understories, classified on a Daubenmire scale	Collected from video camera collars	We expected higher levels of foraging on vegetation in higher understory densities, and higher consumption of white-tailed deer fawns in moderate to dense understory as black bear consumed fawns in the habitats where fawns are commonly bedded down.	Gray et al. 2017, Clevinger 2022, Edge et al. 2023
~ Season	Season was utilized to understand potential changes in foraging over time by the broader classifications of season	Collected from video camera collars	We expected changes in proportions of the diet with season, with higher herbaceous soft mast and deer in spring, fruit and seed soft mast being highest in the summer, and hard mast being highest in the fall due to availability on the landscape (as bears have been shown to be opportunistic omnivores).	Beeman and Pelton 1980, Hellgren et al. 1989, Romain et al. 2013, Hubbard et al. 2022
~ Topographic Point Index (TPI)	TPI was utilized to isolate if certain diet items were consistently consumed at specific elevations	U.S. Geological Survey 2019	We expected higher consumption of white-tailed deer, specifically fawns, at lower elevations and more hard mast at higher elevations because fawns are often bedded, and hard mast is found in, these habitats	Mazur et al. 2013, Clevinger 2022, Alonso, 2023
~ Precipitation	Precipitation was utilized to isolate if levels of precipitation had impact on consumption of certain diet items	PRISM Climate Group 2024	We expected lower frequency of foraging when precipitation was higher because of potentially challenging weather for bears to move around and forage.	Mazur et al. 2013
~ Normalized Difference Vegetation Index (NDVI)	NDVI was utilized to isolate if this vegetation index was a stronger predictor for consumption of certain diet items	U.S. Geological Survey 2022	We expected higher vegetation consumption in early spring as indicated by higher NDVI values compared to fall where NDVI would be lower. We expected higher consumption of hard mast at lower NDVI in fall months.	Birky 2001, Wang et al. 2003
~ Enhanced Vegetation Index (EVI)	EVI was utilized to isolate if this vegetation index was a stronger predictor for consumption of certain diet items	U.S. Geological Survey 2022	EVI is a better indicator of vegetation state in the late spring and summer months, thus we expected higher EVI would drive more foraging on herbaceous soft mast and fruit and seed soft mast in these seasons.	Matsushita et al. 2007, Son et al. 2014
~ Temperature	Temperature was utilized to isolate if certain diet items were consistently consumed at certain temperatures	PRISM Climate Group 2024	We expected changes in foraging as temperatures decrease, particularly in the fall, when bears go into hyperphagia in preparation for hibernation, where bears forage for longer	Hellgren et al. 1989, Klees van Bommel et al. 2022

		periods, which would be reflected in more foraging on hard mast at lower temperatures.	
~ Distance to Human Settlements	Distance to human settlements was collected from GPS coordinates of people in the counties' houses and buildings (including barns if registered with the state) extracted through tax records in Virginia & West Virginia	West Virginia GIS Technical Center 2022, Virginia Geographic Information Network Advisory Board 2023	We expected higher foraging frequency on anthropogenic foods, especially garbage, corn, or bird seed, closer human settlements because the higher presence of these foods near humans, which has been documented in the literature.	Kirby et al. 2016, 2019, Gillman et al. 2022
~ Distance to Agricultural or Croplands	Distance to agricultural or croplands was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency on anthropogenic foods, especially corn, fruit, or livestock feed, closer to agricultural or croplands since these foods are located there and other studies have shown similar results.	Ditmer et al. 2016; Alonso 2024
~ Distance to Mesic (Wet) Forests	Distance to mesic forests was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency on traditional diet items such as fruit and seed soft mast closer to mesic forests because this is where such species in this area grow.	Alonso, 2023
~ Distance to Herbaceous Fields	Distance to herbaceous fields or pasturelands was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency on traditional diet items specifically herbaceous soft mast, and potentially higher levels on anthropogenic foods, especially corn, fruit, or livestock feed, closer to herbaceous fields or pastureland as this is where these species tend to occur.	Alonso, 2023
~ Distance to Forest Edge	Distance to forest edge was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency on traditional diet items, specifically fruit and seed soft mast, closer to forest edges as this is commonly where some species in this diet classification grow (i.e., Rubus spp.).	Alonso, 2023
~ Distance to Early to Mid-Successional Forest	Distance to early to mid-successional forests was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency on traditional diet items such as fruit and seed soft mast and hard mast, closer to early to mid-successional forests as this is commonly where some species in this diet classification grow (i.e., huckleberry & blueberry species.).	Romain et al. 2013
~ Distance to Xeric (Dry) Forests	Distance to xeric forests was extracted from our integrated raster later*	National Land Cover Database (Dewitz 2024), USDA Forest Service 2020	We expected higher foraging frequency for traditional diet items such as hard mast, closer to xeric forests as this is commonly where some species in this diet classification grow (i.e., oaks and hickory species).	Alonso, 2023

223 *We collected the Euclidean distance to habitat type variables by integrating raster layers from the National Land Cover Database (NLCD, Dewitz 2024), the US Forest Service (USDA Forest Service
224 2020), and ground-truthing by the field team(s).

Supplemental Table S2. List of all plant species (163) observed in video camera collars as consumed by black bears in 2018 and 2019 in the Appalachian Mountains of Bath County, Virginia.

Species	Scientific Name	Invasive	# Bears	Spring	Summer	Fall	Winter	Grand Total
Hard Mast Species								
American Beech	*Fagus grandifolia*	-	1	0	0	1	0	1
Bitternut Hickory	*Carya cordiformis*	-	2	0	0	11	0	11
Black Walnut	*Juglans nigra*	-	6	0	12	161	7	180
Hickory (Genus)	*Carya spp.*	-	5	0	12	590	0	602
Mockernut Hickory	*Carya tomentosa*	-	1	0	0	1	0	1
Oak (Genus)	*Quercus spp.*	-	5	0	4	120	12	136
Fungal Species								
Morel (Genus)	*Morchella spp.*	-	1	0	2	0	0	2
Truffle (Genus)	*Tuber spp.*	-	2	5	12	0	0	17
Vascular Plant Species – Fruit & Seeds Consumed								
Alleghany Blackberry	*Rubus allegheniensis*	-	2	0	8	0	0	8
Amur Honeysuckle	*Lonicera maackii*	Invasive	4	0	4	1	0	5
Autumn Olive	*Elaeagnus umbellata*	Invasive	10	0	567	106	0	673
Bearcorn (Squawroot)	*Conopholis americana*	-	7	3	213	2	0	218
Black Cherry	*Prunus serotina*	-	6	0	148	165	0	313
Black Chokeberry	*Aronia melanocarpa*	-	1	0	0	1	0	1
Black Locust	*Robinia pseudoacacia*	-	1	0	0	1	0	1
Black Raspberry	*Rubus occidentalis*	-	8	1	160	0	0	161
Blackberry	*Rubus fruticosus*	-	5	0	95	0	0	95
Blackhaw	*Viburnum prunifolium*	-	3	0	8	2	0	10
Blueberry/Huckleberry	*Vaccinium spp./Gaylussacia spp.*	-	11	47	2957	0	0	3004
Border Privet	*Ligustrum obtusifolium var. obtusifolium*	Invasive	1	0	2	0	0	2
Bristly Greenbrier	*Smilax tamnoides*	-	1	0	0	3	0	3
Callery Pear	*Pyrus calleryana*	Invasive	2	0	1	1	0	2
Cherry (Genus)	*Prunus spp.*	-	8	6	97	7	0	110
Common Buckthorn	*Rhamnus cathartica*	Invasive	2	0	1	3	0	4
Coralberry	*Symphoricarpos orbiculatus*	-	1	0	0	1	0	1
Cucumbertree	*Magnolia acuminata*	-	2	0	0	10	0	10
Deerberry	*Vaccinium stamineum*	-	1	0	6	0	0	6
Dewberry	*Rubus flagellaris*	-	2	0	10	0	0	10
Downy Yellow False Foxglove	*Aureolaria virginica*	-	1	0	1	0	0	1
Florida Prickly Blackberry	*Rubus argutus*	-	1	0	6	0	0	6
Flowering Dogwood	*Cornus florida*	-	1	0	0	2	0	2
Gooseberry	*Ribes uva-crispa*	-	1	0	19	0	0	19
Greenbrier (Genus)	*Smilax spp.*	-	1	0	0	4	0	4
Gum (Genus)	*Nyssa spp.*	-	1	0	7	0	0	7
Hackberry	*Celtis occidentalis*	-	1	0	6	0	0	6
Holly (Genus)	*Ilex spp.*	-	1	0	0	1	0	1

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Honeysuckle (Genus)	*Lonicera spp.*	-	4	2	77	0	0	79
Honeysuckle (Non-Native,Genus)	*Lonicera spp.*	Invasive	2	0	11	4	0	15
Japanese Barberry	*Berberis thunbergii*	Invasive	1	0	1	0	0	1
Japanese Honeysuckle	*Lonicera japonica*	Invasive	1	0	1	0	0	1
Magnolia (Genus)	*Magnolia spp.*	-	3	0	0	57	0	57
Mayapple	*Podophyllum spp.*	-	1	0	1	0	0	1
Morrow's Honeysuckle	*Lonicera morrowii*	Invasive	2	0	1	1	0	2
Mountain Pieris	*Pieris floribunda*	-	1	0	1	0	0	1
Multiflora Rose	*Rosa multiflora*	Invasive	1	0	2	0	0	2
Nettle (Genus)	*Urtica spp.*	-	1	0	1	0	0	1
Pokeweed	*Phytolacca decandra*	-	4	0	18	5	0	23
Raspberry	*Rubus idaeus*	-	4	4	61	0	0	65
Red Chokeberry	*Aronia arbutifolia*	-	1	0	0	1	0	1
Rhododendron (Genus)	*Rhododendron spp.*	-	2	4	3	0	0	7
Rubus (Genus)	*Rubus spp.*	-	11	19	853	2	0	874
Sarsaparilla	*Aralia nudicaulis*	-	1	1	4	0	0	5
Sassafras	*Sassafras albidum*	-	1	2	0	0	0	2
Serviceberry (Genus)	*Amelanchier spp.*	-	3	0	6	0	0	6
Southern Crabapple	*Malus angustifolia*	-	1	0	2	0	0	2
Sparkleberry	*Vaccinium arboreum*	-	2	0	8	0	0	8
Spicebush	*Lindera benzoin*	-	3	0	4	3	0	7
Summer Grape	*Vitis aestivalis*	-	4	0	8	6	0	14
Tartarian Honeysuckle	*Lonicera tatarica*	Invasive	1	0	1	0	0	1
Viburnum (Genus)	*Viburnum spp.*	-	1	0	0	3	0	3
Virginia Creeper	*Parthenocissus quinquefolia*	-	1	0	0	9	0	9
Wineberry	*Rubus phoenicolasius*	Invasive	6	0	327	0	0	327

Vascular Plant Species – Herbaceous Matter Consumed

American Beech	*Fagus grandifolia*	-	2	0	7	0	0	7
American Hornbeam	*Carpinus caroliniana*	-	2	3	0	1	0	4
Apiaceae (Family)	*Apiaceae spp.*	-	1	15	0	0	0	15
Ash (Genus)	*Fraxinus spp.*	-	1	5	0	0	0	5
Aster (Genus)	*Aster spp.*	-	2	8	0	0	0	8
Autumn Olive	*Elaeagnus umbellata*	Invasive	1	0	1	0	0	1
Baneberry	*Actaea rubra*	Invasive	1	5	10	0	0	15
Beaked Hazelnut	*Corylus cornuta*	-	1	0	2	0	0	2
Bedstraw (Genus)	*Galium spp.*	-	1	5	0	0	0	5
Beefsteak Plant	*Perilla frutescens*	Invasive	1	0	1	0	0	1
Birch (Genus)	*Betula spp.*	-	1	5	0	0	0	5
Black Cohosh	*Actaea racemosa*	-	4	5	7	0	0	12
Black Gum	*Nyssa sylvatica*	-	1	0	0	1	0	1
Blackberry	*Rubus fruticosus*	-	2	0	20	0	0	20
Blackhaw	*Viburnum prunifolium*	-	1	0	5	0	0	5

Blueberry (Genus)	*Vaccinium spp.*	-	1	3	0	0	0	3
Blueberry/Huckleberry	*Vaccinium spp./Gaylussacia spp.*	-	4	1	59	0	0	60
Boxelder	*Acer negundo*	-	2	2	1	0	0	3
Broadleaf Arrowhead	*Sagittaria latifolia*	Invasive	1	0	0	1	0	1
Buckeye	*Aesculus glabra*	-	1	0	7	0	0	7
Bull Thistle	*Cirsium vulgare*	Invasive	1	0	1	0	0	1
Callery Pear	*Pyrus calleryana*	Invasive	1	0	1	0	0	1
Cherry (Genus)	*Prunus spp.*	-	1	1	0	0	0	1
Cinquefoil (Genus)	*Potentilla spp.*	-	1	4	0	0	0	4
Clearweed	*Pilea pumila*	-	1	0	0	2	0	2
Clustered Blacksnakeroot	*Sanicula odorata*	-	1	7	0	0	0	7
Coltsfoot	*Tussilago farfara*	Invasive	1	0	2	0	0	2
Common Buckthorn	*Rhamnus cathartica*	Invasive	1	1	0	0	0	1
Common Greenbrier	*Smilax rotundifolia*	-	2	4	0	1	0	5
Common Milkweed	*Asclepias syriaca*	Invasive	1	8	0	0	0	8
Copperleaf	*Acalypha rhomboidea*	-	1	7	0	0	0	7
Coreopsis (Genus)	*Coreopsis spp.*	-	1	0	2	0	0	2
Crabweed (Genus)	*Digitaria spp.*	-	1	30	0	0	0	30
Cucumbertree	*Magnolia acuminata*	-	2	4	4	0	0	8
Dogwood (Genus)	*Cornus spp.*	-	1	0	1	0	0	1
Eastern Cottonwood	*Populus deltoides*	-	1	0	4	0	0	4
Eastern Leatherwood	*Dirca palustris*	-	1	0	8	0	0	8
Elm (Genus)	*Ulmus spp.*	-	1	0	22	0	0	22
Fern (Genus)	*Asplenium spp.*	-	3	3	2	0	0	5
Garlic Mustard	*Alliaria petiolata*	Invasive	2	0	7	0	0	7
Ghost Pipe	*Monotropa uniflora*	-	1	0	2	0	0	2
Goldenrod (Genus)	*Solidago spp.*	-	2	3	4	0	0	7
Grasses (Family)	*Poaceae spp.*	-	8	21	24	2	0	47
Greater Tickseed	*Coreopsis major*	-	1	1	0	0	0	1
Greenbrier (Genus)	*Smilax spp.*	-	1	3	0	0	0	3
Hawthorn (Genus)	*Crataegus spp.*	-	3	7	7	0	0	14
Hickory (Genus)	*Carya spp.*	-	3	0	15	2	0	17
Honewort	*Cryptotaenia canadensis*	-	1	0	1	0	0	1
Horseweed	*Erigeron canadensis*	-	1	0	2	0	0	2
Huckleberry	*Gaylussacia spp.*	-	1	0	6	0	0	6
Indian Cucumberroot	*Medeola virginiana*	-	1	1	0	0	0	1
Jack In the Pulpit	*Arisaema triphyllum*	-	1	26	3	0	0	29
Jewelweed	*Impatiens capensis*	Invasive	9	106	36	7	0	149
Kudzu	*Pueraria montana*	Invasive	1	0	0	2	0	2
Magnolia (Genus)	*Magnolia spp.*	-	3	5	2	1	0	8
Maple (Genus)	*Acer spp.*	-	1	0	3	0	0	3
Maple Leaf Viburnum	*Viburnum acerifolium*	Invasive	1	9	0	0	0	9

Common Name	Scientific Name							
Mayapple	*Podophyllum spp.*	-	4	3	8	1	0	12
Mock Strawberry	*Duchesnea indica*	Invasive	1	0	5	0	0	5
Mountain Laurel	*Kalmia latifolia*	-	1	0	4	0	0	4
Naked-flowered Tick Trefoil	*Desmodium nudiflorum*	-	1	1	0	0	0	1
Nettle (Genus)	*Urtica spp.*	-	8	148	206	6	0	360
New Jersey Tea	*Ceanothus americanus*	-	1	1	0	0	0	1
Oak (Genus)	*Quercus spp.*	-	1	1	7	0	0	8
Osmorhiza (Genus)	*Osmorhiza spp.*	-	1	1	9	0	0	10
Pawpaw	*Asimina triloba*	-	1	0	3	0	0	3
Pear [Fruit]	*Pyrus spp.*	-	1	2	0	0	0	2
Pine (Genus)	*Pinus spp.*	-	1	0	0	2	0	2
Poison Ivy	*Toxicodendron radicans*	-	3	1	2	0	0	3
Poplar - Yellow (Tulip)	*Liriodendron tulipifera*	-	1	8	0	0	0	8
Raphanus (Genus)	*Raphanus spp.*	Invasive	1	0	1	0	0	1
Red Maple	*Acer rubrum*	-	1	0	1	0	0	1
Red Mulberry	*Morus rubra*	-	1	0	0	1	0	1
Rhododendron (Genus)	*Rhododendron spp.*	-	3	0	9	0	0	9
Royal Paulownia	*Paulownia tomentosa*	Invasive	1	1	0	0	0	1
Rubus (Genus)	*Rubus spp.*	-	5	1	9	0	0	10
Saplings (General)	-	-	2	2	25	0	0	27
Sassafras	*Sassafras albidum*	-	2	6	3	0	0	9
Skunk Cabbage	*Symplocarpus foetidus*	-	3	10	27	0	0	37
Solomen's Seal (Genus)	*Polygonatum spp.*	-	1	1	0	0	0	1
Spanish Needles	*Bidens alba*	Invasive	3	6	13	8	0	27
Squash (Genus)	*Cucurbita spp.*	-	1	0	0	1	0	1
Stickweed	*Hackelia spp.*	-	1	0	1	0	0	1
Summer Grape	*Vitis aestivalis*	-	1	0	2	1	0	3
Sweet Cicely	*Myrrhis odorata*	Invasive	1	0	2	0	0	2
Sycamore	*Platanus occidentalis*	-	2	0	1	1	0	2
Thistle (Family)	*Cirsium spp.*	Invasive	1	0	1	0	0	1
Trillium (Genus)	*Trillium spp.*	-	2	5	12	0	0	17
Trumpet Creeper	*Campsis radicans*	-	1	0	0	1	0	1
Viburnum (Genus)	*Viburnum spp.*	-	1	0	1	0	0	1
Viola (Genus)	*Viola spp.*	-	2	0	4	2	0	6
Virginia Creeper	*Parthenocissus quinquefolia*	-	3	8	23	4	0	35
Wild Yam	*Dioscorea villosa*	Invasive	1	0	7	0	0	7
Willow	*Salix spp.*	-	2	0	4	4	0	8
Witch Hazel	*Hamamelis virginiana*	-	2	0	5	0	0	5
Wood Cranesbill	*Geranium sylvaticum*	Invasive	1	0	4	0	0	4

Anthropogenic Species Consumed

Apple	*Malus domestica*	Fruit	12	12	102	5	0	119
Apple	*Malus domestica*	Leaf	1	0	1	0	0	1

Corn	*Zea mays*	Fruit	1	0	1	0	0	1
Pear [Fruit]	*Pyrus spp.*	Fruit	1	4	2	0	0	6
Unknown Species Consumed								
Unknown Fruit	-	-	3	0	70	8	0	78
Unknown Fungus	-	-	1	0	10	2	0	12
Unknown Herbaceous	-	-	3	67	226	20	0	313
Unknown Nut	-	-	2	0	1	199	0	200

227

228 Table S3. Summary of estimates of β coefficients for the top model (ΔAIC< 2.0) for unique
229 deer consumption events (negative binomial distribution in a generalized linear mixed
230 model) for males and females combined, from the Virginia Appalachian Carnivore Study
231 in 2018 and 2019. black bear ID was used as a random effect. β is the beta coefficient
232 depicting the magnitude and direction of covariate influence in the top model(s). CI
233 represents the 95% confidence interval for each beta coefficient. Models in shaded gray
234 represent non-supported effects on observed behavior type (95% CIs include 0). Data come
235 from videos from camera collars placed on 15 black bears in Bath County, Virginia

Model Set	$\beta_{\text{FM-Scavenge}}$ [CI]	$\beta_{\text{FM-Hunt}}$ [CI]	$\beta_{\text{Dist. Human}}$ [CI]	$\beta_{\text{Temp.}}$ [CI]	$\beta_{\text{Dist. Mesic}}$ [CI]	$\beta_{\text{Dist. Crop}}$ [CI]	$\beta_{\text{Dist. Xeric}}$ [CI]
Deer Consumption Duration	-0.77 [⁻1.26-⁻0.32]	4.23^ [3.84-4.67]	0.42 [0.16-0.70]	0.14 [⁻0.05-0.33]	-0.29 [⁻0.50-⁻0.07]	-0.41 [⁻0.63-⁻0.19]	-0.18 [⁻0.39-0.04]

236 ^ represents the intercept, *FM* represents the foraging method the carcass was acquired [*FM-Scavenge* is the carcass was
237 acquired by scavenging, *FM-Hunt* is the carcass was acquired by hunting or likely hunting], *Dist. Human* represents the
238 distance to human settlements, *Temp* represents average daily temperature, *Dist. Mesic* represents the distance to the mesic forest,
239 *Dist. Crop* represents the distance to agricultural or cropland, *and Dist. Xeric* represents the distance to the xeric forest. For
240 distance measurements, a negative β indicates that deer consumption duration increased with decreasing distance (i.e.
241 closer to) the habitat/landscape feature.

242 Table S4. Summary of estimates of β coefficients for top generalized linear mixed models (ΔAIC< 2.0) using binomial distributions for all observed
243 consumption events for males and females from the Virginia Appalachian Carnivore Study in 2018 and 2019. black bear ID was used as a random effect. β is
244 the beta coefficient indicating the magnitude and direction of covariate influence in the top model(s). CI represents the 95% confidence interval for each beta
245 coefficient. Models in shaded gray represent non-supported effects on observed behavior type (95% CIs include 0). Data come from videos of consumption
246 events from camera collars placed on 15 black bears in Bath County, Virginia.

Model Set	Intercept	βDOY [CI]	βTOD [CI]	βUnderstory [CI]	βS-Spring [CI]	βS-Summer [CI]	βS-Fall [CI]	βTPI [CI]	βPrecip [CI]	βNDVI [CI]	βEVI [CI]	βTemp [CI]	βDist. Human [CI]	βDist. Crop [CI]	βDist. Mesic [CI]	βDist. Herb [CI]	βDist. Edge [CI]	βDist. Succ. [CI]	βDist. Xeric [CI]
Anthropogenic Foods Males	—	—	—	-1.57 [-1.99, -1.19]	-0.55 [-2.08, 0.67]	-1.49 [-2.17, -0.82]	-6.43^ [-7.77, -5.31]	—	—	—	—	0.68 [1.32, 1.09]	-3.61 [-5.32, -2.22]	—	1.24 [0.27, 2.17]	-1.12 [-2.19, -0.09]	—	—	—
Insects Females	-0.20 [-1.51, 1.18]	-0.01 [-0.02, -0.01]	0.06 [0.02, 0.09]	-1.41 [-1.62, -1.20]	—	—	—	—	—	—	—	-0.36 [-0.70, -0.03]	0.38 [0.13, 0.63]	—	0.95 [0.62, 1.29]	—	—	—	-0.58 [-0.88, -0.31]
Herbaceous — Males	—	-0.01 [-0.02, -0.01]	—	0.35 [0.21, 0.49]	1.97 [0.77, 3.19]	-0.19 [-1.07, 0.70]	1.00^ [-1.82, 2.83]	-0.24 [-0.38, -0.11]	—	—	—	-0.39 [-0.62, -0.16]	-1.39 [-1.67, -1.12]	—	—	—	0.73 [0.44, 1.00]	—	—
Herbaceous — Females	6.14 [4.92, 7.41]	-0.04 [-0.04, -0.03]	—	-0.15 [-0.27, -0.04]	—	—	—	—	-0.06 [-0.04, -0.17]	0.19 [0.09, 0.29]	—	—	-0.70 [-1.10, -0.31]	—	-1.44 [-1.72, -1.16]	-0.32 [-0.51, -0.13]	—	—	-0.52 [-0.73, -0.32]
Fruit & Seeds — Males	—	-0.01 [-0.02, -0.01]	—	0.62 [0.51, 0.73]	-4.00 [-5.15, -2.93]	0.03 [-0.55, 0.62]	3.01^ [1.01, 5.03]	0.24 [0.14, 0.35]	—	—	—	0.78 [0.59, 0.98]	1.28 [0.97, 1.59]	0.25 [0.09, 0.41]	—	0.27 [0.08, 0.47]	-0.63 [-0.98, -0.31]	—	0.52 [0.38, 0.67]
Fruit & Seeds — Females	—	-0.01 [-0.01, -0.01]	-0.09 [-0.12, -0.06]	0.48 [0.37, 0.59]	-0.36 [-1.40, 0.68]	1.72 [0.96, 2.52]	1.74^ [-0.43, 3.92]	0.26 [0.16, 0.36]	—	-0.29 [-0.39, -0.20]	—	0.24 [0.06, 0.43]	0.64 [0.40, 0.88]	0.86 [0.72, 1.00]	-0.45 [-0.74, -0.16]	-0.24 [-0.44, -0.05]	—	—	0.97 [0.83, 1.12]
Hard Mast — Males	-25.4 [-28.8, -22.4]	0.09 [0.08, 0.11]	—	—	—	—	—	1.04 [0.51, 1.57]	—	—	—	0.87 [0.22, 1.53]	-0.73 [-1.08, -0.39]	—	—	—	—	—	-0.47 [-0.77, -0.17]
Hard Mast — Females	—	0.03 [0.01, 0.05]	—	-0.76 [-1.12, -0.42]	-16.4 [-23.1, -18.1]	-4.51 [-5.78, -3.37]	-8.65^ [-13.4, -3.91]	—	—	—	—	0.87 [0.55, 1.19]	0.97 [0.55, 1.41]	—	-1.45 [-2.30, -0.67]	-0.53 [-0.93, -0.16]	—	—	-0.20 [-0.39, -0.02]
Invasives — Males	—	0.04 [0.03, 0.05]	—	0.50 [0.38, 0.63]	2.43 [1.77, 3.11]	-12.4 [-15.0, -9.97]	-0.22^ [-0.38, -0.07]	-0.25 [-0.37, -0.23]	—	-0.10 [-0.38, 0.18]	0.30 [0.10, 0.51]	—	-0.77 [-0.96, -0.59]	—	—	-1.00 [-1.27, -0.73]	1.04 [0.60, 1.47]	-0.48 [-0.69, -0.29]	-0.35 [-0.54, -0.17]
Invasives — Females	—	0.04 [0.04, 0.05]	0.07 [0.04, 0.11]	0.91 [0.80, 1.03]	4.37 [3.34, 5.43]	3.07 [2.33, 3.85]	-16.0^ [-18.4, -13.7]	-0.17 [-0.28, -0.07]	-0.32 [-0.51, -0.15]	—	—	0.34 [0.22, 0.47]	0.62 [0.76, 1.25]	0.63 [0.25, 1.00]	-0.68 [-0.89, -0.47]	-1.55 [-1.84, -1.29]	—	0.50 [0.34, 0.65]	-0.29 [-0.46, -0.13]

247 ^ represents the intercept, *DOY* is day of the year, *TOD* is time of day, *Understory is* understory density observed in camera collar videos on a Daubenmire scale, *S* is Season [*S-Spring* - events that occurred in
248 spring months, *S-Summer* -events that occurred in summer months, *S-Fall* is events that occurred in fall months], *TPI* represents the topographic position index (TPI), *Precip* is daily precipitation, *NDVI* is
249 normalized difference vegetation index, *EVI* is enhanced vegetation index , *Temp* is average daily temperature, *Dist. Human* represents distance to human settlements, *Dist. Crop* is distance to agricultural or
250 cropland, *Dist. Mesic* is distance to the mesic forest, *Dist. Herb*. is distance to herbaceous fields or pastureland, *Dist. Edge* is distance to forest edge, *Dist. Succ.* is distance to early to mid-successional forest, and
251 *Dist. Xeric* is distance to the xeric forest. For distance measurements, a negative β indicates that deer consumption duration increased with decreasing distance (i.e. closer to) the habitat/landscape feature.

Chapter 4: Conclusions & Future Directions

American black bear (*Ursus americanus*) hibernation and foraging ecology have been widely studied, yet there are still knowledge gaps on key aspects of black bear biology. In the hibernation ecology chapter, we found new insight into the dynamics of hibernation onset and arousal, which could be particularly pertinent in the face of a changing climate. The strong influence of temperature, in particular, could lead to a mismatch between black bear den entry and emergence dates that might be misaligned with plant phenology for several important plant species that bears commonly consume, including jewelweed (*Impatiens capensis*), raspberry species (*Rubus spp.*), and oak (*Quercus spp.*) species. This mismatch may drive increased human-wildlife interactions in Virginia as black bears seek human-provisioned foods when plants are dormant or if plants suffer severe frost damage caused by increasing weather swings, which are predicted to occur in Virginia (Odom & Ford, 2020). Understanding the relative impacts of photoperiod vs. temperature on hibernating species is not commonly assessed in ecological studies. Our study documented the interaction between photoperiod and temperature for several hibernation stages and highlighted the strong influence of temperature, particularly at the onset of hibernation, a period of time important in minimizing human-bear interactions. The Virginia Department of Wildlife Resources' (VADWR) current outreach provides information for the public on 'Living with Black Bears in Virginia' (VADWR 2024) and links to Black BearWise (Black BearWise 2024). These efforts may need modification to account for climate shifts affecting black bear activity in the central Appalachian Mountains.

We also found promising results for surrogate sow and foster cub programs for black bears as mother black bears in our study did not preferentially allocate time toward any cub group. However, our experience has shown that foster cubs can be rejected, especially if done

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3275   after emergence (Kelly, Holcombe, Mesa-Cruz, unpublished data). Cub age at the time of

3276   introduction is important to the successful adoption of foster cubs (Clarke et al. 1980, Alt and

3277   Beecham 1984, Rogers 1986, Ternent 2006, VADWR 2023). Our work confirms that an

3278   increased likelihood of foster cub integration and acceptance into the litter occurs by introducing

3279   cubs before den emergence or soon thereafter to allow a higher chance of acceptance and litter

3280   integration (Alt and Beecham 1984, Beecham 2006, Beecham et al. 2016, Michigan DNR 2016).

3281   In the foraging ecology chapter, we established that the diet composition among black

3282   bears in our study was similar to that found in literature, particularly for studies conducted

3283   elsewhere in the southern Appalachians. However, the large proportion of unknown diet items

3284   displayed in the literature, especially among studies utilizing scat and stomach contents and those

3285   that lacked refined resolution from stable isotope analysis, likely resulted in biased or inaccurate

3286   diet profiles for omnivores. Interestingly, we found that female bears hunted white-tailed deer

3287   (*Odocoileus virginianus*) fawns in spring more often than did males. One of our females had a

3288   cub and perhaps the demands of pregnancy and cub rearing resulted in higher protein demands

3289   than for males. In fact, this female did have the highest consumption of deer across all 7 females.

3290   Overall, male and female bears consumed a similar number of deer through scavenging and

3291   hunting, but females primarily obtained theirs by hunting fawns in spring. Males, on the other

3292   hand, consumed more anthropogenic foods than females, particularly in the spring, whereas

3293   females more often consumed insects than did males. Both of these foods are high in calories and

3294   protein, which perhaps drives consumption after hibernation. Otherwise, males and females

3295   displayed similar levels of consumption of herbaceous soft mast in spring, fruit and seed soft

3296   mast in summer, and hard mast in fall, all of which coincides with typical availability on the

3297   landscape. Interestingly, males and females differed in the timing of consumption of invasive

3298 plant species. Males consumed more invasive species in the spring months, whereas females

3299 consumed more in the summer. Additionally, our video data provided coordinate locations where

3300 bears consumed invasive species. This information could be used for targeted removal of certain

3301 species that seemed localized (e.g., wineberry [*Rubus phoenicolasius*]) rather than widespread

3302 (e.g., autumn olive [*Elaeagnus umbellata*]). Given that female diet overlap was more similar

3303 from spring to summer than males from spring to summer, it appears that females simply have

3304 wider diet breadths, utilizing more species, especially in spring and summer, as Levin's diet

3305 breadth estimates indicated. This can be important as females may be more adaptable to different

3306 food sources being scarce or abundant on the landscape depending on seasonal availability and

3307 environmental impacts of plant production (i.e., poor or strong mast year).

3308　　Further, we found that females began consuming hard mast species (i.e., oaks, hickories,

3309 and walnuts) early in the fall, starting in mid-late August, whereas males started in mid-late

3310 September. This likely is attributed to females' tendency to enter hibernation earlier than males in

3311 preparation for pregnancy onset, and their need to increase fat stores more quickly. This is

3312 important for females' physiological cues during hyperphagia because, in poor mast years, there

3313 may not be enough resources on the landscape for females to capitalize on. In addition, the

3314 forests of the central Appalachian Mountains are even-aged, older stands where many oak

3315 species are entering senescence, resulting in a general decline of mast production (Lafon et al.,

3316 2017). When combined with extended periods before bears enter hibernation as a result of

3317 warmer temperatures, this lack of sufficient hard mast could result in a higher propensity of bears

3318 to seek anthropogenic foods during hyperphagia.

3319　　Using advanced technologies, such as remote surveillance videos and camera collars, can

3320 allow for previously unseen insight into wildlife ecology. Our use of remote video camera

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3321   surveillance to understand behavioral ecology associated with hibernation revealed the complex

3322   interplay between photoperiod and temperature that varied with hibernation stage. Additionally,

3323   our use of camera collars is one of the first studies to use on-board video to study bear diet and

3324   one of the few studies to provide continuous monitoring of foraging ecology and diet

3325   composition compared to scat sampling, which typically provides only a snapshot of a species'

3326   diet. One aspect of video technology that needs improvement is the ability to assess diet during

3327   evening hours, potentially through the use of infrared video to obtain a more complete diet

3328   composition. Scat sampling currently captures a better representation of what bears forage upon

3329   at night. We experimented with limited nighttime (blacked out view) videos between 2-6 AM,

3330   where we could hear the sounds of some movement by bears, but only occasionally, which may

3331   indicate that bears mostly rested instead of foraging. Although video datasets provide valuable

3332   insight into black bear ecology, they produce massive amounts of data that require extensive time

3333   and effort to process, which can become a weakness in using these technologies. Nonetheless,

3334   these emerging technologies likely will provide new insight into aspects of species' ecology

3335   previously unavailable in studies conducted in the wild and thus represent an asset to researchers

3336   and natural resource managers.

3337   *Recommendations*

3338   For landowners who want to manage black bears on their property, our findings offer

3339   opportunities to either increase or decrease the presence of black bears on the landscape as well

3340   as practices to reduce the number of black bears potentially on a property. We found strong

3341   seasonal variation in black bears' diets that, if such foods were either enhanced or conversely

3342   removed, could be used as a management tool to achieve a desired population objective. For

3343   example, promoting a diverse forest mosaic that maximizes the amount of seasonally available,

3344 natural foods on the landscape could aid in increasing bear presence on the landscape. In the

3345 spring months, having more herbaceous soft mast on the landscape, including jewelweed and

3346 nettle species (*Urtica spp.*), would enhance the opportunity for bears emerging from hibernation,

3347 whereas planting additional fruiting species such as raspberry/blackberry in forest edges or mesic

3348 forested areas would help sustain bears during summer months. Thinning and opening the

3349 canopy of aged, forested stands can create areas where blueberry/huckleberry (*Vaccinium spp.*)

3350 will grow and thrive; these species are a major component of a bear's diet in summer.

3351 Provisioning hard mast species commonly consumed by black bears as they enter hyperphagia

3352 often takes longer, but can be enhanced by planting and maintaining oak, walnut (*Juglans spp.*),

3353 and hickory (*Carya spp.*) species on private lands.

3354   For natural resource managers, maintaining black bear populations across the larger

3355 landscape via habitat management could be achieved through timber harvest practices and

3356 prescribed burning. McNitt et al. (2020) found that mixed-severity burns can help aid in

3357 maintaining diverse forest structures, with other studies from our study area showing they

3358 provide benefits that of mimicking historic disturbance levels on the landscape. Maintaining the

3359 current mix of mesic and xeric forests will support a variety of hard mast species in the fall,

3360 whereas creating early successional forest through timber harvest and prescribed burning can

3361 promote blueberry and huckleberry species in the summer months. Eradication of invasive

3362 species (e.g., wineberry) to reduce competition with native species (native Rubus species) may

3363 be needed, and our video data directly provided evidence of where some of these invasives such

3364 species were located on the landscape.

3365   If landowners want to potentially reduce the number of black bears on their property, they

3366 could manage for species not favored by black bears and reduce the presence of preferred

3367 summer food species, such as raspberry, blueberry, and huckleberry species. When reducing the

3368 abundance of natural food resources, it is imperative to also properly secure potential

3369 anthropomorphic food resources (e.g., trash cans, agricultural or livestock feed stores, bird seed

3370 and feeders) from being accessible to black bears. as a means to lower the potential for human-

3371 bear interactions. Finally, where bear numbers are high, property owners may consider

3372 increasing the level of local harvest through hunting to meet desired population objectives.

3373 *Future Directions*

3374 During the VACS study, black bears were equipped with tri-axial accelerometers running

3375 simultaneously to the camera collar recordings. These tri-axial accelerometry units, which

3376 measure acceleration across X (side to side), Y (forward & backward), and Z (up & down) axes,

3377 are not easily interpretable without video validation of actual behaviors (Brown et al. 2013). One

3378 approach to overcome these shortcomings is to simultaneously gather accelerometer and

3379 behavioral data on wildlife species in captivity (Kirchner et al. 2023), however, captive animals

3380 often exhibit different behaviors than those in the wild (Brown et al. 2013). Our study provided

3381 proof-of-concept by documenting observed behaviors of species in the wild linked to

3382 accelerometry data. Our camera collars record videos at set intervals, which then could be used

3383 to validate tri-axial accelerometry data during those intervals, thereby providing unique insight

3384 into resource use of black bears. Thus, camera collars can aid in overcoming the obstacle of

3385 needing live behavioral observations in tandem with accelerometer data to link to observed

3386 behaviors as recorded in videos.

3387 Pairing accelerometer data with behaviors already identified in our study will require a

3388 supervised or semi-supervised machine-learning classification approach that would allow us to

3389 classify several (e.g., >10) behaviors (Kamminga et al. 2020). The behavioral classifications that

3390   we recorded during the foraging analysis provide a dataset that will allow us to link known

3391   behaviors to accelerometer data via the machine learning algorithms to produce a supervised

3392   classification model (Kamminga et al. 2020) that can be extended to black bears without camera

3393   collars on but with accelerometry units (which are included in modern GPS collars). Finally, we

3394   intend to create a usable "app" for natural resource managers to classify broad behaviors into

3395   digestible information that can identify where black bears display for example, foraging

3396   behavior, mating interactions, and resting periods. This will extend the usefulness of this novel

3397   technology even further.

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