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BOBCAT POPULATION ECOLOGY IN WEST VIRGINIA

Stephanie Michelle Landry

**Thesis submitted to the
Davis College of Agriculture, Natural Resources and Design
at West Virginia University**

in partial fulfillment of the requirements for the degree of

**Master of Science
in
Wildlife and Fisheries Resources**

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Amy B. Welsh, Ph.D.**

**School of Natural Resources
Morgantown, West Virginia
2017**

Key Words: Bobcat, *Lynx rufus*, diet content, prey items, parasites, demography, parvovirus, disease, aging, reproduction, implantation rates, survival

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ABSTRACT

Bobcat Population Ecology in West Virginia

Stephanie Michelle Landry

Bobcats (*Lynx rufus*) are a popular furbearer and game species throughout their range in North America, where they serve as a top predator in many of their ecosystems. However, bobcat populations across their range declined during the 1800s and early 1900s due to overharvest. Overharvest and habitat loss in Europe also affected the Iberian lynx (*L. pardinus*), resulting in the listing of all *Lynx* spp. under the Convention on International Trade in Endangered Species in 1977. Bobcats were listed under Appendix II, which required that state management agencies monitor their bobcat populations for stability. Since their listing, bobcat populations have experienced a large-scale increase in abundance in most areas of their range, partly due to the conversion of agricultural lands to early successional forests that supported ample prey populations during the mid-20th century. However, as forests in West Virginia mature, their common, early-successional prey species, such as rabbits and small rodents, may experience population declines. Availability of small mammal populations during winter is an important factor for survival of juvenile bobcats. Bobcats are harvested annually for their pelts in West Virginia, where the bobcat harvest season runs from November – February with a 3-bobcat limit per licensed person per season. West Virginia's bobcat population has not been studied since the late 1970s when there was no annual harvest limit enacted on the population. Therefore, current estimates and demographic data are needed before making further management decisions for the bobcat population. We collected 524 bobcat carcasses from hunters and trappers across West Virginia over 2 harvest seasons (i.e., 2014–2015, 2015–2016) to determine current demographic data, such as age structure, sex ratio, reproductive rates, and survival, which are used to determine population change rates for bobcats under current state harvest regulations. We also subsampled 300 bobcats for stomach contents to determine current winter dietary habits. Proportion and diversity of prey items selected by bobcats is often correlated with prey abundances and habitat quality, which can allude to dietary availability for bobcats over winter. We found that bobcats in West Virginia have an even sex ratio and are predominately adults >2 years old (50%), followed by yearlings (1–2 yr; 30%) and juveniles (<1 yr; 20%). Reproductively active females (>1 yr) averaged 1.54 kittens/female annually, with young born from mid-April to mid-August. Mean juvenile survival over both harvest seasons was 0.82, while mean yearling survival was 0.77 and mean adult survival was 0.61 over both harvest seasons. Rate of population change was +44% after the first harvest season and remained stable after the second. White-tailed deer (*Odocoileus virginianus*), Virginia opossum (*Didelphis virginiana*), and raccoon (*Procyon lotor*) occurred more frequently in the diets of male bobcats, whereas lagomorphs occurred more frequently in females. Small and medium-sized rodents, such as squirrel, mice, and chipmunks (*Tamias* spp.), occurred more frequently in the diets of juveniles than yearling and adults, whereas white-tailed deer occurred more frequently in adults than juveniles and yearlings. There was 92% overlap in overall dietary selection between sexes and 35% overlap between stage classes, with an 87% diversity in prey selection overall. Managers can use these data to determine proper harvest limits and to enact necessary habitat manipulations to support management goals for bobcats in West Virginia.

To my father, Lawrence Joseph Landry Jr.,
your love for the outdoors guided me
to becoming the person that I am today.
I hope I have made you proud.
I love and miss you, dad.

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CHAPTER 1

REVIEW ARTICLE

Introduction to the Ecology and Management of Bobcats in West Virginia

Stephanie Michelle Landry

INTRODUCTION

Bobcats (*Lynx rufus*) are the only *Lynx* spp. whose range spans most of North America, ranging from their northern limit in central British Columbia to their southern limit in central Mexico (Ray 2000, Anderson and Lovallo 2003, Newbury 2013). Throughout their range, bobcats play an important role in culture and economics for many hunters and trappers due to the historical use and current value of their fur (Newbury 2013). According to West Virginia Trappers Association auction results from 2007–2016, bobcats were the most valuable furbearer according to pelt value, ranging from a low of \$34.50 (2010) to a high of \$162.50 (2013) and averaging \$55.41 (unpublished data).

Bobcats were considered a nuisance by many livestock farmers in the 1800s, resulting in the introduction of state bounty programs in hopes of reducing bobcat densities and nuisance complaints (Litvaitis et al. 2006). In 1977, the species was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as a “look-alike species” to the critically endangered Iberian lynx (*Lynx pardinus*, CITES Appendix I). Appendix II requires governing wildlife agencies to affirm stability in their *Lynx* spp. populations before granting exportation authority (CITES); therefore, it does not prohibit the taking of bobcats, but rather regulates the international trade of spotted cat pelts by requiring all

listed specimens sold to international trade to have a CITES permit prior to exportation (Fox 1980, Blair and Beringer 2013, Newbury 2013).

In the United States, management of wildlife populations is the responsibility of state wildlife agencies. Before 1973, bobcats were not considered a legal game species in West Virginia, so there were no legal harvest limits enforced on the population. An official bobcat harvest season was created in 1975, which ran from November through February with no limit on the legal number of bobcats that could be harvested each season. Post-listing in CITES Appendix II, a harvest limit of 2 bobcats/person was first enforced over the 1978–1979 harvest season following results from the first research study on the West Virginia bobcat population (Fox 1980). The harvest limit was increased to 3 bobcats/person over the 2005–2006 harvest season using the same results from the previous study to justify the increase.

Since 1978, the West Virginia Division of Natural Resources (WVDNR) has required all legally harvested bobcats to be checked and tagged, but this tagging is separate from the required CITES tagging (Blair and Beringer 2013). Game tags record important information such as date of kill, weapon used, sex of the bobcat, kill location, in addition to hunter or trapper information such as name, address, email, phone number, and hunting license number. This information is important for assessing harvest and population trends for the state, in addition to providing human dimension data, potential survey contacts, tracking for legal issues and creating relationships with local hunters and trappers.

Trapping, along with hunting, is commonly used by wildlife agencies to help manage populations of certain species according to expected goals (Koehler et al. 2006). These goals can include developing a maximum sustained yield of the species, producing a stable population structure, and maintaining control of wildlife damage or population disease transmission

(Conover 2001). Conover and Decker (1991) reported that 90% of federal and state wildlife agencies manage bag limits during hunting seasons to reduce wildlife damage. For bobcats and other furbearers, such as coyotes (*Canis latrans*), foxes (*Urocyon cinereoargenteus* and *Vulpes vulpes*), and fishers (*Martes pennanti*), trapping and hunting are primary management tools used by biologists to manipulate populations.

Previous Research

Demography of the West Virginia bobcat population was last studied over the 1977–1978 harvest season by Lloyd Fox, where he examined the age structure, reproductive rates, winter food habits, distribution, and harvest impacts on the population for his thesis research (Fox 1980). They found that juveniles (<1 yr) and yearlings (1–2 yr) made up 70% of the population ($n = 26$), the sex ratio was 1:1 ($n = 201$), and implantation rates for yearlings, 2-year-olds, and adult (≥ 3 yr) female bobcats were 1.75, 3.4, and 2.63 kittens/female, respectively (Fox and Fox 1982). Survival was estimated using the Chapman-Robson (1960) catch curve equation, which uses harvest data to determine survival rates. Fox's (1980) estimates of juvenile, yearling, and adult (≥ 2 yr) survival were 0.61, 0.66, and 0.84, respectively.

Fox (1980) also estimated food habits of bobcats in West Virginia, where he noted from previous studies that juvenile survival is controlled by prey availability, specifically small rodents and hares, and that high bobcat densities can lower reproductive rates in females. His wintering diet analyses showed that fall and winter diets of bobcats were dominated by white-tailed deer (*Odocoileus virginianus*, 49.4% occurrence), followed by small rodents (38.4%) and lagomorphs (23.3%; Fox and Fox 1982).

Justification

Bobcats have been an important resource for hunters and trappers in West Virginia for centuries. For the WVDNR to accurately manage the population, it is critical that the population harvest model be kept up-to-date. However, Lloyd Fox's (1980) thesis research on bobcat harvest, survival, productivity, and diet was the only documented demography and diet research on West Virginia's bobcats prior to this study.

The WVDNR is currently using the population harvest model designed in 1975 for exploited bobcat populations in Wyoming (Crowe 1975*b*) with findings from Lloyd Fox's (1980) research from 40 years ago. With that model, WVDNR biologists determined that 21% of the population could be harvested without damaging the population following these specific assumptions: 61% survival in juveniles and 64% survival in adults, average yearly litter of two kittens per adult female, and equal harvest potential of adults and juveniles (Crowe 1975*b*, Fox and Fox 1982).

Crowe's (1975*b*) model:

$$Y = Sa + F(Sy),$$

where Y is the change in population, Sa is adult survival, F is the number of female offspring per female in the population, and Sy is juvenile survival.

Biologists have noticed a rising number of hunters and trappers asking for an increase in the bobcat seasonal harvest limit (Rich Rogers, WVDNR, personal communication), and bobcat populations across North America have been increasing since the mid-1900s (Roberts and Crimmins 2010). However, an increase in the harvest limit, with associated increase in bobcat mortality rates, would violate the current model's limits for maintaining a stable population.

Juvenile survival is the most critical factor in the population harvest model (Fox and Fox 1982). Their survival relies heavily on prey availability (Bailey 1974), which can change with mast production (Ryan et al. 2004).

In Minnesota, bobcat harvest numbers were correlated with season length and number of scent stations visited by bobcats rather than pelt prices (Kapfer and Potts 2012). However, West Virginia bobcat harvest rates tend to be correlated with average pelt prices from the West Virginia Trappers Association auctions (Fig. 1; unpublished data). Since 1980, West Virginia's bobcat harvest trends indicate that the upper limit of population stability may have been reached (Fig. 2). A significant decline in harvest occurred from 2009–2011 that cannot be entirely explained by winter weather or pelt price (Rich Rogers, personal communication).

Crowe's (1975b) model remains an accurate population harvest model, but the estimation of current juvenile survival rates for the population is necessary for proper use of the model in management decisions. Subsequently, WVDNR entered into partnership with West Virginia University to establish current estimates of juvenile and adult survival, reproductive rates, overall health assessment, and current density of the West Virginia bobcat population. The WVDNR can use these results to update management decisions and reassess current harvest limits.

STUDY DESCRIPTION

Study Area

West Virginia, USA (62,755 km²) consists of 55 counties and is bordered by Pennsylvania to the north, Maryland to the east, Virginia to the east and south, and Kentucky and Ohio to the west. Human population density is relatively low, with a population estimate of around 1,854,304 as of 2013 (Christiadi et al. 2014). Elevations range from 73 m above sea level

at Harper's Ferry, which is near the Potomac River in Jefferson County, to 1,482 m above sea level at Spruce Knob, which is in the Monongahela National Forest of the Allegheny Mountains (Mullennex 2010). West Virginia has four distinct seasons, with average annual snowfall ranging from 368 cm down to 51 cm depending on elevation and region (NCDC 2017). Annual precipitation ranges from 136.7 cm in the central Allegheny Plateau, where annual temperatures average 9.4°C, to 92.7 cm in the Appalachian Ridges and Valleys, where annual temperatures average 11.7°C (NCDC 2017).

There are a wide range of habitats found throughout West Virginia, including remote mountain forests, farmlands, meadows, and woodlots all hosting a variety of flora and fauna species, as well as urban settings and restored mountain-top removal sites. The state is 78% forested, with 77% of the state being dominated by oak-hickory forests (Widmann et al. 2007). These forests commonly contain elm (*Ulmus* spp.), hickory (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), oak (*Quercus* spp.), basswood (*Tilia americana*), American sycamore (*Platanus occidentalis*), and ash (*Fraxinus* spp.) trees. Higher elevations are covered by northern hardwood forests that contain maple, birch (*Betula* spp.), beech (*Fagus* spp.), black cherry (*Prunus serotina*), hemlock, and red spruce (Pinaceae family); while oak-pine forests cover the eastern ridge and valley portion of the state and contain various oaks (black (*Q. velutina*), scarlet (*Q. coccinea*), and chestnut (*Q. montana*)) and Virginia (*Pinus virginiana*) and white (*P. strobus*) pines (Widmann et al. 2007). The understory vegetation typically consists of rhododendron (*Rhododendron* spp.), mountain laurel (*Kalmia latifolia*), serviceberry (*Amelanchier arborea*), and dogwood (*Cornus* spp.), which act as cover for bobcat and their prey.

The state is divided into 6 ecological regions (ecoregions) by differing ecological factors, such as average annual temperature, average annual precipitation, predominant forest types, growing season length, soil types, and physiographic subdivisions (Table 1; Uhlig and Wilson 1952). These 6 ecological regions include: Appalachian Ridges and Valleys (ecoregion 1), Allegheny Plateau (ecoregion 2), Cumberland Mountains (ecoregion 3), Monongahela and Upper Ohio (ecoregion 4), Northern Ohio and West Virginia Hills (ecoregion 5), and Southern Ohio and West Virginia Hills (ecoregion 6; Fig. 3).

Research Objectives

The overall objectives of this project were to:

- 1) identify the age structure of harvested bobcats and compare results across West Virginia's 6 ecoregions;
- 2) evaluate productivity of West Virginia bobcats using *Corpora lutea* ("yellow bodies") and placental scar counts and compare results across ecoregions;
- 3) determine juvenile and adult survival rates;
- 4) determine, quantify, and compare the wintering diet of bobcats and compare across ecoregions;
- 5) evaluate the overall physiological health and morphometric measurements of the population and compare among ecoregions;
- 6) refine or verify the current population model to determine its validity and use with harvest data for evaluating potential changes in harvest limits or season structure; and
- 7) evaluate and identify parvovirus presence and infection rates of bobcats and compare results across West Virginia's 6 ecoregions.

Based on these objectives, my overall research goals were to:

1. **Determine age structure, sex ratio, and survival of adult and juvenile bobcats and to compare those results across the six different ecological regions of West Virginia**

(Fig. 3). Age estimates, along with harvest mortality rates, are used to determine survival rates for species under regulated harvest pressure (Molles 2005:260). The survival of juveniles in game populations is often controlled by prey availability and relative mast abundance (Ryan et al. 2004), and juvenile survival estimates are a key component in population change models of a harvested population (McCord and Cardoza 1982).

2. **Estimate net reproductive rates of bobcats by stage class across West Virginia.**

Reproductive success is important for analyzing the population dynamics of a species. By combining survival and age estimates with net reproductive rates, biologists can estimate the rate of change in a population (Molles 2005:262). Using juvenile and adult survival rates with reproductive rates for the population will allow the WVDNR to reassess the current harvest limit of 3 bobcats per year using Crowe's (1975*b*) change in population model.

3. **Compare the dietary content of bobcat stomachs across ecoregions, stage classes, sexes, body morphology and conditions, mast production rates, and average annual snowfall amounts, and to compare results to the previous findings of Fox and Fox (1982) to determine if diets have changed over the last 40 years.** West Virginia bobcat diets were last described by Fox and Fox (1982), where deer was found to be the most common prey consumed by bobcats in winter. However, diet analyses from bobcats in Arizona and Arkansas found that rodents, squirrels, and lagomorphs were consumed

more often by medium-sized bobcats than by larger bobcats (Fritts and Sealander 1978a, Jones and Smith 1979).

4. **Identify the infection rates and variants of parvoviruses among bobcat stage classes and sexes, and across West Virginia's ecoregions.** Concern regarding feline panleukopenia virus and canine parvovirus infections of non-domestic feline populations is growing with increased disease prevalence worldwide, and many scientists have encouraged increased host sampling in species internationally (Allison et al. 2013). Increased human densities have been found to incidentally facilitate disease transmission with the increasing overlap of non-domestic and domestic cat territories (Wasieri et al. 2009, Foley et al. 2013). Therefore, the WVDNR is concerned with analyzing wild bobcat populations for signs of parvovirus infection and to evaluate how these infections affect bobcat ecology.

Management Implications

West Virginia Division of Natural Resources (WVDNR) biologists used Fox's results to set the first bag limit on the population – 2 bobcats/licensed hunter or trapper – for the 1981 harvest season. In 2005, WVDNR increased the bag limit to 3 bobcats, justifying the change in regulation based on increased harvest numbers over previous years (Fig. 2; Rich Rogers, personal communication). However, current data are needed before any additional changes can be made to the harvest limit.

Crowe's (1975b) model is used by the WVDNR and requires current adult and juvenile survival estimates and reproductive rates to calculate change in population for West Virginia bobcats. The results obtained in this study will be used directly with the change in population

model to determine the amount of growth or decline in the population. If the population is growing, then the surplus from yearly replacement in the population can be managed for harvest. The rate of population change, along with current density estimates, will be used to estimate proper harvest limits for population stability.

Body condition and winter diet are important factors of survival, reproductive success, and overall population health. Poor body condition in females could potentially generate unhealthy litters or stillbirths. Prey availability is especially important during winter in West Virginia when harvest pressure increases and young bobcats are forced from their home territories to hunt and fend for themselves. Factors affecting the demography of a game species such as these must be continuously updated to ensure proper management is enforced on the population.

LITERATURE REVIEW

Necropsy

Crowe (1975a) and Fox (1980) performed necropsies on harvested bobcat carcasses to determine population age, growth, and productivity in Wyoming and West Virginia, respectively. Crowe (1975b) devised a model for exploited bobcat populations in Wyoming using data obtained from analyses of age structure and reproductive success. He determined that bobcats could be aged by counting annuli in the cementum of canines (Crowe 1972). Reproductive rates were estimated from *Corpora lutea* and placental scar counts of female bobcats (Crowe 1975a). Necropsy analyses can provide age ratios, reproductive rates, survival estimates, knowledge of potential animal and human health risks associated with parasites or pathogens in wild populations, body and fat condition assessments, harvest characteristics, and

updated wintering food habits to biologists for management purposes. The current change in population model can be updated to more confidently determine the effects of the current harvest regime on the population in this region and determine whether any changes are warranted.

Age Distribution

Calculating the age structure in a harvested species can be used to estimate survival rates for the population. In bobcats, age can be determined by removing a lower canine and counting the cementum annuli (Crowe 1972, Johnson et al. 1981). Much of the basis for aging and tooth replacement was modeled after domestic cats and the Canada lynx (*Lynx canadensis*; Johnson et al. 1981). Permanent canines come in by 6 months of age, and the root canals close sometime between 1 and 1.5 years of age (Crowe 1972). Johnson et al. (1981) used categories for aging bobcat canines from Kansas: deciduous canines (DC) and permanent canines containing open or closed root canals (PC-OR or PC-CR, respectively). In this study, total length (to the nearest 0.05 mm), maximum root width and thickness, and maximum diameter of the root canal opening (if open) of permanent canines were measured and recorded. If the canine was PC-CR, then the tooth was radiographed to measure the width of the pulp canal. The PC-CR canines were then sectioned, stained, and aged by counting the cementum annuli (Johnson et al. 1981). Johnson et al. (1981) found that root thickness, root width, and pulp canal width differed between sexes. Root width was the only variable to differ by age class, but it only differed in males.

Crowe's (1972) method is the most used technique for aging mammals in current literature (e.g., Medill et al. 2009, Axner et al. 2013, Scrivner et al. 2014). To process the canines, Crowe (1972) removed at least one canine and fixed it in 70% ethanol. He noted that yearlings and younger retained an open root apical foramen. They had a closed foramen during

their second winter; however, they had no annuli. The first annulus appeared in the second winter of life (20–23 months), therefore bobcats should have one annulus less than the number of years they have survived (Crowe 1972).

Age assignment has been previously determined using multiple grouping methods. Johnson et al. (1981) assigned females that had ovulated once and had open root canines to be >12 months of age, and those with open root canines that had not ovulated were assigned <12 months of age. Females with a ratio of -10:1 and males with a ratio of -8:1 were >12 months old. Young with deciduous teeth were <6 months old. Litvaitis et al. (1984) estimated age using pulp cavity size at the gum line, which was evaluated as: (pulp cavity width + tooth width) x 100, and adults were estimated to have pulp cavity sizes <20. Fox (1980) decided to break his results into 3 major classes for analyses, following Crowe's (1972) methods: <1 year (juvenile), 1–2 years (yearling), and ≥ 2 years (adult).

Reproduction

Reproductive success is used to determine fecundity schedules in the population, which includes female peak breeding period, average litter size, time of birth, and reproductive history (Molles 2005:262). Crowe (1975a) established a fecundity schedule for bobcats in Wyoming to estimate time of birth. Proestrus was identified by noting an enlargement of the primary follicles in the ovary to greater than one millimeter in diameter. Before proestrus, the follicles were no greater than 0.7–0.9 mm in diameter. The uteri and oviducts were flaccid, rather than enlarged like during estrus, with follicles being no larger than 6–8 mm in diameter. Ovulation occurred after new *Corpora lutea* formed in the ovary (Crowe 1975a). Reproductive rates are typically estimated using *Corpora lutea*, placental scar, and embryo counts of harvested females.

Female bobcats typically have an average of 2.5 kittens/litter/year. Crowe (1975a) determined the reproductive rate for bobcats in Wyoming, which resulted in an average of 2.79 kittens/litter. Rolley (1985) estimated placental scar and embryo counts of bobcats in Oklahoma and determined that the pregnancy rate increased from 46% in yearlings to 92% in adults. He also found that the average litter size of yearlings and adults were 2.3 kittens/litter and 2.7 kittens/litter, respectively. Fritts and Sealander (1978b) calculated an implantation rate of 2.5 kittens/litter using placental scar and embryo counts for bobcats in Arkansas. They also compared placental scar and embryo counts with *Corpora lutea* counts and found that only 59% of eggs were fertilized and implanted (Fritts and Sealander 1978b).

Female bobcats are considered polyestrous, reach sexual maturity by their first year, and remain sexually active until death (Crowe 1975a, Fritts and Sealander 1978b, Johnson and Holloran 1985). However, cats born after March and killed before the following January may show no signs of follicular growth or maturity (Crowe 1975a, Fritts and Sealander 1978b). Males do not reach sexual maturity until their second year of life (Crowe 1975a). Rolley (1985) found that breeding age in bobcats is influenced by food availability.

Because bobcats are polyestrous and can cycle up to 3 times/season (Fritts and Sealander 1978b), *Corpora lutea* can be counted to determine the total number of eggs released during the previous breeding season, and luteal bodies of previous cycles can be counted to determine the number of previous cycles from prior years (Crowe 1975a, Axner et al. 2013). Ovaries examined from older females suggested that luteal bodies remain in the ovaries for relatively long periods of the individual's life (Crowe 1975a); which means that female bobcat ovaries continue to grow with age. Luteal bodies of previous cycles tend to be various shades of brown, possibly representing previous breeding seasons (Crowe 1975a, Axner et al. 2013); however, it is difficult

to estimate which ovulations belonged to which previous breeding seasons, and results can differ from observer bias. *Corpora lutea* often overestimate reproductive rates because luteal bodies do not guarantee successful fertilization during ovulation. Placental scars are more accurate at estimating reproductive rates for a population than *Corpora lutea* counts because fertilization is guaranteed to have occurred (McNay et al. 2006).

Placental scars resemble black dots or entire black shaded areas with a small light-colored band in the middle and are found in uterine horns of reproductively active females (Axner et al. 2013). Their dark coloration is caused by macrophages, which form in response to the ejection of the placenta during parturition. Scars from previous pregnancies can remain and blend with new scarring, making it difficult to distinguish prior breeding season scars from earlier seasons (Lindstrom 1981, Johnson and Halloran 1985).

Lindstrom (1981) and McNay et al. (2006) noted that scar coloration lightens over winter months in red fox (*Vulpes vulpes*) and wolves (*Canis lupus*), respectively. Uterine horn staining can be used to verify placental scar locations when scars are difficult to distinguish (Bray et al. 2003, Fournier-Chambrillon et al. 2010, Ruetten and Albaret 2011). Lindstrom (1981) and Mowat et al. (1996) used a 1–6 color classification system (i.e., 1 = lightest, 6 = darkest) to better determine scars of previous years from scars of the latest breeding season. Though placental scars give more accurate estimates of reproductive success than *Corpora lutea* counts, there are still limitations. Placental scarring occurs regardless of stillbirths and abortions, and can therefore overestimate implantation rates and reproductive success (Lindstrom 1981).

Survival

Age distributions are used to determine survival in harvested populations (Molles 2005:260), and juvenile survival estimates are a key component in population change models of harvested populations (McCord and Cardoza 1982). Henny et al. (1970) and Eberhardt (1988) updated the Lotka and Chapman-Robson change in population equations to be more accurate for today's management needs. Their papers contain multiple equations that can be used for different situations in exploited populations. Henny et al. (1970) noted that knowledge of a population's mortality rate, reproductive age of maturity, recruitment rate, fecundity schedule, and age and sex ratios of the population are all that is necessary to get an idea of population trends for establishing population stability. Gove et al. (2002) explained how to use maximum likelihood methods to estimate population structure using age-at-harvest data. Equations such as these and Crowe's (1975*b*) change in population model for exploited bobcat populations are valuable for understanding the status of a population.

Home Range

In all areas of their range in North America, male bobcats tend to maintain home ranges that are two and a half times greater than the size of female home ranges (Lovallo 2000, Newbury 2013). Species that have a diet consisting primarily of vertebrates have high basal metabolic rates, which requires them to have a home range size that corresponds to their body size (Newbury 2013). Male bobcats tend to overlap female and other male habitat ranges, while females are more exclusive in habitat use. This partial niche segregation between sexes is due to the differences in their size, diet, seasonal habitat use, and activity patterns (Rolley and Warde 1985, Lovallo and Anderson 1996). Females change their home range sizes seasonally, and home

range sizes are influenced by prey availability, sex, geographic region, season, and habitat quality (Litvaitis et al. 1986, Lovallo and Anderson 1996, Newbury 2013).

Extreme winter snows and temperatures may be limiting factors for the northern part of the bobcat's range, where Canada lynx become the dominant felid species (Newbury 2013).

Unlike the Canada lynx, bobcats do not have wide, webbed paws that are meant for walking on snow; therefore, snow can be an important factor driving movement and hunting habits for bobcats during harsh, winter months.

Winter Dietary Habits

Bobcats are generalist carnivores, whose diet is primarily composed of deer, lagomorphs, rodents, squirrels, and birds, with the volume or occurrence of each prey species varying by locality, gender, size, and age of the bobcat (Litvaitis et al. 1984, Rolley 1985, Labisky and Boulay 1998, Brockmeyer and Clark 2007, Newbury 2013). White-tailed deer (8.5%), snowshoe hares (*Lepus americanus*, 12.2%), red squirrels (*Sciurus vulgaris*, 54%), rodents (24.5%), and grouse (<1%) made up the diet of bobcats in northwest Montana (Newbury 2013). Rolley (1985) examined stomachs contents of bobcats in Oklahoma and found their major prey items to be cottontail rabbits (*Sylvilagus* spp.), hispid cotton rats (*Sigmodon hispidus*), eastern woodrats (*Neotoma floridana*), deer mice (*Peromyscus* spp.), and tree squirrels. Litvaitis et al. (1984) found that only 12% of stomach contents from bobcats in New Hampshire consisted of small mammals, such as northern short-tailed shrews (*Blarina brevicauda*), meadow voles (*Microtus pennsylvanicus*), white-footed mice (*P. leucopus*), and southern red-backed voles (*Clethrionomys gapperi*). Rose and Prange (2015) found that eastern cottontails (*S. floridanus*) occurred the most (26.4%) and white-tailed deer had the highest caloric value for Ohio bobcats. McLean et al.

(2005) found Pennsylvania bobcats most frequently ate white-tailed deer (41%), rabbits (22%), and deer mice (18%), with many juveniles having also eaten white-tailed deer. They assume that juveniles were eating deer as carrion (McLean et al. 2005). The researchers also found that the average stomach volume in male bobcats was greater than in females.

Contrasting to previous results, Litvaitis et al. (1984) found that juvenile bobcats did not consume as much white-tailed deer as yearling and adult bobcats. This may be because the younger bobcats have not developed the skills required to capture such large prey, and therefore tend to select smaller prey more often. This could also be due to the differing terminology used by each research group to define age classes. Male bobcats tend to be significantly heavier than female bobcats across all age classes, which may correlate with the higher amount of deer ingested by males than by females (Litvaitis et al. 1984, Sikes and Kennedy 1993). Fritts and Sealander (1978a) also found supporting evidence that females tend to select smaller prey items than males due to the higher availability of smaller prey items in Arkansas. Labisky and Boulay (1998) found that the maximum prey:predator weight ratio for bobcats in the Everglades of Florida was 8:1, which was determined in reference to the bobcat's largest prey item—white-tailed deer. Brockmeyer and Clark (2007) found that 60% of bobcat diets in Iowa consisted of cottontail rabbits, 20% mice and voles, 17% white-tailed deer, 15% fox squirrels (*Sciurus niger*), and 2% birds. Like most bobcat diet studies, white-tailed deer was mostly selected by adult males rather than by females or juveniles of either sex. Similarly, Litvaitis et al. (1984) found that bobcats larger than 10 kg consumed larger prey (i.e., white-tailed deer) more frequently than did smaller bobcats. Therefore, bobcat prey selection for white-tailed deer increases with body size or mass, regardless of bobcat sex or age. This is likely to explain the differences of diet between adults and juveniles, since adults are typically larger. The differences in food habits of

males versus females and juveniles versus adults may reduce dietary competition within bobcat populations.

Morphology and Body Condition

Variations in morphology of species due to resource competition, geographic location, topography, sexual dimorphisms, and dietary variation have been extensively studied. Watson et al. (1981) evaluated the physical condition of bobcats in West Virginia and Georgia by their fat deposits and degree of musculature following the standard necropsy procedures of Crum et al. (1978) on black bears in southeastern United States. Rolley (1985) measured the nutritional condition of bobcats in Oklahoma by measuring carcass weight and indexing fat reserves. Nutritional condition was estimated by visually evaluating and scoring the renal and omental (a layer of fat over the intestines) fat reserves from 0 (none) to 3 (very abundant; Rolley 1985). Litvaitis et al. (1986) also visually evaluated omental and kidney fat deposits of bobcats in Maine and assigned a similar score of 0–3 to describe the amount. Kidney fat indices (KFI) are used to rate body conditions and to estimate energy reserves for white-tailed deer (Finger et al. 1981). Similarly, a general rule of indexing can be created for bobcats to reduce observer bias.

Sikes and Kennedy (1993) observed geographic variations in sexual dimorphisms of bobcats in the eastern United States using 26 skull measurements of 1,056 specimens. Results showed that sexual dimorphism in bobcats is greater in mountainous areas, specifically the Appalachian Mountains, such that the degree of topographic relief might influence body size variation in females more so than in males and that male variation may be due to maintenance of larger home ranges than females.

Parvoviruses

Feline panleukopenia virus (FPV) is a parvovirus with single-stranded DNA that belongs to the genus *Parvovirus* and has been recognized since the 1920s (Siegl et al. 1985, Horiuchi et al. 1996). Canine parvovirus (CPV) is a type of feline parvovirus that became a host variant after a cross-species transfer from FPV in felids to canids (Decaro et al. 2010, Allison et al. 2013, Stuetzer and Hartmann 2014). Discovered in the late 1970s (Decaro et al. 2010, Clegg et al. 2012, Allison et al. 2013), CPV initially had one variation of the virus—CPV-2. It now contains three different antigenic types of parvoviruses: CPV-2a, CPV-2b (Schunck et al. 1995), and most recently CPV-2c, which was detected in Italy in 2000 and has spread worldwide (Decaro et al. 2010). Since the 2000s, newer variants of CPV were found to have adapted to infect feline species as well (Waseiri et al. 2009) and can co-infect an individual feline simultaneously with FPV (Decaro et al. 2008).

Parvoviruses cause acute disease in all members of Felidae (Demeter et al. 2010, Kruse et al. 2010, Foley et al. 2013) and infection can cause multiple symptoms, such as severe gastroenteritis, anorexia, fever, pyrexia, diarrhea, vomiting, leukopenia, lymphopenia, lethargy, and weakness. Symptoms begin 1—4 days post-infection and can last for 2 weeks (Berthier et al. 2000). The combination of these symptoms often leads to death of an infected animal (Schunck et al. 1995), especially in kittens under 6 months of age (Stuetzer and Hartmann 2014) where mortality rates range between 25–90% (Waseiri et al. 2009, Kruse et al. 2010).

Viral particles are shed in high titers and excreted in feces, nasal and ocular discharge, urine, saliva, and vomit for up to 22 days post-infection (Csiza et al. 1971), and may remain highly infectious in the environment for up to a year (Waseiri et al. 2009, Foley et al. 2013). Therefore, these viruses are typically transmitted through fecal ingestion (Schunck et al. 1995) or

contact with contaminated individuals or objects (Wasieri et al. 2009). Parvoviruses may move between hosts during predation or scavenging activity, which is common in non-domestic carnivores such as bobcats (Allison et al. 2013).

Increased human densities have been found to incidentally facilitate disease transmission to wild felids with the increasing overlap of non-domestic and domestic felid territories (Foley et al. 2013, Wasieri et al. 2009), as feral cats have been found to be carriers and common transmitters of parvoviruses to non-domestic felid populations in heavily populated areas (Wasieri et al. 2009, Foley et al. 2013). The West Virginia Division of Natural Resource has become concerned about whether parvoviruses are present in bobcats throughout West Virginia and how infection could affect bobcat ecology or behavior (Appendix I).

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TABLES

Table 1. West Virginia ecoregion characteristics (Uhlig and Wilson 1952).

Ecological Factors	Ecoregions					
	1	2	3	4	5	6
Physiogeographic Divisions	Allegheny Ridges and Valleys	Allegheny Plateau	Cumberland Mountains	Monongahela - Upper Ohio	Northern Ohio - West Virginia Hills	Southern Ohio - West Virginia Hills
Average Annual Temperature (°C)	11 – 12	9 – 11	11 – 13	9 – 12	11 – 13	11 – 13
Average Annual Precipitation (cm)	76 – 102	102 – 152	102 – 152	102 – 127	102 – 127	102 – 127
Predominant Forest Types	red oak; hard pine-oak	northern hardwoods; red oak	cove hardwoods; red oak	cove hardwoods; red oak	red oak	cove hardwoods; red oak

FIGURES

Figure 1. Harvest numbers and average pelt prices for West Virginia bobcats from 2000–2016.

Figure 2. Total harvest of bobcats in West Virginia over the 1977–2016 hunting seasons.

Figure 3. The six different ecoregions of West Virginia (Uhlir and Wilson 1952).

CHAPTER 2

RESEARCH ARTICLE

Population demographics of harvested bobcats in West Virginia

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ABSTRACT

According to bounty harvest records, bobcat populations in West Virginia appear to have declined from the early 1930s until bounty hunts ceased in 1961. By 1978, West Virginia Division of Natural Resources (WVDNR) enacted a 4-month bobcat harvest season and a season harvest limit of 2 bobcats per licensed person. In 2005, WVDNR increased the harvest limit to 3 bobcats per person. Previous research on this population was limited to only one year of data collected from harvested bobcats over the 1977–1978 harvest season; therefore, it is critical to obtain current demographic data before making additional decisions regarding changes to harvest strategies. We determined the current age structure, sex ratio, reproductive rates, body condition and morphometries, and survival rates of bobcats in West Virginia to assist with reevaluation of harvest regulations. We collected and necropsied 524 bobcat carcasses from hunters and trappers over the 2014–2015 and 2015–2016 harvest seasons in West Virginia. Results indicated that juvenile (<1 yr) bobcats represented 20%, yearlings (1–2 yr) represented 30%, and adults (≥ 2 yr) represented 50% of the total bobcats collected over the 2 harvest seasons. The sex ratio was 1:1 males to females over both years. Implantation rates per reproductive stage class assignments were 0.51 kittens/subadult female (1–2 yr), 1.86 kittens/adult female (2–4 yr), and 2.85 kittens/mature adult female (≥ 5 yr) for both harvest seasons combined over an estimated breeding season of mid-February to mid-June. All subadult females ovulated over both reproductive seasons prior to harvest, and mature adult females had a $\geq 93\%$ reproductive success rate over both seasons. Bobcats in West Virginia exhibit sexual dimorphism, such that males have a larger average body size than females. Survival rates decreased with increasing stage classes and between harvest seasons, with the highest survival rate estimated as 0.86 for juveniles over the 2014–2015 harvest season and the lowest rate as 0.52 for mature adults over

the 2015–2016 harvest season. Despite having an annual harvest season for bobcats in West Virginia, population change estimates indicated that the population is stable or increasing with current harvest limits. We recommend that managers maintain the current harvest limit until population abundance data is available and to continue monitoring the population for any density-dependent effects on reproductive success or stable age distribution.

KEY WORDS bobcat, West Virginia, population ecology, age structure, harvest management, fertility, survival, sex ratio, juvenile backdating, morphology

INTRODUCTION

Bobcats (*Lynx rufus*) across North America are commonly harvested for their pelts, with harvest rates often driven by fur market prices and, consequentially, hunter and trapper effort (Kapfer and Potts 2012, Newbury 2013). Harvest rates are also influenced by differing susceptibility between, or selection by hunters and trappers for, certain sexes and ages of bobcats (Chamberlain et al. 1999, Blankenship et al. 2006, Hiller et al. 2014). Higher movement rates of male bobcats may increase their chances for harvest (Crowe and Strickland 1975, Fritts and Sealander 1978, Parker and Smith 1983, Chamberlain et al. 1999), yet the predictability of females, which use smaller home-ranges than males, may increase their susceptibility to harvest (Kapfer and Potts 2012). Young bobcat transients may be less predictable than resident individuals, decreasing their chances for harvest (Blankenship et al. 2006). Alternatively, increased movement from young bobcats dispersing may make them more vulnerable to harvest (Blankenship and Swank 1979, Parker and Smith 1983, Lovallo 2013).

Population age ratios are used to determine life history traits, such as survival and reproductive rates, and effects of harvest pressure (Williams et al. 2002:5–7). Harvests dominated by younger individuals indicate heavily harvested populations (Fredrickson and Rice 1979, Lembeck and Gould 1979, Lovallo 2013) as opposed to unexploited populations which consist of mostly older animals (Fritts and Sealander 1978, Rolley 1985). Age ratios also allude to density-dependent or density-independent pressures on a population (Williams et al. 2002:5–7). Harvest selection bias by hunters and trappers can affect the structure of populations (Cooley et al. 2009), such that hunter-trapper release of young or female bobcats may lead to a larger population of young or females (Zezulak and Schwab 1979, Lovallo 2013) – a response independent of density.

Alternatively, if juvenile harvest is high, population reproduction rates may increase as a density-dependent response (Griffin 2001).

Due to the listing of the critically endangered Iberian lynx (*Lynx pardinus*) under Appendix I of the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora in 1977, all other *Lynx* spp., including bobcats (*L. rufus*), were listed under CITES Appendix II as look-alike species (Anderson 1987), which requires governing agencies to affirm and maintain stability of their *Lynx* spp. populations prior to being granted exportation authority of pelts to the international market (CITES 2017). Proper management of game species requires knowledge of key demographic factors that influence population change (i.e., reproduction, population health, competition, age and sex ratios, and survival) to determine appropriate harvest limits (Williams et al. 2002:5).

Biologists have extensively studied aspects of bobcat demography in most areas of their range (Appendix II), where survival, age and sex ratios, and reproductive rates vary by region (McCord and Cardoza 1982, Knick 1990, Nielsen and Woolf 2002), environmental variables (Blankenship et al. 2006, Roberts 2007, Williams et al. 2002:5), and harvest management (Fritts and Sealander 1978, Gilbert 1979, Litvaitis et al. 2006, Lovallo 2013). However, previous research on West Virginia's bobcats consists of only one year of data collected over the 1977–1978 harvest season (Fox and Fox 1982). Using Crowe's (1975b) population change equation created for bobcats in Wyoming, West Virginia Division of Natural Resources (WVDNR) biologists used the results from the 1970s to determine harvest limits for the population. Therefore, changes in bobcat harvest management in West Virginia cannot be substantially justified without considering current demographic data.

Survival influences yearly change in population, which managers use to determine long-term harvest strategies for game species. Survival can be affected by both biotic and abiotic factors, density-dependent and density-independent effects, harvest pressure, and interspecific or intraspecific interactions, such as competition, disease, and parasitism (Williams et al. 2002:5). Recent fluctuations in West Virginia's bobcat harvest numbers may be due to multiple factors: pelt market prices, hunter-trapper effort, density-independent or -dependent effects, or a combination of those factors. We estimated the age structure, body condition and morphometries, sex ratio, reproductive rates, breeding success, and survival rates of bobcats in West Virginia and compared results across harvest seasons, stage classes, and harvest ecoregions using age-at-harvest data.

STUDY AREA

West Virginia, USA (62,755 km²) consists of 55 counties divided into 6 ecological regions (ecoregions; Fig. 1): Appalachian Ridges and Valleys (ecoregion 1), Allegheny Plateau (ecoregion 2), Cumberland Mountains (ecoregion 3), Monongahela and Upper Ohio (ecoregion 4), Northern Ohio and West Virginia Hills (ecoregion 5), and Southern Ohio and West Virginia Hills (ecoregion 6; Uhlig and Wilson 1952). The ecoregions are defined by differing ecological factors: average annual temperature, average annual precipitation, predominant forest types, growing season length, soil types, and physiographic subdivisions (Table 1; Uhlig and Wilson 1952).

Elevations in West Virginia range from 73 m above sea level at Harper's Ferry near the Potomac River in Jefferson County (ecoregion 1) to 1,482 m above sea level at Spruce Knob in the Allegheny Mountains of Pendleton County (ecoregion 1; Mullenex 2010). West Virginia has 4 distinct seasons, with average annual snowfall ranging from 0.51 m to 3.68 m (NCDC

2017). Annual precipitation ranges from 1.37 m in the central Allegheny Plateau, where annual temperatures average 9.4° C, to 0.93 m in the Appalachian Ridges and Valleys, where annual temperatures average 11.7° C (NCDC 2017).

METHODS

Carcass Collection and Necropsy

We solicited and obtained carcasses from hunters, trappers, and taxidermists across West Virginia over the 2014–2015 and 2015–2016 harvest seasons, which run from November through February, with a goal of collecting 300 carcasses per season (Appendix III). We asked hunters and trappers to record their method of harvest (i.e., trap, gun, bow, roadkill, or nuisance permit), date and location of harvest (i.e., county and ecoregion), and sex for each carcass submitted to the project. We obtained total reported bobcat harvest counts for the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia from WVDNR biologists to determine the proportion of carcass samples collected for the study from the overall harvest totals per season.

We necropsied the carcasses to collect skulls and internal organs, to record morphometric measurements, including mass (kg), back length (cm), and shoulder height (cm), and to estimate body condition of the individuals over winter following the methods of Monson et al. (1974) using mean kidney mass and mean perirenal fat mass from both kidneys (Finger et al. 1981, Lajeunesse and Peterson 1993). We then created an inverse index for kidney fat (KFI_i) using equation: $[\text{mean kidney fat mass (g)} \div (\text{mean kidney mass (g)} + \text{mean kidney fat mass (g)})] \times 100 = \text{KFI}_i$, which provides an index value proportionate to the amount of fat content per individual.

As biologists often use hunter-trapper harvest data to manage game species' populations, managers should know the misclassification rates of game species registered each harvest season. We compared hunter-trapper bobcat sex identifications recorded during harvest registration to sexes observed during necropsy to determine accuracy of hunter-trapper recorded harvest data for West Virginia. We denoted their sex identification responses with a Bernoulli distribution (i.e., 1 = correct, 0 = incorrect).

Survey

West Virginia Division of Natural Resources biologists mailed a confidential survey in 2016 to 11 hunters and 133 trappers that submitted carcasses to the study over the 2015–2016 harvest season. The anonymous survey consisted of questions regarding personal trapping techniques (i.e., sex or age harvest selectivity), amount of days spent in the field (i.e., hunter-trapper effort), and possible factors that influenced trappers to spend less days afield (i.e., weather conditions, pelt prices) during the 2015–2016 bobcat harvest season in West Virginia.

We obtained average pelt price data from the March 2006–2016 West Virginia Trappers Association annual fur auctions (WVTA 2017) and monthly total snowfall data for West Virginia for each harvest season (Nov–Feb) from 2005–2016 from the National Oceanic and Atmospheric Administration (2017) National Centers for Environmental Information. We also obtained total reported bobcat harvest counts for the 2005–2016 harvest seasons (Nov–Feb) in West Virginia from WVDNR biologists. We compared seasonal snowfall totals and annual pelt price data to total reported bobcat harvest counts across the state for each season to identify correlations that may explain hunter-trapper effort. We then compared results to the hunter-trapper survey responses.

Age Structure

We removed lower mandibles from each necropsied bobcat skull and soaked them in 70–90° C tap water for 4–6 hours before removing the canines for aging. Bobcats with deciduous canines (DC) or permanent canines containing open root apical foramen (PC-OR) are <1-year-old and have not reached sexual maturity, while bobcats with permanent canines containing closed roots (PC-CR) are >1 year (Crowe 1975*a*, Johnson et al. 1981; Appendix IV, Fig. i). Deciduous canines are typically found in bobcats <6 months old, with permanent canines beginning to emerge by 6 months of age (Jackson et al. 1988). Root apical foramens typically close sometime between 1–1.5 years of age in bobcats, with the first cementum annulus developing after the individual's second winter of life, when we can then estimate age by sectioning and staining their canines and counting annuli (Crow 1972, 1975*a*; Appendix IV, Fig. ii). We sent PC-CR canines to Matson's Laboratory, LLC (Manhattan, Montana, USA) to be sectioned, stained, and to have cementum annuli counted to approximate age of adult bobcats.

We divided ages into 3 stage classes: juveniles (<1 yr), yearlings (1–2 yr), and adults (≥ 2 yr; Crowe 1975*a*, Johnson et al. 1981, Kapfer and Potts 2012). However, biologists often divide ages into classes by their reproductive potential (e.g., young adult, adult, senectitude; Crowe 1972). Therefore, we analyzed reproductive success of differing age class groupings to assess whether management should concentrate on a separate set of reproductive stage classes for the population according to female reproductive potential.

Juveniles are individuals that have not yet reached sexual maturity (Crowe 1975*a*). However, specific dates of birth for juveniles indicate parturition and breeding schedules. Therefore, we recorded tooth eruption patterns for the upper and lower mandibles for all DC and PC-OR individuals, then backdated the age of each bobcat following the dental eruption schedule

of Jackson et al. (1988) to better determine seasonal breeding parameters for West Virginia's bobcats. We measured canine tooth length (cm; L), diameter at the gum line (cm; D), and diameter of the root apical foramen (cm; FD) for all juveniles, then calculated an index value using Crowe's (1975a) age index (i.e., $AI = (L + D - FD) \times 100$).

Reproductive Rates

We collected reproductive organs during necropsy from 148 female bobcats harvested during the 2014–2015 season and 112 female bobcats harvested during the 2015–2016 season to estimate reproductive success. *Corpora lutea* usually regress to *Corpora albicans* post-parturition (Jewgenow et al. 2014). However, *Corpora lutea* may persist in *Lynx* spp., producing progestogens for a minimum of 2 years post-pregnancy (Painer et al. 2014) and are unreliable for estimating reproductive rates. Therefore, we noted the presence, colors, and sizes of follicles in each ovary to determine if the female had reached reproductive maturity and if she had ovulated at some point over the previous year.

We examined the attached uterine horns over a light board to count the number of visible placental scars, then opened the horns with a scalpel to better examine the color gradient of the scars, if present (Appendix IV, Fig. iii). Scars that contained macrophages (white blood cells) were black or brown in color and formed during parturition of the placenta. Therefore, scars that contained color were counted as successful placental implantations from the previous breeding season and those without color or macrophages were excluded.

We summed the total number of placental scars present/individual (i.e., implantation rate) to estimate average litter sizes for each reproductively active (i.e., *Corpora lutea* present) female stage class (Fritts and Sealander 1978). We determined breeding success for all individuals using

binomial notation: “1” if the female was reproductively active and had at least one placental scar present and “0” if the female was reproductively active but did not contain a valid placental scar.

Analyses

We determined the frequency of bobcats collected across West Virginia by sex, stage class, ecoregion, harvest season, and harvest month, then analyzed sex and stage classes by the ecoregion, season, and month of harvest using chi-squared tests in RStudio™ (RStudio, Inc., Boston, MA, USA), which assumes the use of categorical data from ≥ 2 independent groups (McHugh 2013). We also analyzed sex and stage class frequencies by body condition (i.e., KFI_i) and morphometric measurements (i.e., body mass, shoulder height, and back length) using one-way analysis of variance (ANOVA) in RStudio to determine stage class and sexual dimorphisms by ecoregion. Our data met one-way ANOVA assumptions of independence, normal distribution, and equal homogeneity of variances in the data (Dalgaard 2008).

We evaluated harvest weapons and harvest sites from collected carcasses by ecoregion, season, and month of harvest, and by bobcat sex and stage class using chi-square tests. We then extrapolated bobcat sex misclassification rates for legal hunters and trappers across West Virginia by comparing the number of correct versus incorrect sex identification responses obtained with our samples from hunters and trappers over the 2014–2015 and 2015–2016 seasons combined. We evaluated hunter-trapper misclassification rates across ecoregions and bobcat sex and stage classes using logistic regression in RStudio, which assumes that the dependent variable (i.e., hunter-trapper correctness) contains independent observations that follow the Bernoulli distribution (i.e., incorrect = 0, correct = 1; Stoltzfus 2011).

We analyzed all hunter-trapper survey results using one-way ANOVAs for the continuous data and logistic regression for the dichotomous responses (i.e., “yes” = 1 and “no” = 0). We used simple linear regression to evaluate correlations between total snowfall, pelt price, and total bobcat harvest data. Our analyses met all simple linear regression assumptions of data linearity and normality, equal variance, and no autocorrelation of the residuals (Pena and Slate 2006). We evaluated the data over an 11-year (2005–2016) timespan due to the increase in harvest limit for bobcats in West Virginia from 2 to 3 bobcats/person/season beginning with the 2005–2006 harvest season; therefore, we evaluated the timespan that only included the 3-bobcat harvest limit.

We estimated juvenile bobcat dates of birth in Julian calendar days obtained by backdating age (in days) using tooth eruption patterns detailed by Jackson et al. (1988). We removed all outliers that prevented the data from meeting statistical assumptions (Pena and Slate 2006). We then used simple linear regression to compare the dates of birth across seasons, between sexes, and among ecoregions, and to determine if Crowe’s (1975a) aging index is a strong predictor of juvenile age (in days). Similarly, we used simple linear regression and ANOVA to determine if tooth length, diameter at the gum line, root apical foramen diameter, body mass, shoulder height, back length, body condition, and combinations of those variables are good predictors of juvenile age (in days). We then determined the breeding season for bobcats in West Virginia using copulation dates, which were estimated by subtracting an average 65-day gestation period (Stys and Leopold 1993) from Julian calendar dates of birth.

We used corrected Akaike’s Information Criterion (AICc) to determine if female stage classes should be divided into reproductive stage classes (i.e., immature, sub-adult, adult, mature adult) by their breeding success rates rather than dividing them by the typical 3-stage

classification (i.e., juvenile, yearling, adult), then we estimated breeding success and implantation rates of female bobcats per reproductive stage class. We evaluated implantation rates and breeding success by body condition (i.e., KFI_i), morphometric measurements (i.e., mass, shoulder height, back length), harvest ecoregion, and harvest season using Poisson and logistic regression, respectively, in RStudio. Our data met Poisson regression assumptions, such that our dependent variable (i.e., implantation rates) consisted of count data with independent observations that followed a Poisson distribution of equal mean and variance. We used mean implantation rates and sex ratios from each harvest season to determine fecundity rates (number of female young/female) for all reproductively active females.

We estimated survival rates using the Udevitz and Ballachey (1998) multinomial age-structure survival model modified to accommodate uncertainty in population growth rates and variable capture probabilities with no maximum age class using age-at-harvest data and Bayesian estimates of population change and age class capture probabilities (C. Rota et al., West Virginia University, unpublished data). We bootstrapped capture probabilities (α) and population growth rates (λ), if unknown, to evaluate sensitivity of survival estimates to varying values of α and λ . The model assumes: 1) relative capture probability of the first stage class to all other stage classes is known, 2) population growth of each stage class is known, 3) relative capture probability of the second stage class is equivalent to all older stage classes, 4) survival of last 2 stage classes is the weighted average of the survival probability of the 2 oldest stage classes, and 5) population maintains a stable age distribution. We then modified the models to evaluate multiple different factors to determine the best linear model for the population, which resulted in 16 models. Models varied between 1) age class assignments, 2) including a sex variable, 3) including a year variable, and 4) including both a sex and year variable. We estimated λ using

the mean of harvest rates from 11 years (2005–2016) of statewide reported bobcat harvest data, and we estimated α for the juvenile stage class using hunter-trapper survey results for harvest selectivity. We ran competing models with RStudio using package R2OpenBUGS and OpenBUGS© (Version 3.2.3, <http://www.openbugs.net>, accessed 12 Oct 2017), then selected the model with the lowest Deviance Information Criterion (DIC) value (Table 2). We then used Crowe's (1975b) change in population model for bobcats in Wyoming with our juvenile and combined adult survival rates and fecundity estimates to estimate population change post-harvest season (Nov–Feb) for bobcats in West Virginia. Crowe's (1975b) change in population (λ) model is $\lambda = S_a + F(S_y)$, where S_a is adult survival, F is fecundity, and S_y is juvenile survival.

We used the Predict function in RStudio to determine 95% confidence intervals for all binomial and Poisson estimates, and we used standard errors of the means and F -statistics derived from ANOVA and simple linear regression for the continuous variables. Lastly, we used Tukey's HSD post-hoc analyses for each significant ANOVA to confirm where differences occurred between groups, using a statistical significance of $\alpha = 0.05$ for all analyses. Statistically significant ANOVA results that received non-significant P -values after running post-hoc analyses are reported with the initial estimate first, followed by Tukey's HSD P -value.

RESULTS

Harvest Collection Data

We collected 524 bobcat carcasses from 46 of the 55 counties in West Virginia over the 2014–2015 ($n = 300$) and 2015–2016 ($n = 224$) harvest seasons (Fig. 1). Total bobcat harvest recorded for West Virginia was 1,970 from the 2014–2015 harvest season and 1,380 from the 2015–2016 harvest season. Therefore, our samples represented 15% and 16% of the total bobcats

harvested across West Virginia over the 2 seasons, respectively. Trapping represented the majority harvest type (90.8%; Appendix V, Table i), and forest represented the majority harvest site type (46.4%; Appendix V, Table ii) for our collected samples. Harvest weapons differed between harvest seasons ($\chi^2_3 = 13.3$, $P = 0.004$), harvest site types ($\chi^2_{12} = 371.0$, $P \leq 0.001$), and harvest months ($\chi^2_{18} = 232.3$, $P \leq 0.001$), but not among ecoregions ($\chi^2_{15} = 17.6$, $P = 0.283$), bobcat sexes ($\chi^2_3 = 1.4$, $P = 0.705$), or bobcat stage classes ($\chi^2_6 = 4.9$, $P = 0.558$). Harvest site types did not differ between harvest seasons ($\chi^2_4 = 9.1$, $P = 0.059$), bobcat sexes ($\chi^2_4 = 7.4$, $P = 0.118$), or bobcat stage classes ($\chi^2_8 = 11.3$, $P = 0.188$), but did differ among ecoregions ($\chi^2_{20} = 47.3$, $P \leq 0.001$) and harvest months ($\chi^2_{24} = 262.8$, $P \leq 0.001$).

We estimated a 13.4% misclassification rate of bobcat sex identification by hunters and trappers in West Virginia. Hunter-trapper identified males ($n = 252$) and females ($n = 253$) were correctly identified 80.2% (95% CI = 74.8–84.6) and 92.1% (95% CI = 88.1–94.8) of the time, respectively; while hunter-trapper harvested juveniles ($n = 101$), yearlings ($n = 143$), and adults ($n = 261$) were correctly identified as male or female 76.2% (95% CI = 67.0–83.5), 89.5% (95% CI = 83.3–93.6), and 88.1% (95% CI = 83.6–91.5) of the time, respectively (Appendix V, Table iii). There was no difference in sex misclassification between adults and yearlings ($|z| = 0.42$, $P = 0.675$), but there were differences in misclassification rates of adults to juveniles ($|z| = 2.78$, $P = 0.006$), yearlings to juveniles ($|z| = 2.72$, $P = 0.006$), and males to females ($|z| = 3.76$, $P \leq 0.001$).

Survey Data

We received 73 responses (50.7% response rate) from hunters (i.e., harvest type: “gun” or “bow”; $n = 5$) and trappers ($n = 68$) that donated bobcat carcasses to the project over the 2015–2016 harvest season. Trappers spent an average of 43.2 days (SE = 4.36) in the field trapping for

bobcats, whereas hunters spent an average of 28.6 days (SE = 10.88) in the field hunting for bobcats (Appendix VI, Table i). Twenty-one trappers (31%) spent fewer days trapping over the 2015–2016 harvest season due to external circumstances – 43% noted snow and 57% noted pelt prices as factors influencing fewer days afield (Appendix VI, Table ii).

Twelve trappers (18%) reported that they released bobcats over the 2015–2016 harvest season, with 67% of them having released 1 bobcat, 8% having released 2, and 25% having released 3 bobcats for a total release of 19 bobcats. Trappers stated that they released bobcats because: 1) they were too small (63%), 2) they were female (5%), or 3) other reasons (32%), such as having already met the bobcat harvest limit (Appendix VI, Table iii).

Mean pelt price from the WVTA annual fur auctions decreased by \$21.62 and mean statewide snowfall increased by 0.44 cm from the 2014–2015 harvest season to the 2015–2016 harvest season. Mean pelt prices from the 11-year interval (2006–2016) of annual fur auctions resulted in a mean pelt average of \$61.43 (SE = 7.47). Mean snowfall across West Virginia was 11.54 cm (SE = 2.32) over the 11-year interval of harvest seasons (Nov–Feb). Statewide bobcat harvest totals resulted in a mean harvest of 1,701 (SE = 100.37) bobcats over the 11-year interval (Appendix VII). Statewide bobcat harvest totals declined with increasing snowfall ($F_{1,9} = 16.47$, $P = 0.003$) over the 11-year interval, whereas there was no statistically significant effect of pelt prices on harvest totals ($F_{1,9} = 3.62$, $P = 0.090$) or of snowfall on pelt prices ($F_{1,9} = 1.34$, $P = 0.278$; Fig. 2).

Age Structure, Sex Ratio, and Morphology

Juvenile bobcats represented 20.4%, yearlings 27.5%, and adults 52.1% of the total carcasses collected over the 2014–2015 and 2015–2016 harvest seasons, with the adult and

yearling stage classes differing between harvest seasons ($\chi^2_2 = 29.1$, $P \leq 0.001$) and among ecoregions ($\chi^2_{10} = 23.8$, $P = 0.008$), but not among harvest months ($\chi^2_{12} = 20.7$, $P = 0.055$; Table 3,4). Adult bobcats had larger mean mass ($F_{2,521} = 124.30$, $P \leq 0.001$), shoulder height ($F_{2,383} = 73.13$, $P \leq 0.001$), and back length ($F_{2,520} = 167.00$, $P \leq 0.001$) values than yearlings and juveniles (Table 5; Appendix VIII). However, juvenile bobcats had a similar mean KFI_i value as adults, both of which had higher KFI_i values than yearlings ($F_{2,521} = 4.01$, $P = 0.019$; Table 5).

The sex ratio of males to females was nearly 1 for both seasons, with a total of 264 males and 260 females. Therefore, number of male and female bobcats did not differ between harvest seasons ($\chi^2_1 = 0.004$, $P = 0.950$), nor did it differ among harvest months ($\chi^2_6 = 3.8$, $P = 0.699$) or ecoregions ($\chi^2_5 = 6.1$, $P = 0.299$). Male bobcats had a larger mean body mass ($F_{1,522} = 226.80$, $P \leq 0.001$), shoulder height ($F_{1,384} = 40.95$, $P \leq 0.001$), back length ($F_{1,521} = 110.30$, $P \leq 0.001$), and KFI_i ($F_{1,522} = 7.66$, $P = 0.006$) than females (Table 6; Appendix VIII).

Overall bobcat mass did not differ between harvest seasons ($F_{1,522} = 0.64$, $P = 0.425$), among months ($F_{6,514} = 0.61$, $P = 0.723$), or among ecoregions ($F_{5,517} = 2.63$, $P = 0.023$; Tukey's HSD: $P \geq 0.065$). Similarly, bobcat shoulder heights and back lengths did not differ across ecoregions ($F_{5,379} = 0.55$, $P = 0.742$; $F_{5,516} = 1.51$, $P = 0.184$) or months ($F_{6,376} = 0.50$, $P = 0.811$; $F_{6,513} = 0.65$, $P = 0.690$), respectively. However, shoulder heights ($F_{1,384} = 6.24$, $P = 0.013$) and back lengths ($F_{1,521} = 6.15$, $P = 0.013$) differed between harvest seasons. Body condition (i.e., KFI_i) differed among ecoregions ($F_{5,517} = 4.99$, $P \leq 0.001$) and harvest months ($F_{6,514} = 9.03$, $P \leq 0.001$), but not between harvest seasons ($F_{1,522} = 0.48$, $P = 0.491$).

Juvenile Backdating

Dates of birth for juvenile bobcats collected over the 2014–2015 ($n = 60$) and 2015–2016 ($n = 47$) harvest seasons ranged from 19 April–9 December. Mean date of birth was 20 June (SE = 3.75) when not excluding outliers (i.e., late births). There were 5 outliers: one male born on 30 August, one male born on 22 September, one male born on 14 October, one male born on 11 November, and one female born on 9 December. The latter 4 individuals retained deciduous canines. When these outliers were excluded, birth dates ranged from 19 April–19 August, with a mean birthday of 14 June (SE = 2.75). Using an average gestation period of 65 days (Stys and Leopold 1993) and excluding outliers, we estimated the breeding season for bobcats in West Virginia to range from 13 February–15 June ($\bar{x} = 10$ April, SE = 2.75). There was no difference in mean birthday (or copulation date) across harvest seasons ($F_{1,100} = 0.10$, $P = 0.748$), between sexes ($F_{1,100} = 0.49$, $P = 0.486$), or among ecoregions ($F_{5,96} = 0.99$, $P = 0.431$). Similarly, juvenile bobcat age (in days) did not differ between harvest seasons ($F_{1,100} = 0.02$, $P = 0.897$), sexes ($F_{1,100} = 0.17$, $P = 0.677$), or among ecoregions ($F_{5,96} = 1.71$, $P = 0.139$).

Crowe's (1975a) age index ($\bar{x} = 299.80$, SE = 3.15) was a strong predictor of juvenile bobcat age (in days) ($F_{1,100} = 166.20$, $P \leq 0.001$; Fig. 3). Canine length ($\bar{x} = 2.68$ cm, SE = 0.02) and root apical foramen diameter ($\bar{x} = 0.31$ cm, SE = 0.01) also were strong predictors of juvenile bobcat age (in days; $F_{1,100} \geq 90.55$, $P \leq 0.001$). However, canine diameter at the gum line ($\bar{x} = 0.64$ cm, SE = 0.01) was a poor predictor of juvenile bobcat age (in days; $F_{1,100} = 0.03$, $P = 0.866$). Mass ($F_{1,100} = 35.23$, $P \leq 0.001$), shoulder height ($F_{1,82} = 16.28$, $P \leq 0.001$), and back length ($F_{1,100} = 24.68$, $P \leq 0.001$) were strong predictors of juvenile bobcat age (in days). However, body condition was not a strong predictor of either male ($F_{1,50} = 3.57$, $P = 0.065$) or female ($F_{1,48} = 1.97$, $P = 0.167$) juvenile bobcat age (in days; Appendix IX).

Canine measurements differed by sex, such that juvenile male bobcats had longer ($F_{1,100} = 17.52, P \leq 0.001$), wider (i.e., canine diameter; $F_{1,100} = 75.71, P \leq 0.001$), and bigger root apical foramen diameters ($F_{1,100} = 7.13, P = 0.009$) than juvenile female bobcats. Canine length ($F_{1,50} = 43.66, P \leq 0.001$; $F_{1,48} = 29.72, P \leq 0.001$) increased and root apical foramen diameter ($F_{1,50} = 34.58, P \leq 0.001$; $F_{1,48} = 16.91, P \leq 0.001$) decreased with mass for both male and female juvenile bobcats, respectively, while canine diameter at the gum line ($F_{1,50} = 2.48, P = 0.121$; $F_{1,48} = 2.16, P = 0.148$) had no significant relation with either male or female juvenile bobcat mass (Fig. 4).

Reproduction

Mean implantation rate across all reproductively active age classes (i.e., >1 yr) was 1.54 (SE = 0.107) kittens/female with a breeding success rate of 58.4% (95% CI = 51.6–64.9) when combining results from both harvest seasons. With a 1:1 sex ratio of the population, fecundity resulted in 0.9 female young/reproductively active female from the breeding season prior to the 2014–2015 harvest season and 0.59 female young/female prior to the 2015–2016 harvest season. Implantation rates ($F_{2, 257} \geq 60.40, P < 0.001$) and breeding success ($|z| \geq 4.76, P < 0.001$) differed by stage class. The best model to represent differences in breeding success rates (i.e., $\Delta AICc = 0$) separated reproductive stage classes of females into 4 groups: immature (i.e., juveniles, <1 yr), sub-adult (i.e., yearlings, 1–2 yr), adult (i.e., adults, 2–4 yr), and mature adult (i.e., adults, ≥ 5 yr; Appendix X). Mean breeding success rate for mature adult females ($n = 34$) was 97.1% (95% CI = 81.9–99.6), while adults ($n = 100$) had 75.0% (95% CI = 65.6–82.5) and sub-adults ($n = 75$) had 18.7% (95% CI = 11.4–29.1) mean breeding success rates (Table 7). Mean implantation rate of mature adult females was 2.85 (SE = 0.203) kittens/female, while

adults had 1.86 (SE = 0.141) and sub-adults had 0.51 (SE = 0.136) kittens/female (Table 7). All immature female ovaries showed no sign of follicular growth, while all sub-adults and older contained at least one CL in their ovaries. All reproductive stage classes had a minimum of 0 kittens/female, with a maximum of 5 kittens/female for sub-adults and 6 kittens/female for adult and mature adult females.

Implantation rates of mature adult females differed by mass ($F_{1, 32} = 8.14$, $P = 0.008$) and back length ($F_{1, 32} = 19.68$, $P < 0.001$), but not by shoulder height ($F_{1, 24} = 0.50$, $P = 0.488$), body condition ($F_{1, 32} = 0.52$, $P = 0.477$), harvest season ($F_{1, 32} = 1.89$, $P = 0.179$), or ecoregion ($F_{5, 28} = 13.97$, $P = 0.484$), whereas mature adult female breeding success did not differ by any of the above variables ($|z| \leq 1.23$, $P \geq 0.219$). Similarly, implantation rates and breeding success rates of both adult and sub-adult females did not differ across body sizes, conditions, harvest seasons, or ecoregions ($F \leq 1.72$, $P \geq 0.193$; $|z| \leq 1.67$, $P \geq 0.096$).

Survival Rates

We evaluated survival probabilities of bobcats by bootstrapping capture probability (α) values from 0.63 (± 0.05) for the first stage class, where 0.63 represents the reported rate of juvenile bobcat release by trappers in West Virginia, to 1 for all other stage classes. We estimated a mean population growth (λ) of 1.01 (SE = 0.082) from 11 years of harvest data (2005–2016); therefore, we set λ to vary from 0.93–1.09 when bootstrapping. We selected the linear model with the lowest reported Deviance Information Criterion value (i.e., $\Delta\text{DIC} = 0$): D10 (Table 8). Our top model evaluated 5 parameters: 1) survival of age 0–1 (juvenile or immature), 2) survival of age 1–2 (sub-adult), 3) survival of ages 2–5 (adult), 4) survival of age 5+ (mature adult, right-pooled), and 5) harvest year.

Juvenile survival probabilities using harvest data were estimated as 0.86 (SD = 0.065) from the 2014–2015 harvest season (“first season”) and 0.78 (SD = 0.084) from the 2015–2016 harvest season (“second season”). Sub-adult survival probabilities were 0.81 (SD = 0.079) from the first season and 0.72 (SD = 0.106) from the second season. Adult survival probabilities were 0.68 (SD = 0.052) from the first season and 0.56 (SD = 0.051) from the second season. Mature adult survival probabilities were 0.65 (SD = 0.060) from the first season and 0.52 (SD = 0.081) from the second season (Table 9). Survival probabilities differed between stage classes and harvest years (Fig. 5). Crowe’s (1975*b*) change in population model indicated a 44% post-harvest increase in population size after the 2014–2015 season and a stable population size after the 2015–2016 harvest season.

DISCUSSION

Harvest Collection and Survey

Our goal for each harvest season was to collect 300 bobcat carcasses from hunters and trappers across West Virginia. We reached our goal for the 2014–2015 season, but we only managed to collect 224 carcasses over the 2015–2016 season, despite having continuously contacted all known hunters and trappers in West Virginia via phone calls, mailings, and social media to attempt to increase collection numbers. Though we did not reach our 300 carcasses per season goal during the second season, we did subsample 16% of the total harvest, which was approximately the same subsample percentage achieved over the 2014–2015 season (15%).

We submitted the survey to hunters and trappers submitting carcasses over the 2015–2016 season to determine potential density-independent factors, such as hunter-trapper effort, that might explain the observed decrease in harvest numbers between harvest seasons. Though

mean pelt prices decreased by only \$21.62 and mean annual snowfall increased by only 0.44 cm from the 2014–2015 season to the 2015–2016 harvest season, there was greater variation in harvest totals, pelt prices, and snowfall over the 11-year interval (2005–2016). Regardless of the statistical significance of the results (e.g., pelt price was significant at the $\alpha = 0.1$ level), trapper harvest effort tended to increase with increasing pelt prices and decreasing snowfall. Therefore, results reinforced trapper survey responses of snowfall and pelt prices as factors that may affect annual harvest effort, such that 17.6% of trappers spent fewer trap days in the field due to pelt prices and 13.2% spent less days in the field due to snow.

Our carcasses collected over the 2014–2015 and 2015–2016 harvest seasons followed the decline in statewide harvest totals over the 2 years. Similar to our results from the 11-year interval, pelt prices had a positive correlation and snowfall had a statistically significant negative correlation with the number of bobcats harvested each year. With 91% of our samples harvested via trap, our findings suggest that bobcat harvest rates appear to be influenced by both pelt prices and snowfall for trappers in West Virginia. However, there are likely many other variables that influence hunter-trapper effort that we did analyze. For instance, trap harvest may decline or be restricted in certain areas during deer and waterfowl seasons (e.g., United States Fish and Wildlife Service refuges). These initial data could be used, along with further research, to better determine factors that may affect harvest success in West Virginia.

Misclassification Rates

We determined a 13.7% bobcat sex misclassification rate by hunters and trappers in West Virginia. Juvenile and male bobcats were misclassified more than yearlings, adults, and females, which suggests that females and older individuals could be overestimated in the harvest (Hiller et

al. 2014). Male bobcats reach reproductive maturity after their second winter (i.e., 1.5 years old; Fritts and Sealander 1978), making the identification of juvenile male bobcats challenging (Hansen 2007). Therefore, managers should account for these misclassification rates to eliminate some of the inherent sex biases that occur when utilizing hunter-trapper harvest data to determine sex ratios.

Age Structure and Sex Ratios

The age structure of West Virginia's bobcat population consisted of 20% juveniles, 28% yearlings, and 52% adults over both seasons combined. Harvests dominated by older individuals are typical of unexploited populations (Fritts and Sealander 1978, Rolley 1985). West Virginia has a harvest limit of 3 bobcats/licensed person per season (Nov–Feb) for the entire state, which is higher than Ohio (i.e., no bobcat harvest season) and Pennsylvania (i.e., 1 bobcat/person per season), but lower than Virginia (i.e., no trapping limit on bobcat harvest) and Kentucky (i.e., 5 bobcats/person per season). Therefore, our survey asked trappers if they released any bobcats, and what their reasoning was for release. Of 19 bobcats that were reported released, 63% were described as juveniles, indicating selection bias by trappers in West Virginia. Selection biases, such as opting for older or larger individuals, can alter the age structure of a population (Cooley et al. 2009) and is a potential factor of the higher adult age ratio that we observed in the harvest.

Vulnerability to harvest may be greater for species where males have greater movement and larger home range sizes than females (Crowe and Strickland 1975, Fritts and Sealander 1978, Parker and Smith 1983, Chamberlain et al. 1999); therefore, a harvest sex ratio that does not consist of a higher proportion of males to females may be evidence of heavy exploitation (Garshelis 1990). However, that situation is typical of gun harvested species rather than trapped

species. Additionally, the current 1:1 sex ratio is the same as the pre-harvest limit ratio from the 1970s. Since 90% of the bobcats that we collected were trapped, the current sex ratio of the bobcat population may not be a useful indicator of harvest rates for bobcats.

Morphological Variations

Bobcats in West Virginia exhibit sexual dimorphism, such that male bobcats are larger and have higher fat content than females. Intraspecific sexual dimorphism can be due to resource competition (McLean et al. 2005), sexual selection (Dobson and Wigginton 1996), geographic location (Dobson and Wigginton 1996), topography (Sikes and Kennedy 1993), and dietary variation (McLean et al. 2005). Sikes and Kennedy (1993) found a positive correlation between increased topography and sexual dimorphism in eastern bobcats, and they suggested that the degree of topographic relief might influence body size variation in females more so than in males and that male variation may be due to their maintenance and defense of larger home ranges than females. Sexual dimorphism exhibited by bobcats in Pennsylvania may be related to dietary variation in this species and may encourage intraspecific niche partitioning (McLean et al. 2005). More research is needed to determine influences of sexual dimorphism for bobcats in West Virginia.

Adults and yearlings had a larger mean body size than juveniles, which is expected with maturation. However, juveniles had the highest fat content, followed by adults. We should expect juveniles to maintain higher initial fat content due to post-parturition consumption of milk from their mother (Jackson and Jacobson 1987). It is expected that yearlings would have less fat content than juveniles, as these individuals are transient once they are forced out of their mother's territory. Although the increase in fat content with age may be due to common

physiological changes, such as having decreased physical movement within an established home range or having improved hunting skills over time, more research is needed to better understand the increase in fat with age.

Juvenile Backdating

Crowe's (1975a) aging index is a strong predictor of juvenile bobcat age (in days); however, canine diameter at the gum line was not a strong predictor for bobcat age, yet it is included in the aging index model. Jackson's (1987) tooth eruption schedule for bobcats is likely the most accurate form of aging juveniles; however, it is time-consuming and may introduce additional observer biases when used alone to backdate individuals. We suggest updating the aging index for juvenile bobcats. Juvenile bobcat mass, back length, and shoulder height were strong predictors of age and should be considered in the new aging index, while kidney fat index and canine diameter at the gum line should be excluded, as they were poor predictors of juvenile bobcat age (in days).

Reproductive Rates

Breeding season for bobcats in West Virginia runs from mid-February until mid- to early June, which puts date of parturition between mid-April and mid-August. However, there were individuals who were born as late as December. This may have been due to failed reproduction earlier in the season that led to additional estrus cycling, delayed maturation of the mothers, or a lack of male contact during the main breeding season. Bobcats are polyestric (Goritz et al. 2009), so it is not uncommon for individuals to reenter estrus once copulation or an entire litter fails. However, it is important to note that juvenile backdating by tooth develop can be biased by

nutritional differences between individuals (Fritts and Sealander 1978) and among other traits in development, so these dates should be considered as a rough estimate of bobcat copulation and parturition periods.

All yearling individuals contained evidence of luteal growth, while all juveniles contained no evidence of reaching reproductive maturity prior to harvest. This verifies that female bobcats reach sexual maturity after their first winter, and that all yearling females will cycle during their first breeding season, regardless of successful copulation. Our findings are similar to others found in the literature (i.e., Crowe 1975a, Fritts and Sealander 1978, Miller et al. 1995).

Mean implantation rates for all reproductively active female bobcats in West Virginia was 1.54 kittens/female with a 58.4% breeding success rate. However, both implantation rates and breeding success rates significantly differed by reproductive stage class. Mature adult females (≥ 5 yr) had a higher breeding success rate and more kittens/female than adult females (2–4 yr), while adult female breeding success and implantation rates were more than double the rates of sub-adult (yearlings) females. Though it may be valid to manage the overall population as 3 stage classes, it may be more beneficial to use 4 reproductive stage classes – immature (juveniles), sub-adults, adults, and mature adults – as the 4-stage class model best supported observed variance in the data.

Survival

Though survival for young bobcats is driven by food availability and weather conditions during winter (Bailey 1974, Knick 1990), our survival rates are estimated using age-at-harvest data that are collected strictly over the winter harvest season (Nov–Feb). Therefore, our estimate

of higher survival rates for juvenile bobcats in West Virginia over older individuals may also be influenced by hunter-trapper selection biases. Survival probabilities declined overall between harvest seasons, which was likely an influence of the decreased trapping effort due to the decline in pelt prices and increase in snowfall.

We evaluated survival probabilities across multiple stage-class models: the common, 3-stage model (juvenile, yearling, adult); a 5-stage class model (juvenile, yearling, 2-year old, 3-year old, 4-years and older); a reproductive stage class model (juvenile, sub-adult, adult, and mature adult); and a model with no assigned stage classes. Similar to the top model representing breeding success and reproductive estimates, the reproductive stage class model best represented our bobcat population compared to the other models analyzed and regardless of harvest season or bobcat sex parameter inclusion. Harvest season was the top parameter for each stage-class model analyzed, as bobcat sex did not differ between harvest seasons, stage classes, or among ecoregions in the data. We could not justify evaluating differences in survival by ecoregion because reproduction rates did not differ between ecoregions and sample sizes would drastically decrease for each category in the model. However, the model can be adjusted to incorporate ecoregions and other factors for future management efforts.

Survival probabilities of our younger stage classes were similar to survival estimates of unexploited populations (i.e., adult survival was 0.89 for bobcats in Illinois; Nielsen and Woolf 2002), while our adult stage classes rivaled estimates of other harvested populations. Adult survival of a harvested bobcat population in Massachusetts was 0.62 (Fuller et al. 1995), while survival rates of bobcats in a heavily harvested area of Idaho was 0.45 for juveniles and yearlings and 0.42 for adults (Knick 1990). In contrast to bobcats in Texas where adult survival was higher ($\hat{S} = 0.85$) than juvenile and yearling ($\hat{S} = 0.68$) survival (Blankenship et al. 2006), we had higher

survival rates for our juvenile and yearling stage classes than our adult stage classes; however, our results are likely biased by trapper harvest selection, such that surveyed trappers reported releasing 63% of trapped young due to size preferences.

Similar to Fox and Fox's (1982) findings for the West Virginia bobcat population, the sex ratio for bobcats in West Virginia was nearly 1:1. However, the age structure of the population now differs from the results found in the late 1970s. Previous research was conducted over the 1978–1979 bobcat harvest season (Nov–Feb) when there was no limit on bobcat harvest. Fox and Fox (1982) found that juveniles (46.7%) and yearlings (23.3%) represented the majority of the population, and adults constituted 30%. The sex ratio and age structure results of the late 1970s was characteristically indicative of heavy harvest pressure on bobcats in West Virginia. Similarly, bobcat reproduction rates from the late 1970s indicated average implantation rates of 1.75 kittens per yearling female with a 79% breeding success rate, 3.4 kittens per 2-year old female and 2.79 kittens per adult female ≥ 3 years, with a shared 96% breeding success rate. With the lack of a harvest limit over the 1977–1978 harvest season, the population was likely being harvested above maximum sustainable yield as indicated by a majority of young in the population, which may have triggered a density-dependent reproductive response as compared to our observed current rates (Griffin 2001). Hunter-trapper effort still acts as a density-independent effect on harvest, but reproduction and survival responses do not indicate the same level of harvest pressure as in the late 1970s. We recommend that managers maintain the current harvest limit until population abundance data is available, to continue monitoring the population for changes in reproductive rates or harvest age distributions, and to monitor patterns of harvest with changing pelt prices and snowfall data to better understand influences of harvest effort for trappers in West Virginia.

MANAGEMENT IMPLICATIONS

We used age estimates and harvest mortality rates to determine survival rates for bobcats, which are under regulated harvest pressure in West Virginia. By combining survival and age estimates with net reproductive rates, biologists can estimate the rate of change in a population (Molles 2005:260–262). Results of our research have provided the data necessary to estimate rate of population growth for bobcats in West Virginia. Therefore, using Crowe's (1975*b*) change in population model for bobcats in Wyoming with our juvenile and combined adult survival rates and fecundity estimates, the population size seemed to have increased by 44% after the 2014–2015 harvest season and remained stable after the 2015–2016 harvest season. The demographic statistics and population change estimates from this study, along with accurate abundance estimates, will provide WVDNR biologists with the necessary data to manage the bobcat population according to their management goals and to maintain sustainable harvest of bobcats in West Virginia.

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TABLES

Table 1. West Virginia ecoregion characteristics (Uhlig and Wilson 1952).

Ecological Factors	Ecoregions					
	1	2	3	4	5	6
Physiogeographic Divisions	Allegheny Ridges and Valleys	Allegheny Plateau	Cumberland Mountains	Monongahela - Upper Ohio	Northern Ohio - West Virginia Hills	Southern Ohio - West Virginia Hills
Average Annual Temperature (°C)	11–12	9–11	11–13	9–12	11–13	11–13
Average Annual Precipitation (cm)	76–102	102–152	102–152	102–127	102–127	102–127
Predominant Forest Types	red oak; hard pine-oak	northern hardwoods; red oak	cove hardwoods; red oak	cove hardwoods; red oak	red oak	cove hardwoods; red oak

Table 2. Survival probability models for OpenBUGS analyses. All models were programmed with bobcat harvest counts for 6 age classes: 0, 1, 2, 3, 4, 5, and 6+, where the final age class data was right-pooled. Capture probabilities were bootstrapped with 0 age class values ranging from 0.58–0.68 and all other age classes assumed stable at 1. Population change estimates were bootstrapped with values ranging from 0.93–1.09.

Model	Parameters						
	1	2	3	4	5	6	7
C00							
C01	Sex						
C10	Year						
C11	Sex	Year					
A00	age [0]	age [1]	age [2]	age [3–6+]			
A01	age [0]	age [1]	age [2]	age [3–6+]	Sex		
A10	age [0]	age [1]	age [2]	age [3–6+]	Year		
A11	age [0]	age [1]	age [2]	age [3–6+]	Sex	year	
D00	age [0]	age [1]	ages [2–4]	age [5–6+]			
D01	age [0]	age [1]	ages [2–4]	age [5–6+]	Sex		
D10	age [0]	age [1]	ages [2–4]	age [5–6+]	Year		
D11	age [0]	age [1]	ages [2–4]	age [5–6+]	Sex	year	
B00	age [0]	age [1]	age [2]	age [3]	age [4–6+]		
B01	age [0]	age [1]	age [2]	age [3]	age [4–6+]	sex	
B10	age [0]	age [1]	age [2]	age [3]	age [4–6+]	year	
B11	age [0]	age [1]	age [2]	age [3]	age [4–6+]	sex	year

Table 3. Counts of bobcat carcasses collected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons in West Virginia by stage class, age class, and sex.

Stage Class	Age	Bobcat Carcass Counts				Total
		Season 1		Season 2		
		Male	Female	Male	Female	
Juvenile	0	32	28	24	23	107
Yearling	1	27	30	42	45	144
	2	28	36	22	20	106
	3	24	17	11	8	60
	4	21	14	5	5	45
	5	8	10	1	5	24
	6	7	2	4	2	15
Adult	7	1	2	2	0	5
	8	3	2	0	2	7
	9	0	4	0	2	6
	10	1	1	0	0	2
	11	0	0	1	0	1
	12	0	2	0	0	2
Total		152	148	112	112	524
Sex Ratio		1.03:1		1:1		1.02:1

Table 4. Counts of bobcat carcasses collected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons in West Virginia by stage class and harvest month.

Stage Class	Bobcat Carcass Counts										Total
	Season 1					Season 2					
	November	December	January	February	NA ¹	November	December	January	February	NA ¹	
Juvenile	9	16	23	12	0	3	18	13	13	0	107
Yearling	18	19	18	2	0	18	19	19	29	2	144
Adult	34	48	70	27	4	9	18	40	22	1	273
Total	61	83	111	41	4	30	55	72	64	3	524

¹NA represents missing data or carcasses collected outside of bobcat harvest season

Table 5. Minimum, maximum, and mean morphometric measurements and body condition estimates for bobcats ($n = 524$) collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia by stage class. Values followed by the same letter did not occur at significantly different ($P \geq 0.05$) rates between stage classes for each variable.

Morphometric Variable	Stage Class											
	Juvenile ($n = 107$)				Yearling ($n = 144$)				Adult ($n = 273$)			
	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE
Mass (kg)	2.02	6.41	4.16a	0.10	3.18	11.5	6.78b	0.14	2.7	13.7	7.38c	0.12
Shoulder Height (cm)	16.2	42.3	35.9a	0.42	28.0	49.4	41.7b	0.35	16.4	52.0	42.2b	0.34
Back Length (cm)	13.0	57.6	48.8a	0.53	48.0	73.0	59.0b	0.42	27.6	72.3	59.6b	0.33
KFI _i ¹	8.66	66.6	32.7a	1.07	10.4	52.2	29.1b	0.79	7.08	62.8	31.4ab	0.64

¹ *Inverse Kidney Fat Index: (mean kidney fat mass / (mean kidney mass + mean kidney fat mass)) x 100*

Table 6. Minimum, maximum, and mean morphometric measurements and body condition estimates for bobcats ($n = 524$) collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia by sex. Values followed by the same letter did not occur at significantly different ($P \geq 0.05$) rates between bobcat sexes for each variable.

Morphometric Variable	Sex							
	Male ($n = 264$)				Female ($n = 260$)			
	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE
Mass (kg)	2.39	13.7	7.75a	0.14	2.02	8.42	5.35b	0.07
Shoulder Height (cm)	16.2	52.0	42.2a	0.42	16.4	46.4	39.2b	0.26
Back Length (cm)	13.0	73.0	60.1a	0.47	38.7	72.0	54.4b	0.28
KFI _i ¹	8.41	66.6	32.3a	0.58	7.08	62.8	29.8b	0.69

¹ *Inverse Kidney Fat Index: (mean kidney fat mass / (mean kidney mass + mean kidney fat mass))*

x 100

Table 7. Implantation rates and breeding success of all reproductively active female bobcats ($n = 209$) collected over the 2014–2015 and 2015–2016 harvest seasons in West Virginia by reproductive stage class and age. Values followed by the same letter did not occur at significantly different ($P \geq 0.05$) rates between female bobcat reproductive stage classes.

Reproductive Stage Class	Age Classes	N	Placental Scars ($\bar{x}$)	Breeding Success (%)
Immature	0	51	NA	NA
Subadult	1	75	0.51a	18.67a
Mature	2–4	100	1.86b	75.00b
Senescent	≥ 5	34	2.85c	97.06c

Table 8. Top 10 survival probability models estimated using bobcat harvest data collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia as ranked by deviance information criterion (DIC) values obtained through OpenBUGS.

Model	Ranking	
	DIC	Δ DIC
D10	-95.17	0
B10	-95.07	0.10
A10	-95.05	0.12
B11	-93.12	2.05
A11	-92.98	2.19
D11	-92.95	2.22
C10	-89.64	5.53
C11	-87.74	7.43
A00	-83.45	11.72
D00	-83.13	12.04

Table 9. Survival rates of bobcats collected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons (Nov–Feb) in West Virginia by reproductive stage class.

Season	Stage	Age	Survival Probabilities		
			$\bar{x}$	SD	95% Confidence Interval
1	Juvenile	0	0.86	0.065	0.71–0.96
	Sub-adult	1	0.81	0.079	0.66–0.97
	Mature Adult	2–4	0.68	0.052	0.58–0.78
	Senescent	≥ 5	0.65	0.060	0.53–0.76
2	Juvenile	0	0.78	0.084	0.62–0.93
	Sub-adult	1	0.72	0.106	0.54–0.95
	Mature Adult	2–4	0.56	0.051	0.46–0.66
	Senescent	≥ 5	0.52	0.081	0.36–0.67

FIGURES

Figure 1. Counts of bobcat carcasses collected over the 2014–2015 ($n = 299$) and 2015–2016 ($n = 224$) harvest seasons, respectively, for each ecoregion of West Virginia (Uhlir and Wilson 1952). Harvest location unknown for 1 carcass collected over the 2014–2015 harvest season.

Figure 2. Statewide total snowfall, annual pelt prices, and statewide bobcat harvest totals over an 11-year interval of harvest seasons (Nov–Feb) from 2005–2016 in West Virginia.

Figure 3. Crowe's (1975a) age index as a predictor of juvenile bobcat age in days estimated by tooth eruption pattern (Jackson 1988) of bobcats collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia.

Figure 4. Male and female juvenile bobcat mass as predictors of canine tooth sizes for bobcats collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia.

		2014–2015				2015–2016			
		Juvenile	Sub-adult	Mature Adult	Senescent	Juvenile	Sub-adult	Mature Adult	Senescent
2014–2015	Juvenile	----	0.043 (-0.170–0.233)	0.176 (0.036–0.312)	0.207 (0.040–0.367)				
	Sub-adult		----	0.134 (-0.50–0.323)	0.164 (0.004–0.330)				
	Mature Adult			----	0.031 (-0.137–0.196)				
	Senescent				----				
2015–2016	Juvenile	0.073 (0.022–0.138)	----	----	----	----	0.059 (-0.236–0.315)	0.227 (0.043–0.403)	0.261 (0.049–0.474)
	Sub-adult		0.089 (0.015–0.173)	----	----		----	0.168 (-0.060–0.424)	0.202 (0.005–0.432)
	Mature Adult			0.123 (0.055–0.203)	----			----	0.034 (-0.151–0.217)
	Senescent				0.127 (0.052–0.216)				----

Figure 5. Posterior mean differences between stage class survival probabilities, followed by credible confidence intervals (2.5–97.5%) of the difference in means. Confidence intervals that do not overlap zero represent statistically significant differences in survival probabilities.

CHAPTER 3

RESEARCH ARTICLE

Prey selection by bobcats harvested in West Virginia, USA

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This chapter written in the style of Wildlife Biology.

ABSTRACT

Proportion and diversity of prey species selected by bobcats (*Lynx rufus*) is often correlated with prey abundances and habitat quality, which can allude to dietary availability for bobcats. Bobcats in West Virginia, USA were last studied in the late 1970s. With many important mast producing species declining in the under- and over-stories of West Virginia's forests over the last 40 years, current data are needed to understand effects of compositional changes on dietary selection by bobcats. We analyzed 300 bobcat carcasses collected over the 2014–2015 ($n = 150$) and 2015–2016 ($n = 150$) hunting and trapping seasons (Nov–Feb) in West Virginia to determine dietary habits. We evaluated stomach contents of 145 male and 155 female bobcats with an age class structure of 63 juveniles (<1 yr), 87 yearlings (1–2 yr), and 150 adults (≥ 2 yr). White-tailed deer (*Odocoileus virginianus*, 32%), small rodents (30.7%), lagomorphs (21.3%), Virginia opossum (*Didelphis virginiana*, 18.7%), and medium-sized rodents (17.3%) occurred most frequently. Ungulates, Virginia opossum, and raccoon (*Procyon lotor*) occurred more frequently in males than females, whereas lagomorphs occurred more frequently in females. There was nearly complete overlap (92%) between the overall diet of males and females, and 35% overlap between age classes using Pianka's index. White-tailed deer occurred more frequently in adults than juveniles and yearlings, whereas raccoon occurred more frequently in yearlings than adults and juveniles. Small and medium-sized rodents occurred more frequently in the diets of juveniles than yearlings and adults, respectively. Diversity of prey items indicated 87% probability that two randomly selected prey items belong to different species using Simpson's index. Due to the generality of bobcat prey selection, management of forested lands across West Virginia should focus on providing diverse and abundant mast producing species to support ample prey populations for bobcats over winter months.

Key Words: *Lynx rufus*, diet, occurrence, prey, deer, mice, squirrel, rabbit, mast, ecoregions, generalist, opportunistic

INTRODUCTION

Bobcats (*Lynx rufus*) are opportunistic hunters that take advantage of readily available prey (Baker et al. 2001). Common prey items throughout their range in North America include ungulates, lagomorphs, rodents, squirrels, and birds, with the selection of each prey species varying by locality, gender, size, and age of the bobcat (Litvaitis et al. 1986, Labisky and Boulay 1998, Brockmeyer and Clark 2007, Newbury 2013). In the mid-Atlantic region of the United States, bobcats eat white-tailed deer (*Odocoileus virginianus*), lagomorphs, and small rodents most frequently, with females selecting for smaller prey items more often than males (West Virginia, USA - Fox and Fox 1982; Pennsylvania, USA - McLean et al. 2005; Ohio, USA - Rose and Prange 2015).

The proportion and diversity of prey species eaten by bobcats are often correlated with prey abundances and habitat quality (Baker et al. 2001). Many common prey species are dependent on hard and soft mast (Wentworth et al. 1990, Feldhamer 2002, Steffen et al. 2002), with winter survival of these species dependent upon the previous year's mast production (Litvaitis et al. 1986, McShea and Healy 2002, Ryan et al. 2004). Mast drives reproductive success for many seed-predator species, such that a large boom in mast production will produce a boom in seed-predator species reproduction (McShea and Healy 2002), providing additional prey for bobcats.

Sex and age may also influence selection of certain prey items by bobcats, as larger adult males typically hunt and eat larger prey items, such as white-tailed deer (Fritts and Sealander 1978, Litvaitis et al. 1984, Matlack and Evans 1992, Anderson and Lovallo 2003). Snowfall, as an extrinsic variable, may also affect bobcat prey selection. Bobcats are not equipped with wide, heavily furred paws to support hunting on heavy snowfall like their nearby counterparts –

Canada lynx (*Lynx canadensis*; Fritts and Sealander 1978, Mautz and Pekins 1989, Peers et al. 2013).

Juvenile bobcat survival, a key contributor to bobcat population growth, is largely dependent on prey availability over winter months (Bailey 1974, Blankenship and Swank 1979, McCord and Cardoza 1982) and may thus be considered a limiting factor for bobcats (Williams et al. 2002:5–6). Juvenile bobcats eat medium-sized or smaller prey twice as often as adult bobcats, likely because younger bobcats have not developed the skills necessary to capture larger prey items (Fritts and Sealander 1978, Litvaitis et al. 1986, McLean et al. 2005). However, diets of juvenile and adult bobcats, regardless of sex, may not differ over winter (Godbois et al. 2003, McLean et al. 2005, Rose and Prange 2015) as individuals will ingest carrion when available (DeVault and Rhodes 2002, Brockmeyer and Clark 2007, Hansen 2007, Platt et al. 2010). Identifying food habits and understanding factors that may influence prey availability can aid in understanding bobcat habitat quality and population management needs.

Suitable habitat for bobcats is capable of supporting healthy prey populations (Anderson 1987, Cochrane et al. 2006). Common and preferred prey species often prefer earlier successional habitats with regular disturbance, such as provided by clearcutting and burning, for food and cover rather than old growth forests lacking groundcover and understory structure (Boyle and Fendley 1987, Brockmeyer and Clark 2007). Forested habitats throughout West Virginia have matured since the last bobcat food habits study nearly 40 years ago, where winter diets of bobcats were dominated by white-tailed deer (49.4% occurrence), small rodents (38.4%), and lagomorphs (23.3%; Fox and Fox 1982). Forest maturation has led to increases in average diameter at breast height of trees, while the total number of trees has decreased due to overcrowding (Widmann et al. 2007). Shade-intolerant mast producing species, such as oak

(*Quercus* spp.), American beech (*Fagus grandifolia*), and hickory (*Carya* spp.; Schuler et al. 2017), are declining within overstories and understories of forests in West Virginia due to high-grade timbering (Grushecky et al. 2006, Rentch et al. 2010), intense deer browsing (Rooney and Waller 2003, Miller et al. 2009, Nuttle et al. 2013), insect and disease damage (Houston 1994, Kelly et al. 2007, Thompson et al. 2017), competition with shade-tolerant species (Gundy et al. 2014), and lack of fire regiments (Brose 2014, Gundy et al. 2015, Edgar and Griscom 2017, Saladyga 2017). Such forest compositional changes could lead to a shift in the dietary habits of bobcats. Understanding changes in observed dietary habits compared to the previous study (Fox and Fox 1982) may help managers determine which habitat management (i.e., overstory release or gap creation treatments) and silvicultural applications (i.e., forest thinnings or selection harvest; Rentch et al. 2010, Brose 2014) should be implemented to foster restoration of these important mast-producing species that support prey populations across the state.

Using stomach contents of bobcats harvested over the 2014–2015 and 2015–2016 winter harvest seasons (Nov–Feb) in West Virginia, our research objectives were to: 1) identify important winter prey items for bobcats by calculating relative occurrence of each core prey group in the diet of bobcats; 2) compare relative occurrence of prey items between bobcats of differing ages, sexes, and morphometries; 3) compare prey item occurrence between harvest seasons and among ecoregions; and 4) determine effects of hard mast and snowfall on bobcat dietary selection.

STUDY AREA

West Virginia, USA (62755 km²) consists of 55 counties that are divided into 6 ecoregions (Uhlig and Wilson 1952): Appalachian Ridges and Valleys (ecoregion 1), Allegheny

Plateau (ecoregion 2), Cumberland Mountains (ecoregion 3), Monongahela and Upper Ohio (ecoregion 4), Northern Ohio and West Virginia Hills (ecoregion 5), and Southern Ohio and West Virginia Hills (ecoregion 6; Table 1). Elevations range from 73 m above sea level at Harper's Ferry near the Potomac River in Jefferson County (ecoregion 1) to 1,482 m above sea level at Spruce Knob in the Allegheny Mountains of Pendleton County (ecoregion 1; Mullenex 2010). West Virginia has four distinct seasons, with mean annual snowfall ranging from 51 cm to 368 cm (NCDC 2017). Annual precipitation ranges from 137 m in the central Allegheny Plateau, where annual temperatures average 9.4° C, to 93 cm in the Appalachian Ridges and Valleys, where annual temperatures average 11.7° C (NCDC 2017).

The state is 78% forested, with 77% of that dominated by oak-hickory forests (Widmann et al. 2007). The major hard mast producers in West Virginia include beech (*Fagus* spp.), black oak (*Quercus velutina*), red oak (*Q. rubra*), chestnut oak (*Q. montana*), hickory, scarlet oak (*Q. coccinea*), scrub oak (*Q. ilicifolia*), walnut (*Juglans* spp.), and white oak (*Q. alba*; Richmond et al. 2013, 2014).

METHODS

Carcass Collection, Morphometric and Demographic Data

We solicited and obtained 524 bobcat carcasses from hunters and trappers during the 2014–2015 ($n = 300$) and 2015–2016 ($n = 224$) harvest seasons (Nov–Feb), then randomly selected 150 individuals from each season as subsamples to determine winter dietary habits. We necropsied carcasses to obtain sex, age, stomach content, and morphometric data, which included body mass (without pelt, $n = 300$), back length (base of skull to base of tail, $n = 300$), and mean kidney and kidney fat masses ($n = 300$) for each carcass. We extracted lower canines which were

sent to Matson's Laboratory (Manhattan, Montana, USA) for age analysis. We sorted results into three stage classes: juveniles (<1 yr), yearlings (1–2 yr), and adults (≥ 2 yr).

Stomach Contents

We collected stomachs, flushed contents through a 0.5 mm mesh sieve, and placed wet contents in an oven at 65–70° C for 12–24 hours to dry following methods of Korschgen (1980) and Litvaitis et al. (1984). We then weighed and recorded stomach contents following the point-frame method of Chamrad and Box (1964). We recorded contents as meat, bone, feather, hair, vegetation, or trap debris using 25 sampling points per frame. Trap debris consisted of wire, mesh, cotton fibers, netting, rocks, foam, rope, rubber, plastic, cloth, tape, and paper that were likely ingested by the individual while in containment (Fritts and Sealander 1978). We collected hair samples for species-specific identification.

We used meat, bone, and feather samples to assist with macroscopic identification of prey items, and we created hair slides and cuticle impressions to identify hair samples microscopically, following the methods of Litvaitis et al. (1984) and Quadros (2006). Hair samples were identified using guard hair medulla and scale pattern reference keys (Moore et al. 1974, Teerink 1991, Lanszki et al. 2015), an online hair database (Huffman et al. 2017), and medulla reference slides. We identified hair samples to the lowest possible taxonomic level, then separated them into their taxonomic family for ease of identification. We could only identify meat samples that contained hair or bone on the sample. We identified feathers to taxonomic class. We then categorized taxonomic groupings into 10 core “prey groups” for statistical analyses: birds, ungulates, lagomorphs, small rodents (i.e., mice and rats), medium-sized rodents (i.e., squirrels, chipmunks, and groundhogs), moles and shrews, Virginia opossum (*Didelphis*

virginiana), skunks, raccoon (*Procyon lotor*), and “others” (see Appendix XI). “Others” consists of prey types that occurred in <5% of stomachs (i.e., porcupine (*Erethizon dorsatum*), North American beaver (*Castor canadensis*), canids, felids, and mustelids).

Environmental Data

We obtained mast data collected by West Virginia Division of Natural Resources (WVDNR) biologists from 2013 and 2014 (Richmond et al. 2013, 2014). The mast index, which ranges from 0–100, provides a measure of relative abundance of 18 different soft and hard mast-producing species throughout West Virginia. It is calculated using subjective measurements of mast abundance (i.e., abundant, common, or scarce) for each species per ecoregion (Richmond et al. 2013, 2014). We averaged index values of hard mast species by ecoregion and sample year for evaluation (Table 2). We obtained monthly mean snowfall data by ecoregion from the National Oceanic and Atmospheric Administration (2017) National Centers for Environmental Information to analyze environmental influences on prey item occurrence in bobcat stomachs (Appendix XII).

Bait Use Survey

West Virginia DNR biologists submitted an anonymous survey to 133 trappers who donated bobcats to the project over the 2015–2016 harvest season to determine trapper bait use. We used results from this survey to determine potential biases in stomach content of bobcats that may have ingested trap bait and vegetation or other materials at the trap site.

DATA ANALYSES

Overview

Our data met normality assumptions for analysis of variance (ANOVA), logistic regression, tests of independent proportions, and chi-square analyses for use in RStudio™ (RStudio, Inc., Boston, MA, USA). We used a statistical significance of $\alpha = 0.05$ for all analyses, and we evaluated all significant ANOVA results with Tukey's HSD post-hoc analyses to confirm where differences occurred between groups.

Demographic and Morphometric Data

We determined frequencies of bobcats collected across West Virginia by sex, stage class, and harvest ecoregion, season, and month. We calculated morphometric measurement ranges and created an inverse kidney fat index (KFI_i) for body condition using mean kidney fat mass (Finger et al. 1981), using equation:

$$\left(\frac{\text{Mean Kidney Fat Mass (g)}}{\text{Mean Kidney Mass (g)} + \text{Mean Kidney Fat Mass (g)}} \right) \times 100 = \text{KFI}_i.$$

We evaluated bobcat body condition and overall body size using mass and back length variables by stage class and sex using one-way ANOVAs in RStudio, which assumes that the data are independent, normally distributed, and have equal (homogeneity of) variances (Dalgaard 2008).

Stomach Contents

We calculated relative frequency of occurrence of prey items as the number of individual bobcats that ingested a certain prey item divided by the total number of bobcats sampled (Korschgen 1980, Corbett 1989, Van Dijk et al. 2007) to determine bobcat dietary selection

(Rose and Prange 2015). We evaluated stomach contents as presence or absence of specific prey group items, rather than measuring volume of differing prey items per stomach due to differences in digestibility between individuals, by item types, and by the amount of prey ingested at the time of harvest (Baker et al. 1993, Brockmeyer and Clark 2007, Cherry et al. 2016), though volume was recorded during the identification process. We evaluated the presence of vegetation, debris, and each taxonomic prey group using logistic regression in RStudio, which assumes independence and normal distribution of the data, to evaluate occurrence rates of prey items eaten by bobcats as a function of sex, stage class, harvest month, harvest season, ecoregion, body condition (i.e., KFI), back length (cm), and body mass (kg). We refer to prey items that significantly varied in occurrence by bobcat back length and mass as significantly varying by larger or smaller body size from this point. We then used the predict function, which determines a probability distribution using the linear predictor from each observation in the data under normal logistic regression assumptions (Dalgaard 2008), to determine confidence intervals for the estimates of prey items that occurred at significantly different rates according to the Wald test statistic (z-score; Appendix XIII).

Overlap and Diversity Indices

We used tests of independent proportions (prop.test; χ^2) in RStudio to determine whether there were significant differences in overall stomach content by sex, stage class, and ecoregion of harvest. Pianka's index, which evaluates overlap in niche partitioning between categories (i.e., species, sex; Pianka 1973), was used to determine the amount of dietary overlap between males and females and among the 3 stage classes (Hill 1973, McNeil Jr. et al. 2017).

We calculated Simpson's index of diversity, Shannon's index of diversity, and evenness to evaluate the diversity of ingested prey items. Simpson's index of diversity ($1 - D$) determines the probability that two randomly selected prey items eaten by bobcats belong to different taxonomic prey species (Simpson 1949). Shannon's index (H) measures the number of individual prey items observed for each taxonomic prey species eaten by bobcats and assumes all prey species are represented and randomly sampled from all possible prey items available (Shannon 1948). Evenness (E) measures how similar the occurrences of prey items are for each taxonomic prey group, such that similar proportions of all prey groups result in an evenness value of one (Hill 1973). Both Simpson's and Shannon's indices are influenced by species' evenness and richness, such that the index value will decrease as percent evenness increases for a given species richness (Whittaker 1965, Hill 1973).

Mast and Environmental Variables

We evaluated short-term patterns between two years of hard mast indices (2013, 2014) and mean monthly snowfall (Nov–Feb, 2014–2015; Nov–Feb, 2015–2016) among ecoregions using one-way ANOVA in RStudio. We then compared prey frequencies of occurrence to mast indices recorded from the year prior to harvest using logistic regression to determine relations between the rate of prey species occurrence and the amount of hard mast produced per ecoregion. Similarly, we evaluated prey frequencies of occurrence by mean monthly snowfall for each bobcat harvest season using logistic regression.

RESULTS

Demographics and Morphometries

We analyzed 300 bobcat stomachs from the 2014–2015 ($n = 150$) and 2015–2016 ($n = 150$) hunting and trapping seasons that were collected from 43 of the 55 counties in West Virginia (Fig. 1). Most bobcats were trapped ($n = 277$), while 17 were taken by gun, 4 by bow, and 2 unknown. The sex ratio of the samples was 1:1.1 males to females, with juveniles representing 21%, yearlings 29%, and adults 50% (Table 3). Bobcat mass ranged from 2.0 kg to 12.3 kg ($\bar{x} = 6.5$, $SE = 0.12$), back lengths ranged from 27.6 cm to 73.0 cm ($\bar{x} = 56.9$, $SE = 0.38$), and KFI_i ranged from 9.6 to 66.6 ($\bar{x} = 31.3$, $SE = 0.60$; Appendix XIV). Males had a larger mean body size than females ($F_{1,298} \geq 65.17$, $P < 0.001$; Fig. 2a), whereas juveniles were smaller than both yearlings and adults ($F_{2,297} \geq 61.53$, $P < 0.001$; Fig. 2c). Body condition analyses resulted in males having a slightly higher mean KFI_i value than females ($F_{1,298} = 4.21$, $P = 0.041$; Fig. 2b), while juveniles and adults had higher mean KFI_i values than yearlings ($F_{2,297} = 3.92$, $P = 0.021$; Fig. 2d).

Stomach Contents

Most bobcat stomachs contained hair samples (97% occurrence). Trap debris (9%) and vegetation (81%) did not occur at significantly different rates in bobcat stomachs by stage class, sex, body condition, body size, harvest season, or ecoregion ($|z| \leq 1.89$, $P \geq 0.058$). Vegetation occurred 40% more often in the diets of bobcats harvested via trap than gun or bow ($|z| = 4.00$, $P \leq 0.001$), while debris occurred only in trapped individuals ($|z| = 0.02$, $P = 0.986$).

Ungulates, small and medium-sized rodents, lagomorphs, and opossum were the major prey groups by frequency of occurrence in sampled bobcats (Table 4). Birds, moles and shrews,

raccoons, skunks, and others occurred less frequently overall ($\leq 10\%$, Table 4). Majority of ungulate samples found over both harvest seasons was white-tailed deer (32% occurrence), whereas elk (*Cervus canadensis*) only occurred in one individual (0.33%) – a yearling female from ecoregion 5 harvested over the 2014–2015 harvest season. Though majority of bobcats were trapped as opposed to shot, ungulates occurred 6.3% more often in the diets of individuals harvested via gun or bow than by trap ($|z| = 0.60$, $P = 0.551$).

Old world mice and rats (family: Muridae), beaver, canids, and porcupine were only found in stomachs from the 2014–2015 harvest season, where porcupine had the lowest frequency of occurrence in bobcat stomachs that season (0.67%). Moles (Talpidae) and jumping mice (Dipodidae) were the least commonly occurring taxonomic family groups over the 2015–2016 harvest season, each with a 0.67% occurrence in stomachs that season. Medium-sized rodents occurred in the diets of bobcats more often in the 2014–2015 harvest season ($\bar{x} = 12.6\%$, 95% CI = 8.2 – 16.1) than in the 2015–2016 harvest season ($\bar{x} = 22.0\%$, 95% CI = 19.0 – 29.3; $|z| = 2.11$, $P = 0.035$), while occurrence of moles and shrews decreased from the 2014–2015 season ($\bar{x} = 8.0\%$, 95% CI = 4.6 – 13.6) to the 2015–2016 season ($\bar{x} = 2.7\%$, 95% CI = 1.0 – 6.9; $|z| = 1.96$, $P = 0.050$; Appendix XV, Fig. i).

Ungulates ($|z| = 2.73$, $P = 0.006$) and Virginia opossum ($|z| = 2.04$, $P = 0.042$) occurred more often in the diets of male bobcats than female bobcats, whereas lagomorphs ($|z| = 2.34$, $P = 0.019$) occurred more often in the diets of female bobcats than male bobcats (Appendix XV, Fig. ii). Ungulates ($|z| = 2.80$, $P = 0.005$) occurred more often in the diets of adults than juveniles, whereas raccoon ($|z| = 2.12$, $P = 0.034$) occurred more often in the diets of yearlings than adults. Small rodents ($|z| = 2.31$, $P = 0.021$) occurred more often in the diets of juveniles than yearlings,

and both small ($|z| = 3.14$, $P = 0.002$) and medium-sized ($|z| = 3.51$, $P < 0.001$) rodents occurred more often in the diets of juveniles than adults (Appendix XV, Fig. iii).

Larger bobcats, based on back length and body mass, had a higher frequency of occurrence of ungulates ($|z| \geq 2.37$, $P \leq 0.018$) and Virginia opossum ($|z| \geq 2.12$, $P \leq 0.034$) in their diets, whereas smaller bobcats had a higher occurrence of small rodents ($|z| \geq 2.80$, $P \leq 0.005$) and medium-sized rodents ($|z| \geq 2.37$, $P \leq 0.018$). Similarly, bobcats with better body conditions (i.e., higher KFI_i values) had a higher frequency of occurrence of Virginia opossum ($|z| = 3.42$, $P < 0.001$) in their diets, whereas those with less optimum body conditions (i.e., lower KFI_i values) had a higher occurrence of lagomorphs ($|z| = 2.34$, $P = 0.019$; Appendix XV, Fig. iv – viii). Birds, skunks, and others were not eaten at significantly different rates between bobcat stage classes, sexes, harvest seasons, ecoregions, body condition, or body sizes ($|z| \leq 1.50$, $P \geq 0.134$).

Overlap and Diversity Indices

Tests of independent proportions resulted in no significant differences for overall prey frequencies of occurrence in stomachs between bobcat sexes ($\chi^2_1 = 0.89$, $P = 0.345$), stage classes ($\chi^2_2 = 1.51$, $P = 0.470$), or ecoregions ($\chi^2_5 = 4.16$, $P = 0.527$). Pianka's index resulted in a 92.3% dietary overlap between bobcat sexes and a 34.7% overlap between bobcat stage classes. Simpson's index of diversity resulted in 87.0% probability that two randomly selected prey items belong to different species. Shannon's index of diversity (H) resulted in 2.26 (out of a possible 2.28), which indicates a high level of dietary diversity, and evenness (E) was calculated as 80.0% similarity between all core prey groups.

Environmental Variables

Hard mast indices for West Virginia increased from 2013 to 2014 when analyzing across all ecoregions ($F_{1,298} = 120.10$, $P < 0.001$), where mean index values for hard mast ranged from 26.92 in ecoregion 1 in 2013 to 55.33 in ecoregion 6 in 2014 (Table 2). Bobcats had a higher frequency of occurrence of medium-sized rodents in their stomachs over the 2015–2016 harvest season when accounting for increased hard mast indices from 2014 (+56.9% predicted slope; $|z| = 2.26$, $P = 0.024$).

Snowfall ranged from 0 cm in December in ecoregions 4, 5, and 6 to 58.5 cm in ecoregion 2 in February of the 2014–2015 harvest season, and ranged from 0 m in November in all ecoregions except 2 and 3 to 49.9 cm in ecoregion 2 in January of the 2015–2016 harvest season (Appendix XII). Total snowfall varied between harvest seasons ($F_{1,295} = 11.23$, $P \leq 0.001$) and among harvest months ($F_{3,293} = 65.80$, $P \leq 0.001$). Bobcats had a higher frequency of occurrence of felids (+1.8% predicted slope; $|z| = 2.73$, $P = 0.006$) in their stomachs with increased snowfall (Fig. 3).

Bait Use Survey

We received 68 anonymous responses (51% response rate) from trappers that donated bobcat carcasses to the project over the 2015–2016 harvest season. Fifty-five of the trappers used bait (81%), with 16.5% of that as deer parts. Rabbit, beaver, feathers, rodents, and other bait items were also used (Table 5).

DISCUSSION

Demographics and Diet Content

Based on identified stomach contents, male bobcats selected for ungulates more often than did females, whereas female bobcats selected for lagomorphs more often than did males. These results are likely due to sexual dimorphism in bobcats, such that males have a larger mean body size than females. Previous research indicates sexual dimorphism explains dietary differences between sexes, as evidenced by males hunting and taking larger prey items than females due to size and energy requirements for taking larger prey (Fox and Fox 1982, Sikes and Kennedy 1993, McLean et al. 2005, Rose and Prange 2015).

Young bobcats ate medium-sized or smaller rodents (i.e., mice, rats, chipmunks, squirrels) over 50% more often than did adult bobcats. Adult bobcats may vary in their selection of larger prey items from younger individuals due to better developed skills as hunters (Fritts and Sealander 1978, Litvaitis et al. 1986, McLean et al. 2005). Similarly, larger bobcats ate more ungulates and Virginia opossum, whereas smaller bobcats ate more medium-sized or smaller rodents; and bobcats with more optimum body conditions ate more Virginia opossum, whereas those with less optimum body conditions ate more lagomorphs. As with sex, morphometric differences between stage classes may also explain variations in prey selection, as larger individuals are able to successfully hunt and kill larger prey items (Fritts and Sealander 1978, Litvaitis et al. 1984, Matlack and Evans 1992, Anderson and Lovallo 2003, McLean et al. 2005).

Prey size is assumed to be a predictor of digestibility (Floyd et al. 1978). White-tailed deer was 95.7% digestible to bobcats in ground form (Powers et al. 1989); however, the estimate did not include skin, bone, or organs. For bobcats used in a controlled study in Georgia, USA, white-tailed deer did not meet the assumption of increasing digestibility with increasing size,

though all other tested prey items followed that assumption (Baker et al. 1993). Prey items persist in bobcat stomachs at different rates depending on multiple factors, such as hair type, bone size, time between meals, and meal size, that may affect digestibility (Baker et al. 1993). Therefore, prey size may not be a strong predictor of digestibility for all prey items.

Bait Use and Carrion Availability

White-tailed deer occurred in individuals of all stage classes and sexes, likely due to increases in carrion availability over winter and trappers' use of deer parts as bait in trap sets (DeVault and Rhodes 2002, Brockmeyer and Clark 2007, Hansen 2007, Platt et al. 2010). Bobcat harvest season overlaps deer harvest seasons in West Virginia. In 2015, deer hunters harvested a total 138,493 deer (Crum 2016), adding to the amount of carrion readily available to bobcats. Therefore, bobcat selection for white-tailed deer in eastern North America may not necessarily be linked to predatory skills or behavior, as mentioned when discussing differences between sex or stage class, when carrion is readily available.

In addition to increased carrion availability over winter due to hunter harvest, 81% of surveyed trappers reported using bait in their sets, where 16.5% of reported bait contained white-tailed deer parts. Rabbits, beaver, feathers, small and medium-sized rodents, and other items were also used as bait and may have influenced the diversity of prey items found in bobcat stomachs over winter. Interestingly, ungulates occurred 6.3% more often in the diets of individuals harvested via gun or bow than by trap, although majority of bobcats were trapped as opposed to shot. Since we were unable to quantify the proportion of each prey item's occurrence in the diets of bobcats that was due to bait use or carrion ingestion, we assumed and examined all

prey occurrences as the result of typical dietary food habits of bobcats in West Virginia over winter.

Felid hair occurred in 10 individuals from the total 300 bobcats sampled with no discernible differences between bobcat stage classes, sexes, or morphology. Though majority of identified felid hair was noted as bobcat, not all felid hair samples were identified to genus or species level. Therefore, occurrence of felid hairs in a bobcat's stomach could be due to: grooming behavior, bait use, infanticide or cannibalism, ingestion of domestic or feral cats, or self-mutilation while trapped (Eckstein and Hart 2000, Naidenko 2001, McNeil Jr. et al. 2017, Proulx and Rodtka 2017). Nine of the 10 stomachs containing felid hair also contained small to medium prey items (i.e., mice, squirrel, Virginia opossum, birds, shrews, and raccoon). Only one of those 9 stomachs also contained white-tailed deer hair; however, deer hair only represented 4% of the total volume of stomach content from that individual, with the remaining content identified as 52% unidentified meat, 16% Virginia opossum hair, 20% felid hair, and 8% vegetation. As most small to medium prey species eaten are not commonly left as carrion, this suggests that the bobcats either caught and killed the prey items themselves or ate road-killed prey. Since felid species are commonly known for self-grooming (Eckstein and Hart 2000), we suggest that felid hair may have been ingested via self-grooming post-kill of prey items. The one individual that did not contain small prey items along with felid hair contained mostly vegetation and 1 whisker, which also suggests the common self-grooming behavior of felids (Eckstein and Hart 2000, Wells and Egli 2004, Molla et al. 2011).

Another potential explanation for feline hair in stomach contents could be self-mutilation, though it is rarely reported by West Virginia trappers. Yet, one of the 10 individuals that ingested felid hair also had metal wire (i.e., trap debris) in its stomach, which suggests self-mutilation as

an attempt to escape the trap (Hubert et al. 1996, Proulx and Rodtka 2017). The same individual had also ingested raccoon, which is one of the bait types used by trappers according to survey results. Though domestic and feral cats are sympatric within bobcats' range (Ordenana et al. 2010, Bevins et al. 2012, Carver et al. 2016), diet contents suggest that most winter ingestion of felid hair is due to self-grooming or possible self-mutilation at trap sites.

Overlap and Diversity Indices

Bobcats are solitary, territorial individuals, aside from the few months that kittens remain with their mothers (Bailey 1974). Yet, female offspring exhibit philopatry (Janecka et al. 2007, Croteau et al. 2010) where their established home ranges overlap or are congruent with their mother's home range (Kapfer 2014). Males have more overlap and larger home ranges than females, especially when kittens are present (Bailey 1974, Knick 1990, Lovallo and Anderson 1996, Diefenbach et al. 2006, Tucker et al. 2008). Sociality in bobcats is affected by relatedness, sex, prey availability, and conspecific densities (Chamberlain and Leopold 2001, Benson et al. 2004, Thornton et al. 2004, Cochrane et al. 2006, Diefenbach et al. 2006). We found that diet diversity was not significantly different overall between sex, stage class, and ecoregion of harvest, despite their differences in home range size and low degree of overlap at certain periods of their lifecycles (Bailey 1974).

Simpson's and Shannon's indices of diversity indicated a high diversity of prey items ingested by bobcats during winter in West Virginia, while evenness supported generality in bobcat dietary selection. Pianka's index of overlap suggested a nearly complete dietary overlap of male and female bobcats, despite sexual dimorphism (Sikes and Kennedy 1993) and low degree of overlap in home ranges (Bailey 1974), and only a third of dietary overlap between

juvenile, yearling, and adult bobcats. The lower overlap of dietary content between stage classes is expected for young versus adult, as young are not large enough or skilled enough to take down larger prey items (Matlack and Evans 1992, Anderson and Lovallo 2003, McLean et al. 2005). Overall, bobcats in West Virginia have considerably high dietary diversity, which supports the theory of bobcats as generalist carnivores.

Environmental Variables

Snowfall over the two harvest seasons did not seem to affect prey selection for many of the prey species observed, aside from the increased occurrence of felid hair (mostly identified as bobcat hair) in bobcat stomachs with increasing snowfall, which may be due to increased grooming. However, we did find a correlation between increased hard mast production the year prior to increased medium-sized rodent (i.e., squirrel and chipmunk) selection by bobcats. Since winter survival and the following year's reproductive success for medium-sized rodents is dependent upon the production of hard mast over the previous growing season (Wentworth et al. 1990, Feldhamer 2002, Steffen et al. 2002), further research and longer-term trend analyses may enable the prediction of feeding behavior and retention rates for bobcats (Litvaitis et al. 1986, McShea and Healy 2002, Ryan et al. 2004), as prey availability over winter months drives juvenile survival for bobcats (Bailey 1974, Blankenship and Swank 1979, McCord and Cardoza 1982). Diet is a limiting factor for bobcats in many areas of their range (Williams et al. 2002:6); therefore, their prey populations should be managed accordingly.

Bobcat habitat suitability is dependent on the ability of the habitat to support diverse prey populations (Anderson 1987, Cochrane et al. 2006), with many of their common prey species preferring early successional habitats dependent on regular disturbance (Boyle and Fendley

1987, Brockmeyer and Clark 2007). With increasing maturity of West Virginia's forests over the last 40 years since Fox and Fox's (1982) study, there have been shifts in dietary frequencies of occurrence for most core prey groups by differing bobcat demographics (i.e., stage class, sex). White-tailed deer decreased by 17% in dietary occurrence for all sexes and stage classes of bobcats, while opossum and raccoon increased in occurrence by 13.5% and 5% over all sexes and stage classes, respectively. Small rodent occurrence decreased by 9.5% in the diets of all bobcats except juveniles, where the small and medium-sized rodents increased in occurrence by 7% and 11.6%, respectively, and lagomorphs decreased in occurrence by 10% since the late 1970s.

Current frequencies and diversity of prey species found in bobcat stomachs in West Virginia as compared to 40 years ago can only begin to highlight prey densities and habitat quality across the state (Baker et al. 2001). Therefore, further and longer-term research should focus on management of bobcat habitat suitability by evaluating prey densities, habitat quality, and effects of mast production on prey survival and reproduction. Since bobcats are game animals in West Virginia, biologists should focus on population regulation by managing possible limiting factors (i.e., prey availability), while maintaining a consistent harvest yield that attains management goals for the population across the state (Williams et al. 2002:5–6).

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TABLES

Table 1. West Virginia, USA ecoregion characteristics (Uhlig and Wilson, 1952).

Ecological Factors	Ecoregions					
	1	2	3	4	5	6
Physiogeographic Divisions	Allegheny Ridges and Valleys	Allegheny Plateau	Cumberland Mountains	Monongahela - Upper Ohio	Northern Ohio - West Virginia Hills	Southern Ohio - West Virginia Hills
Average Annual Temperature (°C)	11 – 12	9 – 11	11 – 13	9 – 12	11 – 13	11 – 13
Average Annual Precipitation (cm)	76 – 102	102 – 152	102 – 152	102 – 127	102 – 127	102 – 127
Predominant Forest Types	red oak; hard pine-oak	northern hardwoods; red oak	cove hardwoods; red oak	cove hardwoods; red oak	red oak	cove hardwoods; red oak

Table 2. Hard mast species' index values averaged by ecoregion from 2013 and 2014 mast surveys (Richmond et al. 2013, 2014). The surveys include indices of the relative abundance for each of the 9 selected hard mast-producing species throughout West Virginia, USA, which are calculated using subjective measurements of mast abundance (i.e., abundant, common, or scarce) for each species by Ecoregion and converted to an index number ranging 0–100 (Richmond et al. 2013, 2014).

Year	Ecoregions					
	1	2	3	4	5	6
2013	26.92	32.65	32.04	30.91	33.51	29.38
2014	36.24	29.78	34.82	30.95	43.70	55.33

Table 3. Counts of bobcat carcasses sampled for stomach contents by sex, stage class (J = juvenile (<1 yr), Y = yearling (1–2 yr), A = adult (≥ 2 yr)), ecoregion, harvest month (N = November, D = December, J = January, F = February, NA = harvest month unknown), and harvest season (1 = 2014–2015, 2 = 2015–2016) in West Virginia, USA.

Sex	Bobcat Carcass Count																Total
	Season		Ecoregion						Stage Class			Month					
	1	2	1	2	3	4	5	6	J	Y	A	N	D	J	F	NA	
Male	72	73	10	17	46	19	32	21	32	39	74	25	39	46	33	2	145
Female	78	77	17	14	49	23	35	17	31	48	76	26	44	52	32	1	155
Total	150	150	27	31	95	42	67	38	63	87	150	51	83	98	65	3	300

Table 4. Frequency and relative occurrence values for common bobcat prey groups selected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons (Nov–Feb) by bobcats in West Virginia, USA. “Others” consists of prey groups that occurred in <5% of individuals: porcupine (*Erethizon dorsatum*), North American beaver (*Castor canadensis*), canids, felids, and mustelids. Values followed by the same letter did not occur at significantly different rates ($\alpha = 0.05$) between harvest seasons, bobcat sexes, or bobcat stage classes for each prey item.

Common Prey	Frequency (<i>n</i> = 300)	Occurrence (%)							
		Overall (<i>n</i> = 300)	Season		Sex		Stage Class		
			1 (<i>n</i> = 150)	2 (<i>n</i> = 150)	Males (<i>n</i> = 145)	Females (<i>n</i> = 155)	Juveniles (<i>n</i> = 63)	Yearlings (<i>n</i> = 87)	Adults (<i>n</i> = 150)
Ungulates	97	32.33	29.33a	35.33a	40.00a	25.16b	19.05a	29.89ab	39.33b
Small Rodents	89	29.67	26.67a	32.67a	25.52a	33.55a	46.03a	27.59b	24.00b
Lagomorphs	65	21.67	20.67a	22.67a	15.86a	27.10b	15.87a	22.99a	23.33a
Virginia Opossum	56	18.67	15.33a	22.00a	23.45a	14.19b	19.05a	20.69a	17.33a
Medium-sized Rodents	52	17.33	12.67a	22.00b	17.93a	16.77a	30.16a	20.69a	10.00b
Birds	30	10.00	11.33a	8.67a	11.03a	9.03a	9.52a	11.49a	9.33a
Skunks	24	8.00	8.67a	7.33a	7.59a	8.39a	9.52a	9.20a	6.67a
Others	22	7.33	11.33a	3.33a	9.66a	5.16a	7.94a	5.75a	8.00a
Raccoon	19	6.33	4.67a	8.00a	8.97a	3.87b	4.76ab	11.49a	4.00b
Moles and Shrews	16	5.33	8.00a	2.67a	4.14a	6.45b	1.59a	6.90a	6.00a

Table 5. Results of bait types, use, and proportions of all bait types from trappers ($n = 68$) that donated bobcat carcasses to the project over the 2015–2016 harvest season. Fifty-five of the trappers used bait (81%).

Bait Type	<i>N</i>	%
Paste	45	35.43
Urine	12	9.45
Lure	14	11.02
Animal Parts:		
Beaver	4	3.15
Deer	21	16.54
Mouse	2	1.57
Chipmunk	1	0.79
Squirrel	1	0.79
Rabbit	6	4.72
Opossum	2	1.57
Raccoon	1	0.79
Groundhog	1	0.79
Bird	2	1.57
Sardines	1	0.79
Unknown (meat chunks)	14	11.02
TOTAL	127	100

FIGURES

Figure 1. Counts of bobcats sampled for stomach contents over the 2014–2015 and 2015–2016 harvest seasons by county for each ecoregion of West Virginia, USA (Uhlig and Wilson 1952).

Figure 2. Body sizes and conditions of bobcats sampled for stomach contents over the 2014–2015 and 2015–2016 harvest seasons in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means. *First row:* Bobcat sex as a function of (A) body mass and back length, and (B) inverse kidney fat index (KFI) and body mass. *Second row:* Bobcat stage class as a function of (C) body mass and back length, and (D) inverse kidney fat index (KFI) and body mass.

Figure 3. Mean snowfall (cm) as a predictor of felid occurrence in the stomachs of bobcats collected over the 2014–2015 and 2015–2016 harvest seasons in West Virginia, USA. Grey area represents the confidence intervals (± 1 SE) of the means.

Appendices

APPENDIX I

Parvovirus Infection Rates of Bobcats in West Virginia

West Virginia Division of Natural Resource biologists were concerned about whether parvoviruses are present in bobcats throughout West Virginia and how infection could affect bobcat ecology or behavior. Therefore, we collected bobcat carcasses from hunters and trappers across West Virginia over the 2014–2015 ($n = 265$) and 2015–2016 ($n = 189$) harvest seasons for parvovirus testing. We obtained ecoregion data for each carcass submitted to the study. We then necropsied each carcass and collected entire spleens for parvovirus DNA testing. We stored carcasses and collected spleens at -20°C between procedures.

We collected a 10–15 mg subsample from each spleen sample collected ($n = 454$) and placed it into a 1.5 mL microcentrifuge tube. We completed DNA extractions using the ThermoFisher GeneJet Tissue and Cells DNA Extraction Kit (Thermo Fisher Scientific, Waltham, MA, USA). The manufacturer's suggested protocol was utilized throughout the extraction procedures—except for the initial 3-hour incubation, where we added 30 μL of 1 M dithiothreitol to the recommended reagents to assist in the denaturation of splenic proteins. We normalized the DNA extracts to a 10 ng/ μL concentration using a Thermo Fisher NanoDrop Lite spectrophotometer. To quickly screen out negative parvovirus DNA samples, we used the VP1 and VP2 primer pair (Schunck et al. 1995) to amplify parvovirus DNA from each spleen extract. This primer set was purposefully selected since it has less specificity than other available primer sets; thus, it would be able to amplify other viruses than just CPV and FPV. We used polymerase chain reaction (PCR) protocols to multiply viral particles, if present, and we completed the PCR analyses using the following reagents: 5 μL Qiagen Multiplexing Master Mix, 1 μL of the VP1 and VP2 pre-mixed primer set, and 4 μL of DNA template. We modified the thermal cycling

conditions from Schunck et al. (1995) to make them more consistent with modern PCR methods. We resolved the PCR products on a 1% agarose gel at 120 V for 30 minutes. The presence of a band at roughly 200 nucleotides (nt) indicated a positive result for parvovirus DNA in the bobcat spleen extract.

We then amplified all potentially parvovirus-positive spleen samples that we identified from the agarose gels a second time via PCR. The VP1 and VP2 primer set was designed to specifically sequence a variable region of the parvovirus genome that allows for differentiation of the different types of parvoviruses (i.e., FPV, CPV-2a, CPV-2b, CPV-2c; Buonavoglia et al. 2001). The PCRs were completed in 20 μ L reaction sizes with 10 μ L of Qiagen Multiplexing Master Mix, 2 μ L of the primer mix, and 8 μ L of template DNA. We ran 20 μ L of PCR product on another 1% agarose gel at 120 V for 30 minutes to resolve the PCR products, with a positive result indicated by a band at roughly 550 nt. We prepared samples that successfully amplified parvovirus DNA for DNA sequencing using the remaining 10 μ L from the previous PCR and a QIAquick 96-well plate PCR Purification Kit (QIAGEN Sciences, Germantown, MD, USA) for each sample to remove primers and contaminants. We then sent the PCR products for Sanger sequencing at the West Virginia University Genomics Core Facility. Completed sequences were then provided for further analyses.

We sampled 454 bobcats for parvovirus presence, which resulted in an estimated infection rate of 18.9% for the population. Of the 86 individuals identified as positive for parvovirus infection, we identified 22.1% as having been infected with the CPV2a variant ($n = 19$) and 74.4% as infected with CPV2b ($n = 64$) variant, whereas only 1.2% were infected with CPV2c ($n = 1$) and 2.2% with FPV ($n = 2$). We did not identify any individuals as coinfecting with more than one parvovirus variant. Results are summarized in Table i.

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Table i. Parvovirus results for 265 bobcats collected over the 2014–2015 (season 1) harvest season and 189 collected over the 2015–2016 (season 2) harvest season grouped by harvest season, stage class (J = juvenile, <1 yr; Y = yearling, 1–2 yr; A = adult, $\geq$ 2 yr), sex, and ecoregion of harvest. Note: NA represents unknown harvest ecoregion.

	Overall				Parvovirus Positive by Variant								
	Total <i>N</i>	Parvovirus			CPV2a		CPV2b		CPV2c		FPV		
		Positive <i>N</i>	Negative <i>N</i>	Positive %	<i>N</i>	% of Positives	<i>N</i>	% of Positives	<i>N</i>	% of Positives	<i>N</i>	% of Positives	
Season													
1	265	41	224	15.47	11	26.83	29	70.73	1	2.44	0	0.00	
2	189	45	144	23.81	8	17.78	35	77.78	0	0.00	2	4.44	
Stage													
J	102	21	81	20.59	6	28.57	15	71.43	0	0.00	0	0.00	
Y	122	33	89	27.05	8	24.24	23	69.70	0	0.00	2	6.06	
A	228	32	196	14.04	5	15.63	26	81.25	1	3.13	0	0.00	
Sex													
M	228	44	184	19.30	11	25.00	31	70.45	0	0.00	2	4.55	
F	226	42	184	18.58	8	19.05	33	78.57	1	2.38	0	0.00	
Ecoregion													
1	36	5	31	13.89	2	40.00	3	60.00	0	0.00	0	0.00	
2	47	4	43	8.51	0	0.00	4	100.00	0	0.00	0	0.00	
3	147	17	130	11.56	2	11.76	14	82.35	0	0.00	1	5.88	
4	67	15	52	22.39	4	26.67	11	73.33	0	0.00	0	0.00	
5	96	32	64	33.33	10	31.25	21	65.63	1	3.13	0	0.00	
6	59	13	46	22.03	1	7.69	11	84.62	0	0.00	1	7.69	
NA	2	0	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00	
TOTAL	454	86	368	18.94	19	22.09	64	74.42	1	1.16	2	2.33	

APPENDIX II

Bobcat Demographics of North America

Table i. Bobcat demographic statistics of harvested populations by region and state across their range in North America.

Region	State	Authors	Reproductive Rates	Survival Rates	Age Ratios (J:Y:A)	Sex Ratios (M:F)
Northeast	Massachusetts	Fuller et al. 1995	NA	0.62	NA	NA
	Maine	Litvaitis et al. 1987	NA	0.67	NA	NA
East-Central	West Virginia	Fox and Fox 1982	2.3	NA	2:1:1.3	1:1
	Pennsylvania	McLean et al. 2005	NA	NA	1:NA:5.4	1.06:1
Southeast	Arkansas	Fritts and Sealander 1978; Rucker and Tomlinson 1985	2.5	0.62	1.06:1:3.8	1.7:1
	Mississippi	Chamberlain et al. 1999	NA	0.80 ¹	NA	NA
Midwest	Illinois	Nielsen and Woolf 2002	NA	0.84–0.94 ¹	NA	1.08:1
	Iowa	Koehler 2006	2.5–3.0	0.56–0.82 ¹	NA	1.08:1
North-Central	Michigan	Pruess 2005	NA	NA	1:NA:6.5	2 m:f
	Minnesota	Fuller et al. 1985	NA	0.19, 0.61	NA	2:1
Northwest	Wyoming	Crowe 1975A	2.8	0.67	1.3:1:1.4	1:1
	Idaho	Knick 1990	2.3	0.67 ¹ , 0.49	1.3:1.2:1	1.1:1
Southwest	Texas	Blankenship et al. 2006	NA	0.88 ¹	1:NA:2.7	1.2:1
	Oklahoma	Rolley 1985	2.5	0.53–0.66	1:1.2:1.65	0.93:1

¹Survival rates from an unharvested population.

Figure i. Bobcat range in North America (IUCN 2017).

Citation:

IUCN 2017. *The IUCN Red List of Threatened Species. Version 2017-1.*

<<http://www.iucnredlist.org>>. Downloaded on 12 May 2017.

APPENDIX III

Bobcat Carcass Collection Outreach Materials and Necropsy Recording Sheets

DIVISION OF NATURAL RESOURCES
Wildlife Resources Section
324 4th Avenue
South Charleston, West Virginia 25303-1228
Telephone (304) 558-2771
Fax (304) 558-3147

Earl Ray Tomblin
Governor

Robert A. Fala
Director

WVDNR / WVU BOBCAT ECOLOGY PROJECT

October 15, 2015

TO: West Virginia Hunters and Trappers

SUBJECT: Carcass Collection Information

Dear Trappers and Hunters,

Included in this envelope is everything that you need to know about the West Virginia Division of Natural Resources (WVDNR) and the West Virginia University BOBCAT ECOLOGY PROJECT.

Bobcats in West Virginia have not been studied since the late 1970s. To better manage the population, WVDNR started a bobcat carcass collection, in cooperation with West Virginia University, to determine population dynamics and overall health of West Virginia bobcats. We are now entering our second and final year of carcass collection for the project.

We are collecting a target goal of 300 bobcat carcasses from hunters and trappers across West Virginia over the 2015 – 2016 trapping season. Biologists will use all internal organs and teeth from collected carcasses to determine age, reproductive success, parasite and disease prevalence, and diet habits of the West Virginia bobcat population. Results will help WVDNR to improve management decisions for the population using current estimates.

You can receive a **\$20 GIFT CARD** of your choice **PER CARCASS** submitted to the project in proper condition. If you are interested in helping out with this project, please review the bobcat carcass checklist before you go out hunting or trapping this season, as well as review the other information included in this packet for the carcass collection requirements.

For WVDNR to continue managing bobcat hunting and trapping in West Virginia, your participation is vital. We urge you to contact other West Virginia bobcat trappers and hunters to get them involved with the project. For more information, please contact us at WVUBobcat@mail.wvu.edu or call (304)293-0050. Thank you for your part in this cooperative effort.

Sincerely,

Stephanie Landry
Graduate Research Assistant
West Virginia University
WVDNR Bobcat Ecology Project

Figure i. Information packet – page 1.

BOBCAT COLLECTION CHECKLIST

1. AFTER COLLECTING THE BOBCAT FROM THE TRAP/KILL SITE

- ☐ Record GPS coordinates of trapping/kill location if possible. If not, gather information such as nearby roads, addresses, and the county to tell us the closest description that you can.

NOTE: None of this information will be shared outside of project purposes. It is only used for the purpose of better understanding and managing the West Virginia bobcat population.

- ☐ Take photo of trap/kill site if possible. Try to include all surrounding vegetation. If a camera is not available, be prepared to check off a description that best describes the site.
- ☐ **Freeze carcass as soon as possible – within 12 hours!**

2. AFTER SKINNING THE BOBCAT CARCASS

- ☐ Please keep skull attached to carcass. If you have to remove the skull from the carcass for a specific reason, you will need to remove the lower jaw from the skull using a hacksaw and place it in a plastic bag (See included image of where to saw jaw). Write the 13 – digit game tag number associated with the jaw on the bag.
- ☐ Place entire carcass in a large trash bag. Please position the carcass on its side at the very bottom of the bag. Roll the bag by flipping the carcass over from the bottom of the bag toward the top. Once rolled, tape the bag closed and write the 13 – digit game tag number on the tape with a sharpie. Place in freezer. Please try to do this **within 12 hours of kill** to preserve carcass materials.
- ☐ Fill out one of the provided information sheets to the best of your ability. This will be required for payment consideration.
- ☐ Call your local WVDNR biologist as soon as possible (see map for regional biologist list). A biologist will then meet with you to collect the carcass and information sheet. Please make sure that the 13 – digit game tag number is labeled on all items.

NOTE: The game tag number is NOT your hunting license number.

- ☐ Contact WVUBobcat@mail.wvu.edu, call (304)293-0050 (ask for Stephanie), or call your local WVDNR office for more information.

Figure ii. Information packet – page 2.

JAW REMOVAL INSTRUCTIONS FOR TRAPPERS MOUNTING THEIR BOBCATS

IF YOU ARE KEEPING THE SKULL SEPARATE FROM THE CARCASS FOR A SPECIFIC REASON, THEN WE ARE **REQUIRING** THAT YOU SEND US THE ENTIRE LOWER JAW OR THE PORTION DENOTED BELOW AT MINIMUM. TAXIDERMISTS USUALLY USE ARTIFICIAL TEETH ON OPEN-MOUTHED MOUNTS. IF ARTIFICIAL TEETH WILL BE USED, SAW OFF THE LOWER JAW PORTION AS ILLUSTRATED BELOW.

USE HACKSAW ON DOTTED LINE

THE MOST RELIABLE WAY TO AGE A BOBCAT IS BY SLICING THIN SECTIONS FROM THE ROOT OF THE LOWER CANINES. UNDER A MICROSCOPE, RINGS SIMILAR TO THOSE ON A TREE STUMP CAN BE COUNTED TO DETERMINE THE BOBCAT'S AGE.

WE NEED TO KNOW THE AGE COMPOSITION OF THE BOBCAT POPULATION IN ORDER TO ESTIMATE SURVIVAL AND RECRUITMENT. CURRENT INFORMATION ABOUT WEST VIRGINIA'S BOBCAT POPULATION IS NECESSARY TO MANAGE THIS VALUABLE RESOURCE.

Figure iv. Information packet – page 4.

TAG NUMBER: _____

Trapper/Hunter Information Sheet

Trapper/Hunter Information:

Name: _____

Address: _____

Phone: _____

Email: _____

Hunting License Number: _____

NOTE: Please provide accurate information if you would like to receive payment for your carcass.

Bobcat and Trap/Weapon Information:

GPS Coordinates of Kill: _____ N _____ W

Example: 39°34'35.9"N 79°54'11.9"W

County of Kill: _____

Kill Area Site Description:

(Please check all that apply)

☐ Forest	☐ Field
☐ Pine	☐ Pasture
☐ Hardwood	☐ Cropland
☐ Shrubs	☐ Strip Mine
☐ Bare Understory	☐ Hayfield
☐ Recent Clearcut	

Other: _____

Date of Trap/Kill: _____

Weapon Used: ☐ Gun
☐ Trap
☐ Bow

Gender: _____

NOTE: None of this information will be shared outside of project purposes. It is only used for the purpose of better understanding and managing the West Virginia bobcat population. It will not be shared with any parties aside from West Virginia DNR and West Virginia University.

Figure v. Information packet – page 5.

WVDNR / WVU Bobcat Necropsy Record

Date _____

Technician Name _____

Volunteer/Recorder Names _____

Bobcat Tag # _____ Sex _____ Age _____ Weight _____ kg

Condition of Carcass (Description): _____

Measurements:

Front Right Paw Pad: _____ mm

Front Right Leg Length: _____ cm

Back Right Paw Pad: _____ mm

Back Right Leg Length: _____ cm

Skull Length: _____ cm

Body Length: _____ cm

Total Length: _____ cm

Tail Length: _____ cm

Necropsy Exam:NotesTrachea, Heart, and
Lungs☐

Check Lungs

☐

Blood Sample

☐

Liver Sample

☐

Spleen (x2)

☐

Stomach & Esophagus

☐

Right Kidney

☐

Wt w/ Fat: _____ g Wt w/out Fat: _____ g

Fat Index: _____

Left Kidney

☐

Wt w/ Fat: _____ g Wt w/out Fat: _____ g

Fat Index: _____

Reproductive Tract
(if applicable)☐

Intestine Sample w/
Feces☐

Omentum Fat

☐

Fat Wt: _____ g

Mesenteric Lymphnode

☐

Intestines

☐

Check Bladder

☐

Head

☐

Pg. 1

Figure vi. Necropsy data sheet – page 1.

Parasites (List Name and Relative Amount: 0, L, M, H)

Panleukopenia (Circle):

Positive Negative

Diet:

Item	Weight	Volume (%)
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>

Corpora Lutea:

Placental Scars:

Pg. 2

Figure vii. Necropsy data sheet – page 2.

Interested in **BOBCAT** trapping?

The **West Virginia Division of Natural Resources**
and **West Virginia University** are

collecting skinned bobcat carcasses

from hunters and trappers over the 2015 — 2016 trapping season
for a population assessment of West Virginia bobcats.

You will receive a
\$20 gift card of your
choice for each carcass
submitted to the study.

For more information,
email WVUBobcat@mail.wvu.edu or
call **(304)293-0050** and ask for Stephanie.

Figure viii. West Virginia Trappers Association carcass collection outreach flyer.

APPENDIX IV

Images of Canine Aging and Estimation of Implantation Rates in Bobcats

Figure i. Development of bobcat canine teeth collected from hunters and trappers over the 2014–2015 and 2015–2016 bobcat harvest seasons (Nov–Feb) in West Virginia. *Left to right:* Replacement of a deciduous canine by a permanent canine with an open apical root foramen (PC-OR); advanced PC-OR from a juvenile bobcat.

Figure ii. Stained cementum annuli of a sectioned canine tooth from a 3-year-old bobcat collected over the 2015–2016 bobcat harvest season (Nov–Feb) in West Virginia (Matson’s Laboratory, LLC).

Figure iii. Implantation rates were estimated by counting placental scars in the uterine horns of reproductively mature bobcats collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia. *Left to right:* An adult bobcat’s uterine horns showing a total of 3 placental scars; an immature juvenile bobcat’s ovaries and uterine horns.

APPENDIX V

Hunter-Trapper Bobcat Carcass Submission Data

Table i. Bobcat carcass counts by harvest type collected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons (Nov–Feb) in West Virginia.

Weapon	Bobcat Carcass Counts			
	Season 1	Season 2	Total	%
Trap	269	207	476	90.84
Gun	23	7	30	5.73
Bow	0	6	6	1.13
Roadkill	3	4	7	1.34
NA ¹	5	0	5	0.95

¹NA represents unreported data.

Table ii. Bobcat carcass counts by harvest site type collected over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons (Nov–Feb) in West Virginia.

Site	Bobcat Carcass Counts			
	Season 1	Season 2	Total	%
Forest	147	96	243	46.37
Field	94	58	152	29.01
Edge	53	60	113	21.56
NA ¹	3	8	11	2.10
Anthropogenic ²	3	2	5	0.95

¹NA represents unreported data.

²Anthropogenic represents 2 subcategories that were combined due to small sample sizes: Urban ($n = 0, 1$) and Highway ($n = 3, 1$).

Table iii. Misclassification rates and counts of hunter-trapper bobcat sex identification by stage class and sex for 524 carcasses collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia.

Response Accuracy	Count of Bobcat Sex Responses						
	Total	%	Sex		Stage Class		
			Male	Female	Juvenile	Yearling	Adult
Correct	435	83.02	202	233	77	128	230
Incorrect	70	13.36	50	20	24	15	31
NA ¹	19	3.63	12	7	6	1	12
Total	524	100	264	260	107	144	273

¹NA represents unreported data.

APPENDIX VI

Hunter-Trapper Survey Response Data

Table i. Hunter-trapper days spent in the field hunting or trapping for bobcats over the 2015–2016 bobcat harvest season (Nov–Feb) in West Virginia.

Category	N	Hunting (days)		Trapping (days)	
		$\bar{x}$	SE	$\bar{x}$	SE
Trappers	68	28.6	10.88	43.2	4.36
Hunters	5	NA ¹	NA ¹	0	0
Total	73	286 days	---	2980 days	---

¹NA represents unreported data.

Table ii. Hunter-trapper responses to pelt price and snow as drivers for fewer hunt or trap days spent in the field hunting or trapping for bobcats over the 2015–2016 bobcat harvest season (Nov–Feb) in West Virginia.

Category	<i>N</i>	“Yes” Responses	
		Snow?	Pelt Price?
Trappers	68	9	12
Hunters	5	0	0
Total	73	9	12

Table iii. Trapper responses and counts for bobcats released over the 2015–2016 bobcat harvest season (Nov–Feb) in West Virginia.

	Responses	Total Bobcats Released	Reason	<i>N</i> Responses	<i>N</i> Bobcats Released	% of <i>N</i> Bobcats Released
Trappers	Yes = 12	19	Small	7	12	63.16
	No = 56		Female	1	1	5.26
	Total = 68		Other (limit, etc.)	4	6	31.58

APPENDIX VII

Potential Drivers of Fewer Hunt-Trap Days Spent in the Field

Table i. Annual mean bobcat pelt prices, statewide mean snowfall, and statewide bobcat harvest totals over the 2005–2016 harvest seasons (Nov–Feb) in West Virginia.

Harvest Season	Pelt Price (\$)	Snowfall (cm)	Harvest (<i>N</i>)
2005–2006	53.00	10.54	1652
2006–2007	61.23	9.57	1901
2007–2008	56.81	10.23	1976
2008–2009	46.81	13.97	1449
2009–2010	47.83	32.27	992
2010–2011	60.63	14.72	1495
2011–2012	61.59	2.80	1857
2012–2013	124.60	4.48	1994
2013–2014	84.57	10.07	2014
2014–2015	47.59	8.94	1970
2015–2016	31.03	9.38	1380

APPENDIX VIII

Bobcat Body Size Measurements

Fig. i. Body mass, back length, shoulder height, and inverse kidney fat index (KFI) by stage class and sex for bobcats collected over the 2014–2015 ($n = 300$) and 2015–2016 ($n = 224$) harvest seasons (Nov–Feb) in West Virginia.

APPENDIX IX

Juvenile Bobcat Age Index and Canine Measurements

Table i. Male and female juvenile bobcat canine measurements in cm – length (L), diameter (D), and foramen diameter (FD) – and calculated age index (AI; Crowe 1975a) for carcasses collected over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia. Values followed by the same letter did not occur at significantly different rates ($\alpha = 0.05$) between bobcat sexes for each measurement.

Sex	N^1	Canine Measurements						AI ²	
		L		D		FD		$\bar{x}$	SE
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Male	52	2.76a	0.03	0.67a	0.01	0.35a	0.02	308.61a	4.40
Female	50	2.59b	0.03	0.60b	0.01	0.28b	0.01	290.64b	4.17

¹Not including outliers

$$^2AI = (L + D - FD) \times 100$$

APPENDIX X

Selecting Best Model for Predicting Reproductive Success

Table i. Corrected Akaike's Information Criterion (ΔAICc) values for variables that support reproductive success of reproductively active female bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia.

Model (Success~)	AICc	ΔAICc
Stages: 1, 2-4, 5+	201.69	0
Stages: 1, 2+	210.06	8.37
Shoulder Height	270.46	68.77
~1	285.85	84.16
Back Length	319.67	117.98
Body Mass	324.92	123.23
Harvest Season	357.67	155.98
KFI ¹	360.27	158.58
Ecoregion	361.47	159.78
Harvest Month	363.24	161.55

¹*Inverse Kidney Fat Index*

APPENDIX XI

Prey Species of West Virginia

Table i. Potential bobcat prey species by taxonomy and common names.

Phylogeny	Prey Taxonomy	Common Names
Class	Aves	* Birds
Class	Mammalia	Mammals
Order	Artiodactyla	Even-toed Ungulates
Family	Cervidae	* Ungulates
	<i>Odocoileus virginianus</i>	White-tailed deer
	<i>Cervus canadensis</i>	Elk
Family	Suidae	Pigs
	<i>Sus scrofa</i>	Wild boar
Family	Bovidae	Goats
	<i>Capra hircus</i>	Domestic goat
Order	Carnivora	Carnivores
Family	Canidae	³ Canids
	<i>Canis familiaris</i>	Domestic dog
	<i>Canis latrans</i>	Coyote
	<i>Urocyon cinereoargenteus</i>	Gray fox
	<i>Vulpes Vulpes</i>	Red fox
Family	Felidae	³ Felids
	<i>Felis catus</i>	Domestic cat
	<i>Lynx rufus</i>	Bobcat
Family	Mustelidae	^{3,4} Weasel, fisher, otter, ferret, mink
Family	Mephitidae	* Skunks
	<i>Mephitis mephitis</i>	Striped skunk
	<i>Spilogale putorius</i>	Eastern spotted skunk
Family	Procyonidae	* Raccoon
	<i>Procyon lotor</i>	Northern raccoon
Order	Didelphimorphia	Western Hemisphere Marsupials
Family	Didelphidae	* Opossum
	<i>Didelphis virginiana</i>	Virginia opossum

Order	Insectivora	Insect Eaters
Family	Soricidae	¹ Shrews
Family	Talpidae	¹ Moles
Order	Lagomorpha	Rabbits and Pika
Family	Leporidae	* Lagomorphs
	<i>Lepus americanus</i>	Snowshoe hare
	<i>Sylvilagus floridanus</i>	Eastern cottontail
	<i>Sylvilagus obscurus</i>	Appalachian cottontail
Order	Rodentia	Rodents
Family	Castoridae	³ Beaver
	<i>Castor canadensis</i>	North American beaver
Family	Cricetidae	² New World rats, mice, voles, muskrats, lemmings, hamsters
Family	Dipodidae	² Jumping mice
Family	Erethizontidae	³ New World Porcupine
	<i>Erethizon dorsatum</i>	North American porcupine
Family	Muridae	² Old World mice and rats, gerbils
Family	Sciuridae	* Medium-sized Rodents
	<i>Sciurus</i> spp.	Tree squirrels
	<i>Tamias striatus</i>	Eastern chipmunk

*denotes core prey groups

¹ Combined into group – * moles and shrews

² Combined into group – * small rodents

³ Combined into group – * others (<5% occurrence)

⁴ Referred to as mustelids

APPENDIX XII

Environmental Data

Table i. Mean monthly snowfall (cm) by ecoregion for the entire state of West Virginia, USA over the 2014–2015 (season 1) and 2015–2016 (season 2) bobcat harvest seasons (Nov–Feb).

Season	Ecoregion	Mean Snowfall (cm)			
		November	December	January	February
1	1	3.09	0.57	7.50	11.82
	2	17.70	4.42	24.18	58.47
	3	1.80	0.74	3.86	27.74
	4	1.50	0.00	7.43	13.02
	5	0.48	0.00	5.47	12.61
	6	0.33	0.00	0.75	11.03
2	1	0.00	0.30	26.19	5.63
	2	0.09	1.76	49.90	33.47
	3	0.01	0.25	23.36	13.44
	4	0.00	0.21	20.32	7.51
	5	0.00	0.19	17.52	7.02
	6	0.00	0.08	13.24	4.62

APPENDIX XIII

Support for Z-scores

Logistic regression presents standard z-scores, which determines the probability of the estimate occurring within a normal distribution and compares the resulting estimates by standardizing them such that the mean is 0 and standard deviation is 1. Z-scores result in the number of standard deviations that the estimate is from the assumed mean of 0, which generally ranges from -3 to +3 standard deviations of the normal distribution curve. The formula for calculating the standard score is the estimate (x), minus the mean estimate (μ), divided by the standard deviation (σ).

APPENDIX XIV

Subsampled Morphometric Data

Table i. Minimum, maximum, and mean morphometric measurements and body condition estimates for bobcats sampled for stomach contents ($n = 300$) over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia, USA by stage class.

	Stage Class											
	Juvenile ($n = 63$)				Yearling ($n = 87$)				Adult ($n = 150$)			
	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE
Body Mass (kg)	2.02	6.41	4.21a	0.13	3.18	11.53	6.83b	0.20	3.80	12.25	7.35c	0.16
Back Length (cm)	35.30	67.50	50.02a	0.66	48.00	73.00	58.86b	0.55	27.60	72.00	58.70b	0.48
KFI _i ¹	14.29	66.60	33.01a	1.34	10.39	49.19	28.78b	1.02	9.56	62.30	32.04a	0.85

¹ Inverse Kidney Fat Index: (mean kidney fat mass / (mean kidney mass + mean kidney fat mass)) x 100.

Table ii. Minimum, maximum, and mean morphometric measurements and body condition estimates for bobcats sampled for stomach contents ($n = 300$) over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia, USA by sex.

	Sex							
	Male ($n = 145$)				Female ($n = 155$)			
	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE
Body Mass (kg)	2.39	12.25	7.83a	0.19	2.02	8.42	5.33b	0.09
Back Length (cm)	27.60	73.00	59.80a	0.59	38.70	72.00	54.23b	0.38
KFI _i ¹	9.56	66.60	32.55a	0.77	10.39	62.30	30.12b	0.89

¹ Inverse Kidney Fat Index: (mean kidney fat mass / (mean kidney mass + mean kidney fat mass)) x 100.

APPENDIX XV

Bobcat Prey Occurrence Rates

Figure i. Occurrence of (A) medium-sized rodents and (B) moles and shrews in the diet of bobcats harvested over the 2014–2015 (season 1) and 2015–2016 (season 2) harvest seasons (Nov–Feb) in West Virginia, USA. Bars represent 95% confidence intervals (± 1 SE) of the mean. Different letters indicate statistically significant differences ($\alpha = 0.05$) between sampling years.

Figure ii. Occurrence of (A) ungulates, (B) Virginia opossum, and (C) lagomorphs in the diets of male and female bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia, USA. Bars represent 95% confidence intervals (± 1 SE) of the mean. Different letters indicate statistically significant differences ($\alpha = 0.05$) between sexes.

Figure iii. Occurrence of (A) ungulates, (B) medium-sized rodents, (C) small rodents, and (D) raccoon in the diets of juvenile (J), yearling (Y), and adult (Ad) bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) in West Virginia, USA. Bars represent 95% confidence intervals (± 1 SE) of the mean. Different letters indicate statistically significant differences ($\alpha = 0.05$) between age classes.

Figure iv. (A) Mass and (B) back length of bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) as predictors of ungulate selection by bobcats in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means.

Figure v. (A) Mass and (B) back length of bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) as predictors of medium-sized rodent selection by bobcats in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means.

Figure vi. (A) Mass and (B) back length of bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) as predictors of small rodent selection by bobcats in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means.

Figure vii. (A) Mass, (B) back length, and (C) inverse kidney fat index (KFI) of bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) as predictors of Virginia opossum selection by bobcats in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means.

Figure viii. Inverse kidney fat index (KFI) of bobcats harvested over the 2014–2015 and 2015–2016 harvest seasons (Nov–Feb) as a predictor of lagomorph selection by bobcats in West Virginia, USA. Grey area represents the 95% confidence intervals (± 1 SE) of the means.