The Factors Affecting Female Black Bear Harvest Rates in Pennsylvania

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ABSTRACT: Pennsylvania's black bear (*Ursus americanus*) population increased in abundance and distribution during the latter third of the 20th century, leading to an increase in human-bear conflicts. Increases in harvest opportunities from 2002–2018 aimed to stabilize black bear population growth but did not substantially increase harvest, and annual harvest was often below the desired goal of 20% removal. Consequently, additional changes to Pennsylvania's black bear hunting seasons occurred from 2019–2021, including starting harvest earlier, expanding the length of seasons, and adding additional seasons (i.e., a muzzleloader and special rifle season). Understanding how earlier harvest seasons and new methods of take (i.e., muzzleloader) influence female black bear harvest vulnerability is important to informing harvest management. We trapped and GPS-collared adult female bears in the Sproul State Forest in northcentral Pennsylvania from 2019–2021 to determine home range sizes, patterns of resource selection, and sources of mortality during fall harvest seasons. We assessed annual variability in relative abundance of fall hard mast. We evaluated temporal and spatial variation in hunter activity with road-side surveys and remote camera traps, respectively. We estimated fall and weekly home range size with utilization distributions through an autocorrelated kernel density estimation and evaluated the influence of predictors hypothesized to influence third-order resource selection using generalized linear mixed models. We investigated factors hypothesized to influence female black bear survival during hunting seasons with known-fate models. Mean fall home range size was 248.7 km^2 (range = 6.1–2636.1 km^2). Home range sizes varied by year and were generally smaller during archery harvest season than other periods. Patterns of weekly resource selection indicated bears selected steeper slopes and higher elevations outside of harvest seasons but shifted to less-steep areas in the week before harvest and the first week of harvest, and to lower elevations during harvest. Bears selected for areas containing oak (*Quercus* spp.) trees throughout the fall. Survival was lower in older age bears, greater relative mast abundance conditions, steeper slopes, and areas of greater hunter space use during the general firearms season. Survival was higher in areas of greater hunter space use during archery season. Harvest rate of adult female bears was 0.345 in 2019, 0.321 in 2020, and 0.150 in 2021, and averaged 0.272 across all three years. The probability of an adult female black bear surviving all harvest seasons each year was 0.611 (SE = 0.086, 95% CI = 0.436, 0.761). The high harvest rate and low predicted survival may lead to population reduction.

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INTRODUCTION

This study was part of a cooperative research program between the Pennsylvania Game Commission (PGC) and the U.S. Geological Survey Oklahoma Cooperative Fish and Wildlife Research Unit at Oklahoma State University. The project goal was to address knowledge gaps in our understanding of female black bear harvest in Pennsylvania and to evaluate the significance of harvest season changes adopted in 2019. A thesis from this research was written by Brandon Snavely as a partial requirement of Master of Science degree investigating home range size, resource selection, and survival of adult female black bears in Pennsylvania (Snavely 2023).

In Pennsylvania, black bear abundance increased from ~3,500 bears in the 1970s to >20,000 bears by 2019, leading to increased bear distribution and human-bear conflict (Ternent 2006). Human-bear conflicts can include threats to personal safety, property damage, vehicular collisions, and agricultural depredations (Hristienko and McDonald 2007). Human-bear conflict may be mitigated or reduced through harvest of black bears (Garshelis et al. 2020). A harvest rate of 15–20% has been suggested to stabilize black bear populations (Bunnell and Tait 1980, Miller 1990), but populations in Pennsylvania continued to increase despite consistent annual harvest rates of 15–20% (Diefenbach et al. 2004, Ternent 2006). From 2019–2021, black bear harvest seasons in Pennsylvania increased in duration and commenced earlier in the fall than in previous years. Modifications to harvest seasons included the expansion of the archery and extended rifle seasons and the establishment of muzzleloader and a special firearms seasons. Pregnant females may enter winter dens earlier than unpregnant females in Pennsylvania (Ternent 2006). Consequently, earlier harvest seasons may have a greater influence on reproduction due to an increased risk of harvest to pregnant females. Furthermore, hunting and human disturbances may influence space use of large mammals due to perceived risks (Millspaugh et al. 2000, Frid and Dill 2002). Changes in harvest seasons may influence the perceived risks for bears and lead to temporal variation in space-use patterns among harvest and non-harvest periods. Understanding the dynamic patterns of home range size and shifts in resource selection for bears within their home ranges can inform population management.

The objectives of this project were to (i) estimate female black bear harvest rates during the muzzleloader, archery, and general firearms seasons (2019–2021) and compare 2019–2021 and 2010–2018 harvest rates; and (ii) assess the relative influence of food conditions, bear movements, hunting season structure, and hunter behavior on variation in female black bear harvest rates. To accomplish these objectives, we analyzed adult female black bear weekly home range size, resource selection, and survival during fall 2019–2021. We also compared statewide harvest estimates provided by PGC and summarized hunter survey data collected by PGC.

METHODS:

Study area.—Our study occurred in ~308 km^2 of the Sproul State Forest in northcentral Pennsylvania, which was characterized as primarily mixed-oak hardwood forest and overlapped with an area used since 2002 for annual baseline monitoring of black bear reproduction (Ternent 2018). The study area was south of Renovo, Pennsylvania, and encompassed portions of Clinton and Centre counties in the west branch of the Susquehanna River drainage (Snavely 2023).

Black bear capture and monitoring.—We captured black bears from late May through August annually during 2019–2021 with barrel-style traps baited with waste pastries (Gould et al. 2021, Snavely 2023). We immobilized captured bears with either 1.0 ml/45.5 kg NalMed-A (Wolfe et al. 2016), 1.0 ml/45.5 kg BAM (Wolfe et al. 2008), or a 2:0.8 mixture of ketamine hydrochloride (4.4 mg/kg) and xylazine hydrochloride (1.8 mg/kg; Williamson et al. 2018); all anesthetics were delivered intramuscularly by CO^2-propelled darts (Snavely 2023). We tagged each bear with unique metal ear tags (Hasco Tag Company, Dayton, Kentucky), tattooed one ear tag number on the inside of the upper lip of adults (≥1 year old), and fitted adult females weighing ≥40 kg with an Iridium GPS satellite collar (Vectronics, Germany). For each captured bear, we monitored vital rates (i.e., temperature, heart rate, and respiration rate) and documented sex and standard physical measurements (Snavely 2023). We used atipamezole HCL (5 mg/mg) and naltrexone HCL (1.3 mg/mg) to reverse immobilization of bears anesthetized with BAM and NalMed-A, and we used yohimbine hydrochloride (0.15 mg/kg) to reverse bears anesthetized with the Ketamine/Xylazine mixture. We visited dens of radio-collared bears in February or March (2020 –2021) to recover location data not transmitted by satellites and adjust the fit of collars. Capture and handling procedures were in accordance with the American Society of Mammalogists guidelines (Sikes et al. 2016) and approved by the Institutional Animal Care and Use Committees for South Dakota State University (Protocol 2002-005A) and Oklahoma State University (Protocol IACUC-21-19). Radio-collars were programmed to attempt a GPS-fix every 2.25 hours and location data were obtained by satellite transmissions (via GPS Plus X and Inventa; Vectronics, Germany) or physical download (e.g., when a collared black bear was harvested or recaptured). We investigated collars indicating a mortality (i.e., inactive for ≥8 hours) to determine the cause of mortality. Additional details are available in Snavely (2023).

Home range analyses.—We evaluated weekly and fall home range sizes for each collared bear over the period from 1 September until den entry or mortality each year (Snavely 2023). We only included individuals with ≥30 locations for any weekly or seasonal period. We produced 95% fall home range estimates, and 95% and 50% weekly home range estimates, using autocorrelated kernel density estimation (AKDE) as implemented in the R package ctmmweb in the program R version 4.2.0 (Calabrese et al. 2021, R Core Team 2022). Additional details and consideration for home range analyses are available in Snavely (2023).

Resource selection analyses.—We used weekly 50% (i.e., core) AKDE home range estimates to assess weekly variation in third-order resource selection (Johnson 1980, Manly et al. 2002) by bears from 1 September through den entry or mortality events, and to associate resource selection with topographic (i.e., elevation and slope), land-cover (i.e., canopy height, oak stands, and distance to rivers or streams), and anthropogenic (i.e., distance to state forest camps, and distance to primary or secondary roads) features (Snavely 2023). We used the lme4 package (Bates et al. 2015) and generalized linear mixed effects models to evaluate *a priori* models reflecting hypotheses about factors driving female black bear resource selection (Snavely 2023). We used Akaike's Information Criterion corrected for small sample sizes (AICc) to evaluate relative support among models (Burnham and Anderson 2002). We also considered models with year as an additional random effect to account for temporal heterogeneity not accounted for by our covariates, and we considered models including whether the bear was harvested or not as a fixed effect. Details on covariates and model structures are available in Snavely (2023).

Survival analyses.—We evaluated weekly female black bear survival during the fall harvest seasons using known fate models with program MARK (White and Burnham 1999) and considering weekly home range size, weekly mean step length, weekly mean slope, weekly mean elevation, relative hard mast abundance, year, day of year, age, harvest season, reproductive status (with offspring and not), and indices of hunter activity characterizing harvest risk (Snavely 2023). We developed a candidate model set by generating models for all possible additive combinations of uncorrelated predictors and evaluated support for competing models with AICc. Using the most-parsimonious model, we assessed both daily and fall (across all harvest seasons each year) survival probabilities. We assessed beta coefficients (with 85% confidence intervals, CIs) for predictors in the most-parsimonious model. Additional details on covariates and model structures are available in Snavely (2023).

Mast surveys and analyses.—We estimated percent crown containing acorns (PCA) of mast-producing trees during late summer (2019–2021). We surveyed 10, 1.6-km transects with random starting locations on existing roads in the study area. Each transect was surveyed once annually by assessing the species, diameter at breast height (DBH), and PCA for four randomly selected dominant hard mast-producing oak trees (*Quercus* spp.) within sight of the vehicle at 0.16-km intervals. We also assessed PCA of five permanent hard mast plots containing ~50 trees. We grouped oak trees into two groups: red oaks (*Erythrobalanus*) and white oaks (*Leucobalanus*). We used the product of DBH and PCA to produce a relative hard mast score (hereafter, PCA score) for each tree that was sampled (Greenburg and Warburton 2007). We employed a Kruskal-Wallis test (Kruskal and Wallis 1952) to assess the effect of year and a Wilcoxon signed-rank test (Wilcoxon 1945) to assess the effect of the interaction between year and group on hard mast relative abundance (PCA score). Additional details and consideration for mast surveys are available in Snavely (2023).

Hunter space-use surveys and analyses.—To quantify the risk of bears encountering a hunter, we indexed spatial variation in hunter activity with motion-triggered cameras and occupancy modeling (MacKenzie et al. 2002), and temporal variation (among seasons and years) in hunter activity with road transects. We combined indices of spatial variation (i.e., probability of use) and temporal variation (i.e., hunters/day from road surveys) for each season and year to generate an index of risk that varied temporally and spatially. Additional details and consideration for assessing spatio-temporal variation in hunter activity are available in Snavely (2023).

PGC bear hunter surveys.—The PGC surveyed hunting camp owners and bear hunters. Following 2019–2021 bear harvest seasons, PGC mailed surveys to the addresses of 110 camp owners located on the study area to assess participation in bear hunting and overall satisfaction in changes to bear harvest regulations. Additionally, the PGC distributed a statewide bear hunter survey to 5,000 Pennsylvania bear hunters in spring of 2021 to assess participation in black bear hunting (e.g., over time, among harvest seasons, and among wildlife management units), method of take, perceptions related to bear check stations, and satisfaction with the PGC, among other interests of the PGC. The PGC provided anonymized data (i.e., data without any personal identifying information), and we summarized key patterns in the survey results.

RESULTS:

Black bear capture and monitoring.—Trapping occurred between 28 May and 20 August 2019–2021. We collared 45 unique female bears, with 29 females available for analysis in 2019, 28 available in 2020, and 16 available in 2021 (Snavely 2023). A lower proportion of collared bears was harvested during archery seasons than other harvest seasons, despite the archery season having the longest duration (Snavely 2023). Additional details are available in Snavely (2023).

Home range analyses.—The mean 95% home range size during the fall across all three years was 248.7 km^2 (range = 6.1–2636.1 km^2). Home range sizes varied by year (largest in 2020 and smallest in 2021) and were generally smaller during archery harvest season than other periods. On average, home range estimates of harvested bears were generally larger than those of non-harvested bears across all weeks (Snavely 2023). Additional details are available in Snavely (2023).

Resource selection analyses.—Over a 17-week sampling period, harvest occurred during weeks 8–10 (muzzleloader, archery, and special firearms season) and 13 (general firearms). There was relatively high uncertainty for beta coefficients (β) during weeks 14–15 due to decreasing sample sizes, and we were unable to assess resource selection during weeks 16–17 due to small sample sizes (Snavely 2023). Bears generally selected for steeper slopes outside of harvest seasons, but we observed a shift to areas with lower slope in the week just prior to harvest and the first week of harvest. Bears generally selected for higher elevations outside of bear harvest seasons and generally lower elevations during harvest seasons. Bears selected for oak stands throughout the fall; bears showed either no selection or selection for area with lower tree heights throughout the fall, excluding the first week of harvest when bears selected for areas with greater tree heights. Bears initially selected for areas farther from roads prior to harvest seasons, selected for areas closer to all roads in weeks 8–10, and selected for areas farther from roads from weeks 11–15. Considering the spatial distribution of bears in the study area, space use was distributed relatively evenly across the study area during the pre-hunt weeks but shifted to lower elevation and more remote regions of the study area when harvest occurred during weeks 8–10. Bear space use was more sporadic (i.e., few areas with high use) during the later non-harvest (weeks 11–12) and firearms (week 13) seasons. Additional details are available in Snavely (2023).

Mast surveys and analyses.—We estimated the relative hard mast (PCA score) of mast producing trees between 16 August–6 September during 2019–2021. Overall PCA score declined annually from 9.45 (SE = 1.07) in 2019 and 7.15 (SE = 0.96) in 2020 to 1.83 (SE = 0.35) in 2021, influenced largely by patterns observed in red oaks. PCA scores for red oaks declined and white oaks increased over the course of the study (Snavely 2023).

Hunter space-use surveys and analyses.—Indices of hunter activity indicated temporal and spatial variation. Roadside surveys indicated hunters/day was lowest in 2019 and greatest in 2020. During the muzzleloader and archery harvest seasons, the index of hunters/day was lowest in 2021 and greatest in 2020. In contrast, the greatest index of hunters/day in the general firearms season occurred in 2021. The greatest index of hunters/day occurred during the earlier muzzleloader and archery harvest seasons in 2020 and corresponded to the year with the lowest index of hunters/day during the later general firearms season. Camera surveys detected humans across the majority (85%) of sites monitored with cameras. Our most-parsimonious model of human use indicated that high human space use was positively associated with elevation (β = 7.9, SE = 5.1, 85% CI = -0.5, 15.3), whereas detection of humans was negatively associated with rain (β = -2.2, SE = 1.6, 85% CI = -4.5, 0.1) and positively associated with rifle season (β = 2.3, SE = 0.4, 85% CI = 1.8, 2.9). Additional details are available in Snavely (2023).

Survival analyses.—During the muzzleloader, archery, special firearms, and general firearms seasons, the collective statewide harvest rates for all bears in Pennsylvania declined from 20.8% in 2019 to 20.1% in 2020 to 18.2% in 2021 (Carrollo 2022). Statewide harvest rates were higher during 2019–2021 than during 2010–2018; for female bears in Pennsylvania, statewide harvest rate increased from ~13% during 2010–2018 to ~19–20% during 2019–2021 (Snavely 2023). All 2019–2020 mortalities of collared females were due to harvest except for one bear that was killed by a vehicle collision in 2019. Harvest rate of collared bears decreased annually from 0.345 in 2019 to 0.321 in 2020 to 0.150 in 2021 (2019–2021 mean = 0.272). The most-parsimonious model of female survival contained bear age, relative hard mast abundance, mean slope, and risk, and it produced an estimated probability of surviving all harvest seasons in any given year of 0.611 (SE = 0.086, 95% CI = 0.436, 0.761). Among harvest seasons, daily probability of survival was lowest during the general firearms season and greatest during the archery season. Survival was lower for older bears, when mast was more abundant, and in steeper slopes. Survival was greater in areas of greater human space use (risk) during archery harvest and lower in areas of greater human space use (risk) during the general firearms season. Additional details are available in Snavely (2023).

PGC hunting camp owner surveys.—On average, the PGC received responses from 59.4% of hunting camp owners following the 2019, 2020, and 2021 bear harvest seasons. Among respondents for 2019–2021, 65.3% of camp owners indicated that members of their camp hunted, of which 20.9% only hunted bears, 24.5% primarily hunted bear (but hunted white-tailed deer [*Odocoileus virginianus*] incidentally), and 54.5% hunted bears incidentally (while hunting primarily for white-tailed deer). More hunting camp owners reported being satisfied or neutral to changes in bear harvest regulations than dissatisfied. For the muzzleloader season, 40.0% were satisfied, 41.0% were neutral, and 19.0% were dissatisfied. For the special firearms season, 37.1% were satisfied, 47.0% were neutral, and 15.5% were dissatisfied. For the archery season, 41.9% were satisfied, 41.0% were neutral, and 17.1% were dissatisfied. For the regular firearms season, 47.2% were satisfied, 28.5% were neutral, and 24.4% were dissatisfied.

PGC statewide bear hunter surveys.—The PGC received a response from 2,236 (44.7%) of statewide bear hunters surveyed. Nearly 67% of respondents participated in bear hunting in both 2019 and 2020, while ~20% participated during only 2019 or 2020. Among respondents that hunted bears in 2019, 2020, or both, 70.2% had greater confidence in the PGC's ability to develop black bear harvest estimates when mandatory check stations were employed, whereas 8.9% did not have greater confidence. Similarly, 69.5% of respondents supported mandatory check stations, whereas 10.9% did not. Among respondents, there was little difference in the type of bear that a hunter would harvest if it was, or was not, the last day of the season. Only 21.9–25.4% of respondents would harvest a collared bear. A greater proportion of respondents would harvest a solitary bear (75.7–78.7%) than a bear in a group (35.0–40.1%). Among those that would harvest from a group of bears, 6.0%–8.3% indicated they would harvest the smallest bear in the group, whereas 54.4–54.9% indicated they would harvest the largest bear in the group. Approximately a third of respondents (33.6–37.2%) indicated they would harvest a bear with visible health conditions (e.g., mange).

DISCUSSION:

The mean fall home range estimate of females that we observed was 248.73 km^2 and was substantially larger than estimates previously reported in Pennsylvania (~50 km^2, Alt et al. 1980) and in other deciduous forest systems (~4–21 km^2; Garshelis and Pelton 1981, Smith and Pelton 1990, Jones et al. 2015). Our larger estimates were likely a consequence of retaining exploratory trips in our home range estimation and using AKDEs to estimate home range sizes. Justifications and consequences of retaining exploratory trips and using AKDEs are detailed by Snavely (2023).

We observed shifts in resource selection patterns for slope, tree height, and elevation, as bears used areas with lower slopes, lower elevation, and forest stands with greater canopy heights during the week prior to harvest and the first week of harvest season; bears then returned to patterns of selection more similar to pre-harvest (i.e., steeper slopes, lower canopy heights, and higher elevations) during subsequent weeks (Snavely 2023). Hunter activity may be greater during weeks prior to harvest season than weeks after harvest seasons (Root et al. 1988), due to scouting activities. Shifts in resource selection during periods just before and at the start of harvest could have been a consequence of greater human activity during these periods compared to later in the harvest season. Bears in our study selected for areas closer to roads during the muzzleloader and archery seasons, which was in contrast to both our prediction of bears avoiding anthropogenic landscape features and to patterns of selection previously documented in bears (Brody and Pelton 1989). These patterns may be a result of bears shifting space use to different areas in their home ranges during initial periods when human densities may have increased due to hunting.

Bears may change their foraging behavior prior to entering winter dens, and pregnant females enter dens earlier than females with offspring or males (Powell et al. 1997). Female bears in our study generally began entering dens in late October, and home range estimates tended to be smallest during late October–early November (the period aligning with muzzleloader and archery seasons). Previous research in Pennsylvania indicated that black bear home range sizes decreased closer to den entrance (Alt et al. 1980). Thus, the similar timing of den entrance and early harvest seasons made it difficult to determine whether the smaller home ranges during late October–early November were influenced by behavioral patterns associated with entering dens, response to hunting pressure, or both.

Fall food resources (primarily mast) can influence home range size in bears (Garshelis and Pelton 1981), and poor mast production can lead to larger movements and decreased survival (Pelton 1989). From 2019–2021, home range size estimates in 2021 were the smallest and least variable, despite 2021 being the year with the lowest relative hard mast abundance during our study. Smaller home ranges during periods of poor mast production contradicts our predictions and may indicate that other factors (e.g., hunting intensity) may be affecting home range sizes in our study system. Evidence exists for earlier den entry by bears in years with poorer food conditions (Johnson and Pelton 1980). However, collared bears in our study entered dens later in 2021, which was the year with the poorest hard mast conditions. Bears cannot be harvested from dens in Pennsylvania and, therefore, are less vulnerable to harvest mortality after they enter winter dens. However, our results indicated that survival was greater during years with poorer acorn abundance and later den entrance. A potential explanation may be that bears reduced energy expenditure associated with movements in 2021, which led to small home ranges and may have reduced exposure to hunters.

Vulnerability to harvest typically decreases with increasing age in female bears (Ternent 2006), potentially due (at least in part) to younger bears entering winter dens later (Tietje and Ruff 1980), making them available for harvest longer. However, our results indicated older female bears experienced reduced probability of survival. Timing of historical harvest seasons (i.e., which commenced later in the fall) may have protected older females that entered winter dens prior to harvest (Alt et al. 1980), leading to a negative association between harvest vulnerability and age that is not supported with earlier harvest seasons. Additionally, older individuals may typically have lower overall health (Ricklefs 2010), reducing their ability to avoid harvest.

In Pennsylvania, the population estimates of bears decreased annually from 2019–2021 (Carrollo 2022). Harvest rates for collared adult females in our study were greater in 2019 and 2020, and lower in 2021, than statewide harvest rates. However, harvest rates for our study system may not be directly comparable with statewide estimates, as the entirety of our study area was public land and accessible for hunting whereas other portions of the state are predominantly private lands. Additionally, our study area was not open for an extended bear hunting season, which occurred concurrently with Pennsylvania's white-tailed deer firearms season in some other areas. Bears in our study area had higher daily probabilities of survival during archery season, which may have been a result of lower bear hunter engagement during this period. Daily probability of survival was noticeably lower during the general firearms seasons, and this may be a result of more effective methods of take, more hunters afield during this season, or both. Black bears may avoid areas where there is a high perceived risk (Stillfried et al. 2015). Relative risk was higher during the general firearms season than other seasons, and there was evidence that survival was inversely related to risk during this season. Bears selected for lower elevations during the general firearms season, while during the same period the higher risk areas were leading to lower probabilities of survival. This pattern supports the premise that bears may have avoided areas in which they were most likely to experience mortality during the general firearms season.

Shifts in patterns of home range sizes and resource selection may influence survival, food acquisition, and subsequent reproduction. There was evidence that increased human presence on the landscape may initially influence bear resource selection patterns. If these shifts in resource selection result in (i) bears using suboptimal food resources to mitigate risks, (ii) decreased food availability or nutritional quality, or (iii) increased competition among bears, these changes could lead to secondary effects on fitness, such as reduced short-term or long-term survival or decreased reproductive capacity. Survival of female bears may be influenced by age, fall food conditions, slope, and risk associated with hunting pressure during harvest. Older adult females generally produce larger litters (Alt 1982) and therefore a decrease in predicted survival in older individuals may amplify effects on population dynamics, which could help managers achieve current population management objectives but may have prolonged effects on population size. Hard mast data collected prior to bear harvest seasons each fall could be used to inform upcoming harvest susceptibility for adult female bears, allowing managers to potentially adjust harvest seasons (e.g., timing or lengths of seasons) annually to account for variation in fall food abundance.

Despite an increase in annual bear hunting license sales between 2017–2018 and 2019–2021 (Carrollo 2022), bear hunter success was lower during 2019–2021 (~1.87%; Carrollo 2022) than the previous 10 years (mean = 2.2%; Ternent 2019). If decreased hunter success is a result of increasing bear hunting opportunities, negative impressions of expanded harvest seasons could occur. Further discussion is provided in Snavely (2023).

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