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Abstract: An understanding of black bear (*Ursus americanus*) population trends and cause-specific mortality is needed to direct management decisions in northern Georgia given an increasing human population. Therefore, we evaluated black bear population trends and mortality sources across 26 counties and 18 Wildlife Management Areas in northern Georgia from 1979–2014. We collected harvest data from 6,433 individuals during the study period. Using age-at-harvest data, population reconstruction illustrated an increasing trend in the bear population for both males ($\lambda = 1.113$) and females ($\lambda = 1.108$). Bait station indices reflected a similar increase in the bear population based on increased visitation over time (min: 12.3% visitation in 1983; max: 76.7% visitation in 2009). Bear-vehicle mortalities also increased from 1986–2014 and were greater for males relative to females, especially males ≤2 years old. Bear-vehicle mortalities were greater for males than for females during May–July; however, bear-vehicle mortalities increased for both sexes during August–November. Current population trajectory suggests black bear populations in northern Georgia will continue to increase. If bear population trends continue to increase, we suggest further evaluation of current bear harvest regulations in northern Georgia to reduce potential bear-human conflicts.

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Black bears (*Ursus americanus*) were nearly extirpated from Georgia by the 1930s due to unregulated hunting, illegal harvest, and large-scale habitat loss (Carlock et al. 1983). Subsequently, hunting season was prohibited to promote population recovery from the early 1920s to 1979 (Carlock et al. 1983). In 1979, the Georgia Department of Natural Resources, Game and Fish Division re-initiated a limited bear hunting season. Today, black bears occur in three distinct populations in Georgia in the northern, central, and southern regions of the state; the largest population is located in northern Georgia, which is associated with the southern region of the Appalachian mountain range. Vehicle collisions have been shown to be a strong source of mortality for bears (Wooding and Brady 1987, Brody and Pelton 1989, Warburton et al. 1993, Wooding and Hardisky 1994, Garrison et al. 2007). Human populations and associated vehicle traffic are expected to increase 46% in Georgia by 2030 (Georgia Office of Planning and Budget 2010). Therefore, we evaluated bear population trends and mortality sources to direct future population management decisions (e.g., regulation change) given the expected increase in the human population in Georgia.

During early summer, male bears are at the greatest risk of vehicle mortality (Warburton et al. 1993), a time which corresponds to breeding season and dispersal movements (Hamilton 1978, Hellgren and Vaughan 1990). During late summer and fall, males and females have been found to be equally vulnerable to vehicle mortality (Warburton et al. 1993). Food acquisition prior to denning likely increases vulnerability to vehicle mortality in these seasons (Rogers 1987). Hellgren and Vaughan (1990), for example, found females made extensive shifts in their home ranges during the late summer and early fall to locate natural fall foods (e.g., oak mast).

Black bear populations are primarily managed through legal harvests (Bunnell and Tait 1985, Warburton et al. 1993). In 1979, hunters in northern Georgia harvested 21 bears during the first legal bear hunting season on Chattahoochee, Chestatee, Cooper's Creek, and Rich Mountain Wildlife Management Areas (WMAs; Carlock et al. 1983). In 2013, the harvest and harvest area expanded to 386 bears across 12 WMAs and 22 counties (Georgia Department of Natural Resources, unpublished data). These data suggest the bear population is increasing in northern Georgia; however, limited information currently exists on current population trajectory.

We evaluated historical black bear population trends (1979–2014) and characteristics of mortality (harvest and vehicle-collisions) in northern Georgia. Our research objectives were to: (1) document sources of mortality (legal harvest, known illegal harvest, and bear-vehicle mortalities), (2) evaluate population growth using population reconstruction techniques, and (3) evaluate trends in bear-vehicle mortalities. We predicted that legal harvest would be the greatest source of mortality followed by bear-vehicle mortalities and known illegal harvest. We also predicted that younger males

(≤2 years old) would constitute the majority of mortalities given their increased home range size and dispersal behaviors relative to females (Hamilton 1978, Hellgren and Vaughn 1989). Finally, we predicted that bear-vehicle mortalities would increase during the study primarily, and that the majority of bear-vehicle mortalities would occur during the fall months when bears were searching for food resources prior to denning.

Study Area

Our study was conducted in 26 counties and 18 WMAs in northern Georgia representing a total of 21,651.7 km^2 (Figure 1). The counties included: Banks, Bartow, Catoosa, Chattooga, Cherokee, Cobb, Dade, Dawson, Fannin, Floyd, Forsyth, Gilmer, Gordon, Gwinnett, Habersham, Hall, Lumpkin, Murray, Pickens, Rabun, Stephens, Towns, Union, Walker, White, and Whitfield. The WMAs included: Allatoona, Blue Ridge, Chattahoochee, Chestatee, Cohutta, Coopers Creek, Coosawattee-Carter's Lake, Coosawattee, Dawson Forest, Duke's Creek, Lake Burton, Lake Russell, McGraw Ford, Pine Log, Rich Mountain, Swallow Creek, Tallulah Gorge, and Warwoman. Physiographic regions included in this study area included Blue Ridge Mountains, Ridge and Valley, and Upper Piedmont.

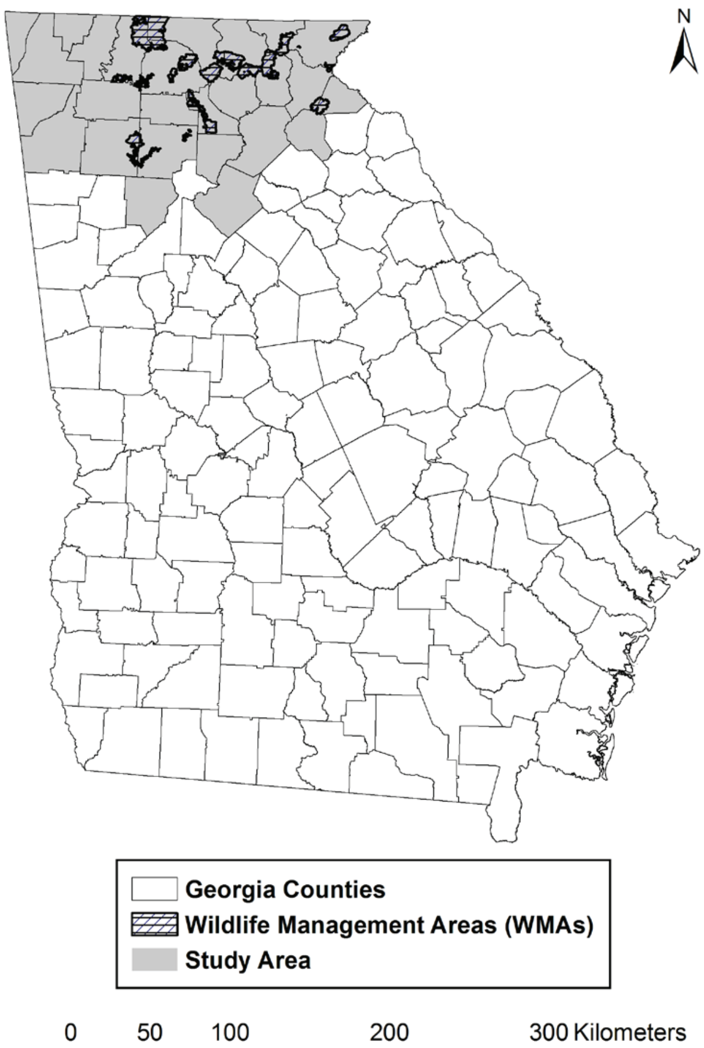

Figure 1. Black bear (*Ursus americanus*) mortality study area in northern Georgia.

Methods

Mortality events

Bear hunting was permitted in the fall of each year with a limit of 1 bear per hunter from 1979–2010. In 2011, hunting regulations in northern Georgia were changed in to allow the harvest of 2 bears per hunter. Harvest of females with cubs or bears weighing <34 kg (live-weight) and use of bait when hunting was prohibited. No spring bear harvest was permitted in Georgia. Registration of harvested black bears is mandatory; therefore, Georgia Department of Natural Resources (hereafter, Georgia DNR) personnel recorded biological data from all harvested bears including sex, age, and weight. Additionally, hunter information was collected including county or WMA of harvest and method of harvest (rifle, shotgun, crossbow, handgun, muzzleloader, or archery). Records of registered hunter harvested bears were used to calculate total harvest during the study period. Georgia DNR personnel extracted a premolar for aging using cementum annuli (Willey 1974). All teeth were sectioned and aged at Matson's Laboratory (Manhattan, Montana).

Bear hunting was permitted in the counties and WMAs beginning in mid-September for archery equipment and in mid-October for muzzleloaders and modern firearms; it ended in early December. Use of dogs for hunting bear was prohibited. Illegal harvest (e.g., use of bait, harvest of bears weighing <34.0 kg, bears harvested outside of legal hunting season, etc.) did occur during the study period. When bears were illegally harvested, conservation law enforcement officers confiscated the carcasses and/or issued a citation.

Using the mortality data, we determined: 1) percentages of legal harvest, known illegal harvest, and bears killed by vehicles; 2) percentages of harvest by legal weapon type; 3) percentages of harvest mortality by age class; and 4) percentages of vehicle mortality by sex and age class. Bears killed by vehicles were reported to the local 911 center following a collision and/or accident reports from law enforcement officers. We calculated percentages of legal harvest, known illegal harvest, and vehicle mortality by totaling the number of mortalities in each category and dividing by the total number of mortality events during the study period multiplied by 100. We calculated percentages of harvest by legal weapon type by totaling the number of mortalities by each type of weapon (archery/crossbow, handgun, muzzleloader, rifle, and shotgun) and dividing by the total number of mortality events during the study period multiplied by 100. We calculated percentages of harvest mortality and vehicle mortality by sex and age class (cubs: 0.25–0.75 years old; yearlings: 1–1.75 years old; 2-year-old: 2–2.75 years old; 3-year-old: 3–3.75 years old, and 4+ year old) by totaling the number of mortalities in each age class and dividing by the total number of mortality events during the study period multiplied by 100.

Population trends

We used population reconstruction to estimate bear population growth (Downing 1980). Population reconstruction is a population estimation technique that uses age-at-harvest data and backward addition of cohorts to estimate minimum population size over time and is commonly used by state agencies for black bear and white-tailed deer (*Odocoileus virginianus*) population estimation (Davis et al. 2007). The advantage of population reconstruction is that it requires only total harvest by year and age-at-harvest by year (Downing 1980) and can be used by biologists and managers to identify trends in abundance over time (Tilton 2005). We analyzed sexes separately because males and females may experience differing levels of harvest mortality. We collapsed ages into five classes as previously defined for males and females. We reconstructed the population from 1979–2014 using program PopRec2011 (Pond and Property, LLC, Newport, Virginia), which uses Downing's (1980) method of population reconstruction. For years of complete reconstructed cohorts, we calculated the annual population growth rate (λ_t) as

$$\lambda_t = N_{t+1}/N_t$$

where N_t was the total reconstructed abundance in year t. We censored years 2012–2014 due to incomplete cohorts; therefore, our final reconstructed population was from 1979–2011. The assumptions of Downing's (1980) population reconstruction include: 1) the proportion of deaths accounted for is constant over time for each cohort; 2) the mortality rates for the oldest two reconstructed age classes are equal; and 3) subsamples of ages are unbiased. Population reconstruction does not account for deaths due to natural mortality thus reconstructed abundances are underestimates of total population abundance (Davis et al. 2007). We recognize the potential problems with population reconstruction resulting from biases in aging and variability in mortality rates (Roseberry and Woolf 1991). However, this method has been found to be suitable for estimating population growth rate (λ) for populations experiencing no trend in harvest rate or natural mortality rate over time, and is especially valuable with estimating black bear populations (Davis et al. 2007).

We also used bait-station surveys as an index to population abundance and distribution, and to evaluate relative trends in the bear population over time (Clark et al. 2005). Bait-station surveys were conducted in 11 counties and on 10 WMAs covering a linear distance of approximately 451 km of bear habitat from 1983–2013. Surveys were conducted annually or biannually in July. Each bait-station survey route consisted of 5–26 bait sites ($\bar{x} = 13$) and were established along paved and gravel roads, major trails, and wooded paths. Bait-stations were spaced approximately 0.81 km apart. A bait station was comprised of three partially opened cans of sardines hung in a small tree >3 m above the ground. Each site was checked after five nights and bear visits were determined based on claw marks on the tree trunk or canine tooth-sized holes in the sardine can (Johnson 1990). We pooled all bait stations for each WMA and then pooled all WMAs sampled in northern Georgia to calculate an annual percentage of bait sites visited by bears.

We used bear-vehicle mortality data collected by Georgia DNR personnel to evaluate trends in mortality over time. Bear-vehicle mortality data were available from 1986–2014 from all 26 counties in our study area. We modeled bear-vehicle mortalities as a function of year using a negative binomial generalized linear mixed model implemented in program R version 3.1.3 (R Core Team 2013). We included county as a random effect to account for spatial variation in bear-vehicle mortalities (Gillies et al. 2006). We also included total vehicle miles travelled (or traffic volume) as an offset in the model to account for variation in traffic trends by county over time since bear-vehicle collisions are increasingly likely in areas with increased traffic volume. We collected traffic volume data from the Georgia Department of Transportation (2016). We used vehicle miles traveled (VMT), a measure of traffic volume, which is calculated as the product of traffic volumes on road sections (urban and rural) and the length of those road sections for each county (S. Susten, Georgia Department of Transportation, personal communication). Additionally, we evaluated the relationship between the number of bear-vehicle mortalities and estimated population size based on population reconstruction using a simple linear regression modelling framework. We also included total vehicle miles travelled as an offset in the model to account for variation in traffic trends across the entire study area. We evaluated bear-vehicle mortalities by month to determine when males and females were most vulnerable to collisions. We used a Chi-square goodness of fit test to evaluate whether males or females were more vulnerable to bear-vehicle mortalities. We analyzed the monthly vehicle collision data by sex in program R version 3.1.3. We used an alpha level of 0.05.

Results

Mortality events

We documented 6,433 black bear mortalities from 1979–2014. Of this total, legal harvest comprised 90.5% ($n = 5{,}821$), bear-vehicle mortality 7.1% ($n = 454$), and known illegal harvest 2.5% ($n = 158$; Table 1). Bears were primarily harvested by rifle (64.0%), followed by archery (28.7%), muzzleloader (5.8%), and unknown weapon (1.1%), shotgun (0.2%), and handgun (0.1%; Table 2).

Ages were estimated for 95.0% of all harvested bears ($n = 5{,}658$, legal and known illegal) and for 58.8% of all bear-vehicle mortalities ($n = 267$) from 1979–2014. We found the proportions of males and females harvested legally differed by age class ($X^2 = 622.29$, df = 4, $P < 0.001$). Males (≤2 years old) were most likely to be legally harvested; whereas, females (≥4 years old) were most likely to be legally harvested (Table 3). We assessed known illegal harvest by sex and age group and found the proportions of males and females harvested illegally did not differ by age class ($X^2 = 5.54$, df = 4, $P = 0.236$; Table 3).

Population trends

Minimum population size of black bears has increased during 1979–2011 (Figure 2). Annual population growth rate (λ) for males and females was 1.113 and 1.108, respectively. Bear bait station indices also reflected an increasing population trend based on increased visitation over time ($\beta = 2.14$; $r^2 = 0.94$; min: 12.3% visitation in 1983; max: 76.7% visitation in 2009; Figure 3).

The earliest reported bear-vehicle mortality occurred in 1986. The number of bear-vehicle mortalities increased 8.7% (SE = 0.009, $P < 0.001$) annually after adjusting for county-level vehicle traffic volume. This is further illustrated by an increasing number of bear-vehicle mortalities from 1986–2014 (min = 0 [1987 and 1988]; $\bar{x} = 16.6$; max = 68 [2009]; Figure 4). We also found a positive relationship between the number of bear-vehicle mortalities and the increasing bear population ($\beta = 0.0019$; SE = 0.0002; $r^2 = 0.57$; $P < 0.001$; Figure 5). For subsequent analyses, we omitted 42 bears from the total vehicle-kill (9.3%; 42 of 454) because sex was unknown. Of the remaining 412 bears (253 males and 159 females), we assessed bear-vehicle mortalities by month for male and females. Bear-vehicle mortalities occurred in all months when totaled for all years from 1979–2014 (Figure 6). Proportions of males and females killed by vehicles differed during the year ($X^2 = 29.75$, df = 11, $P = 0.002$); differences in road mortality between males and females were greatest from May to July. However, both sexes (male, 67.3%; female, 47.8%) were more vulnerable to collisions during August to November. We also assessed bear-vehicle mortalities by sex and age group and found the proportions of males and females killed by vehicles differed by age class ($X^2 = 28.59$, df = 4, $P < 0.001$;

Table 1. Number of black bears (*Ursus americanus*) mortalities due to legal harvest, known illegal harvest, and bear-vehicle collisions in northern Georgia, 1979–2014.

Year	Legal harvest	Illegal harvest	Vehicle-kill
1979	21	0	0
1980	32	0	0
1981	18	0	0
1982	27	0	0
1983	18	0	0
1984	18	0	0
1985	23	0	0
1986	17	0	2
1987	24	2	3
1988	64	1	0
1989	40	1	0
1990	89	1	2
1991	59	0	2
1992	73	5	13
1993	125	1	5
1994	111	0	3
1995	156	8	5
1996	102	7	7
1997	158	15	10
1998	197	6	10
1999	218	7	4
2000	242	2	23
2001	225	6	8
2002	206	8	15
2003	257	15	21
2004	156	3	17
2005	258	14	13
2006	249	4	8
2007	285	8	39
2008	320	8	27
2009	423	15	70
2010	286	7	26
2011	531	3	30
2012	260	0	15
2013	386	11	63
2014	147	0	13
Total	5,821	158	454

Table 2. Number of black bears (*Ursus americanus*) harvested (legal and known illegal) by weapon type in northern Georgia, 1979–2014.

	Legal harvest		Illegal harvest	
Weapon type	%	*n*[a]	%	*n*[a]
Archery/crossbow	28.7	1673	18.4	29
Handgun	0.1	7	0.6	1
Muzzleloader	5.8	340	2.5	4
Rifle	64.0	3726	53.2	84
Shotgun	0.2	11	1.9	3
Unknown	1.1	64	23.4	37
Total	100	5821	100	158

a. We censored harvest data where weapon type was unknown.

Table 3. Known sex and age structure of black bear (*Ursus americanus*) mortalities due to legal harvest, known illegal harvest, and bear-vehicle collisions in northern Georgia, 1979–2014.

	Legal harvest			Illegal harvest			Bear-vehicle mortalities		
Age class	**Male (%)**	**Female (%)**	***n*[a]**	**Male (%)**	**Female (%)**	***n*[a]**	**Male (%)**	**Female (%)**	**n[a]**
Cubs[b]	1.0	0.7	93	4.9	5.7	13	5.6	3.7	25
Yearlings[c]	23.1	11.	1898	15.4	14.6	37	22.1	6.0	75
2 year olds	15.5	9.4	1381	12.2	4.9	21	18.7	5.6	65
3 year olds	7.0	5.8	704	8.1	4.9	16	7.9	5.2	35
Adults[d]	6.9	9.4	1459	21.1	8.1	36	10.1	15.0	67
Total	53.5	46.5	5535	61.8	38.2	123	64.4	35.6	267

a. We censored harvest data where age information was unknown.
b. <1 year old.
c. 1 year old.
d. ≥4 years old.

Figure 2. Reconstruction of population size for male and female black bears (*Ursus americanus*) in northern Georgia, 1979–2011. We censored population estimates for 2012–2014 because incomplete age class data were available.

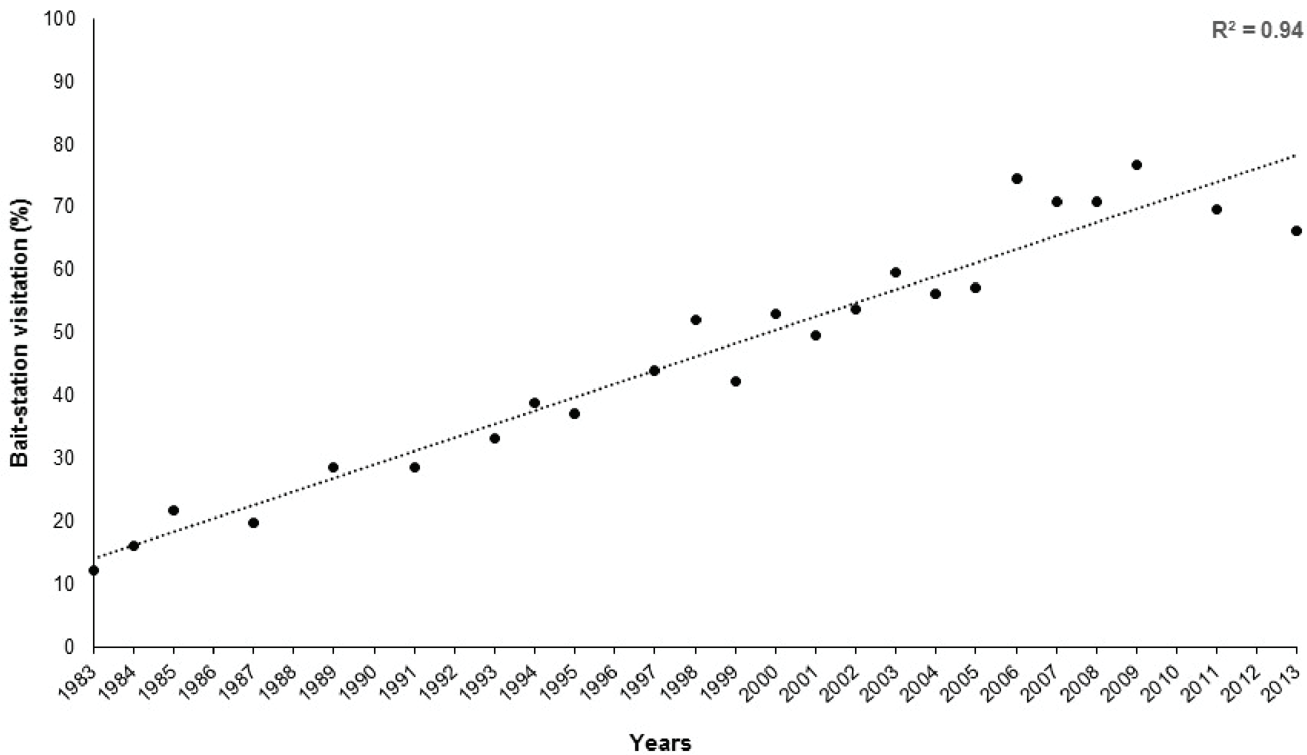

Figure 3. Annual percentage of bait-stations visited by bears (*Ursus americanus*) in northern Georgia, 1983–2013.

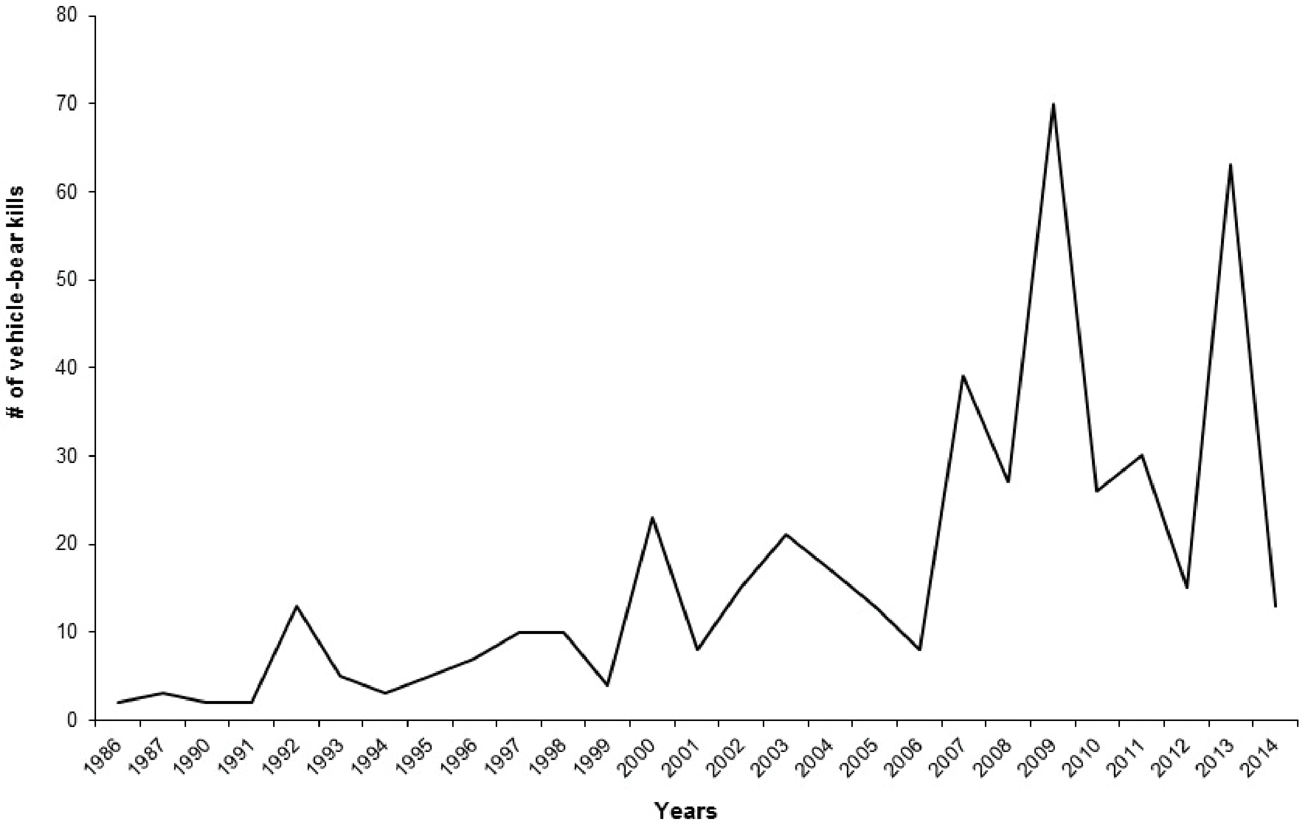

Figure 4. Total number of black bears (*Ursus americanus*) killed by vehicles by year in northern Georgia, 1986–2014.

Table 3). Males (≤2 years old) were most vulnerable to vehicle-collisions; whereas, females (≥4 years old) were most vulnerable to vehicle-collisions (Table 3).

Discussion

Our results illustrate an increasing black bear population over the past 35 years in northern Georgia with 1.113 and 1.108 annual population growth for males and females, respectively. Bear populations have been increasing throughout North America with black bears currently occupying 59% of their historical range (Ripple et al. 2014). Specifically, in the southeastern United States, state agencies have reported increasing black bear population trends (Telesco 2013).

We note that population reconstruction estimates are conservative given that this technique provides minimal population estimates (Davis et al. 2007). State wildlife agencies typically use reconstructed population estimates to identify trends in abundance over time (Tilton 2005). Roseberry and Woolf (1991) noted potential biases in aging and variability in mortality rates and their influence on population reconstruction outcomes. Davis et al. (2007) also found that changes in management and harvest rates during

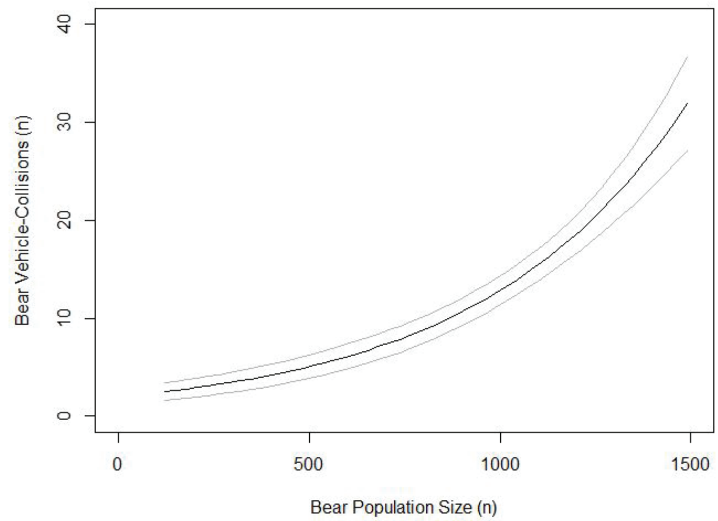

Figure 5. Predicted bear-vehicle collisions based on bear population size in northern Georgia, 1986–2014.

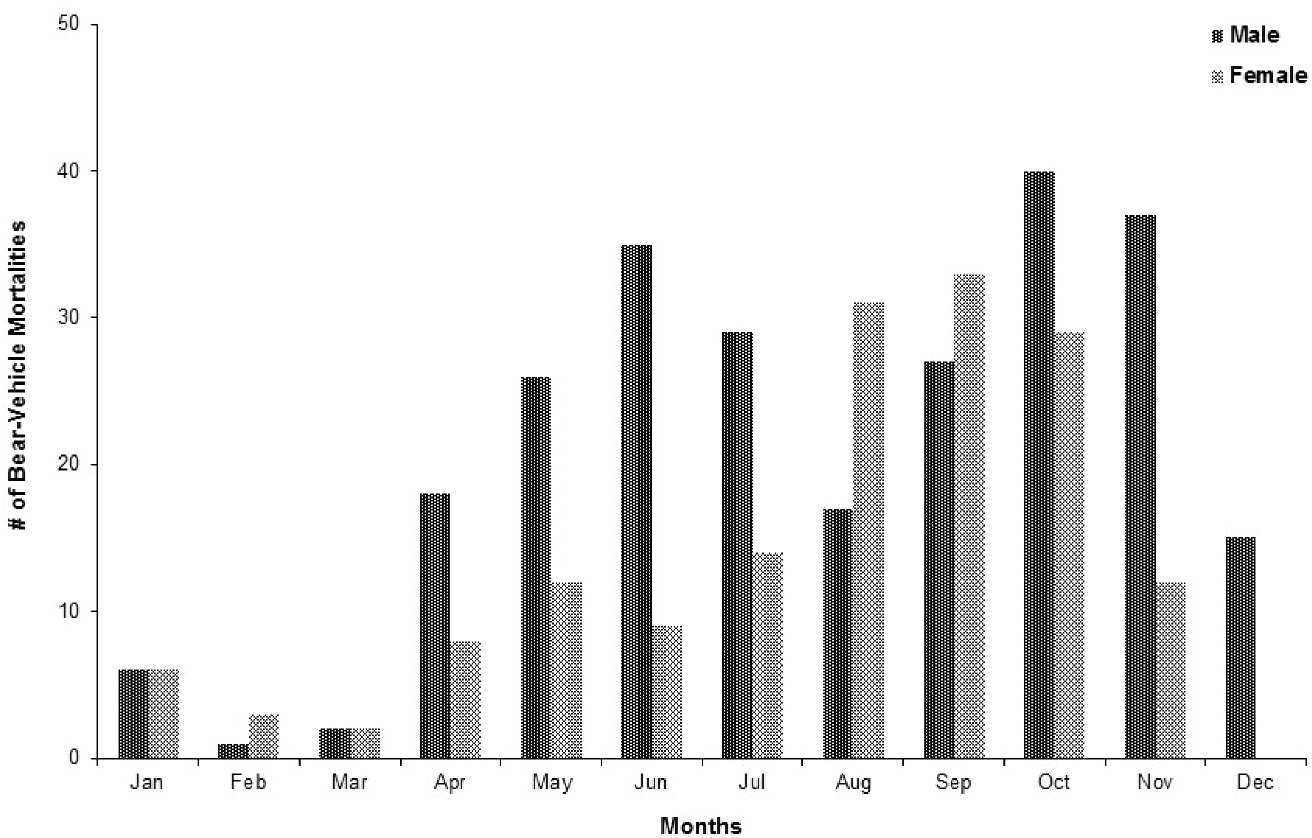

Figure 6. Total number of male and female black bears (*Ursus americanus*) killed by vehicles by month in northern Georgia, 1986–2014.

the reconstruction period would result in an underestimation of the population growth rate. We believe we met all the assumptions of the Downing's population reconstruction method and suggest that our results provide a conservative estimate of population growth. Furthermore, we used bait station indices as additional evidence to support the population reconstruction estimates. Another limiting aspect of population reconstruction is the lack of confidence intervals. We suggest our results be used as an index of abundance because it consistently underestimates true abundance. Future research should focus on new methodologies to improve confidence in black bear population estimates such as statistical population reconstruction (Clawson 2015).

Legal harvest accounted for the majority of bear mortality and was biased towards younger males (≤2 years old), which is likely related to home range size, breeding, and dispersal behaviors (Hamilton 1978, Hellgren and Vaughn 1989). Our results indicate that harvest of younger females (≤2 years old) was lower than younger males (≤2 years old). For example, males (≤2 years old) comprised 74.0% of males harvested; whereas, females (≤2 years old) comprised only 45.8% of females harvested. We did observe increased harvest pressure on older age females (≥4 years old), which is likely related to home range expansion in the fall to find adequate food resources prior to denning (Alt et al. 1980, Rogers 1987, Hellgren and Vaughn 1990).

Our study shows that bear-vehicle mortalities were greater for males relative to females during May to July. Our findings are consistent with previous research (Hamilton 1978, Hellgren and Vaughn 1990, Warburton et al. 1993). Increased movements associated with breeding and dispersal during this time period likely increases their vulnerability to bear-vehicle mortalities (Hamilton 1978, Hellgren and Vaughan 1990). For example, in coastal North Carolina and Virginia, Hellgren and Vaughn (1990) found mean male home range size during early to late summer ranged from 10.7–16.2 km^2; whereas, mean female home range size during early to late summer ranged from 4.6–6.9 km^2.

Bear-vehicle mortalities increased during late summer and fall for both sexes. Our results are supported by previous research that found both sexes were equally vulnerable to vehicle mortalities during the late summer and fall months (Warburton et al. 1993). We suggest the most plausible explanation for the vulnerability to bear-vehicle mortalities amongst sexes during the fall months is the acquisition of food resources. Bears commonly select for high energy foods during fall months to increase fat content (Landers et al. 1979, Rogers 1987) in preparation for the winter denning period. Previous research has also documented extensive home range shifts during late summer and fall months for both males and females (Hellgren and Vaughn 1990). Additionally, they found that home range shifts for females during late summer and fall months were primarily influenced by spatial and temporal distribution in food resources. Similarly, Alt et al. (1980) found female movements were greater than male movements during September and October in northeastern Pennsylvania. We also found vehicle mortalities for females were greater than for males in August and September, suggesting females are moving greater distances to locate food resources.

Management Implications

Overall, our findings provide evidence of an increasing black bear population in northern Georgia with legal rifle harvest acting as the primary source of mortality. The increasing bear population has led, in turn, to increased human-bear conflicts such as bear-vehicle mortalities. We suggest biologists can mitigate human-bear conflicts, if so desired, by adjusting harvest regulations. However, we also suggest biologists consider alternative methods to reduce bear-human conflicts, especially in areas where hunting is not permitted.

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