ESTIMATING BLACK BEAR POPULATION SIZE, GROWTH RATE, AND MINIMUM VIABLE POPULATION USING BAIT STATION SURVEYS AND MARK-RECAPTURE METHODS

by

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ABSTRACT

We initiated bait station surveys for black bears in southwestern Virginia in 1999. Bait station surveys are intended to be used as an index to follow bear population trend over time. We compared the bait station visitation (black bear visitation) to black bear harvest and mast surveys 1999 – 2002. The mean bait station visitation rate during 1999 – 2002 was 15.3% (SE = 2.89, n = 4). The number of bears harvested in the 3 counties that also had bait station surveys was 48 (31 males, 17 females), 59 (44 males, 15 females), 45 (32 males, 13 females), and 43 (26 males, 17 females) in 1999, 2000, 2001, and 2002, respectively. Harvest of males and females differed (n = 2, F = 19.44, df = 1, P = 0.0045). Bait station visitation and female harvest had a strong functional relationship with a negative slope (n = 4, r = -0.78, P = 0.22). The strongest relationship was between male harvest and total harvest (n = 4, r = 0.97, P = 0.03). Mean index to mast production for 1999 – 2002 was 2.3 (range 1.5 – 3.1), 2.7 (range 1.8 – 3.4), 2.3 (range 1.6 – 3.6), and 1.6 (range 1.2 – 2.4), respectively. The overall summary for mast production for the same years was described as fair, good, fair, and poor to fair. Mast production was significantly different between years (n = 4, F = 3.44, df = 3, P = 0.0326), and soft and hard mast production appeared to be above average in 2000. This corresponded with the lowest visitation (10.2%) of the 4 years. There was no correlation between bait station visitation and mast production (n = 4, r = 0.11, P = 0.87).

Since 1998, the annual bear harvest in Virginia has exceeded 900 individuals (with the exception of 824 in 2001), and peaked in 2000 when 1,000 bears were harvested. Though harvest rates were high, a reliable population estimate did not exist for black bears in Virginia. We estimated population size, growth rate, and minimum viable population size using data collected between 1995-2000. We used Jolly-Seber, direct recovery, and minimum population size methods to estimate population size. The Jolly-Seber method estimate of adult female density was 0.23-0.64 bears/km^2, and 0.01 bears/km^2 for adult males. We estimated a density of 0.09-0.23 bears/km^2 for all sex and age classes using direct recovery data. Using minimum population size, we found adult female density was higher than any other sex or age class ($n = 6$, $t = 2.02$, $df = 40$, $P < 0.0001$) with an average density of 0.055 adult females/km^2.

We used mark-recapture data collected from 148 individual bears (96 males:52 females) captured 270 times in program MARK to estimate survival using recapture, dead recovery, and Burnham's combined models. Adult females had the highest survival rate of 0.84-0.86, while yearling males had the lowest with 0.35. Using direct recovery data, adult females again had the highest survival rate with 0.93 (0.83-1.0) and 3-year old males had the lowest with 0.59 (0.35-0.83). We estimated growth rate using population estimates from Jolly-Seber, direct recoveries, and minimum population size methods. The lowest growth rate estimated was for all females (ages lumped) using minimum population size data (λ=0.82). Direct recovery data for all bears (sex and age lumped) during 1995 – 2000 showed the highest positive annual growth rate ($\lambda = 1.24$).

We developed a population model using Mathcad 8 Professional to determine population growth rate, MVP, and harvest effects for an exploited black bear population in southwestern Virginia. We used data collected during the CABS study (1995 – 2000) in the model including population estimates derived from direct recovery data, age and sex specific survival rates, and cub sex ratios. When we used actual population values in the model, the bear population in southwestern Virginia did not go extinct in 100 years ($\lambda = 1.03$, $r = 0.03$). When we reduced adult female survival from 0.94 to 0.89, the probability of extinction in 100 years was 3.0% and $\lambda = 0.99$ ($r = -0.01$; Table 3.2). When the survival was reduced by an additional 0.01 to 0.88, the probability of extinction increased to 13.0% ($\lambda = 0.99$, $r = -0.01$). Growth rate and extinction probabilities were very sensitive to adult female survival rates. Two-year old and 3-year old females did not impact extinction probabilities and growth rates as much as adult females. Their survival could be decreased by 44.0%, and still be less than the 5.0% extinction probability.

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And finally, thank you to all of the bears that made this study possible. I am sorry I tricked many of you into thinking there was food on the other side of the barbed wire, but trust me, it sure beat getting trapped. You have my deepest respect and admiration. And, I still believe there is no better smell in the world than the smell of a bear.

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INTRODUCTION

A reliable estimate of the number of black bears (*Ursus americanus*) in southwestern Virginia does not exist, yet bears are hunted there each year. Bears in Virginia are managed by setting bag limits (e.g., 1 bear/person/season), weight limits, season lengths, and by gating roads on public lands (Martin 1991), but there is no limit on the number of bear licenses sold and the number of bears that can be harvested (Vaughan 1998). Since 1998 the annual bear harvest in Virginia has exceeded 900 (excepting 824 in 2001), and peaked in 2000 when 1,000 bears were harvested. During 1970 – 1988, the annual harvest increased an average 21 bears/year (Martin and Steffen 1998), and may be reason for concern. An increase in number harvested does not necessarily indicate an increasing bear population. If the number of bears harvested continues to increase without managers understanding the dynamics of the bear population, the population could be overharvested. If this occurs, it could take years for the population to recover.

Pressures on the bear population such as fragmentation of habitat, habitat loss, hunting, and environmental factors (e.g., drought, mast failures) can all contribute to a decline in the bear population. It is critically important to learn about the size and growth rate of Virginia's bear population if the population is to be effectively managed.

To date there has not been a comprehensive demographic study on the exploited bear population in Virginia. To address this, the Cooperative Alleghany Bear Study (CABS) was initiated in 1994 by the Virginia Department of Game and Inland Fisheries (VDGIF), in cooperation with Virginia Polytechnic Institute and State University (VPI&SU) and the U. S. Forest Service (USFS). The overall objective of CABS is to develop an understanding of the exploited black bear population in Virginia. Solving some of the unknowns of bear population dynamics will aid wildlife managers in evaluating and predicting population trends, and ultimately allow them to effectively manage Virginia's black bear population (Vaughan 1998). The implications of flawed population management can be serious. Bears have delayed reproductive maturity and low reproductive rates, so a reduced population would need many years to recover. Simulation results by Miller (1990) showed that when reproductive rates were high, natural mortality was low, and harvests were 75% of maximum sustainable rates, a black bear population reduced by 50% would need >17 years to recover.

The overall objective of CABS cannot be met without a better understanding of black bear population dynamics. Results from this thesis will aid in meeting CABS' goals and allow for better management of Virginia's hunted black bear population. Specific objectives were as follows:

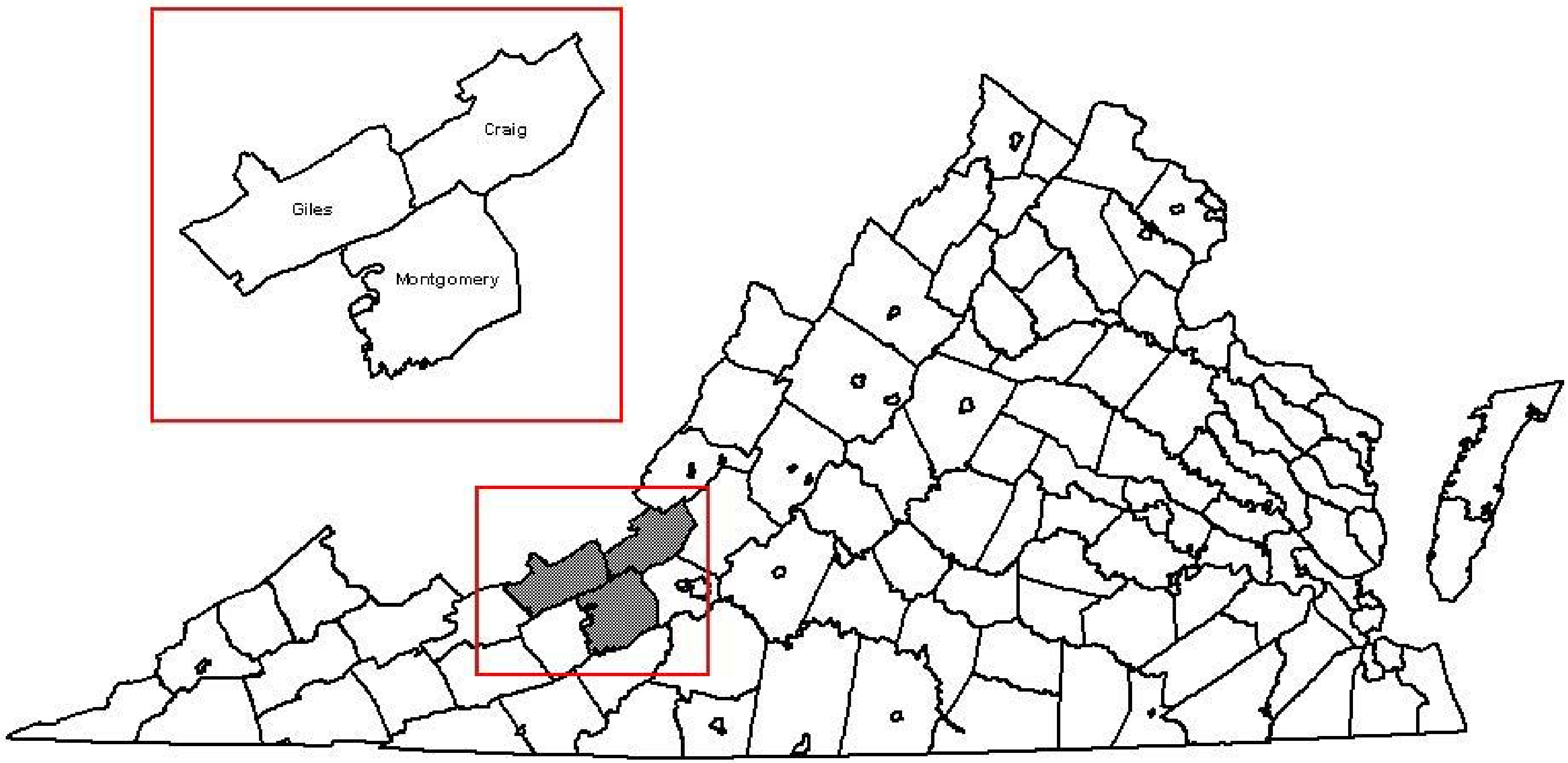
Objectives

1. Analyze mark-recapture data collected since 1995 to estimate population size, growth rate, and minimum viable population for black bears in the southwestern study area of the Cooperative Alleghany Bear Study.
2. Establish bait station surveys and determine the relationship between this index to population size and population size estimates.

STUDY AREA

The 1,544-km^2 southwestern CABS study area in the George Washington – Jefferson National Forest (GWJNF), includes parts of Giles, Montgomery, and Craig Counties (Figure 1). There is an abundance of privately owned properties fragmenting the forest in this study area (Higgins 1997). The study area comprises 33.7% public lands and 66.3% privately owned lands. Elevation ranges from 492 m to 1,378 m. The most dominant tree species found in the steep mountainous areas are hickories (*Carya* sp.), oaks (*Quercus* sp.), poplars (*Populus* sp.), and yellow pine (*Pinus* sp.). The drainages mostly have white pine (*P. strobus*), hemlock (*Tsuga mertensiana*), rhododendron (*Rhododendron maximum*), and mountain laurel (*Kalmia latifolia*) (J. Overcash as cited in Higgins 1997). Annual average temperatures were 7.6°C at Mountain Lake, and ranged from –23.8 to 29.2°C (Klenzendorf 2002). Monthly precipitation ranged from 7cm to 246cm (Ryan 1997).

Figure 1. The southwestern study area of the Cooperative Alleghany Bear Study.



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CHAPTER 1: BAIT STATION SURVEYS

INTRODUCTION

Bait station surveys for black bears are a series of transects with bait or scent placed every 0.8 km to attract bears (Tennessee Wildlife Resources Agency et al. 1983). They are designed so that bear visits are easily identified from other species attracted by the bait. Bait station surveys are intended to be used as an index to follow bear population trend over time.

Bait station survey techniques for bears were first developed and used in the Great Smoky Mountain National Park, Tennessee in the 1970's, and they later were tested in North Carolina, South Carolina, Georgia, and other areas in Tennessee (Tennessee Wildlife Resources Agency et al. 1983). The Idaho Fish and Game Department began conducting bait station surveys using the same techniques used in the southern Appalachians with comparable results (Tennessee Wildlife Resources Agency et al. 1983), which may indicate the technique can be used rangewide. Michigan, Arkansas, Oklahoma, Wisconsin, Minnesota, New Hampshire, Mississippi, Louisiana, and Quebec also have employed bait station surveys as a sampling technique (Tennessee Wildlife Resources Agency et al. 1989).

Not everyone agrees on the efficacy of bait station surveys. Clark (1991) found a positive, but non-linear correlation of bait station visitation rates with population density. Clark claimed it was an unreliable technique for monitoring annual population changes. Visitation to the sites could be affected by environmental factors including weather patterns and food availability, rather than a change in bear density. Conversely, Smith (1983) believed bait station surveys could be used to estimate relative density in Arkansas and based on his study, were reliable when compared to absolute density estimates. Tennessee Wildlife Resources Agency et al. (1989) support bait station surveys as a valid, feasible, and useful methodology to objectively monitor relative density and distribution of black bears. They also stress that consistency in survey protocol is of utmost importance so comparisons may be made across the black bear's range.

Objective

1. Establish bait station surveys and determine the relationship between this index to population size and population size estimates.

METHODS

Bait Stations

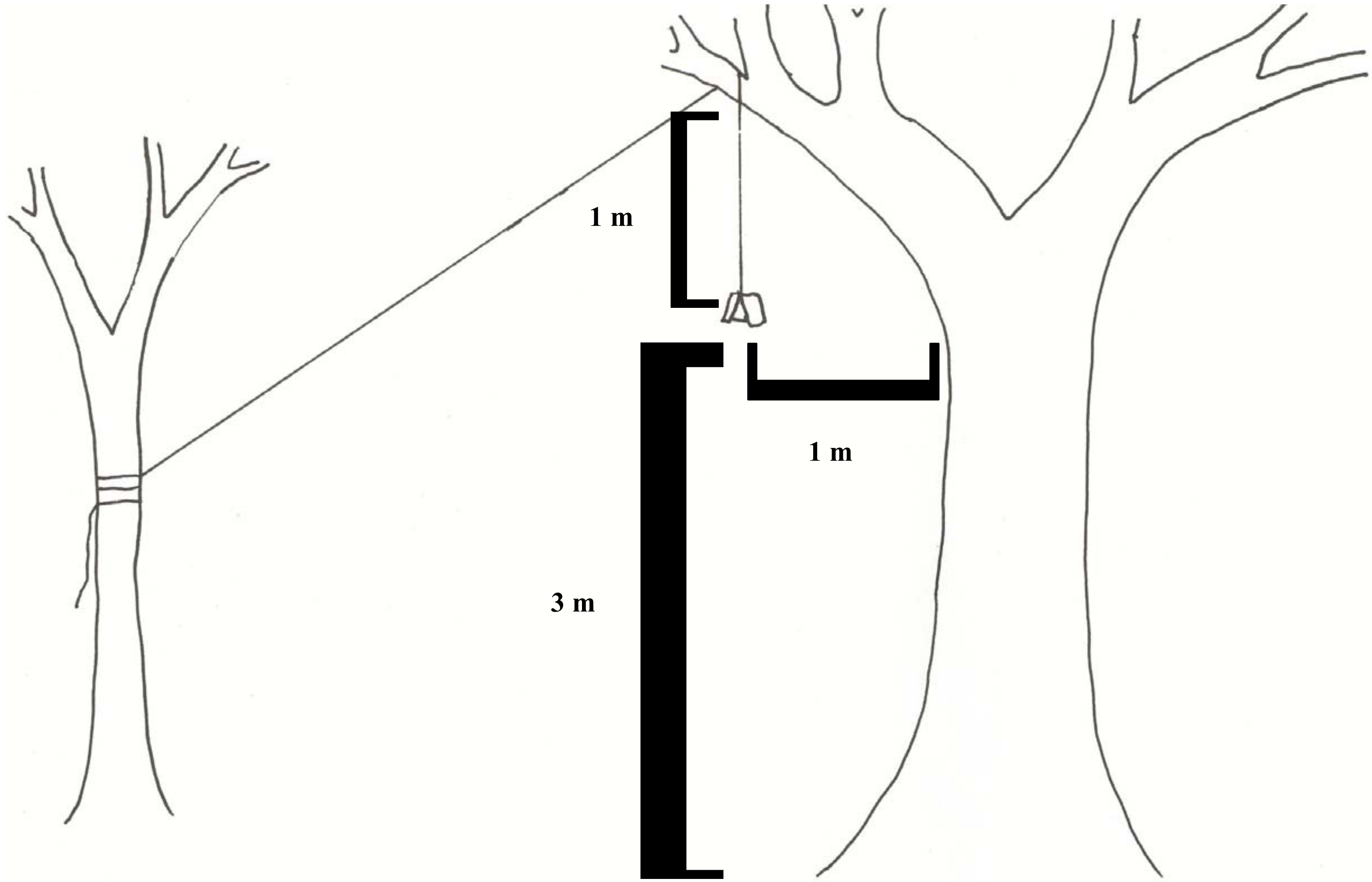
We identified 11 survey routes within the southern study area of CABS, which were at least 8.0 km in length on roads bordered by public lands. CABS and VDGIF personnel ran the surveys between 14 and 28 August 1999, 17 and 30 August 2000, 18 and 29 August 2001, and 14 and 29 August 2002. Three routes were not run in 2001 and 1 was not run in 2002 (Table 1.1).

We established a bait station at the starting point (kilometer 0) of each route and at each 0.8 km thereafter to the end of the route. A bait station consisted of 3 half-opened sardine cans tied together by a string, and hung over a tree limb at a height of 3.0 m above the ground and a distance of 1.0 m from the tree trunk (Figure 1.1). This protocol reduced the likelihood that animals other than bears could reach the bait. We tied the string used to hoist the cans to a tree other than the tree from which the sardine cans were hanging. We selected bait station trees not visible from the road, and on alternate sides of the road for consecutive stations when possible.

We left the baits out for 5 nights and returned on the sixth day to document bear sign and to remove remaining bait. Bear claw marks and damaged or missing cans indicated a bear visit.

I tested for normality of the data using the Kolmogorov-Smirnov test before using a one factor ANOVA and Fisher's LSD to test for visitation differences among years (SAS Institute Inc., Cary, NC). I also compared visitation confidence intervals each year (Johnson 1999) to see if there were differences between years.

Figure 1.1. Schematic of a black bear bait station used in the Cooperative Alleghany Bear Study, southwestern VA, 1999 – 2002.



Density Estimates

I qualitatively compared density estimates I derived in Chapter 2 to bait station visitation for 1999 and 2000. As I only had 2 data points for densities, I could not run correlations

Harvest

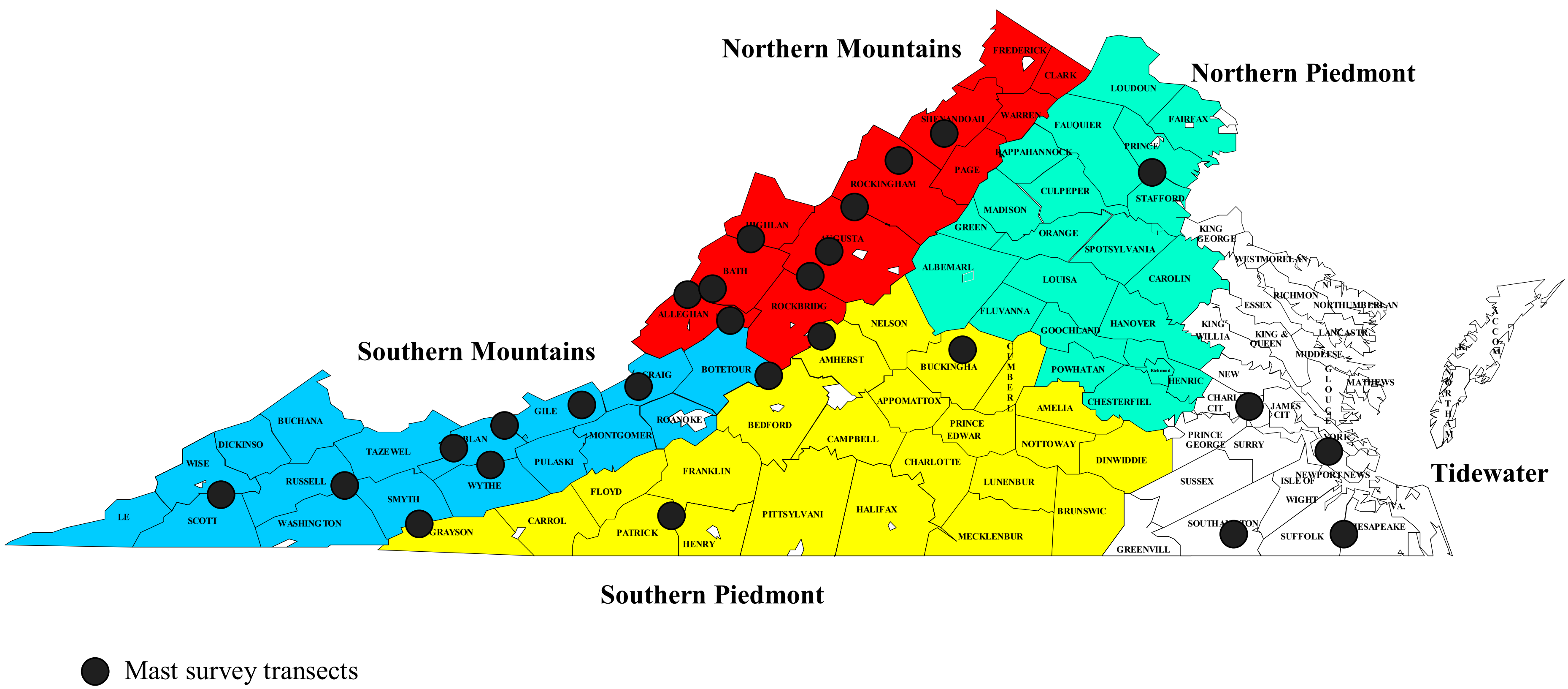
VDGIF collects black bear harvest information at check stations throughout the state. Information recorded includes sex, weight (live or dressed), date and location of kill, type of weapon used, and whether the bear was marked for study (i.e. eartags, tattoo, collar). VDGIF compiles this information by county (Martin and Steffen 1998). I used the data collected for the 3 counties composing my study area - Craig, Giles, and Montgomery counties to determine if there was a relationship between bait station visitation rate and harvest level the same year.

I used a one factor ANOVA and Fisher's LSD (SAS Institute Inc., Cary, NC) to test for differences in number and sex harvested between years, and sex harvested across years. I also compared the confidence intervals (Johnson 1999) of number and sex harvested each year to see if there were differences. I used correlation analysis (SAS Institute Inc., Cary, NC) to compare harvest to bait station visitation by calculating their correlation coefficient.

Mast Surveys

VDGIF personnel estimate mast production (primarily acorns) each year and derive a qualitative rating that they use to draw inferences about the relationship between food abundance and harvest of different species (Coggin and Perry 1973). This information is collected by region (i.e. northern Piedmont, southern mountains) rather than by county. I used mast data collected for the southern mountain region of the state, which covers my entire study area as well as bordering areas (Figure 1.2), for analyses that examined the relationship between mast production and bait station visitation rate. I used a one factor ANOVA and Fisher's LSD (SAS Institute Inc., Cary, NC) to test for between year differences in mast crop. I also compared the confidence intervals (Johnson 1999) of mast production each year to see if there were differences. I used correlation

Figure 1.2. Virginia Department of Game and Inland Fisheries mast survey regions.



analysis (SAS Institute Inc., Cary, NC) to compare mast survey data to bait station visitation by calculating their correlation coefficient.

RESULTS

Bait Stations

The mean bait station visitation rate during 1999 – 2002 was 16.2% (SE = 2.89, n = 4; Table 1.1). The visitation rates were 14.6%, (SE = 4.52, n = 11), 10.2% (SE = 4.88, n = 11), 29.0% (SE = 9.56, n = 8), and 10.8% (SE = 3.35, n = 10) in 1999, 2000, 2001, and 2002, respectively. When only routes that were run every year were compared (n = 7), mean visitation rates were 16.4% (SE = 6.67), 11.2% (SE= 6.49), 31.4% (SE = 10.69), and 14.0% (SE = 4.11) for the same years (Table 1.2).

The data were normally distributed (n = 28, D = 0.18, P = 0.02). Based on visitation alone, results from the 4 survey years indicate the bait station survey failed to detect change in the population size during the sampling period (n = 4, F=1.48, df = 3, P = 0.244). Because there was no difference in population size, I did not perform the Fisher's LSD test. Confidence intervals overlapped also, indicating there was no change in the black bear population size during the sampling period (Table 1.3).

Density Estimates

I compared bait station visitation rates to density estimates derived using minimum population size and direct recoveries. I could not compare visitation rates to estimates derived using the Jolly – Seber model because estimates could not be calculated for the years that the bait stations were run (see Chapter 2). Overall, densities for all sex and age classes increased from 1999 to 2000 while bait station visitation decreased (Table 1.4).

Harvest

The number of bears harvested in the 3 counties covered by bait station surveys was 48 (31 males, 17 females), 59 (44 males, 15 females), 45 (32 males, 13 females), and 43 (26 males, 17 females) in 1999, 2000, 2001, and 2002, respectively. Harvest of males and females differed (n = 2, F = 19.44, df = 1, P = 0.0045, Table 1.5).

Table 1.1. Bait station survey visitation results in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1999 – 2001.

	Number of stations				Number visited by bears				Percent visitation			
Road Name/Location	1999	2000	2001	2002	1999	2000	2001	2002	1999	2000	2001	2002
Brush Mountain	23	19	9	10	5	1	8	2	21.7	5.3	88.9	20.0
Poverty Creek	10	10	10	10	0	0	1	0	0.0	0.0	10.0	0.0
Craig Creek[a]	15	15	0	8	0	0	NA	0	0.0	0.0	NA	0.0
Earn Knob[b]	14	14	16	NA	1	0	2	NA	7.1	0.0	12.5	NA
John's Creek/ Larkin Line	15	15	12	15	1	1	5	4	6.7	6.7	41.7	26.7
Tub Run[a]	29	29	0	28	7	0	NA	0	24.1	0.0	NA	0.0
Butt Mountain[a]	21	21	0	21	3	7	NA	2	14.3	33.3	NA	9.5
Minnie Ball	11	15	15	11	0	0	2	2	0.0	0.0	13.3	18.2
7-Mile Road	15	15	15	15	1	0	3	0	6.7	0.0	20.0	0.0
North Fork	10	10	10	10	4	2	1	1	40.0	20.0	10.0	10.0
Pocahontas	15	15	14	13	6	7	5	3	40.0	46.7	35.7	23.1
Totals	178	178	101	141	28	18	27	14	14.6	10.2	29.0	10.8
Totals all years	**598**				**87**				**16.2**			

[a]These lines were not set in 2001.
[b]This line was not set in 2002.

Table 1.2. Bait station survey visitation results for routes completed every year in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1999 – 2001.

	Number of stations				Number visited by bears				Percent visitation			
Road Name/Location	1999	2000	2001	2002	1999	2000	2001	2002	1999	2000	2001	2002
Brush Mountain	23	19	9	10	5	1	8	2	21.7	5.3	88.9	20.0
Poverty Creek	10	10	10	10	0	0	1	0	0.0	0.0	10.0	0.0
John's Creek/ Larkin Line	15	15	12	15	1	1	5	4	6.7	6.7	41.7	26.7
Minnie Ball	11	15	15	11	0	0	2	2	0.0	0.0	13.3	18.2
7-Mile Road	15	15	15	15	1	0	3	0	6.7	0.0	20.0	0.0
North Fork	10	10	10	10	4	2	1	1	40.0	20.0	10.0	10.0
Pocahontas	15	15	14	13	6	7	5	3	40.0	46.7	35.7	23.1
Totals	99	99	85	84	17	11	25	12	16.4	11.2	31.4	14.0
Totals all years		**367**				**70**				**18.3**		

Table 1.3. Confidence intervals for bait station visitation rates in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1999 – 2001.[a]

	1999	2000	2001	2002
n[b]	7	7	7	7
Mean	16.4	11.2	31.4	14.0
Confidence interval (95%)	(0.1, 32.8)	(0.0, 27.1)	(5.2, 57.5)	(3.9, 24.1)

[a]Using data from routes completed every year.
[b]*n* = number of routes

Table 1.4. Black bear bait station visitation rate and black bear density estimates (bears/km^2) in the southern study area of the Cooperative Alleghany Bear Study, VA, 1999 and 2000.

	1999	2000
Visitation (%)	14.6	10.2
Direct recoveries	**0.21**	**0.23**
Minimum population size		
Female Total	0.050	0.058
Adults	0.042	0.032
3-year olds	0.000	0.009
2-year olds	0.003	0.011
Yearlings	0.003	0.006
Male Total	0.005	0.010
Adults	0.001	0.001
3-year olds	0.000	0.002
2-year olds	0.003	0.004
Yearlings	0.001	0.002
All age and sex classes	**0.054**	**0.068**

Table 1.5. Comparison of male and female mean harvest for Craig, Giles, and Montgomery counties combined, 1999 – 2001, using confidence intervals and P-value.

	Males	Females	P-value
n	4	4	0.0045
Mean	33	15.5	
Standard error	3.9	1.0	
Confidence intervals (95%)	(20.7, 45.3)	(12.5, 18.5)	

Bait station visitation and female harvest were highly correlated with a negative slope (n = 4, r = -0.78, P = 0.22; Table 1.6). The strongest relationship was between male harvest and total harvest (n = 4, r = 0.97, P = 0.03; Table 1.6).

Mast Surveys

In Virginia, mast data collected in the fall is summarized on a 5-point scale ranging from 0 (failure) to 4 (excellent). The numbers correspond with descriptions of the mast crop for the year (Coggin and Perry 1973). Mean index to mast production for 1999 – 2002 was 2.3 (range 1.5 – 3.1), 2.7 (range 1.8 – 3.4), 2.3 (range 1.6 – 3.6), and 1.6 (range 1.2 – 2.4), respectively. The overall summary for mast production for the same years was described as fair, good, fair, and poor to fair. Mast production was significantly different between years (n = 4, F = 3.44, df = 3, P = 0.0326; Table 1.7), and soft and hard mast production appeared to be above average in 2000. There was no correlation between bait station visitation and mast production (n = 4, r = 0.11, P = 0.89; Table 1.6).

DISCUSSION

Bait Stations

Bait station surveys may need to be run for many (>10) years before any relationship to absolute density estimates can be determined. The comparison made in this study between bait station visitation rates and density estimates includes only 4 years of data and is likely to be inconclusive.

The Tennessee Wildlife Resources Agency et al. (1983) suggested a sampling density of 1 bait site per 2.6 km^2. I have not been able to determine why this was a recommendation, but I speculate that by having this many sites, there would be approximately 4 “traps” (bait stations) per home range, which is a general trapping recommendation. If we had followed this recommendation, we would have had established 594 sites covering approximately 475 km of transects in our 1,544 km^2 study area. We were able to establish and monitor only 30.0% (178 sites) of the suggested number in 1999 and 2000, only 17.0% (101 sites) sites in 2001, and 23.7% in 2002. The number of routes and sites were reduced in 2001 due to lack of personnel. If we had the

Table 1.6. Correlation coefficients for relationships between bait station visitation rates, harvest, and mast production (n = 4) in the southern study area of the Cooperative Allegheny Bear Study, VA, 1999-2000.

	Bait Station Visitation Rate	Mast Production	Total Harvest	Male Harvest	Female Harvest
Bait Station Visitation Rate	1.00				
Mast Production	0.11	1.00			
Total Harvest	-0.41	0.83	1.00		
Male Harvest	-0.19	0.90	0.97	1.00	
Female Harvest	-0.78	-0.48	-0.13	-0.38	1.00

Table 1.7. Bait station visitation rates[a], number of bears harvested, and mast production index in the southern study area of the Cooperative Alleghany Bear Study, VA, 1999 – 2001.

	1999	2000	2001	2002	P-value
Visitation (%)	16.4	11.2	31.4	14.0	0.1843
Harvest (actual # harvested)	48	59	45	43	
Mast rating (n = 7 for each year)	2.3	2.7	2.3	1.6	0.0326

[a]Uses data from routes completed every year.

resources to establish and maintain the suggested number of sites for our study area, a clearer trend may have resulted.

Other factors such as extreme weather fluctuations and topography may influence the reliability of the data (Clark 1991). Long-term (> 10 years) data collection may be required before a relationship between visitation and population density is apparent. A study in Great Smoky Mountain National Park, Tennessee, using over 20 years of mast and bait station visitation data showed only a weak correlation between visitation and population size (Frank van Manen, University of Tennessee, pers. comm.). Despite this, van Manen believes bait stations can be used as a general trend indicator, but the trends do not become evident until data have been collected for 5-10 years. Fortunately, the cost and time involved in this type of monitoring is not prohibitive. However, bait station surveys alone are not informative. It is essential that the relationship between bait station surveys and population estimates (e.g., trapping, hair snares) be known before bait stations are used as an index to population trend.

Density Estimates

Density could be estimated only for 1999 and 2000, thus only 2 data points were available to compare with bait station visitation. Since > 2 points are required for correlation analysis, I could not determine the relationship between bait station visitation and population density. However, Klenzendorf (2002) found that bait station visitation and population estimates correlated well ($n = 5$, $r = 0.97$, $P = 0.007$) in the northern study area of CABS. The relationship in the southern study area should be reanalyzed when density estimates and visitation rates for additional years are available.

Harvest

Harvest and mast production were strongly and positively correlated (Table 1.6). When food is plentiful, bears tend to enter dens later, and are available for harvest longer (Beecham et al. 1983). This is particularly true for males and not females. Klenzendorf (2002) supports this claim with data demonstrating when mast was good, harvest was high. We would expect this relationship to lead to a negative relationship between harvest and bait station visitation. Total harvest was only weakly correlated with bait station visitation, but female harvest showed a stronger negative relationship (Table 1.6). This indicates that mast production may have an influence on bait station visitation. Because bait station surveys were conducted prior to peak hard mast, the negative relationship we observed for female harvest may be an artifact of soft mast production. The relationship could be a result of small sample size also.

A better understanding between bait station visitation rates and harvest may be found by separating the study area into counties for data collection. Both harvest and bait station visitation by county is known. However, only 2 bait station transects were run in each of Craig and Montgomery counties. A larger sample size is needed for this comparison.

Another interesting observation from these data was that female harvest is not related to total harvest ($n = 4$, $r = -0.13$, $P = 0.87$; Table 1.6). This suggests that hunters intentionally avoid harvesting females (Inman and Vaughan 2002). This also supports the high adult female survival calculated with direct recovery data (Chapter 2).

Mast Surveys

Bait station visits may be affected by the success or failure of fall mast crops, if bait station surveys are conducted late in the summer, as they are now. Mast fluctuations may have an impact on the effectiveness of this type of survey to predict population shifts and density. Food distribution and availability can affect home range size and movement patterns of black bears (Jonkel and Cowan 1971; Amstrup and Beecham 1976; Young and Ruff 1982; Hellgren 1988). During poor mast years, bears may need to travel more and increase their seasonal homerange to find enough food to sustain them through the winter months (Rogers 1987). If bears increase their mobility, they may encounter more stations yielding a higher visitation rate. This may result in incorrect assumptions that the density of bears is higher or has increased from the previous year. Though bait station surveys are cost effective and may be a valid index after a number of years, they should not be the only factor considered when making management decisions. Mast surveys should be run concurrently and compared annually.

RECOMMENDATIONS

I first want to address using indices in general. One school of thought promotes the use of indices as being worthless and suggests they never should be used (Anderson 2001). Maybe this can be argued for very visible species, or species that are easily captured, however this is not the case with black bears. Studies that do involve capturing and handling are time consuming and costly. If data are available, especially data collected for many years, there is no reason not to look for a trend in the data. As managers, we have to take advantage of the tools that are available to us. For instance, using tag returns, age structure from teeth, houndsmen, nuisance activity, etc. can all be used in combination to effectively manage Virginia's black bear population. If managers did not have the history available, or simply did not use the data at their disposal, there would need to be continual invasive mark recapture studies for black bears. I do believe however, that concurrent mark-recapture studies need to be conducted for at least 10 years so there is a baseline to compare index data.

I used the program MONITOR (Gibbs 1995) to calculate the probability of detecting a 10% increase or decrease in population size, given the number of routes we were conducting. With $\alpha = 0.1$, there was a 0.98 probability of detecting a 10% increase and a 0.57 probability of detecting a 10% decrease in population size over a 10-year period, running 11 routes per year. By doubling the number of routes conducted each year, we improved the probabilities to 1.0 for detecting an increase, and 0.81 for detecting a decrease. Biologists need to identify what is an acceptable probability and how large of a change is important to detect before deciding on the number of routes conducted per year.

To effectively monitor black bear population trends using bait station surveys, the survey needs to be run the same time and manner each year. Though this survey method is low in cost and time, we were unable to find enough people to run the same routes each year due to conflicting responsibilities. A small amount of time needs to be devoted each year to this survey in order to compare across years and get the most accurate results possible.

The 1983 progress report (Tennessee Wildlife Resources Agency et al. 1983) recommends running bait station surveys in July to sample the resident bear population.

They also conducted surveys in spring, summer, and fall to assess seasonal distribution and activities. If lack of time and personnel are the obstacles to running this survey, perhaps running it only during mid-summer may be a good decision to determine trends of the resident population and avoid a "mast-effect."

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CHAPTER 2: ESTIMATING POPULATION SIZE, DENSITY, AND GROWTH RATE USING MARK-RECAPTURE AND HARVEST DATA

INTRODUCTION

Different habitats support markedly different black bear densities throughout their range as demonstrated by the following density estimates for some exploited and unexploited black bear populations in the eastern U.S.: 0.52 – 0.66 bears/km^2 in the Great Dismal Swamp, Virginia (unexploited; Hellgren and Vaughan 1989), 0.67 – 1.04 bears/km^2 in Shenandoah National Park, Virginia (unexploited; Carney 1985), 0.08 and 0.09 bears/km^2 in 2 Arkansas populations (unexploited; Clark 1991), 0.30 bears/km^2 in Arkansas (unexploited; Smith 1983), 0.27 bears/km^2 in Massachusetts (exploited; Garshelis 1994), 0.19 and 0.20 bears/km^2 in Maine (exploited; McLaughlin et al. 1994), and 0.29 bears/km^2 in Great Smoky Mountain National Park (GSMNP), Tennessee (unexploited; Eiler et al. 1989).

Food availability also can affect bear densities. For instance, Elowe and Dodge (1989) reported that fall mast crop fluctuations in Massachusetts influenced black bear reproduction and their densities. Female bears on diets low in fat and carbohydrates did not produce cubs, while those with a high fat and carbohydrate diet produced cubs. Rogers (1976) and Elowe and Dodge (1989) concluded that fluctuations in the availability of natural foods were important in regulating bear populations. Kasbohm et al. (1995) found that bears easily switched from hard mast to soft mast when acorn crops failed, but Rogers (1987) noted that black bears could not successfully turn to a food source normally unexploited by them, if one of their primary crops fails. For instance, they do not have the physiological capability to efficiently rely on grasses and forbs, or the agility for efficient predation. Rogers (1987) documented a 35% population decline during 3 consecutive poor mast years and attributed it to reproductive failure and deaths of cubs and yearlings. Population density appeared to be directly correlated with food supply in a black bear population in Washington (Jonkel and Cowan 1971).

Density dependent growth in black bear populations has not been reported (Garshelis 1994). In Massachusetts, an increase in bear population growth rate and density apparently led to intra-specific cannibalism, aggression, and predation (Elowe and Dodge 1989), although Rogers (1987) did not find any clear documentation of this in his 16-year study of black bears in Minnesota. Using a modified population model for black bears, Clark and Smith (1994) calculated finite growth rates of 1.05 and 1.29 for 2 populations in Arkansas with densities of 0.08 and 0.09 bears/km^2, respectively.

The sex ratio (Harris 1984, cited in Miller 1990) and the age structure of a harvest are indicators of population status. However, in Virginia the harvest may not directly reflect the composition of the population because hunters there avoided shooting collared bears, most of which were females (Higgins 1997; Klenzendorf 2002). Hunter impact on the black bear population is another factor that is difficult to identify and assess. Hunters in Virginia buy a big game license, which allows them to hunt deer, turkeys, and bears (M. R. Vaughan, VPI&SU, pers. comm.), but prevents accurately calculating hunter effort, hunter success, and ultimately hunter impact on any 1 of the 3 big game species. More accurate harvest rate estimates may provide a better understanding of hunter impact.

Bear managers must incorporate sources of significant mortality, other than harvest, into bear management efforts. Nuisance kills, crippling loss, poaching, (Miller 1990), and roadkills could represent a significant portion of annual mortality, which must not be ignored.

Objective

1. Analyze mark-recapture data collected since 1995 to estimate population size, growth rate, and minimum viable population for black bears in the southwestern study area of the Cooperative Alleghany Bear Study.

METHODS

Capture and Handling

During 1995 – 2000, we trapped black bears from the first week of June through late August (end date at least 45 days prior to the archery hunting season in October). We used modified Aldrich foot snares and culvert traps to trap bears. The number of trap lines and traps set varied depending on VDGIF personnel and graduate student availability. We determined trap sites in May of each year by identifying suitable habitat, reviewing past trapping experience, and locating recent bear sign. We pre-baited trap sites with donuts, pastries, and molasses prior to setting traps. We hung bait in trees at a minimum height of 3.0 m, and also placed bait under large, heavy rocks. We pre-baited for 2 weeks or until there was sign (e.g., claw marks, scat) of a bear visitation, whichever came first. We set snares and culverts at bait sites where bear visitation was documented.

We immobilized trapped bears with a 2:1 mixture of ketamine hydrochloride: xylazine hydrochloride (Rompun) using a blowpipe, jab stick, or dart gun. We administered the drug at a dosage of 1.0 cc ketamine:Rompun/44 kg body weight. We fitted suitable bears (males: ~68.0 kg to ~114.0 kg and females > ~36.0 kg) with radio collars (LOTEK, Wildlife Materials Inc., Telonics, and Advanced Telemetry Systems; 150 – 151 MHz.) with 30-minute, 4-hour, 5-hour, and 8-hour mortality delays and a breakaway cotton spacer (Hellgren et al. 1988). Small bears (<36.0 kg) received eartag transmitters (Advanced Telemetry Systems) equipped with a 12 hours on-12 hours off switch function, and a 4-hour mortality delay. We marked all captured bears with numbered black plastic ear tags and a tattoo of the same number on the inside of their upper lip. We extracted a vestigial premolar and sent it to Matson's Laboratory, LLC (Milltown, MT) for age determination (Willey 1974), and collected blood and hair samples. We took morphological measurements and assessed overall body condition. We fitted recaptured bears with new collars and spacers or ear tag transmitters, replaced black plastic ear tags, and re-tattooed as necessary. We attempted to have at least 30 bears (23 females and 7 males) fitted with radios (collar or ear tag) by each summers' end. We recorded all data collected on a capture data sheet.

Population Estimation

The effective sampling area was delineated by applying a homerange buffer around each road trapped (Clark and Smith 1994, Otis et al 1978, Costello et al 2001). This buffer was equal to the mean homerange radius for male and female bears. Homerange size used was 15 km^2 (2.19 km radius) for females and 169 km^2 (7.33 km radius) for males (Hellgren 1988, Kasbohm 1994). The area sampled was calculated by year for both sexes using ArcView.

Jolly-Seber

I estimated population size and density for adult males and adult females using the Jolly-Seber open population model (Seber 1982) for mark-recapture data collected from 1995 through 2000 in Microsoft Excel. One year's trapping data was considered one trapping period and recaptures within the period were ignored. I calculated male and female density for the effective sampling area, and extrapolated it to the entire 1,544 km^2 study area.

Direct recoveries

I also estimated population size using a direct recovery model. I used a closed Lincoln – Petersen model with Chapman's (1951) modification: $N = \frac{(n_1+1)*(n_2+1)}{(m_2+1)} - 1$, where n_1 is the number of marked animals in the population, n_2 is the number of animals recaptured, and m_2 is the number of marked animals recaptured. I estimated confidence intervals using the Poisson approximation, $n_1 * n_2$ * (upper and lower limit factor from Poisson Table) (Chapman 1948).

Bears caught during the summer were the marked sample, and bears harvested that same year were considered the recapture sample. Bears that were trapped within the study area, but harvested outside were excluded from analysis. I lumped all sex and age classes, except for cubs, to have a large enough sample size to use the model. I used the entire 1,544 km^2 study area to estimate density.

Minimum population size

I reconstructed the resident bear population (Eberhardt and Knight 1996) by counting individuals that I knew to be in the study area. No dispersal of adult females was observed on our study area, so if an adult female was captured, she was "back-counted" and considered a resident from the age of 4. Adult males moved on and off of the study area sporadically, so they were only counted as residents during the years they were captured. I counted yearlings, 2-year olds, and 3-year olds only for the years they were captured. I calculated densities for the effective sampling area for all of the above age and sex classes, and extrapolated them to the entire 1,544 km^2 study area. I also calculated density and population size for all sex and age classes lumped. I tested for density differences between sex and age classes using a one factor ANOVA and Fisher's LSD.

Survival

Cormack Jolly-Seber

I used program MARK (White 1995), to estimate survival for yearlings, 2 – year olds, 3 – year olds, and adults of both sexes using live encounter and mortality data collected between 1995 and 2000. Causes of bear mortalities included those from handling, roadkills, unknown causes, and harvest. I first used the standard Cormack-Jolly-Seber (CJS; Cormack 1964) method with live encounter data to estimate survival for the sex and age classes listed above. Capture data from the first summer (1995) were considered the initial marked sample, and capture data from the following summers (1996 – 2000) were the recaptured samples. I used data for all sex and age classes in the same model to increase sample sizes (e.g., after the first year in the model a 3-year old became an adult). I chose the most parsimonious model based on Akaike's Information Criterion (AIC) values (Burnham et al 1995).

Burnham model

I also used MARK to calculate separate survival rates for adult males and adult females using a combination of live encounter and recovery data (Burnham 1993) for 1995 – 2000. I used only data collected for the adult age (4+ years) class for both sexes as opposed to the previously described method. This method allows both live encounter and recovery data to be used simultaneously to estimate survival, and calculates the fidelity (F) of the individual to the study area between capture periods, as well as a reporting probability (r) of the individual's death between capture periods. I chose the most parsimonious model based on Akaike's Information Criterion (AIC) values (Burnham et al 1995).

Direct recoveries

I used direct recovery data to calculate harvest survival and assumed non-harvest survival to be 1.0. I calculated harvest survival for each age and sex class for each year between 1995 and 2000. The harvest survival estimate was the 6-year average for each age and sex class.

Growth Rate

I used results from population estimation methods described above to estimate growth rate for the bear population as a whole (age and sex classes lumped), as well as for individual sex and age classes. I estimated the finite rate of increase (λ) using the equation $\lambda^t = \frac{N_t}{N_0}$, where N_t is the population size at time t, and N_0 is the initial population size. I estimated the intrinsic rate of increase using $\lambda = e^r$.

RESULTS

Capture and Handling

We handled 180 bears 307 times during the summer capture seasons between 1995 – 2000. Due to incomplete records, I used only 148 bears (96 males, 52 females) handled 270 times during the same period for the analyses (Table 2.1). Trapping success was not calculated for 1995 because of incomplete records. Trapping effort varied between 7.4 trapnights/capture in 1998, to 15.5 trapnights/capture in 1999 (Table 2.2). There were 73 known mortalities of marked bears from the beginning of the study (June 1995) through hunting season 2000 (6 January 2001).

Population Estimation

The effective sampling area varied across years. It ranged from 139.6 – 348.9 km^2 for females, and 743.5 – 2,247.2 km^2 for males (Table 2.3).

Jolly-Seber

I calculated densities of adult females for 1996 through 1998 and adult males for 1997 (Table 2.4). Estimated density of adult females ranged from 0.23 – 0.64 bears/km^2 resulting in a population size of 359 – 994 adult females on the study area during the 3 years. The estimated density of adult males in 1997 was 0.01 bears/km^2 for a total of 21 bears in the study area in 1997. Based on these data, the ratio of adult males to adult females in 1997 was 1:47. I could not calculate densities for other age classes, as the study spanned 6 years, and bears within these age classes (i.e., yearlings, 2-year olds, and 3-year olds) remained in the age class for only 1 year.

Table 2.1. Summary of black bear captures and mortalities in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

	Females					Males					
Capture Type	Adult	3-year olds	2-year olds	Yearlings	Cubs	Adults	3-year olds	2-year olds	Yearlings	Cubs	Total
Original	21	8	14	6	3	10	14	39	28	5	148
Repeat	32	4	5	5	-	16	23	21	14	2	122
Mortalities											73
Legal harvest	8	3	1	1	-	13	8	14	13	-	61
Indirect handling[a]	-	-	-	3	-	-	-	-	-	-	3
Direct handling	1[b]	-	-	-	-	-	-	1[c]	-	-	2
Illegal harvest	-	-	1	-	-	-	-	-	1	-	2
Crippling loss	1	-	-	-	-	-	-	-	-	-	1
Self-defense	-	-	-	-	-	1	-	-	-	-	1
Roadkill	-	-	-	-	-	-	1	-	-	-	1
Natural[d]	1	-	-	-	-	-	-	-	-	-	1
Unknown	1	-	-	-	-	-	-	-	-	-	1

[a]All were killed by another bear while caught in snare.
[b]Suffocated in den tree after being immobilized.
[c]Died from drug reaction.
[d]Apparently fell from tree

Table 2.2. Trapping success (effort/capture) in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1996 – 2000.

Year	Effort (trapnights)	Captures	Trapping success (effort/capture)
1996	892	67	13.3
1997	304	37	8.2
1998	250	34	7.4
1999	557	36	15.5
2000	578	63	9.2

Table 2.3. Effective sampling area (km^2) for male and female black bears in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

Sex	1995	1996	1997	1998	1999	2000
Female	176	169	140	227	288	349
Male	743	1041	901	1290	1580	2247

Table 2.4. Jolly – Seber density estimates (bears/km^2) for adult males and adult females in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1996 – 1998.

	1996		1997		1998	
Sex	Density	Pop. Size	Density	Pop. Size	Density	Pop. Size
Male	-	-	0.013	21	-	-
Female	0.353	545	0.644	994	0.232	359

Direct recoveries

The estimated number of black bears for the 1,544 km^2 study area ranged from a low of 138 in 1995 to a high of 359 individuals in 2000. Density estimates for the same time period ranged from 0.09 – 0.23 bears/km^2 (Table 2.5). Confidence intervals overlapped indicating a stable population over the 6-year period. Harvest rates of marked bears ranged from a low of 0.12 in 1997 and 1999 to a high of 0.30 in 1996 and 1998 (Table 2.5). The mean harvest rate of marked bears for the study period was 0.21.

Minimum population size

Adult female density was higher than any other sex or age class and ranged from 0.03 – 0.08 bears/km^2, resulting in a minimum population of 49 – 119 adult females on the study area during 1995 – 2000 (Table 2.6). Mean density of adult females was greater ($n = 6$, $t = 2.02$, $df = 40$, $P < 0.05$) than all other sex and age classes (Table 2.7). Results indicate that the population of all sex and age classes generally decreased, over the 5-year period (Table 2.6). However, this may be a result of reduced trapping success.

Survival

At least 73 (52 males, 21 females) marked bears died from summer 1995 through winter 2000 (Table 2.1). Sixty-one of the 73 marked bears (83.6%) were legally harvested. Other causes of mortality included roadkill, natural and unknown causes, self-defense, crippling loss, direct and indirect handling, and illegal harvest.

Cormack-Jolly-Seber

The numbers of recaptures were insufficient to calculate survival estimates using the CJS method in MARK except for adult females. Estimates using both live encounters and dead recoveries were derived for all other sex and age classes.

Burnham model

Annual survival estimates for adult females using 2 methods and 3 different models were similar (Tables 2.8 and 2.9) and confidence intervals for the 3 overlapped. Confidence intervals for adult male survival estimates also overlapped in the 2 models used. Adult females had the highest survival rate (0.84, 0.85, and 0.86), followed by yearling females (0.81) and adult males (0.77 and 0.80; Tables 2.8 and 2.9). Yearling

Table 2.5. Population estimates, density estimates (bears/km^2), and harvest rates of black bears using direct recovery data in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

	Year					
	1995	1996	1997	1998	1999	2000
Marked bears (n_1)	44	47	33	27	26	47
Harvested bears (n_2)	39	76	35	95	48	59
Marked harvested bears (m_2)	12	14	4	8	3	7
Population estimate[a]	138	246	244	298	330	359
Standard error	25.64	45.83	85.65	74.06	130.83	101.98
Confidence intervals (95%)[b]	(73, 253)	(137, 433)	(80, 853)	(135, 657)	(92, 1536)	(156, 857)
Density (bear/km^2)	0.09	0.16	0.16	0.19	0.21	0.23
Confidence intervals (95%)	(0.05, 0.16)	(0.09, 0.28)	(0.05, 0.55)	(0.09, 0.43)	(0.06, 0.99)	(0.10, 0.56)
Harvest rate	0.27	0.30	0.12	0.30	0.12	0.15

[a] $N = \frac{(n_1+1)*(n_2+1)}{(m_2+1)} - 1$; Chapman 1951

[b] $n_1 * n_2$ * (upper and lower limit factor from Poisson Table); Chapman 1948

Table 2.6. Density (bears/km^2) and population size estimates using minimum population size data for all sex and age classes for the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

	Year											
	1995		1996		1997		1998		1999		2000	
	Density	Pop. size	Density	Pop. size	Density	Pop. size	Density	Pop. size	Density	Pop. size	Density	Pop. size
Male Total	0.019	30	0.019	30	0.018	28	0.005	7	0.005	7	0.010	15
Adult	0.003	5	0.003	5	0.003	6	0.001	2	0.001	1	0.001	3
3 year-olds	0.004	7	0.002	3	0.004	7	0.002	3	0	0	0.002	3
2 year-olds	0.005	9	0.007	11	0.006	9	0	0	0.003	4	0.004	6
Yearlings	0.005	9	0.007	11	0.003	6	0.001	2	0.001	2	0.002	3
Female Total	0.109	169	0.107	165	0.109	168	0.067	103	0.050	77	0.058	90
Adult	0.063	97	0.077	119	0.072	111	0.048	75	0.042	65	0.032	49
3 year-olds	0.011	18	0	0	0.029	45	0	0	0	0	0.009	14
2 year-olds	0.017	27	0.030	46	0.007	12	0.004	7	0.003	6	0.115	18
Yearlings	0.017	27	0	0	0	0	0.013	21	0.003	6	0.006	9
Grand Total	**0.129**	**199**	**0.126**	**195**	**0.127**	**196**	**0.071**	**110**	**0.054**	**84**	**0.068**	**105**

Table 2.7. Sex and age class mean density differences using minimum population size data and Fisher's LSD for the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995-2000. Classes with the same letter are not different (n = 6, t = 2.02, df = 40, P < 0.05) from each other.

Age and sex class	Mean density (bears/km^2)	t-grouping		
Adult Female	0.055	A		
2-Year Old Female	0.012		B	
3-Year Old Female	0.008		B	C
Yearling Female	0.007		B	C
2-Year Old Male	0.004		B	C
Yearling Male	0.003		B	C
3-Year Old Male	0.002		B	C
Adult Male	0.002			C

Table 2.8. Annual survival estimates for all sex and age classes using live encounter and dead recovery data from the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000 using the model {Phi(different across groups, time constant) p(different across groups and years) r(different across groups and years) F(group constant, different across years)}. Phi for 2- and 3-year old females was lumped. The model used data collected from all 8 sex and age classes.

Sex and age class	Survival rate	Confidence interval (95%)	GOF[a] (P – value)
Adult female	0.86	0.67 – 0.95	< 0.001
3-year old female	0.64	0.44 – 0.79	
2-year old female	0.64	0.44 – 0.79	
Yearling female	0.81	0.59 – 0.93	
Adult male	0.77	0.47 – 0.93	
3-year old male	0.50	0.31 – 0.69	
2-year old male	0.51	0.37 – 0.65	
Yearling male	0.35	0.21 – 0.52	

[a]Goodness of Fit test

Table 2.9. Annual survival estimates for adult females and adult males using live encounter and dead recovery data in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000. Each model used data collected on either adult females or adult males only.

Model	GOF[a] (p-value)	Sex and age class	Recapture rate (p)	Confidence interval (95%)	Survival rate	Confidence interval (95%)
{Phi(constant) p(constant)}[b]	0.15	Adult female	0.32	0.15 – 0.56	0.84	0.50 – 0.96
{Phi(constant) p(constant) r(year) F(year)}[c]	0.02	Adult female	0.41	0.24 – 0.61	0.85	0.72 – 0.93
{Phi(constant) p(constant) r(year) F(year)}[c]	0.08	Adult male	0.27	0.09 – 0.59	0.80	0.59 – 0.92

[a]Goodness of Fit test

[b]CJS model – only live encounter data were used

[c]Burnham model – both live encounter and dead recovery data were used

males (0.35) and subadult males (0.50 and 0.51) had the lowest and second lowest survival rates (Table 2.8).

Direct recoveries

The 6-year average of harvest survival rates showed adult females with the highest survival of 0.94 and 3-year old males with the lowest of 0.59 (Table 2.10). Adult females and 3-year-old males were the only age and sex class whose confidence intervals did not overlap.

Growth Rate

Using population estimates from Jolly – Seber, direct recoveries, and minimum population size methods, I estimated average growth rates for the black bear population in the study area. The data showed an increasing population for the Jolly-Seber and direct recoveries methods (Table 2.11). The male population also showed positive growth rate for the minimum population size method. The lowest growth rate estimated was for all females (ages lumped) using minimum population size data between 1996 and 1998 ($\lambda = 0.82$). Direct recovery data for all bears (sex and age lumped) during 1995 – 2000 showed the highest positive growth rate ($\lambda = 1.24$).

DISCUSSION

Population Estimation

The effective sampling area was estimated by placing homerange buffers around roads trapped during 1995 – 2000. More accurate population estimates may have resulted had buffers been placed around individual trapsites rather than roads. I could not calculate the effective sampling area this way because all trap sites were not accurately defined each year. UTM coordinates were not recorded for some traps, while other trapsites were not accounted for if no bears were captured at that location. I knew which roads were trapped each year, as well as approximate beginning and ending points (some year's data were better than others). Though there is some error included in calculating the effective sampling area, I believe the error is negligible and would not significantly alter the density estimate.

Table 2.10. Annual harvest survival estimates for all sex and age classes using direct recovery data from the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

Sex and age class	Survival rate	Standard error	Confidence interval (95%)
Adult female	0.93	0.10	0.83 - 1.0
3-year old female	0.83	0.41	0.40 - 1.0
2-year old female	0.81	0.31	0.49 - 1.0
Yearling female	0.92	0.20	0.71 - 1.0
Adult male	0.85	0.17	0.67 - 1.0
3-year old male	0.59	0.23	0.35 - 0.83
2-year old male	0.75	0.17	0.57 - 0.93
Yearling male	0.72	0.22	0.49 - 0.95

Table 2.11. Finite and instantaneous rates of increase for black bears in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995 – 2000.

Population estimation method	Sex and age class	Years included	r	λ	Population status
Jolly – Seber	Adult females	1996 – 1998	0.09	1.09	Increasing
Direct recoveries	All age and sex lumped	1996 – 1998	0.10	1.11	Increasing
" "	" "	1995 – 2000	0.22	1.24	Increasing
Minimum population size	All females	1996 – 1998	-0.20	0.82	Decreasing
" "	" "	1995 – 2000	-0.09	0.91	Decreasing
" "	All males	1995 – 2000	-0.14	0.87	Decreasing
" "	All age and sex lumped	1995 – 2000	0.06	1.06	Increasing

Density estimates from this study, although comparable to other exploited populations in the eastern United States, were lower on average (Table 2.12). Density estimates for the northern study area of CABS had remarkably higher (8-10-fold) density estimates than the southern study area.

Though the effective sampling area generally increased from 1995 – 2000, trap success and number of captures did not (Table 2.13). I compared these data by calculating their correlation coefficients and I did not find functional relationships between area sampled and trapping success or number of bears caught (Table 2.14).

Instead of trapping new areas with minimal personnel, we would have been better served to focus attention on trapping and retrapping areas during the same summer in order to estimate densities using a closed Lincoln – Petersen model. The modified Lincoln – Petersen method, using live encounter and dead recovery data, in this study produced estimates similar to other black bear studies in the United States. The sampling period for this method is shorter than with the Jolly – Seber and minimum population size methods, and reduces the likelihood of data being confounded by immigration/emigration and births/deaths. I believe having another density estimate using live encounter data with the Lincoln – Petersen method would have supported and strengthened the estimates calculated using the direct recovery method.

Jolly – Seber

Assumptions for the Jolly – Seber method (Seber, 1973) are:

1) All animals which are alive and in the population when a sample is taken have the same probability of being caught in that sample,
2) all marked animals have the same probability of surviving and remaining in the population from the i^{th} to the $(i + 1)^{th}$ sample,
3) all animals caught in a sample have the same probability of being returned to the population,
4) no marks are lost, and all samples are instantaneous (i.e., sampling time is negligible).

Assumptions 1, 2, and 4, were difficult to meet for this study, making this model, and subsequently the estimations, inappropriate to use for these data. The first assumption is clearly

Table 2.12. Density estimates (bears/km^2) for black bear populations in the eastern United States.

State	Status	Density estimate (bears/km^2)	Citation
Maine	Hunted	0.19 and 0.20	McLaughlin et al. 1994
Arkansas	Not hunted	0.08 and 0.09	Clark 1991
Massachusetts	Hunted	0.27	Fuller, cited in Garshelis 1994
Virginia	Hunted	0.05 – 0.13	This study
Virginia	Hunted	0.09 – 0.27	This study
Virginia	Hunted	0.68 – 0.73	Klenzendorf 2002
Virginia	Hunted	0.55 – 1.03	Klenzendorf 2002
Virginia	Hunted	0.66 – 1.03	Klenzendorf 2002
Virginia	Not hunted	0.52 – 0.66	Hellgren and Vaughan 1989
Virginia	Not hunted	0.67 – 1.04	Carney 1985
Arkansas	Not hunted	0.30	Smith 1983
Tennessee	Not hunted	0.29	Eiler et al. 1989

Table 2.13. Comparison of effective sampling area (km^2), number of captures, trapnights/capture, and trapping success (captures/trapnight) in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995–2000.

	1995	1996	1997	1998	1999	2000
Effective sampling area						
Female	176	169	140	227	288	349
Male	743	1041	901	1,290	1,580	2,247
Number of captures	--	67	37	34	36	63
Trapnights/capture	--	13.3	8.2	7.4	15.5	9.2
Trapping success (%)	--	7.5	12.2	13.6	6.5	10.9

Table 2.14. Correlation coefficients for relationships between female and male effective sampling areas, number of captures, and trapping success (n = 6) in the southern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995-2000.

	Female effective sampling area	Male effective sampling area	Number of captures	Trapping success
Female effective sampling area	1.00			
Male effective sampling area	0.98	1.00		
Number of captures	0.18	0.31	1.00	
Trapping success	-0.15	-0.07	-0.34	1.00

violated as shown by the male:female capture ratio of 1.8:1 (n = 148, Z = -3.617; P = 0.0003) and population estimates which demonstrate the female segment of the population is much higher than the male segment (Tables 2.4 and 2.6).

After examining harvest data of marked bears, the second assumption of all animals having the same probability of surviving and remaining in the population from 1 sampling period to the next is apparently violated also (Fig 2.1). The proportion of marked males in the harvest (78.7%) compared to marked females in the harvest (21.3%) is different from 1:1 (n = 61, Z = -4.48, P < 0.0001), demonstrating that males have less chance than females to remain in the population to be recaptured.

Regarding the fourth assumption, we know from our capture histories that some bears lose their eartags, and that some tattoos fade beyond recognition. Thus, marked harvested bears may be overlooked at check stations and simply not recorded. Although poaching does not appear to be high, marked bears that are taken illegally are not reported.

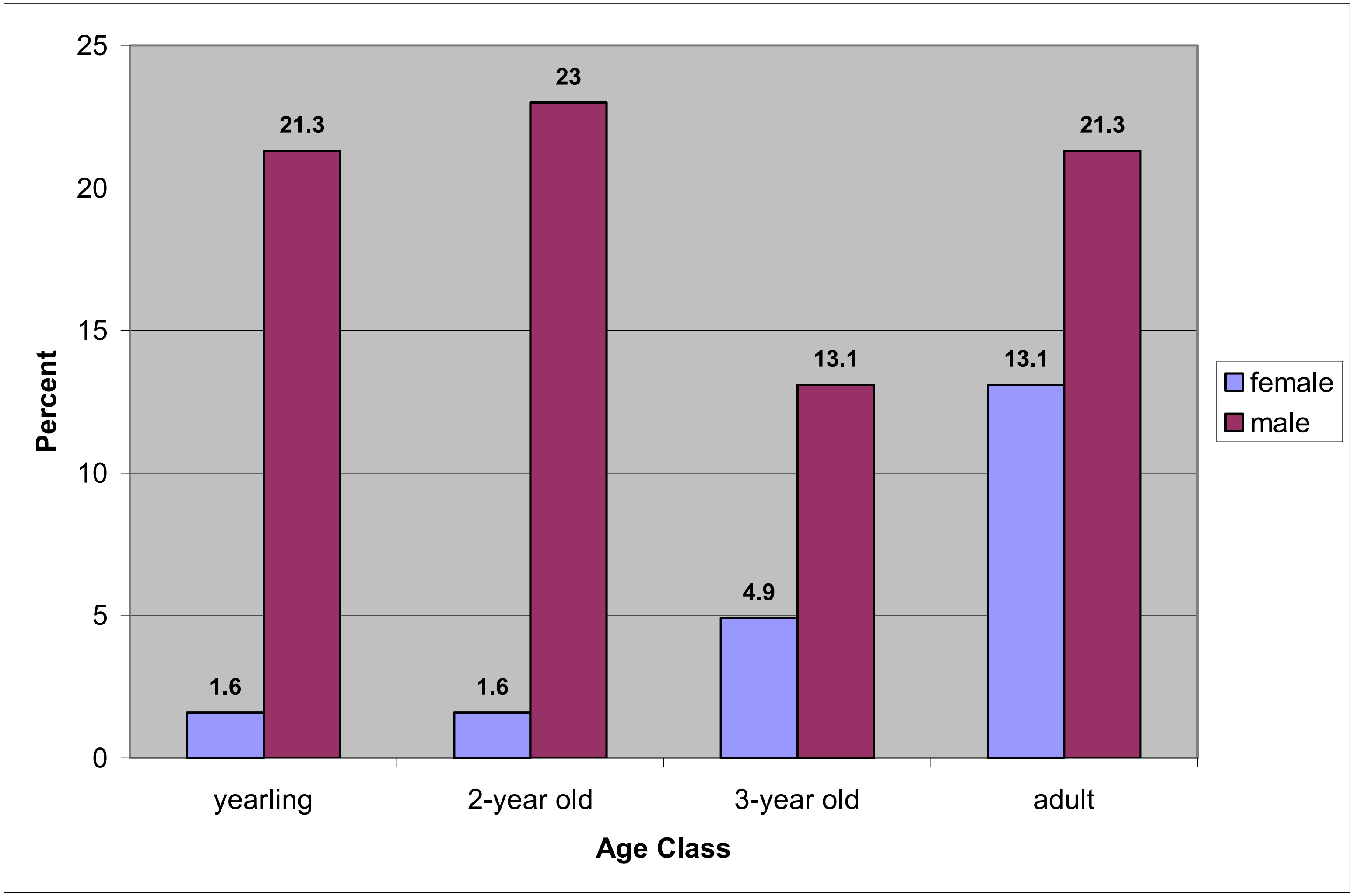
Because of low recapture rates, I was able to calculate densities for 3 years (1996 – 1998) only for adult females and for 1 year (1997) for adult males. I could not calculate the standard error or confidence intervals because the data were too sparse. Based on the estimations and assumption violations, I do not feel that the CJS model represents the data well, and other models may produce more accurate estimates.

Direct recoveries

When using a Lincoln-Peterson estimator, one must assume demographic and geographic closure. We know that some collared bears left the study area (permanently and temporarily) from 1995-2000, and unfortunately, there is not a sufficient recorded history for me to calculate the percent of time spent on the study area (Garshelis 1991). This would have allowed me to adjust calculated population estimates that may be slightly high.

Demographic closure is a little easier to address. This population estimator used data outside of the birthing period (January), and was relying on harvest data for the recaptured population. I assumed no other mortality occurred during this time period. We know immigration and emigration does occur, but we assumed it to be equal.

Figure 2.1. Percent of harvest by age and sex class for marked bears in the southwestern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery counties, VA, 1995-2000.



Equal catchability is another important assumption of the Lincoln-Peterson estimator. Recapture rates could be calculated only for adult females and adult males (Table 2.9). Though the confidence intervals overlap, indicating no difference in capture rates, I believe this assumption was violated. My recaptured sample was composed of harvested bears, but equal catchability during harvest seems unlikely. For example, pregnant females tend to den before the hunt, inexperienced young males may be more visible, and yearling females may be too small to harvest (i.e., Virginia law prohibits the harvest of bears that are under 100 pounds). Because of this bias, the estimate for marked harvested bears (m_2) likely is low. It is not truly a random sample if females are not available for harvest.

The main drawback to this method was not having enough recaptures (harvested bears) in each age and sex class. Because of this, I had to combine data and calculate 1 population estimate.

Despite the above, I believe that this was the most accurate method to estimate black bear population size and density for this study. This data set was the best and most complete for the study area and the time period for mark and recapture was approximately 7 months. Overall, density and survival results from this method were comparable with other studies of exploited black bear populations.

Minimum population size

Telemetry data showing the proportion of bears in each sex and age class that left the study area would have made this estimate better. Except for adult females, I assumed that during years when bears were not recaptured, they were not in the study area. This likely is an incorrect assumption and may support underestimates of bear densities in the study area. Because these data were lacking, I do not believe this method produced a reliable estimate of population size and densities.

Survival

Estimated survival rates were consistent with survival rates reported for exploited black bear populations in the United States (Table 2.15). However, the survival rates I calculated for adult males (0.77 and 0.80) were higher than most reported in this country for a hunted population.

Table 2.15. Survival estimates for black bear populations in the United States.

		Survival Estimate			
State	Status	Adult Female	Adult Male	Estimator	Citation
Virginia	Hunted	0.84	0.72	Brownie Dead Recoveries	Klenzendorf 2002
Virginia	Hunted	0.87	0.65	Burnham's combined model	Klenzendorf 2002
Virginia	Hunted	0.85	0.80	Burnham's combined model	This study
Virginia	Hunted	0.86	0.77	Burnham's combined model	This study
Virginia	Hunted	0.84	-	Cormack - Jolly - Seber	This study
Minnesota	Hunted	0.81	0.73	Cormack - Jolly - Seber	Rogers 1977
Virginia	Hunted	0.84	0.62	Cormack - Jolly - Seber	Klenzendorf 2002
Colorado	Not hunted	0.96	0.70	Heisey-Fuller	Beck 1991
Arkansas	Not hunted	0.98	0.85	Heisey-Fuller	Clark and Smith 1994
Maine	Hunted	0.80	-	Heisey-Fuller	McLaughlin 1998
Virginia	Hunted	0.87	0.61	Heisey-Fuller	Hellgren 1988
Virginia	Hunted	0.92	0.73	Heisey-Fuller	Klenzendorf 2002
Alaska	Hunted	0.85	0.72	Kaplan-Meier	Schwartz and Franzmann 1992
Montana	Hunted	0.79	0.73	Kaplan-Meier	Kasworm and Their 1994
Virginia	Hunted	0.98	0.90	Kaplan-Meier	Klenzendorf 2002

Adult female survival was the highest for any sex and age class. This may be attributed to the timing of hunting season with hounds (December), which accounts for most of the bear harvest for the state of Virginia (Martin and Steffen 2000). Hound season does not begin until December, after most adult female bears have denned. Legal harvest is the largest cause of mortality for black bears (83.6% in this study) in Virginia, and adult females escape this pressure by denning early. Adult females made up only 13.1% of the legal harvest during 1995 – 2000 (Martin and Steffen 2000).

Yearling and subadult males had the lowest estimated survival rates, 0.35 and 0.50 – 0.51 respectively. Dispersal and roaming by individuals in these age classes may in part, explain the high mortality they experience. They likely are more visible to hunters and hounds, which would explain their high harvest rate (43.2%). The northern study area of CABS found the same pattern. Klenzendorf (2002) calculated a 39.0% harvest rate for 2-year old males, and estimated a survival rate of 0.40 – 0.60. Lee (2003) estimated survival rates of 0.32 for yearling males, and 0.59 for subadult males. Yearling and subadult males composed 57.4% of the harvest from 1995 through 2000 in the southern study area. The percentage of subadult males harvested in the northern study area was higher than the south at 75.0% (Klenzendorf 2002).

It appears, in this study, that causes of mortality other than legal harvest are not significant and may not affect the bear population. Only 8.1% (n = 12) of the bears handled in this study, died from other mortality causes (Table 2.1). These causes constituted 16.4% (n = 12) of all mortalities between 1995 – 2000.

Though the numbers of individuals that died by means other than legal harvest appears insignificant, the age and sex distribution of these mortalities may be important. Females accounted for 66.7% (n = 8) of the "other" mortalities; half of these were adult females (n = 4). Adult female survival affects population growth more than any other sex or age class (see Chapter 3), so when their mortality rate is increased due to causes other than legal harvest, it should be documented and watched closely. Harvest rates may have to be adjusted if adult female mortality from other causes is high.

Growth Rate

The calculated growth rate using direct recovery data, $\lambda=1.24$, was much higher than those calculated in other studies in Virginia. Klenzendorf (2002) calculated a growth rate of $\lambda=1.04$ for a hunted population in the northern study area. Unexploited populations in Shenandoah National Park had an estimated growth rate of $\lambda=1.0$ (Carney 1985) and Great Dismal Swamp was estimated to be $\lambda=1.0032$ (Hellgren 1988). It is important to keep in mind that the growth rate calculated for this study is a 6-year average (range 0.99-1.78; median 1.11).

Virginia Department of Game and Inland Fisheries has thought for a long time that the bear population was increasing (D. Steffen, pers. comm.). They used several indices such as harvest, nuisance activity, age structure, and miscellaneous mortality, to monitor black bear population status in Virginia (Martin and Steffen 2000). The combined use of the indices suggests a growing bear population.

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CHAPTER 3: MINIMUM VIABLE POPULATION, GROWTH RATE, AND HARVEST EFFECTS MODEL

INTRODUCTION

Historically, both black bears and grizzly bears (*Ursus horribilis*) were regarded as obstacles impeding development and threats to human safety (Miller 1990). This attitude was one factor that led to a major reduction in the black bear population in the southern United States (Jonkel 1987), and influenced the present day general objectives for black bear management, conservation and sustained yield (Miller 1990).

An increasingly popular approach to bear management is use of population viability analyses (PVA) and minimum viable population (MVP) estimates. MVP's have been defined several ways, but the most accepted definition of MVP is "the size of the population which, with a given probability, will ensure the existence of the population for a stated period of time" (Ewens 1987).

Shaffer (1981) contended one of the most important relationships conservationists need to understand is the relationship between a population's size and its probability of extinction. Reed et al. (1986) further claimed there is a great need to include MVP estimations in management. MVP recommendations originally were based on genetic and evolutionary arguments (Shaffer 1981), and typically were calculated only for species at risk of extinction. However, exploited populations may also benefit from developing an MVP estimate, especially if hunter impact is not clearly understood.

Shaffer (1983) defined MVP as the smallest population capable of surviving 100 years with a 95% probability. Using data from Craighead et al. (1974), Shaffer (1983) estimated an MVP for Yellowstone grizzly bears of 50-90 bears. An MVP was calculated for the same population by Suchy et al. (1985) using a slightly higher mortality rate. They used the same definition as Shaffer, and estimated MVP to be 125 bears. Hellgren and Vaughan (1989) calculated an effective population size (N_e) for an unexploited black bear population in Virginia to be 56 individuals. Based on Nunney's and Campbell's (1993) suggestion that most MVP estimates should be at least 5 – 10 times N_e, the MVP for this population could be 280 – 560 individuals.

METHODS

I developed a population model using Mathcad 8 Professional (MathSoft Inc., Cambridge, MA) to determine population growth rate, MVP, and harvest effects for an exploited black bear population in southwestern Virginia. I defined MVP as the smallest population able to survive at least 100 years with a 95% probability. I used data collected during the CABS study (1995 – 2000) in the model including population estimates derived from direct recovery data, age and sex specific survival rates (see Chapter 2), and cub sex ratios (Table 3.1). I used 100 years as the time period in the model, and I repeated population growth rate simulations 1,000 times (Appendix 1).

Cub survival and reproduction are strongly correlated with mast production across most of black bear range (McLaughlin 1994). Some areas report complete reproductive failure in their black bear population during years when mast crops fail (McLaughlin 1994). Mast survey data showed that production was fair or good in the southern mountain region of Virginia (see chapter 1) during the period data were collected (1995 – 2000). Though we did not see a total soft or hard mast failure during this study, I included stochasticity in the model to better estimate population growth under changing and biologically stressful conditions. Historic mast data in Virginia showed mast failures occurred 3 times in a 10 year period, on average (Denny Martin, VGDIF, pers. comm.). Based on this, I set mast production to equal a random number between 0 and 1. If the random number was less than 0.3, mast was considered to be poor and subsequently, cub survival would be 0. If the random number was between 0.3-1.0, then mast was considered good, and did not negatively impact reproductive rates.

To estimate reproduction, or cubs/female/year, I used the average litter size, 2.2, and the percentage of available breeding females in the population, 65.6% (Ryan 1997), and assumed they gave birth every other year. Because cubs do not contribute to reproduction, are dependent on the sow for survival, and are not normally harvested, I did not include them when calculating MVP. All other age-classes were included.

The primary cause of mortality for bears in this study was harvest, so survival rates used in the model were equivalent to harvest survival rates (i.e., harvest accounted for 100% of mortality). Using the direct recovery data from Chapter 2, I estimated

Table 3.1. List of Parameters used in the minimum viable population model for an exploited black bear population in southwestern Virginia.

Parameter	**Estimate**	**Where estimate was obtained**
Mast production	Random variable between 0 – 1.0	Denny Martin, VDGIF, pers. com.
Cubs/adult female/year	0 or 0.722	Ryan 1997; CABS unpubl. data
Cub ratio, f:m	1:1	Klenzendorf 2002
Cub survival	0 or 0.8	McLaughlin et al 1994; Klenzendorf 2002
Yearling female survival	0.92	This study
Yearling male survival	0.72	This study
2 year old female survival	0.81	This study
2 year old male survival	0.75	This study
3 year old female survival	0.83	This study
3 year old male survival	0.59	This study
Adult female survival	0.94	This study
Adult male survival	0.85	This study
Initial population size	270	This study

survival for each age and sex class each year from 1995 – 2000, and used the 6-year average for each age and sex class.

The most important factors to consider in population dynamics are natatlity and mortality (Bunnell and Tait 1980). Eberhardt (1990) identified adult female survival as the main factor influencing black bear populations. Because of this, I believed the population growth rate and sensitivity to harvest rates in the model would be driven by adult (reproducing) females, so I did not vary or change the survival for any male age class. However, to estimate different extinction probabilities and MVPs, I changed 2-year-old female, 3-year-old female, and adult female survival rates. I began with the parameter estimates in Table 3.1, and increased harvest (decreased survival) of adult females in 0.01 increments, while keeping all other parameters constant. I repeated this for 2-year old and 3-year old females simultaneously (i.e., their harvest rate increased by 0.01 increments at the same time), while keeping all other parameters constant. I also used a random survival rate for adult females (0.83-1.0) based on direct recovery data from Chapter 2 (see confidence bounds in Table 2.10).

To estimate MVP, I began with the estimated population size of 270 and reduced or increased it until the 5.0% extinction probability was reached.

RESULTS

Using the original data in Table 3.1 with no modifications, the model predicted that a population of 270 individuals had a 0% probability of extinction given the current harvest rates. The mean finite growth rate (λ) was 1.03 ($r = 0.03$). The estimated MVP given these data was 37 individuals with a probability of extinction of 4.8% in 100 years. The mean finite growth rate (λ) was 1.019 ($r = 0.02$).

Reducing adult female survival in 0.01 increments only allowed for a total reduced survival of 0.06 to 0.88 before observing an extinction probability of greater than 5.0% in 100 years ($\lambda = 0.99$; $r = -0.01$; Table 3.2).

After changing the adult female survival rate of 0.94 to the variable rate of 0.83 – 1.0, the probability of extinction still remained 0% in 100 years, for a starting population of 270 individuals, but $\lambda = 1.0$ ($r = 0$). The estimated MVP with a variable adult female

Table 3.2. Finite (λ) and intrinsic (r) growth rates, and probability of extinction when adult female black bears experience decreased survival in an exploited bear population in the southwestern study area of the Cooperative Alleghany Bear Study, Craig, Giles, and Montgomery Counties, VA.[a]

Adult female survival rate	λ	r	Probability of Extinction (%)
0.94[b]	1.03	0.03	0
0.93	1.01	0.01	0
0.92	1.01	0.01	0
0.91	1.00	0.0	0.002
0.90	0.98	-0.02	0.007
0.89	0.99	-0.01	0.03
0.88	0.99	-0.01	0.13
0.87	0.97	-0.03	0.34

[a] Starting population of 270 individuals
[b] Actual survival calculated using harvest data (See Chapter 2)

survival rate was more than doubled to 80 individuals, with a probability of extinction of 4.2% in 100 years.

Two-year old and 3-year old females did not impact extinction probabilities and growth rates nearly as much as adult females. Their survival could be decreased by 44.0%, and still be less than the 5.0% extinction probability cut off defined above. When survival was reduced simultaneously by 44.0% for both age classes the probability of extinction was 3.1%, and the mean growth rate was $\lambda = 0.95$ ($r = -0.05$).

DISCUSSION

It is especially important to use caution in estimating black bear harvest rates. Bears have delayed reproductive maturity and low reproductive rates, so an overexploited population would need many years to recover (Miller 1990). Since very few factors other than harvest affect an adult bear's survival rate (Eberhardt 1990; Klenzendorf 2002) changes in harvest rates could have a detrimental impact on bear population size and growth rate if not managed correctly.

Like Klenzendorf (2002), I found the single most important factor influencing growth rate and population persistence was adult female survival. However, my model required a much higher adult female survival rate to maintain growth rate at $\lambda \approx 1.0$. This was not surprising since the northern study area's bear density estimates are 3 – 4 times those of the southern study area. In addition, I introduced stochasticity into the model in the form of variable cub survival and adult female reproduction based on mast production. This was an important component of the model because it more closely depicts natural conditions. The model included a 33.3% chance of total mast failure each year. Though we never observed a complete mast or reproductive failure during this study, it is not an uncommon event. However, if the southern mountains in Virginia do experience a complete mast failure, we may not see the effects reflected in black bear reproduction. There is a great deal of supplemental feeding that occurs in Virginia. Almost 3 million kilograms of supplemental food is provided to black bears in Virginia by hunters (Gray 2001). Although feeding black bears on public land became illegal in 2000, it was still allowed on private land. Just over half of the land within the southern study area is private, so black bears still may receive a lot of supplemental food eliminating any effect a mast failure might have on the population. However, in July 2003 all feeding of black bears, including on private land, was made illegal. Future mast failures now may have an increased effect on black bear reproduction.

The calculated MVP of 37 individuals is lower than found in most unexploited bear populations (Shaffer 1981, 1983). This estimate was calculated using adult female survival of 0.94. When I changed adult female survival to a variable rate (0.83 – 1.0; Tables 2.8 and 2.10), although still low, a more realistic estimate of 80 individuals was calculated. Using a variable survival rate may be a better approach because it more closely reflects what happens in natural populations. During the 6 year study, the range for adult female survival was 0.75 – 1.0, with a mean of 0.94. Though harvest was the main cause of mortality, survival varied from year-to-year for all age and sex classes. The fluctuations we observed in survival can be driven by mast production (poor or good), hunter success, or related variables (e.g., weather conditions). I chose only to use a variable survival rate for adult females in the model because it mattered very little what male survival was, and we demonstrated how much subadult female survival could be changed before detecting a difference in probability of extinction.

Though models are an abstract approach to wildlife management, they can be useful tools in predicting trend in populations, especially in those that may be difficult to study. What increases their validity, and perhaps reduces abstraction, is using real data from the population you are studying. Only 2 parameters (cub survival and cub sex ratio) in this model were not estimated from results of this study or from data collected in the study area (Table 3.1), but instead was estimated from the northern study area of CABS. It is just as important to include stochasticity in models to aid in predicting different outcomes for scenarios that deviate from ideal or normal situations. With simple modifications this model can be used for black bear populations almost anywhere they exist. However, in order to make accurate predictions, field data are needed from the population being studied.

This model demonstrates the importance of accurate adult female harvest rate estimates. Small increases or decreases in adult female harvest rates have profound effects on the overall bear population and should be monitored closely.

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APPENDICES

Appendix 1. Population model using Mathcad 8 Professional (MathSoft Inc., Cambridge, MA) to determine population growth rate, MVP, and harvest effects for an exploited black bear population in southwestern Virginia.

$$\text{mast}(x) := \begin{cases} 0 & \text{if } x < 0.3 \\ .8 & \text{otherwise} \end{cases} \qquad \text{mast2}(x) := \begin{cases} 0 & \text{if } x < 0.3 \\ \dfrac{1.443}{2} & \text{otherwise} \end{cases} \qquad \text{testforzeroN}(N, \text{sex}, \text{time}) := \begin{cases} 0 & \text{if } N_{\text{sex},\text{time}} < 1 \\ N_{\text{sex},\text{time}} & \text{otherwise} \end{cases}$$

$$\text{beargen}(N, \text{Ncubs}, \text{Njuvs}, \text{Njuvs2}, \text{Njuvs3}, m) := \left| \begin{array}{l} \text{for } i \in 0, 1 .. m \\ \quad \text{for } t \in 0, 1 .. 200 \\ \quad\quad r \leftarrow \text{runif}(1, 0, 1) \\ \quad\quad \text{cubsurv} \leftarrow \text{mast}(r_0) \\ \quad\quad \text{Njuvs}_{0,t+1} \leftarrow \text{Ncubs}_t \cdot 0.5 \cdot \text{cubsurv} \\ \quad\quad \text{Njuvs}_{1,t+1} \leftarrow \text{Ncubs}_t \cdot 0.5 \cdot \text{cubsurv} \\ \quad\quad \text{Njuvs}_{0,t+1} \leftarrow \text{testforzerojuv}(\text{Njuvs}, 0, t+1) \\ \quad\quad \text{Njuvs}_{1,t+1} \leftarrow \text{testforzerojuv}(\text{Njuvs}, 1, t+1) \\ \quad\quad \text{Njuvs2}_{0,t+1} \leftarrow \text{Njuvs}_{0,t} \cdot .92 \\ \quad\quad \text{Njuvs2}_{0,t+1} \leftarrow \text{testforzerojuv2}(\text{Njuvs2}, 0, t+1) \\ \quad\quad \text{Njuvs2}_{1,t+1} \leftarrow \text{Njuvs}_{1,t} \cdot .72 \\ \quad\quad \text{Njuvs2}_{1,t+1} \leftarrow \text{testforzerojuv2}(\text{Njuvs2}, 1, t+1) \\ \quad\quad \text{Njuvs3}_{0,t+1} \leftarrow \text{Njuvs2}_{0,t} \cdot .81 \\ \quad\quad \text{Njuvs3}_{0,t+1} \leftarrow \text{testforzerojuv3}(\text{Njuvs3}, 0, t+1) \\ \quad\quad \text{Njuvs3}_{1,t+1} \leftarrow \text{Njuvs2}_{1,t} \cdot .75 \\ \quad\quad \text{Njuvs3}_{1,t+1} \leftarrow \text{testforzerojuv3}(\text{Njuvs3}, 1, t+1) \\ \quad\quad r1 \leftarrow \text{runif}(1, .83, 1) \\ \quad\quad N_{0,t+1} \leftarrow \text{Njuvs3}_{0,t} \cdot .83 + N_{0,t} \cdot .94 \\ \quad\quad N_{0,t+1} \leftarrow \text{testforzeroN}(N, 0, t+1) \\ \quad\quad N_{1,t+1} \leftarrow \text{Njuvs3}_{1,t} \cdot .59 + N_{1,t} \cdot .85 \\ \quad\quad N_{1,t+1} \leftarrow \text{testforzeroN}(N, 1, t+1) \\ \quad\quad \text{birthrate} \leftarrow \text{mast2}(r_0) \\ \quad\quad \text{Ncubs}_{t+1} \leftarrow N_{0,t} \cdot \text{birthrate} \\ \quad\quad \text{Ncubs}_{t+1} \leftarrow \text{testforzerocub}(\text{Ncubs}, t+1) \\ \quad\quad \text{Ncubs}_{t+1} \leftarrow \text{testformoms}(N, \text{Ncubs}, t+1) \\ \quad\quad \text{Ncubs}_{t+1} \leftarrow \text{testfordads}(N, \text{Ncubs}, t+1) \\ \quad\quad \text{Ntally}_{i,t+1} \leftarrow N_{0,t+1} + N_{1,t+1} + \text{Njuvs3}_{0,t+1} + \text{Njuvs3}_{1,t+1} + \text{Njuvs2}_{0,t+1} + \text{Njuvs2}_{1,t+1} + \text{Njuvs}_{0,t+1} + \text{Njuvs}_{1,t+1} \\ \text{Ntally} \end{array} \right.$$

Appendix 2. Definition of terms for population model for an exploited black bear population in southwestern VA.

mast(x)	= cub survival
mast2(x)	= reproductive rate
N	= number of adult bears
Ncubs	= number of cubs
Njuvs	= number of yearlings
Njuvs2	= number of 2-year old bears
Njuvs3	= number of 3-year old bears
m	= maximum number of iterations
i	= iteration
t	= time
r	= random number between 0 and 1 that dictates cub survival and reproductive rate
cubsurv	= cub survival (mast(x))
testforzero	= if the number for a particular age and sex class is 0 < 1, it will be made to equal to 0 for that time period.
r_1	= adult female survival, when random (between 0.83 and 1.0)
birthrate	= reproductive rate (mast2(x))
Ntally	= number of bears after 100 years

Subscripts (for N, Ncubs, Njuvs, Njuvs2, Njuvs3)

0 = female
1 = male

VITA

Deborah M. O'Neill was born to Francis and Barbara O'Neill in Winsted, Connecticut on 15 January 1972. She was raised in Winsted, where she attended high school at The Gilbert School. She attended the University of Connecticut and The University of Rhode Island, where she graduated with a B.S. degree in Natural Resources in August 1996. After graduation, she went to work for the Utah Department of Wildlife Resources as a technician, and 3 years later found herself employed there full time as an endangered species biologist. She left Utah to attend graduate school, and enrolled at Virginia Polytechnic Institute and State University in January 1999. There she studied the population dynamics of an exploited black bear population, and initiated bait station surveys for the southern study area of the Cooperative Alleghany Bear Study. After she fulfilled the classwork requirement for her degree, she left Virginia to begin a human-black bear interaction study with the Hornocker Wildlife Institute in Grand Teton National Park, Wyoming. She currently is the Nongame Small Mammal Coordinator for the Arizona Game and Fish Department. She resides in Scottsdale, Arizona, but returns to her other home in Moose, Wyoming as often as she can.