ESTIMATES OF POPULATION DENSITY AND GROWTH OF BLACK BEARS IN THE SMOKY MOUNTAINS

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Abstract: To estimate population abundance, data were collected from 1,239 black bears (*Ursus americanus*) trapped in 3 areas of the Smoky Mountains (SM), 1972-89. Bears were tagged, tattooed, and released, and using the Jolly-Seber open population model, density estimates ranged from 0.09 to 0.35 bears/km^2. Year-to-year density estimates and the observed rate of growth (0-2%) indicated a stable to slightly increasing population. The predictions of the population model, BEAR, indicated the importance of hard mast to this population; in years of good mast, the numbers of bears increased, whereas in years of poor or varying mast availability the population declined.

Int. Conf. Bear Res. and Manage. 9(1):253-261

Habitat loss and fragmentation constitute considerable threats to wildlife populations (Dasmann 1981, Harris 1984). Black bears have lost more than 90% of their original range in the southeastern United States (Pelton 1986), and much of what remains lies in scattered tracts of public lands (Maehr 1984). Due to their sensitivity to habitat alterations, black bears are considered environmental indicators (Pelton and Beeman 1975). As such, and to assist proper management, an understanding of population density and growth is desired.

In portions of the Smoky Mountains (Smokies), such as Cherokee (CNF) and Pisgah (PNF) National Forests, black bears are legally harvested, though poaching is a significant source of mortality as well. In Great Smoky Mountains National Park (GSMNP) legal harvest of bears has been prohibited for more than 50 years, but poaching persists. To better understand the survival, movements, density, and reproduction of bears of these mountains, researchers have collected information for nearly 20 years. The purpose of this analysis was to assimilate the collected information and characterize the black bear population in terms of density and growth.

The authors gratefully acknowledge a number of contributions. Many students collected the field data; without their collective contribution of 20 years of data, this work would not have been possible. Frank Teunissen van Manen kindly provided several of the illustrations; his friendship and support have been appreciated. Our pilot, Bill Kindy, helped locate dens of females. Dr. Ken Pollock, of the Institute of Statistics at North Carolina State University, advised our population estimation efforts. Dr. John Higgins helped in calculating the estimates of population growth. Dr. Dan Johnson and Mark Mathis and his fellow students of East Tennessee State University assisted with the modelling. Jim Wentworth of the University of Georgia, Greg Wathen, Doug Scott, David Whitehead of the Tennessee Wildlife Resources Agency, Bill Cook of the National Park Service, and John Collins of the North Carolina Wildlife Resources Commission provided the data on hard mast; Steve Pozzanghera contributed, in large part, to its analysis. A number of people assisted us in the field and for this and their friendship, we are thankful. Last, but most important, we are indebted to our families for their support in this and other endeavors. The project was funded through McIntire-Stennis grant No. 39, the Department of Forestry, Wildlife, and Fisheries and the Graduate Program in Ecology of the University of Tennessee, and the Great Smoky Mountains Conservation Association.

STUDY AREA

Great Smoky Mountains National Park, visited by nearly 10 million people annually, is located in eastern Tennessee and western North Carolina (Fig. 1). Approximately ¼ (506 km^2) of the park, the northwest portion, served as 1 study area from 1968 to 1989. The park is characterized by steep ridges, narrow valleys, coves, and fast-flowing streams (King and Stupka 1950). Elevation ranges from 230 to 2,035 m (Pelton et al. 1980). Average temperatures vary from 14°C at low elevations to 8°C at high ones (Shanks 1954). Considered a temperate rain forest (Thornthwaite 1948), the park receives 140 cm of annual precipitation at low elevations and 230 cm at high elevations (Stephens 1969). Six major forest types are recognized (Shanks 1954): cove hardwood, hemlock (*Tsuga canadensis*), northern hardwood, open oak-pine (*Quercus* spp.-*Pinus* spp.), closed oak, and spruce-fir (*Picea rubens-Abies fraseri*). Understory vegetation is dominated by mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron* spp.), blueberries (*Vaccinium* spp.), and huckleberries (*Gaylussacia* spp.).

The Pisgah National Forest study area comprises 114 km^2 (Brody 1984) in western North Carolina (Fig. 1).

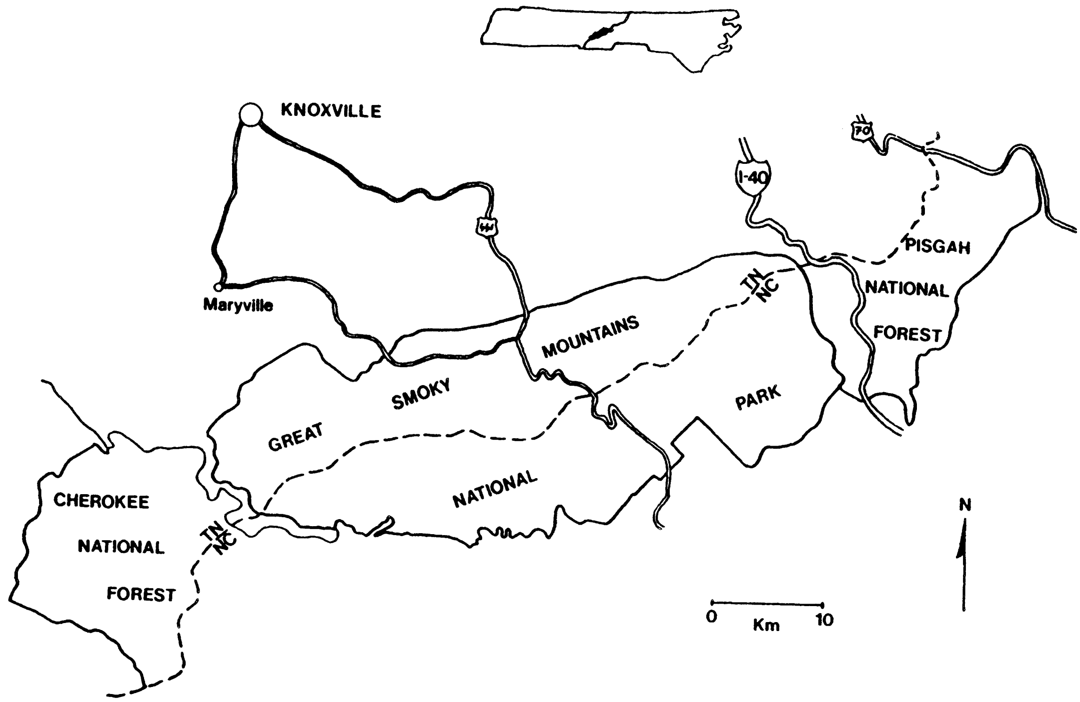

Fig. 1. Location of Great Smoky Mountains National Park and Cherokee and Pisgah National Forests in eastern Tennessee (TN) and western North Carolina (NC).

This area, northeast of GSMNP, is similar to the park in terms of climate and geology. Elevations commonly range from 439 to 1,411 m (Beringer 1986). Of the nearly 2,000 plant species identified in this national forest, several are predominant in the overstory including white (*Q. alba*), northern red (*Q. rubra*), scarlet (*Q. coccinea*) and chestnut oaks (*Q. prinus*), hickory (*Carya* spp.) and yellow-poplar (*Liriodendron tulipifera*); nearly 90% of the study area is in hardwoods with oak or oak-associates comprising 74% (USFS 1981 in Beringer 1986). In 1971, the area was designated as the Harmon Den Bear Sanctuary with hunting restricted to that of small game (excluding raccoon) and deer (Beringer 1986). The area's high road density provides easy access for hunters and other recreationists, and bear poaching within and around the sanctuary is reputedly a significant source of mortality. Logging operations, managed by the U.S. Department of Agriculture Forest Service, continue today though not with the same intensity as during the early 1900s (Beringer 1986). The University of Tennessee has conducted black bear research in Pisgah National Forest since 1981.

To the southwest of the park lies the Cherokee National Forest study area (Fig. 1). It is situated within the Tellico Ranger District, Tennessee, and constitutes about 760 km^2 (Clevenger 1986). It also is similar in geology and climate to that of the park (Clevenger 1986). Elevations range from 450 to 1,550 m; the area is characterized generally by steep mountains and fast-flowing streams (Clevenger 1986). It is 99% forested with 5 major plant communities recognized: cove hardwood, northern hardwood, oak-hickory, pine, and mesic hemlock (Clevenger 1986). The forest cover was significantly altered by logging and associated fires until the Forest Service purchased the land in the 1930s (Clevenger 1986). A 124-km^2 segment of the study area serves as a bear refuge reserved for small game hunting (Clevenger 1986). Black bears were trapped in an approximately 80-km^2 portion of the study area. Black bear data were collected in the Cherokee study area from 1972 to 1983.

MATERIALS AND METHODS

Black bears were trapped June through September, 1972-88. Trapping and marking techniques outlined by

Johnson and Pelton (1980*a,b*) were employed, though barrel traps sometimes were used. Bears were sedated with a 20:10:2 mg/ml mixture of ketamine, rompun, and carbocaine; in the first years of the study, other immobilizing drugs were employed (Cook 1982). To age bears, the first premolar, a vestigial tooth, was extracted, sectioned, and stained (Eagle and Pelton 1978). Ages were assigned according to Willey (1974), and bears ≥3 years were considered adults. The female bear's reproductive condition was evaluated via vulva and teat examination and the presence of young. Pitocin or oxytocin were administered to help detect lactation. Beginning in 1978, radio collars were fitted to females enabling us to locate them in winter.

During winter, 1978-89, the reproductive status of denning females was assessed. The presence of young was noted, and sonagram analysis sometimes was used to determine cub number (Wathen 1983).

The maximum percent production index (MPPI) (Pozzanghera 1990) and the Whitehead index (C.J. Whitehead, Oak mast yields on wildlife management areas in Tennessee, Tenn. Game and Fish, unpubl. rep., 11pp., 1969) were used to assess hard mast production (see McLean 1991). The MPPI measures mast production in southern Appalachian oaks relative to their theoretical maximum yields (Pozzanghera 1990). The MPPI is calculated using the equation $Ni = (Ci \cdot Ti \cdot Fi) \div 10^4$, where Ni is the percentage of maximum possible mast crop for each sample tree, Ci is the percentage of the crown in fruit, Ti is the percentage of twigs within the productive crown which bear fruit, and Fi is the percentage of the maximum number of fruits per twig (Pozzanghera 1990); to account for the fact that Ci, Ti, and Fi fail to reach their maximum potential production in excellent years, scalars are incorporated into the equation (see Pozzanghera 1990). The MPPI is comparable to the Whitehead index but improves on its shortcomings; apparently, the calculation of the Whitehead index has no "biological rationale" (Nicholas and White 1984:23). Only the MPPI results were used in determining the quality of the annual mast crop.

Field data were organized and statistically analyzed with the Statistical Analysis Systems procedures (SAS Institute 1985). Where sample sizes for the national forest study areas were too small and the data for these areas were comparable, data were combined to make meaningful statistical comparisons. Age of primiparity, based on evidence of lactation and/or presence of young, and birth interval were determined from reproductive histories. Mortality rates were derived from life table (Craighead et al. 1974, Caughley 1977) and capture analyses (Program Jolly, Pollock et al. 1990); the numbers of bears in the age classes of the life tables were smoothed to account for inconsistencies in these numbers (Craighead et al. 1974, Caughley 1977). The few drug- or trap-related mortalities were excluded from these analyses. Program Jolly generated population estimates from data which included mortalities in the study areas. The observed rate of population growth, *r*, was calculated using regression analysis of the actual population estimates (Table 1, Caughley 1977).

Black bears of the Smokies likely belong to 1 population although some of the analysis may suggest otherwise. Emigration and immigration of bears among the study areas (Quigley 1982, Carr 1983) indicate a single population; long-distance movements, particularly by males, ensure gene flow between bears in the national forests and the park. However, because management in the park differs from that in the national forests, one might expect regional differences within the population; demographic features of park bears might vary from those of the national forest. This analysis attempts to examine some of the possible differences.

Table 1. Jolly-Seber (Program Jolly) population estimates for black bears in the Smoky Mountains, 1973-87.

Year	Great Smoky Mountains National Park *n* (95% CI)	Cherokee National Forest *n* (95% CI)	Pisgah National Forest *n* (95% CI)
1973	100.1 (-33-233)	-	-
1974	65.4 (31-99)	-	-
1975	119.8 (58-181)	-	-
1976	147.4 (77-218)	-	-
1977	127.8 (72-183)	-	-
1978	165.0 (79-251)	15.0 (-)	-
1979	132.6 (77-188)	24.5 (-)	-
1980	118.0 (76-160)	46.2 (-)	-
1981	149.1 (87-211)	45.5 (-)	-
1982	83.9 (43-125)	19.5 (-)	-
1983	247.7 (107-388)	20.0 (-)	20.9 (7-35)
1984	143.5 (69-217)	-	28.6 (-8-65)
1985	165.4 (56-275)	-	27.0 (-7-61)
1986	265.7 (10-521)	-	12.0 (-)
1987	187.5 (37-338)	-	29.2 (-32-91)
Mean (SD):	147.9 (52.62)	28.4 (13.81)	23.5 (6.48)

To simulate the effects of hard mast on reproduction and population abundance, a population model composed of the Leslie matrix (Leslie 1945) and a component representing the stochastic variation in food supply (Mathis et al. 1991) was used. The Leslie matrix, among the simplest of population models, predicts population number using age- and sex-specific fecundity and survivorship rates. Alone, the predictions of the matrix must be interpreted broadly; however, in combination with other variables, such as vulnerability to hunting (Bunnell and Tait 1980) and food, the predictive capabilities of the model become more consistent with reality.

RESULTS

Including summer captures and winter den visits, 1,239 (605 individual) bears in the Smoky Mountains were handled. Most (n = 946) of these captures and visits were in Great Smoky Mountains National Park; 161 (81 individual) and 130 (60 individual) black bears were examined in Cherokee and Pisgah National Forests, respectively. Annually, 41.3 $\pm$ 12.16 captures (n = 17 yr) and 13.5 $\pm$ 9.58 (n = 10 yr) den visits were made in the park, 8.1 $\pm$ 7.57 captures (n = 13 yr) and 3.8 $\pm$ 4.17 den visits (n = 6), and 11.7 $\pm$ 2.22 captures (n = 7 yr) and 3.3 $\pm$ 1.75 den visits (n = 6 yr) were made in CNF and PNF, respectively.

Estimates of density varied within the study area. From 1973 to 1987, the average population estimate for the park study area was 148 $\pm$ 52.6 bears (Table 1) or 0.292 bears/km^2. The estimated number of park adults and subadults was 113 $\pm$ 53.6 and 10 $\pm$ 6.3 bears, respectively. During the first half of the study (1972-79), the estimated size of the park population was 123 $\pm$ 32.5 bears (n = 7 yr) or 0.243 bears/km^2, and from 1980 to 1988, this estimate rose to 170 $\pm$ 61.9 bears (n = 8 yr) or 0.336 bears/km^2 (Fig. 2); these estimates are not significantly different (P = 0.085). The population estimate for the CNF study area was 28 $\pm$ 13.8 bears (n = 6 yr, Table 1) or 0.350 bears/km^2, and the PNF study area was estimated to have 24 $\pm$ 6.5 bears (n = 5 yr) or 0.211 bears/km^2.

The observed rate of growth, r, was 0.054 (5%) in GSMNP and 0.000 (0%) in the national forests combined.

To represent the effects of food on the reproductive

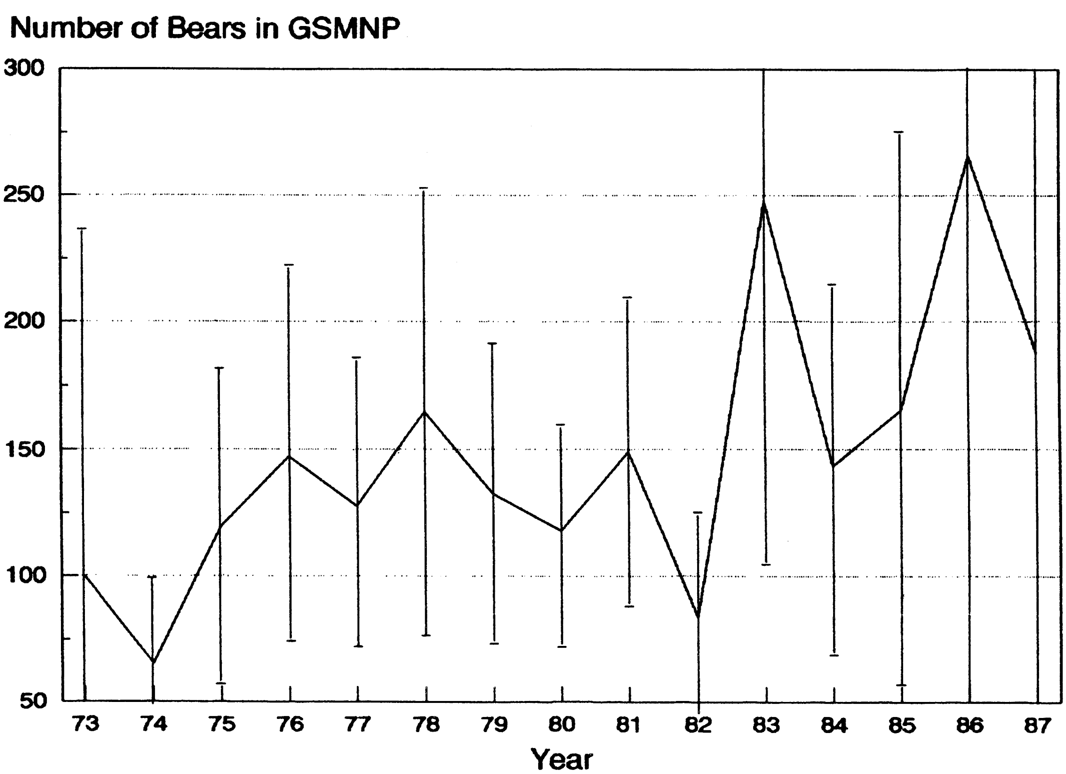

Fig. 2. Annual fluctuations in the number of black bears in Great Smoky Mountains National Park, 1973-87, based on Jolly-Seber population estimates.

rates of females in GSMNP (see Table 2), the population model, BEAR, uses a series of multipliers. These multipliers are calculated based on the percentage of females lactating following good, bad, and average years of hard mast (Mathis et al. 1994); in GSMNP, 58%, 26%, and 42% of the females ≥5 years were lactating following good, bad, and average mast years, respectively. Thus, the multiplier for good years becomes .58/.42 or 1.39; for bad years, the multiplier is .26/.42 or 0.62. In a good year, for example, the fecundity rate for females ≥15 years (normally, 0.643 [taken from life table], see Table 2) becomes (1.39)(0.643) or 0.894, and, in a bad year, the food-adjusted fecundity rate for these females is (0.62)(0.643) or 0.399. To account for delayed maturation due to food shortage (Eiler et al. 1989), the multiplier for 3-year-old females is 0, except in good mast years (multiplier = 1.0). In bad mast years, fewer 4-year-old females likely reproduce (Eiler et al. 1989) thus the multiplier for these females becomes 0.4; in good or average years the multiplier for these females is 1.0.

Table 2. Life-history characteristics of female black bears in Great Smoky Mountains National Park, 1972-89, used in BEAR (Mathis et al. 1991), a population model.

Age class	N [a]	Survivorship rate (P_x)	Fecundity rate (m_x)[b]
0.5	70	0.545	0.000
1.5	38	0.880	0.000
2.5	33	0.864	0.000
3.5	29	0.852	0.500
4.5	25	0.847	0.428
5.5	21	0.832	0.360
6.5	18	0.828	0.464
7.5	14	0.811	0.479
8.5	12	0.811	0.536
9.5	10	0.794	0.500
10.5	8	0.793	0.500
11.5	6	0.783	0.500
12.5	5	0.778	0.542
13.5	4	0.750	0.500
14.5	3	0.762	0.562
15.5[c]	1	0.750	0.643

[a] Based on a total population of 592 bears.
[b] No. female young per adult female per year.
[c] Mean values of female bears ≥15 yr.

The percentages of lactating females in the national forests following good, bad, and average years of mast were 0.757, 0.235, and 0.600, respectively. These values were used to calculate multipliers that, in combination with values of life history parameters of national forest females (see Table 3), produced food-adjusted fecundity rates.

The multipliers representing survival of females ≤4 years are 1.25, 1.00, 0.75 representing good, average, and bad mast years, respectively. These multipliers reflect food-dependent cub survival as well as the fact that food availability affects the degree of social intolerance, dispersal, and, ultimately, survival of young bears (Garshelis and Pelton 1981).

The model simulations clearly demonstrated that within 20 years, hard-mast availability can have a dramatic impact on bear numbers (Figs. 3 and 4). The numbers of female bears expanded in consecutive years of good mast; successive years of bad mast caused a substantial decline in bear numbers. Year-to-year variation in food supply also produced a decline in bear numbers. The trends in the numbers of national forest bears were similar to those projected for park bears (Fig. 4).

DISCUSSION

Estimates of population density in the Smokies were consistent with previous estimates. Using various

Table 3. Life-history characteristics of female black bears in Cherokee and Pisgah National Forests, 1978-89, used in BEAR (Mathis et al. 1991), a population model.

Age class	N [a]	Survivorship rate (P_x)	Fecundity rate (m_x)[b]
0.5	4	0.952	0.000
1.5	3	0.842	0.000
2.5	3	0.821	0.000
3.5	3	0.798	0.625
4.5	2	0.774	0.469
5.5	1	0.758	0.500
6.5	1	0.753	0.333
7.5	1	0.724	0.562
8.5	1	0.709	1.000
9.5	1	0.688	0.750
10.5[c]	1	0.375	0.690

[a] Based on a total population of about 40 bears.
[b] No. female young per adult female per year.
[c] Mean values of female bears ≥10 yr.

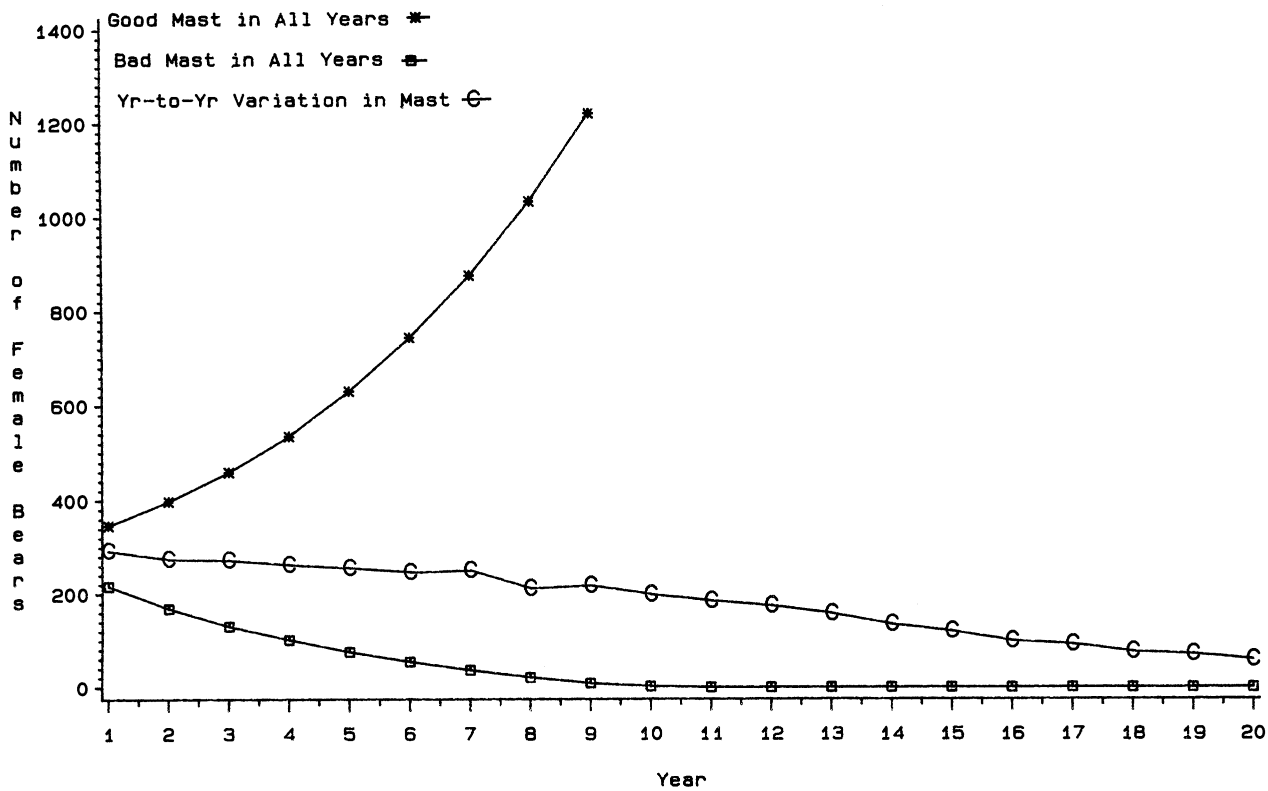

Fig. 3. Changes in the number of female black bears (based on model simulations) in Great Smoky Mountains National Park given an initial number of 297 females and varying mast availability.

methods, Carlock et al. (1983) estimated the density of bears in Smoky Mountains at 0.18-0.46 bears/km^2 and in GSMNP at 0.08-0.59 bears/km^2. Using radioisotopes and scat counts, Pelton and Marcum (1975) placed the GSMNP density at 0.251 bears/km^2. Based on capture data, Brody and Stone (1987) estimated the density of bears in PNF to be 0.193 bears/km^2. In comparison to other populations in North America, these estimates are low to intermediate on a low-high density continuum (Table 4).

Although the Jolly-Seber method of population estimation violates the fewest assumptions and incorporates the most data (Carlock et al. 1983, Hallett et al. 1991), the population estimates, especially those of the national forest, must be interpreted carefully. Generally, mark-recapture analyses require very large samples and are better-suited to small-mammal populations; although our sample is large, particularly for a large vertebrate, it is small relative to what normally is used in a population analysis. Estimating population size by sex or age group better meets the method's assumption of equal catchability (Garshelis 1991), but still large samples are required; combining the estimated numbers of park adults and subadults produces an estimate (123 bears) lower than the average population estimate (148 bears). In the park, trapping was extensive, and a large number of bears usually were caught each year ($\bar{x}$: 41.3 $\pm$ 12.16 bears/yr, n = 17 yr); however, sampling in the national forests was less extensive, and far fewer bears were captured yearly (9.4 $\pm$ 6.23 bears/yr, n = 20 yr). Also, the ratio of trapline length to area was much greater in the national forests (16km:97km^2 = 0.16) than in the park (40km:506km^2 = 0.08); although well-distributed, the comparatively fewer traplines in the park left some areas unsampled. Adjusting for this disparity by randomly disregarding one-half (0.08 $\div$ 0.16 = 0.5) of the trap records of national forest bears generated perhaps more realistic population estimates of 15 bears (0.18 bears/km^2) and 10 bears (0.09 bears/km^2) in CNF and PNF study areas, respectively. Last, the number of traplines and the weeks in which they were open varied from year to year; such inconsistency tends to confound population estimation.

Few estimates of the rate of population growth (r) of black bears exist. For bears in Shenandoah National

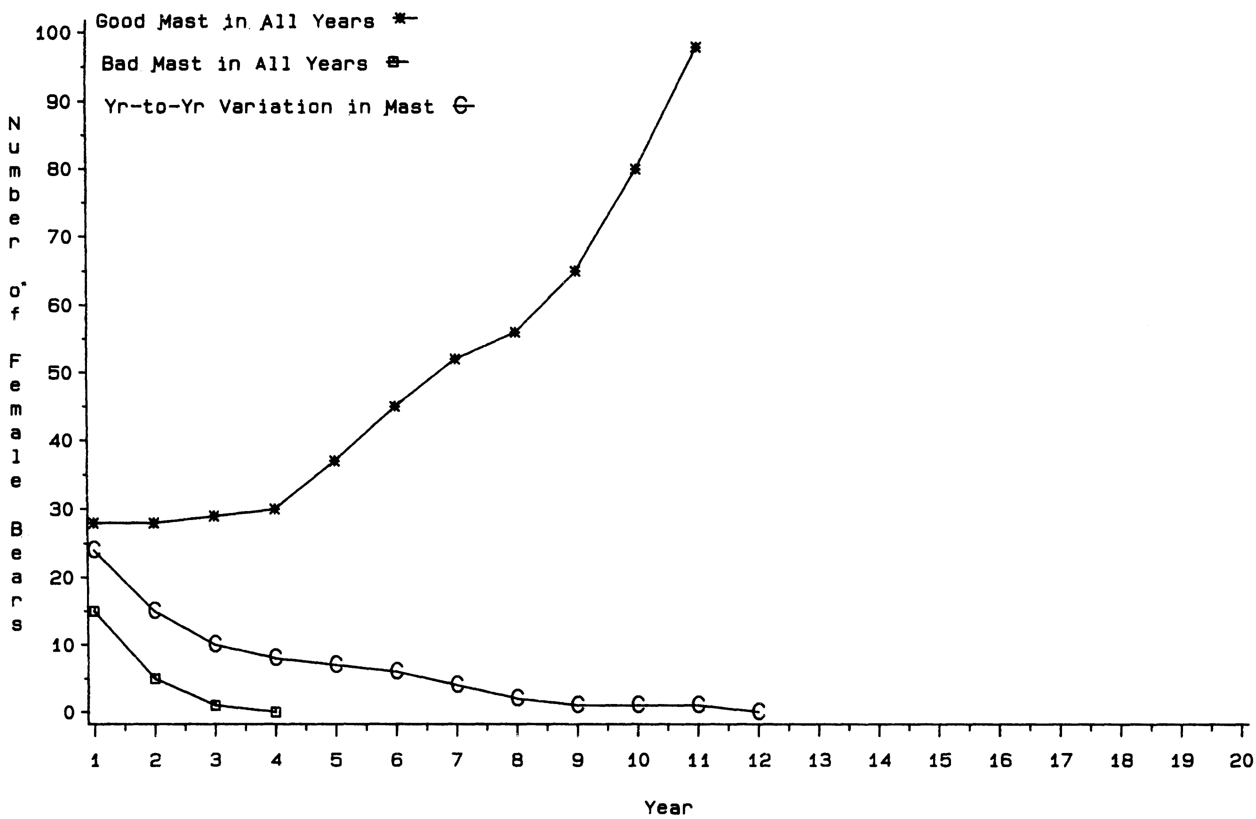

Fig. 4. Changes in the number of female black bears (based on model simulations) in Cherokee and Pisgah National Forests given an initial number of 20 females and varying mast availability.

Park and Great Dismal Swamp, Virginia, r = 0.000 (Carney 1985), and r = 0.0032 (Hellgren 1988), respectively, indicating that these bear populations were virtually stable. Estimates for SM indicate a stable (0%, national forest) to slightly (5%, GSMNP) increasing population, an indication consistent with that of the Jolly-Seber population estimates for the park (Fig. 2).

The estimates of size and growth rate indicate that the Smoky Mountains bear population is in fair to reasonably good health; however, given the imprecise nature of these estimates and the mounting human-related pressures (e.g., landfills, road and resort development, poaching) in and around the park and national forests, the population status is considered guarded and a conservative management practice is recommended.

In illustrating the importance of hard mast to reproduction and survival of black bears in the Smokies, the model simulations indicate both outcomes: exponential growth and extinction. Despite the extreme outcomes, the model is useful in that it does illustrate the importance of food and consequent trends in population growth.

However, the fact that the model predicts a population decline even with year-to-year variation in mast indicates weaknesses in the model. Mast availability described as good, bad, and average may be inadequate in portraying oak mast production in the Smokies; more qualitative divisions (e.g., fair, fairly good/poor, etc.) might be more consistent with reality and improve the model's predictive capabilities. Although adding a variable (e.g., food availability) to the model adds realism, the Leslie matrix is a simple model. It inherently predicts extremes in population growth or decline depending on the initial numbers in the population (S. Stringham, pers. commun.). The low initial numbers of national forest bears (e.g., 20 females, see Fig. 4) probably explain their rapid decline in bad mast years and failure to respond in good ones. Given possible periodic fluctuations in mast production and the long-lived nature of black bears, 20 years is not enough time to adequately assess the variations of mast and its influence on bear reproduction; undoubtedly,

Table 4. Density estimates of selected black bear populations in North America.

Location and reference	Density (bears/km^2)
Smoky Mts. This study	0.21-0.35
GSMNP This study	0.29
CNF+PNF This study	0.21-0.35
Shenandoah Natl. Pk., Va. Carney 1985	0.67-1.04
Great Dismal Swamp, Va. Hellgren 1988	0.46
Ont. Yodzis and Kolenosky 1986	0.2-0.6
White River Nat. Wildl. Refuge, Ark. Smith 1985	0.17-0.42
Minn. Rogers 1987	0.22
Mont. Jonkel and Cowan 1971	0.23-0.48
Ariz. LeCount 1982	0.33
Wash. Lindzey and Meslow 1977	1.12-1.49
Alas. McIlroy 1972	3.12

more years of data would improve the validity of the model.

The model also fails to include other factors that influence the population. Soft mast, such as berries (*Rubus* spp., *Vaccinium* spp., *Gaylussacia* spp.), cherries (*Prunus serotina*), and grapes (*Vitis* spp.), likely moderates the effects of hard mast failures (Garshelis and Pelton 1981, Eiler et al. 1989). Individual variation in bears also is neglected in the model as are the direct effects of immigration and density. In the future, revisions of the model should attempt to incorporate some of these effects.

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