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Black bear relocation as a method to reduce elk calf predation within Great Smoky Mountains National Park

Joseph Gene Yarkovich
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Joseph Gene Yarkovich entitled "Black bear relocation as a method to reduce elk calf predation within Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Joseph Clark, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Dr. Lisa Muller

Dr. Ed Ramsay

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BLACK BEAR RELOCATION AS A METHOD TO REDUCE ELK CALF PREDATION WITHIN GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Joseph Gene Yarkovich

May 2009

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ABSTRACT

An experimental release of elk was initiated in 2001 to assess the feasibility of population reestablishment in Great Smoky Mountains National Park. Initial analysis was conducted in 2006 and calf survival across that period averaged 0.592 with adult survival ranging from 0.689 to 0.926, differing by age and sex. Initial population projections produced annual growth rates that ranged from 1.051 at year 1 to 0.984 at year 25 with an average of 0.988. Under these conditions, the population failed to maintain a positive growth rate in 70% of projections. From May 2006 through July 2008, I trapped bears in Cataloochee Valley and relocated them to the western portion of the Park during elk calving season attempting to increase calf survival. We trapped and relocated 49 bears from 2006–2008, and most adult bears were radiocollared (n = 30). Forty-seven percent (n = 14) of collared bears returned to the capture area, 16% (n = 5) experienced mortality after release, 10% (n = 3) did not show homing behavior, and the fates of the remaining 27% (n = 8) were unknown. At the end of 2008, a total of 42 additional calves had been radio collared and tracked to determine fates. Average calf survival in program MARK changed from 0.592 to 0.690 from before (2001–2005) to after (2006–2008) bear relocation, but predation by black bears remained the largest known source of calf mortality from 2006 to 2008. Adult survival increased, with 2006–2008 rates ranging from 0.846 to 0.947 for males and 0.910 to 0.970 for females. Calf production rates for females from 2006–2008 increased to 0.429, 0.800, and 0.923 for females in the 2-year old, 3–9 year old, and 10–14 year old age classes, respectively. Using the 2006–2008 parameters, I estimated long-term growth rates and simulations maintained a positive growth rate in 100% of trials and produced an average annual growth rate of 1.117. Analyzing the entire reintroduction period, 2001–2008, simulations

maintained a positive growth rate in 100% of trials and produced an average annual growth rate of 1.070.

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CHAPTER I

INTRODUCTION

Though elk (*Cervus elaphus*) were once abundant throughout North America (Figure 1), the arrival of European settlers to the continent and their unregulated harvest practices and habitat alterations dramatically reduced elk populations over a relatively short time (Christensen 1998, O'Gara and Dundas 2002, Great Smoky Mountains National Park 2000). The Eastern elk subspecies (*C. e. Canadensis*), once native and abundant throughout southern Appalachia, was driven to extinction by excessive hunting pressure, habitat loss, and competition with domestic livestock (Bryant and Maser 1982). Today, elk occupy a small fraction of their historic ranges (Figure 2).

Increasingly, managers have been using reintroductions as a tool to restore free-ranging elk populations in the eastern United States. Recent successful elk reintroduction projects have been underway in the southeastern states of Tennessee, Arkansas, and Kentucky (Larkin et al 2003, O'Gara and Dundas 2002). This has prompted interest from conservation groups and wildlife managers to seek additional locations for potential reestablishment in the Southeast, including Great Smoky Mountains National Park (GSMNP). One mission of the National Park Service is to preserve endangered and restore extirpated species whenever feasible (Great Smoky Mountains National Park 2000). Consequently, the National Park Service, the University of Tennessee, Rocky Mountain Elk Foundation, and various local agencies worked together to perform an experimental release of elk within GSMNP. The cooperative goal of the National Park Service, Rocky Mountain Elk Foundation, University of Tennessee, and other agencies involved is to re-establish a permanently viable elk population in GSMNP. The objectives of this experiment included estimating population parameters and viability, determining factors that influence reintroduction success, estimating population growth rates, and developing a plan for herd reestablishment (Murrow 2007, Murrow et al. 2009).

In 2001 twenty-five elk were transported from Land Between the Lakes, Kentucky, placed in an acclimation facility, and released after about 60 days into Cataloochee Valley in the southeastern portion of GSMNP (Murrow 2007). In 2002, an additional 27 elk from Elk Island National Park, Alberta, Canada were placed in the holding pen at Cataloochee and subsequently released. A third group of elk was originally scheduled to be translocated to bring the experimental herd to its target number of 75–90 animals, but these animals were not obtained due to regulations passed halting the importation of cervids into North Carolina (Murrow 2007).

Since 2001 the herd has been closely monitored by personnel from the University of Tennessee and the National Park Service. The majority of adult female elk have bred and produced calves annually between May and early August (Murrow et al. 2009). Twenty-nine calves were monitored from 2001 to 2005. Sixteen of those survived to one year of age, and calf survival was estimated to be 0.592. Initial population analysis for the GSMNP herd indicated a slightly negative annual population growth rate ($\lambda = 0.988$) after 25 years with a 70% chance of population growth rates averaging <1.0 during that time (Murrow et al. 2009). The most significant factor associated with low population growth was low calf recruitment. In addition, Raithel et al. (2007) have shown that calf survival might be the single most important factor influencing population growth in ungulates.

Bears are efficient predators of neonatal ungulates, (Beckman and Berger 2003, Testa et al. 2000, Vreeland et al. 2004, Mattson 1997, Onorato et al. 2006) and have been observed on multiple occasions searching for, killing, and devouring neonatal elk calves throughout

Cataloochee Valley and the surrounding area. Approximately 70% of neonatal mortality in the GSMNP herd has been due to predation by black bears (*Ursus americanus*; Figure 3; Murrow 2007). Bear densities in GSMNP are high (1/ km^2, J. Laufenberg, University of Tennessee, unpublished data) and the translocated elk had no prior experience with bears. Consequently, GSMNP elk may not have known how to properly defend or hide neonates.

One possible contributing factor to these predation rates is the lack of adequate understory cover in and around Cataloochee Valley. Prescribed burning is now taking place in and around Cataloochee on a biennial basis. This burning may create more hiding cover for calves by altering the composition and density of the understory as well as maintaining grassy openings (Tiedemann et al. 2000). However, the effects this may have on elk calf predation rates are not known and would likely take many years to produce any real changes in calf survival.

Temporary predator removal has been suggested as one means of increasing populations of reintroduced species (McKinney et al. 2006). Bear relocations have proven successful in reducing predation rates in livestock (Armistead et al. 1994, Linnell et al. 1997). In addition, Murrow (2007) suggested that predator management in calving areas may increase calf recruitment within the GSMNP herd. In 2006, National Park Service staff decided to implement an experimental predator management program in an effort to increase calf survival and thereby decrease extinction probabilities for the GSMNP elk herd.

Black bears have impressive homing capabilities, and have traveled up to 271 km to return to their previous home ranges (McArthur 1981, Rogers 1987, Stiver 1991). Studies have shown that the majority of adult black bears consistently return to their original home ranges when translocated ≤64 km (Sauer et al. 1969, Rogers 1986). Studies have also shown that many bears translocated ≤64 km within GSMNP will return regardless of natural barriers (Beeman and

Pelton 1976, Stiver 1991). The size of GSMNP and relative location of Cataloochee Valley allowed for bears to be translocated $\geq$64 km away, while remaining within the Park (Figure 4). This suggested that many of the bears would return to the capture area.

Objectives and Hypotheses

My study focused on the removal of bears from Cataloochee Valley during the elk calving season to evaluate effects on elk survival and population growth. I also evaluated the effects of relocation on the bears. The specific objectives of my study were to:

1) determine whether the temporary trapping and translocation of black bears from calving areas increased survival of elk neonates;

2) estimate potential homing movements of translocated bears;

3) determine the effects of these actions on the local bear population; and

4) determine the implications these actions might have on the growth and viability of the GSMNP elk herd.

My research hypotheses were:

1) translocating bears from Cataloochee Valley creates a temporary, localized decrease in the bear population, thereby decreasing calf mortality due to predation;

2) translocation efforts will only cause a temporary decrease in the bear density around Cataloochee Valley with no long-term effects to the local bear population; and

3) these actions will cause a decrease in the overall chance of population sustainability for the GSMNP elk herd through increased calf survival.

CHAPTER II

STUDY AREA

GSMNP is a 2,072-km^2 biosphere reserve approximately located between 35° 26’ and 35° 47’ N latitude and 83° 2’ and 84° 0’ W longitude. GSMNP covers portions of Haywood and Swain counties in North Carolina, as well as Blount, Sevier, and Cocke counties in Tennessee. GSMNP is partially encompassed by large forested tracts of land including Cherokee National Forest to the northeast in Tennessee and Nantahala and Pisgah national forests to the south in North Carolina. The majority of land north of the Park is privately owned. The southeastern section of the Park also borders the Cherokee Indian Reservation. Trapping efforts occurred in and around Cataloochee Valley in the southeastern section of GSMNP (35° 38’ 23.000 north latitude and 83° 04’ 55.000 west longitude, Figure 3) located in Haywood County, North Carolina. The greatest numbers of elk within GSMNP reside and give birth to young in this area (Murrow 2007).

Topography

The Great Smoky Mountains are a part of the Unaka Mountain Range in the Blue Ridge Province of the Southern Appalachian Highlands (Fenneman 1938). The area is predominantly steep-sloped mountainous terrain with narrow valley bottoms. A 113-km main crest transverses the center of the Park from northeast to southwest with abundant finger ridges and peaks stemming from the main ridge. Elevations range from 230 m at Abrams Creek to 2,024 m at Clingmans Dome. The Park contains >900 km of streams that primarily drain into the Little Pigeon and Little Tennessee rivers in Tennessee, and the Oconaluftee and Tuckasegee rivers in

North Carolina. Soil composition within GSMNP is primarily Ocoee Series sandstone, quartzite, and noncalcareous shale (King and Stupka 1950).

Climate

The climate within GSMNP has been classified as mesothermal perhumid (warm-temperate rain forest) and varies according to elevation, slope, and aspect (Thornthwaite 1948, Stephens 1969). Highest precipitation occurs in July and annual precipitation averages 140 cm at lower elevations and 220 cm at higher elevations (Stephens 1969). Average annual temperatures are 8° C at higher elevations and 14° at lower elevations with a temperature gradient of 4° per 1,000 m change in elevation (Shanks 1954). Mean annual number of days with snowfall is approximately 7 at lower elevations and about 26 at higher elevations (Shanks 1954).

Flora and Fauna

GSMNP has received worldwide recognition for its great diversity in plant and animal communities. More than 1,570 species of vascular plants, 1,200 non-vascular plants, 2,200 fungi, 4,200 invertebrates, and 450 vertebrate species are known to inhabit GSMNP with an additional estimated 90,000 species yet to be classified (Sharkey 2001). Known vertebrates include $\geq$60 species of mammals, $\geq$200 species of birds, $\geq$80 species of reptiles and amphibians, and $\geq$80 species of fish (King and Stupka 1950).

CHAPTER III

METHODS

Bear Translocation and Telemetry

Murrow (2007) documented that most parturient female elk in GSMNP gave birth between late May and early July. As such, we began prebaiting efforts for bear trapping in the second week of May each year with traps initially being set for capture 23, 22, and 20 May 2006–2008, respectively. Neonatal ungulates are most susceptible to black bear predation within the first 2 weeks of life with rapidly decreasing chances of predation thereafter (Testa et al. 2000). Consequently, our trapping efforts ceased shortly after the last suspected pregnant cow gave birth within Cataloochee, occurring on 23 June, 5 July, and 3 July 2006–2008, respectively.

Trap sites were selected based on current bear sign (e.g., trails, scat, sightings), areas of previous bear sightings and trapping success, and proximity to elk natal areas. Traps consisted of aluminum culverts with guillotine-style doors and Aldrich spring-activated foot snares (Aldrich Animal Trap Co., Clallam Bay, Washington, USA). We modified all snares with swivels and automobile hood springs to reduce likelihood of capture-related injuries (Johnson and Pelton 1980). We used culvert traps at sites heavily travelled by elk to reduce chances of non-target captures and we baited all traps with sardines, bacon, donuts, or, if a kill site of an elk calf was found, pieces of the carcass. We immobilized bears with a mixture of ketamine hydrochloride (Bristol Laboratories, Syracuse, New York, USA; 200mg/ml) and xylazine hydrochloride (Rompun, Haver-Lockart, Inc., Shawnee, Kansas, USA; 100mg/ml) at a rate of 1ml/110 kg estimated body mass (Kreeger et al 2002) by pole syringe or gas-powered pistol (Pneu-Dart Inc., Williamsport, Pennsylvania, USA).

We applied sterile lubricant (Artificial Tears, Maury Biol. Co., Los Angeles, California, USA) to the eyes of each immobilized bear to prevent desiccation. Body temperature, pulse, and respiration were monitored while bears were being processed. Each bear was given a unique numbered ear tag (3.6 x 10 cm; Nasco, Fort Atkinson, Wisconsin, USA) and corresponding tattoo on the upper lip and flank (Johnson and Pelton 1980). We extracted a first premolar from most bears and sent them to Matson's Laboratory LLC (Milltown, Montana, USA) for aging by cementum-annuli counts (Willey 1974) with the exception of bears easily recognized as cubs or yearlings by body size. Bears were classified as cubs (<1 year old), yearlings (1 year old), sub-adults (2–4 years old), or adults (≥5 years old) and morphological data and reproductive status were recorded. Bears weighing >32 kg were fitted with radio transmitters (MOD-500; Telonics, Inc., Mesa, Arizona, USA) equipped with a cotton spacing section designed to fall off in <2 years (Hellgren et al. 1988). All radio collars were equipped with a mercury tip-switch mortality sensor designed to give a faster signal if the collar remained motionless >4 hours. Bears that were translocated in 2006 were not fitted with radio collars. Yohimbine hydrochloride (Yohimbine, Sigma Chemical Co., St. Louis, Missouri, USA; 0.2mg/kg body mass) was given intravenously as an antagonist for xylazine hydrochloride before transport if the bear was still unresponsive.

Bears were loaded into transfer cases and adult and sub-adult bears were released in the Twentymile area in the southwestern section of GSMNP, approximately 64 km from the capture location (Figure 4). Bears estimated to be yearlings were transported and released in the Nolan Creek area of GSMNP, approximately 40 km from capture location. Relocation distances for yearlings were shorter because young bears are less likely to home over larger distances than adult bears (Rogers 1986). All bear capture and handling was done in accordance with University of Tennessee Office of Laboratory Animal Care (IACUC #1706).

Translocated bears that display homing behavior tend to disperse from release sites within 1 week, and return to their home ranges within 1 month of release (Rogers 1986). We attempted to radio-locate translocated bears once daily during their first post-release week and 2-3 times weekly thereafter. Radiotelemetry triangulations were recorded using a 5-element Yagi antenna (Wildlife Materials, Inc., Carbondale, Illinois, USA) and ≥3 azimuths separated by >30 degrees were taken ≤40 minutes apart. If a radio signal was heard but a successful triangulation could not be obtained, the general area of the bear was noted to establish a direction of travel from previous locations and whether it had returned to the Cataloochee area. In many cases terrain, large movements by bears, and limited land accessibility impeded successful triangulation on bears. In cases where signals could not be found via ground tracking methods, aerial locations were collected from a Cessna 182 fixed-wing aircraft using a toggle box that made it possible to switch between antennae affixed to each wing strut. Aerial locations were obtained by flying in increasingly tighter circles over radiocollared bears until directly over the animal, at which point global positioning system (GPS) coordinates were taken from a handheld receiver (Garmin International Inc., Olathe, Kansas, USA). Capture, release, and recovery locations from bears were obtained from handheld GPS units using X and Y coordinates of the Universal Transverse Mercator (UTM) grid system. Specific locations could not always be determined. Distances between points were determined using the Pythagorean Theorem resulting in a straight-line distance without regard to topographic or hydrologic features (Stiver 1991).

In a homing study on black bears in GSMNP, Beeman and Pelton (1976) classified bears as returning if they were located within 8 km of capture site, and noted that nearly all bears that did return were located within 2 km of capture site. Other researchers have defined bears as returning if they were located within distances ranging up to 20 km of the capture location (Fies et al. 1987, Rogers 1986, Stiver 1991). Unfortunately, Cataloochee Valley is topographically shaped like a large basin surrounded by steep ridges, which reduces effective telemetry range to within its confines (approximately 5–6 km range). As such, we considered bears to have returned to the capture area if their radio signals were heard from within Cataloochee Valley or the immediate area.

Since 1981, GSMNP has conducted an annual bait-station survey as part of a regional monitoring project examining trends in relative distribution and densities of black bears (Carlock et al. 1983). Several portions of this survey transversed the Cataloochee Valley study area. We examined bait-station visitation rates during our study period as a possible indicator of density fluctuations in the area. Trapping efforts ceased around early July each year and the annual bait station surveys are conducted during mid-late July of the year.

Elk Calf Production and Survival

One goal of this study was to compare population parameters and growth rates with those recorded prior to predator relocation from Cataloochee. Murrow et al. (2009) conducted extensive population analyses on the GSMNP elk herd using data collected between 2001 and April 2006. I followed similar techniques to estimate elk population parameters from 2006 to 2008.

I monitored females ≥2 years of age daily by visual observation and radiotelemetry within Cataloochee Valley. Adult female elk typically isolate themselves from the herd just prior to parturition (Murrow 2007). Therefore, if a female was observed leaving the group a calf search was performed approximately 24 hours later. I located the female by radiotelemetry and stalking techniques, and then performed systematic grid searches approximately 200 m in each direction from that location. The area around the female was searched twice daily during the early morning and late afternoon for up to 2 weeks after separation from the herd or until a calf was successfully located and captured. Physical signs of having given birth (e.g., vaginal discharge, swollen teats, sunken flanks) were noted when present. If a female was observed giving birth we waited several hours before handling the calf to allow for initial imprinting and post-natal care (Espmark 1971).

In cases where a calf was not immediately observed, but the female exhibited physical signs of having given birth, she was considered to have reproduced and the calf was classified as having an unknown fate. If a calf was never observed after the female returned to the herd, the calf was classified as a mortality with an unknown cause.

Annual calf production was estimated as the proportion of females that gave birth out of the total number of females for each age class per year. I estimated calf production for female elk that were 2, 3–9, 10–14, and 14–20 years of age (Raithel et al. 2007). Calf production was estimated by individual year for the period prior to predator removal (2001–2005), for the period during predator removal (2006–2008), and for all 8 years pooled (2001–2008). Comparisons of calf production rates before and during bear relocation were made using Student's t-tests.

We physically restrained and quickly blindfolded calves to reduce stress (Vreeland et al. 2004). They were fitted with expandable breakaway radio collars (MOD-315; Telonics, Inc., Mesa, Arizona, USA) that had been cleaned with human-scent neutralizing detergent (Hunter's Specialties, Inc., Cedar Rapids, Iowa, USA). We determined sex and recorded morphological data when the calf or the cow did not appear greatly stressed. Rubber gloves were worn when handling calves to prevent transfer of human scent. Calf handling typically took <5 minutes to avoid prolonged stress on the animal.

We checked radio signals on calves ≥3 times per day for the first 2 weeks of life and at least once daily thereafter for up to 5 weeks (Vreeland et al. 2004). Signals were checked for status (active or mortality) and general areas where calves were located were noted. If a mortality signal was detected, we immediately investigated the area. Attempts were made to determine causes of mortality on all calf fatalities which required finding dead calves shortly after death. Field observations were performed to determine probability of predation, including claw marks, canine punctures, broken vertebrae, and internal hemorrhaging on the carcass, and predator sign left at the kill site (Mattson 1997, Wade and Bowns 1993).

Individual calf survival was summarized monthly and a known-fate analysis was performed using Program MARK (White and Burnham 1999). We used the approximate calving season midpoint (June 1) as the starting period for survival rate estimates. We examined calf survival as a potential function of sex, year, origin of the mother (LBL or EINP), and age of mother. Survival of some uncollared calves was determined by periodic visual observations throughout the year; only cow and uncollared calf pairings that were regularly seen or radio-located were included in that sample. The delta method was used to derive standard errors (SE) for annual calf survival rates from monthly estimates (Seber 1982).

Non-calf Survival

Survival for elk ≥1 year of age was monitored using radiotelemetry. Adult elk within GSMNP were fitted with VHF radio collars (MOD-600; Telonics, Inc., Mesa, Arizona, USA) equipped with tip-switches and mortality sensors. All elk in this class were radio-located ≥2 times per week to monitor survival. Radio collars for adult male elk were equipped with elastic spacing material to allow for swelling of the neck during the rut without airway impairment (Telonics Inc., Mesa, Arizona, USA). Carcasses of dead elk were removed and taken to the University of Tennessee College of Veterinary Medicine for full necropsy whenever feasible. If the entire carcass could not be safely or practically removed, field necropsies were performed or vital organs packed out and taken for disease and parasite testing. Necropsy reports were reviewed to determine cause of death or reason for euthanasia. In the event of a malfunctioning or dropped collar, attempts were made to chemically immobilize the animal and replace the collar as soon as possible.

Individual survival for non-calves was summarized monthly and known-fate analysis in Program MARK was used to estimate survival (White and Burnham 1999). Initial analysis indicated that some elk died within 1 month after release (n = 4), probably due to capture- or transfer-related stress. These elk should not be included in survival estimates used to project future herd growth, so the first month following the 2 original releases was censored from analysis. Elk were grouped into 1-, 2–9-, 10–14-, and 15–20-year age classes for survival estimates based on approximate life stages (Raithel et al. 2007).

Population Growth

Population growth and extinction probabilities were estimated using an individual-based model in Program Riskman (version 1.5.413; Ontario Ministry of Natural Resources, Toronto, Ontario, Canada). This program required estimates of starting population size, maximum age, standing age distribution, calf survival, age-specific male and female survival, calf sex ratio, and age-specific calf production rates. Riskman performs stochastic growth projections by exposing individuals to a series of trials according to random normal deviates of vital rate means based on SEs provided by the user. I calculated the annual process variation of each model parameter to incorporate temporal variation into the error terms of the stochastic trials (White et al. 2002). This was done to account for possible process variance while minimizing or eliminating sampling variance from our parameters. Variances of output parameters are estimated by Monte Carlo techniques within the program. Density effects were not included in either phase of the study. Population growth projections were evaluated based on our conservation goal of population sustainability (i.e., mean growth rate [λ] >1.0) and compared to those of Murrow et al. (2009). I also estimated the proportion of runs for which the population declined to below half its initial size. Simulations were done using 1000 trials and a 25-year timeline.

One goal of this project was to compare effects of population parameter changes on population growth. To do so, I used the standing age distribution and population size on 1 June 2006 by Murrow (2007; Table 1). Projections and growth rates were obtained using parameters for the initial 5 years of study without predator management (2001–2005), the following 3 years with predator relocation (2006–2008), and using parameters averaged across the entire 8 years of study (2001–2008). Comparisons in λ were made using Student's t-tests. I also performed an analysis by individually substituting parameters in the models to determine which had the greatest effect on overall λ. To perform that analysis, I recorded the change in λ as a result of a change in each parameter and divided that by the sum of all rate changes in λ. Simulations were also done using the parameters from the entire study period (2001–2008) with the estimated age and sex distribution of 1 March 2009, the time of current analysis, as starting conditions (Table 2). This produced growth rate estimates for the current herd structure.

CHAPTER IV

RESULTS

Bear Translocations

We captured and relocated 49 bears (22 male, 26 female; the sex of 1 was unknown because it was never immobilized) from 2006 to 2008 (Table 3). In 2006, we captured 15 bears (5 male, 9 female, 1 unknown) in and around Cataloochee Valley, though none of those bears were fitted with radio collars. Of those captured, 8 (5 adults, 3 yearlings) were released at Twentymile (Figure 3), 6 (4 adults, 2 yearlings) were released along Parson's Branch Road (8 km northwest of Twentymile), and 1 yearling was released near Sterling Gap (7.5 km north of Cataloochee). During 2007 we captured and relocated 12 bears a total of 13 times (6 male, 6 female). Male bear 437 was relocated, returned to the study area, and was recaptured and moved a second time during the same season. Eleven adults or sub-adults were fitted with radio collars and released at the Twentymile release site. Two yearlings were captured and released at Nolan Creek without being fitted with radio collars due to small body size and anticipated rapid growth. Relocation distances ranged from 69 to 74 km from capture location (Table 3). Twenty-two bears (11 male, 11 female) were captured during the 2008 field season. All bears were adults or sub-adults and were released at Twentymile. Only 19 of these bears received radio collars due to higher than anticipated capture success. These bears were relocated distances ranging from 70 km to 75 km (Table 3).

Of the 30 bears that were tracked, 47% (*n* = 14) returned to the Cataloochee Valley area of GSMNP in periods ranging from 11 to 100 days (Table 3). Five relocated bears died (16%) with 1 being killed by a vehicle in Athens, Tennessee (55 km west of the release site) and 1 killed by a vehicle in Cumming, Georgia (about 140 km south of the release site). The 3 other bears were killed during the regular North Carolina bear hunting season on private or state lands outside GSMNP.

Three bears did not exhibit homing behavior (10%); 2 of those were never radiolocated >10 km of the release site, and 1 dropped its collar in a den approximately 14 km south of the release site. The fates of the remaining 8 relocated bears (27%) are unknown. A few of these bears dropped their collars almost immediately after being released; radio signals of the others were simply lost due to collar malfunction or extensive movements outside our search area.

The Cataloochee Divide bait-station survey, bordering the study area to the south, resulted in bear visitation rates of 47%, 71%, and 64% for 2006, 2007, and 2008, respectively. This route had a visitation rate of 60% in 2005, the year prior to predator removal. The Mount Sterling route, along the northern border of the study area, had visitation rates of 77%, 25%, and 69% during predator removal years. The Heintooga-Round Bottom route, bordering Cataloochee to the west, had visitation rates of 97%, 81%, and 94% in predator removal years (Figure 5). Combined, the three routes had average visitation rates of 74%, 59%, and 76% for 2006–2008, respectively, and a total average visitation rate of 70%. Prior to bear relocation these routes averaged 57%, 75%, and 67% for 2003–2005, respectively, and had a total average visitation rate of 66%.

Elk Calf Production and Survival

Calving occasions ranged from May through August with most births occurring during the last week of May and the first week of June. A total of 49 calving events were documented between 2006 and 2008. Forty-two of these calves (26 male, 16 female) were successfully radio collared or monitored closely enough to determine fate (survived to 1-year or died; Table 4). Of the 12 calves that died, we were able to determine cause of death for 7 (Figure 3). Predation by black bears accounted for 4 mortalities (58%), 1 was killed by a dog or coyote (*Canis latrans*), 1 was struck by a vehicle, and 1 is suspected to have died of pneumonia. Overall mean annual calf survival was 0.690 for 2006–2008, and averaged 0.656 for the entire 8-year study period. Pooling the data by years prior to and during predator control did not improve model performance nor was calf survival as a function of age of the mother (Table 6). The average sex ratio of calves for 2006–2008 ranged from 0.500 male (2007) to 0.688 male (2008) with an overall mean of 0.595 male ($n = 42$). Mean calf production rates were 0.429 ($n = 7$), 0.800 ($n = 35$), and 0.923 ($n = 13$) for females ages 2, 3–9, and 10–14, respectively (Table 7). Calf production rates were higher than those reported by Murrow et al. (2009) for 3–9-year old elk ($t = 3.142$, $P < 0.001$) but not the other age classes ($t < 1.244$, P > 0.107). Likewise, calf sex ratios did not differ before compared with during bear relocation ($t = 0.364$, $P = 0.358$).

Non-calf Survival

From 2006–2008, 13 mortalities for elk ≥1 year of age were documented. Meningeal worm (*Parelaphostronglus tenuis*), a parasitic nematode, accounted for 23% ($n = 3$) of known adult mortalities (Table 8). Unknown cause of death, typically due to significant predation and decomposition by the time the carcass was retrieved, accounted for 38% ($n = 5$) of adult mortalities. Other causes of mortality included being struck by vehicles ($n = 2$), injuries from fighting ($n = 2$), or poaching ($n = 1$). Estimates of annual survival for elk ≥1 year of age from 2006–2008 ranged from 0.846 to 0.947 for males and 0.910 to 0.970 for females, depending on age (Table 9). In Program MARK, models that showed no annual temporal variation performed better than those in which temporal variation occurred (Table 5). Sex as a source of survival variation received about as much support as models without that covariate. Also, grouping years before and during bear relocation performed about as well as models whereby survival was constant across all years, but those models were supported more than models whereby survival differed by year. The 2006–2008 estimates generally were higher than those from 2001–2005 (Murrow et al. 2009, Table 10). Only 1 elk reached the 15–20 year-old age class, and was thus included in the 10–14 year-old age class to avoid using a single individual to represent an entire age class. Estimates from Raithel et al. (2007) were used for 15–20 year age class survival parameters. Process standard errors were low because year was not a strong predictor of adult survival.

Population Growth

Population projections using data from the bear relocation period (2006–2008) resulted in a mean λ of 1.117 (SD = 0.012) after 25 years, with growth rates ranging from 1.236 at year 1 to 1.103 at year 25. The mean λ using data from the entire elk reintroduction period (2001–2008) was 1.070 (SD = 0.013) after 25 years, with growth rates that ranged from 1.157 at year 1 to 1.064 at year 25. The population reached sustainability in 100% of the simulations for both projection periods. Estimates of λ from 2006–2008 and 2001–2008 were greater (t = 3.32, $P <$ 0.001 and t = 5.33, $P <$ 0.001, respectively) than those reported for 2001–2005 by Murrow et al. (2009; λ = 0.988, SD = 0.021; Figure 6). Increases in calf production from 2001–2005 to 2006–2008 had a greater proportional effect on changes in λ (38.3% for all ages combined) than did increases in adult female survival (30.7% for all ages combined), adult male survival (16.6% for all ages combined), or calf survival (12.6%, Table 11).

Growth projections were also obtained using the estimated age and sex distribution of 1 March 2009, the time of analysis (Table 2). Results from this set of trials also indicated a mean annual growth rate of 1.070, and without regard to density effects estimated a population of 495 elk at year 25.

CHAPTER V

DISCUSSION

Bear Translocations

Most bears disperse from release sites within 1 week and, of bears that returned, homing tendencies were evident within 1 month of release (Sauer et al. 1969, Rogers 1986). My data support these findings in that 86% (n = 12) of bears with known times of return took <30 days to return to Cataloochee. The remaining 2 bears that homed were located only sporadically via aerial telemetry between release and capture locations and returned to Cataloochee Valley after 98 and 100 days; those animals may have returned sooner but were not detected.

The overall homing rate (47%) in my study was similar to that of other studies of bear homing within GSMNP. Beeman and Pelton (1976) reported that 47% of bears translocated ≤64 km within GSMNP returned to within 8 km of capture location. Stiver (1991) reported approximately 30% of bears relocated similar distances returned to the capture area. Though my results reflect similar rates of return, previous studies have focused on bears known to be human-habituated or human food-conditioned. My study occurred in an area that had human use, but had no known nuisance bears at the time, suggesting homing tendencies are similar for "wild" versus "nuisance" bears in GSMNP. Also, because previous studies of bears in GSMNP depended on recapture or re-sighting as a means of determining return rates, those estimates may have been biased low. It should be noted that, since the time radio-collared bears returned to Cataloochee, there were no sightings by visitors or staff despite the high visibility of the white radio collars used.

Mortality rates of translocated bears in my study (16%) were similar to or lower than those of other studies. Stiver (1991) reported a mortality rate of 18.5% for bears that were translocated within GSMNP. All but one mortality in his study were human-related with hunting being the primary cause. Beeman and Pelton (1976) also reported hunting as a probable source of mortality for some translocated bears and Fies et al. (1987) reported hunting as a primary source of mortality for translocated bears bordering National Parks. Similarly, Comly and Vaughan (1994) report similar findings for bears relocated in or near Shenandoah National Park. In my study, 3 bear mortalities occurred as part of the regular state bear hunting season. The North Carolina bear hunting season occurs during November and December of each year, at least 4 months after bear relocation efforts had ceased. These bears were killed south and southeast of the Twentymile release site, making it unlikely that they were displaying homing behavior.

Our study area was relatively small, and a seemingly large number of bears were removed. However, the bait-station routes for the study area, though highly variable, seemed to remain within normal bounds during the period of predator removal (Figure 5). Clark et al. (2005) suggested that the annual bait-station survey should not be used as an indicator of bear population growth in small geographic areas such as Cataloochee Valley because of high variability and the effects of other environmental variables on bear visitation rates. Regardless, my data did not indicate a dramatic decrease in bear density surrounding Cataloochee.

Elk Calf Production and Survival

Calf survival rates in GSMNP are similar to other unhunted elk herds that have bears as predators (Gunther and Renkin 1990, Singer and Harting1997, Smith and Anderson 1998). However, my findings did not support the hypothesis that calf survival was greater as a result of predator removal. Black bear predation continued to be the major calf mortality factor; during the 3 predator removal years, 57% (4 of 7) of known calf mortalities were due to black bears compared with 69% (9 of 13) during initial years (Murrow 2007).

Reproductive rates for elk herds are highly variable in the literature (40%–92%) and are correlated with female body condition prior to breeding, as is age of primiparity (Hudson et al. 1991, Kohlmann 1999, Larkin et al. 2003). Reproductive rates for the GSMNP herd varied by age class (0.364–0.875) and were similar to those reported for reintroduced elk in the Southeast (Larkin et al. 2003) and of source herds (Rob Kaye, Elk Island National Park, unpublished data, Curtis Fowler, Land Between the Lakes, personal communication). A study by Noyes et al. (1996) showed that female pregnancy rates increased when older bulls (≥5 years old) served as the primary herd breeders. However, this should not be an influential factor as the age of available bulls has always included those ≥5 years old. Murrow (2007) conducted fecal analyses and concluded that GSMNP elk foraging habits consisted primarily of graminoids, typical of most western elk herd diets (Kingery et al. 1996). This shows that although the vast majority of elk habitat available was forested, they were mainly utilizing open grazing land as forage and not exploiting forested resources (Murrow 2007). Though no fecal analysis was conducted during 2006–2008, field necropsies of several dead elk indicated they were heavily utilizing acorns (*Quercus rubra*) as a food source during fall and winter. Additionally, the majority of GSMNP elk remained almost exclusively within forested areas for approximately 2 months each winter, rarely using the open fields of Cataloochee during that time, which differs from winter behavior in initial study years. This suggests changes in foraging habits of GSMNP elk during my study period, which may be a primary factor for increasing calf production. The calf sex ratio has remained skewed towards males (0.577) serving as additional possible evidence of abundant food resources (Kohlmann 1999).

Animals that were initially released into Cataloochee appeared to be naïve to bears as predators. We observed individual female elk losing calves to predators within Cataloochee, then moving to areas outside of GSMNP to successfully give birth. These females typically returned to Cataloochee a few weeks after giving birth. Offspring of these females have been observed displaying similar reproductive behavior with a high degree of success. More recently we have also witnessed female elk defending neonates against bears and coyotes within Cataloochee. Such behavior can serve as an indication of females learning to cope more effectively with local predators. This may prove to be an important factor in determining long-term success of recruitment within the herd.

Non-calf Survival

Survival of most non-calf elk from 2006–2008 was generally higher than during 2001–2005 (Tables 9 and 10). In examining the entire 8-year reintroduction period, survival was similar to other unhunted elk populations (Eberhardt et al. 1996, Ballard et al. 2000, Larkin et al. 2003, Bender et al. 2006). Murrow (2007) documented that adult female survival may have been the most influential factor affecting population growth rates in GSMNP elk. Similarly, my analysis indicated that female survival was an influential parameter affecting the change in growth rates between study periods (Table 11). Elk survival is significantly impacted by forage availability and nutritional quality (Cook 2002, Skovlin et al. 2002) and the increased use of higher quality foods such as acorns may have been a factor in the higher non-calf survival rates that we documented.

Another factor affecting elk survival is use of land outside of GSMNP. The number of elk hit and killed by vehicles has increased in recent years (*n* = 3), and many more reports indicate elk utilizing habitat along major highways and roads outside of GSMNP, increasing potential for elk-vehicle conflict. There have been increased reports of nuisance elk on private property bordering the Park. Several individual elk were captured and returned to GSMNP. In addition, one elk was known to have been poached in 2008. As the GSMNP elk herd continues to grow and expand its range, human-elk conflict is likely to increase and become a more realized factor affecting elk survival.

Meningeal worm remained the largest known cause of adult and sub-adult mortality (Table 8). It has been hypothesized that meningeal worm can limit elk populations in areas where elk are conspecific with white-tailed deer (*Odocoileus virginianus*), though many factors influence the degree of severity (Bender et al. 2005). White-tailed deer in GSMNP are known to be a frequent host of meningeal worm, which does not seem to affect deer but can be pathogenic to elk and other cervids (Samuel et al. 1992, Davidson 2006). Elk have been successfully reintroduced in other areas with high white-tailed deer density (Comer et al. 1991, Bender et al. 2005) but a possible factor contributing to herd success is that infection is not uniformly fatal in exposed elk (Samuel et al. 1992). The largest proportion of mortality due to meningeal worm was found in sub-adult elk, which is typical of infected herds (Larkin et al. 2003, Alexy 2004).

Overall, survival rates were higher for female elk than for male elk (Table 9). As a result, although the sex ratio of calves has been skewed slightly towards males, the overall sex ratio for the GSMNP elk herd is slightly in favor of female elk (0.452 male).

Population Growth

Though Murrow (2007) suggested that adult female survival was the most influential factor affecting population growth rates in GSMNP elk, my analysis indicated that female survival was second in importance to calf production in affecting the change in λ between study periods (Table 11). However, the distinction is that Murrow (2007) performed a sensitivity analysis which essentially compares equal changes in population parameters on λ whereas I used a perturbation analysis which evaluated realized changes in individual vital rates (Mills 2007). Regardless, my analysis indicated that the potential changes in calf survival due to bear relocation had only a small effect on the realized increase in λ.

Projections using the sex and age distribution estimated for 1 March 2009, the time of analysis, produced a similar growth rate of 1.071. However, the chances of declining to less than half its initial size decreased from 70 to 0%. Larger populations are less sensitive to random stochastic events (Raithel et al. 2007). As such, it is likely that using the larger population size would produce fewer trials that result in extinction. However, the GSMNP elk herd remains small (93 animals) and thus will likely remain sensitive to slight changes among survival and fecundity rates for several years to come.

CHAPTER VI

MANAGEMENT IMPLICATIONS

Persistence of a species should not be dependent on human intervention across long time periods, and as such, I do not recommend long-term bear translocation as a management tool. It should also be noted that the bear management activities associated with this project resulted in a high degree of public opposition from hunting groups. I do, however, recognize the potential of bear management for increasing calf recruitment in the short term, when public interests can be balanced with management needs. The GSMNP herd was relatively small, and as such was sensitive to slight variations in survival and fecundity rates. As reintroductions of elk become more common in black bear habitat, managers may face similar situations and could use bear relocation as a means of increasing herd numbers in the short term when additional elk cannot be supplemented to the population. It should be recognized that several other factors will be more important in determining long-range success, most notably that female elk must learn the behavior necessary to successfully rear their young. Elk that were originally released into Cataloochee were naïve at dealing with bears as predators. As more of the GSMNP herd consists of elk born there, there will likely be continued learning about how to successfully reproduce in bear habitat.

Habitat composition may be an additional factor contributing to high predation of elk calves in GSMNP. As such, the continued prescribed burning of Cataloochee Valley and its surroundings probably holds long-term potential for increasing elk calf survival by providing more adequate hiding cover. In addition, GSMNP elk seem to be utilizing forest resources more frequently than in previous years. However, most elk still use the open grasslands of

Cataloochee as their primary food source. Prescribed burning and mowing regimes will remain necessary to maintain these critical open areas. In addition to protecting calves, other adaptations to a new environment by translocated elk (e.g., effectively utilizing food resources) cannot be overemphasized. This cumulative learning likely contributed to the increase in calf recruitment equal to or greater than the bear relocations.

The GSMNP elk herd remains small and as such is sensitive to stochastic changes in vital rates. The continued monitoring of the herd remains essential in determining its long term potential. The needs of research must also be balanced with the economic constraints of managers as well as the values of public visitation to the area. The cost of continuing such extensive research is significant, as is the manpower necessary. In addition, a large portion of the public has expressed interest in viewing and photographing elk that look more natural (i.e. without ear tags and radio collars). Adult female survival and calf recruitment remain the most important factors affecting herd growth and should continue to be monitored. Because projections are not as sensitive to adult male survival, and this is also the demographic component that receives the most public attention, adult males could be monitored less intensively. This would provide managers with a means of saving money and manpower, while balancing concerns of the public in this high-profile reintroduction project.

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APPENDICES

APPENDIX A: TABLES

Table 1. Sex and age distribution of elk in Great Smoky Mountains National Park, 1 June 2006 (From Murrow et al. in press).

Age class	Male	Female
Calf	7	6
Yearling	0	3
2–9 year old	20	21
10–14 year old	0	4
15–20 year old	0	0
Total	27	34

Table 2. Sex and age distribution of elk in Great Smoky Mountains National Park, 1 March 2009.

Age class	Male	Female
Calf	13	7
Yearling	6	6
2–9 year old	17	28
10–14 year old	6	10
15–20 year old	0	0
Total	42	51

Table 3. Capture, release, and return summary for translocated black bears in Great Smoky Mountains National Park, 2006–2008.

Date	Bear ID	Sex	Age	Collared	Distance relocated	Fate
5/24/2006	404	F	1	No	73.7	Unknown
5/25/2006	401	F	9	No	70.1	Return
5/25/2006		Unk	1	No	46.1	Unknown
5/25/2006	411	F		No	73.0	Unknown
6/1/2006	402	M	1	No	70.3	Unknown
6/1/2006	418	F		No	75.3	Unknown
6/1/2006		F		No		Mortality
6/2/2006	416	F		No	73.5	Unknown
6/14/2006	44	M	1	No	73.0	Unknown
6/14/2006	43	F	1	No	70.3	Unknown
6/14/2006	422	F		No	70.0	Unknown
6/14/2006	407	F		No	71.8	Unknown
6/21/2006	423	M	4	No	73.7	Return
6/22/2006	425	M	7	No	73.7	Return
6/23/2006	428	M		No	71.8	Unknown
5/23/2007	438	M	1	No	39.9	Unknown
5/25/2007	401	F	10	Yes	70.0	Return
5/31/2007	439	F	6	Yes	72.9	Mortality
5/31/2007	437	M	3	Yes	70.6	Return
6/1/2007	423	M	5	Yes	71.8	Return
6/7/2007	386	M	3	Yes	70.6	Mortality
6/11/2007	440	F	6	Yes	71.8	Unknown
6/12/2007	441	F	17	Yes	75.1	Return
6/21/2007	442	F	1	No	46.0	Unknown
6/22/2007	443	M	4	Yes	70.6	Non-Return
6/22/2007	445	M	2	Yes	73.5	Mortality
7/5/2007	448	F	5	Yes	70.0	Unknown
7/8/2007	437	M	3	Yes	70.6	Return
5/21/2008	449	F	4	Yes	72.9	Unknown
5/21/2008	437	M	4	Yes	71.6	Return
5/22/2008	450	F	11	Yes	71.8	Non-Return
5/22/2008	460	F	3	Yes	70.0	Non-Return
5/22/2008	461	M	3	Yes	73.5	Unknown
5/22/2008	444	F	6	Yes	70.6	Return
5/29/2008	462	M	2	Yes	73.5	Unknown
5/30/2008	471	M	3	Yes	73.5	Return
5/30/2008	470	F	7	Yes	70.8	Mortality
6/4/2008	473	F	6	Yes	71.8	Return
6/5/2008	472	F	11	Yes	73.5	Mortality
6/5/2008	425	M	9	Yes	70.8	Return

Table 3. Continued.

Date	Bear ID	Sex	Age	Collared	Distance relocated	Fate
6/6/2008	474	M	3	Yes	70.0	Return
6/6/2008	475	M	adult	Yes	70.6	Unknown
6/6/2008	476	F	3	Yes	73.5	Return
6/10/2008	481	M	3	Yes	71.8	Unknown
6/11/2008	423	M	6	Yes	75.1	Return
6/12/2008	478	F	7	Yes	70.0	Unknown
6/17/2008	482	F	11	Yes	70.3	Return
6/19/2008	479	F	7	No	70.0	Unknown
6/20/2008	480	M	3	No	70.0	Unknown
6/20/2008	373/483	M	adult	No	71.8	Unknown

Table 4. Summary of elk calves with known fates born in Great Smoky Mountains National Park 2006–2008.

Calf ID	Sex	Date observed	Age of mother	Fate at 1-year
94	F	5/30/2006	6	Alive
96	M	6/14/2006	5	Dead
97	F	6/5/2006	4	Alive
98	M	6/5/2006	9	Alive
99	F	6/8/2006	9	Alive
100	M	6/12/2006	9	Alive
101	M	6/16/2006	9	Dead
102	M	6/16/2006	5	Alive
103	M	6/23/2006	12	Alive
104	F	7/4/2006	8	Alive
105	M	8/4/2006	11	Alive
106	M	9/1/2006	2	Alive
107	F	11/1/2006	6	Alive
108	F	6/1/2007	5	Alive
109	M	6/5/2007	2	Alive
110	F	6/6/2007	6	Alive
111		6/7/2007	7	Dead
112	M	6/10/2007	10	Dead
113	F	6/14/2007	10	Alive
114		6/18/2007	13	Dead
115	M	6/18/2007	3	Dead
116	M	6/18/2007	9	Alive
117	F	6/26/2007	6	Alive
118	M	6/26/2007	12	Alive
119		7/2/2007	11	Alive
120	M	7/6/2007	5	Dead
121	M	7/22/2007	10	Alive
122		7/8/2007	7	Alive
123	F	7/30/2007	2	Alive
124	F	8/7/2007	10	Dead
125	F	6/1/2007	6	Alive
126	F	5/23/08	11	Alive
127	M	6/2/08	6	Alive
128	M	6/2/08	3	Alive
129	M	6/3/08	8	Dead
130	M	6/9/08	7	Alive
131	M	6/11/08	7	Alive
132	F	6/11/08	12	Alive
133		6/12/08	10	Dead
134	M	6/12/08	13	Alive
135	M	6/14/08	11	Alive

Table 4. Continued.

Calf ID	Sex	Date observed	Age of mother	Fate at 1-year
136	M	6/16/08	4	Alive
137	F	6/18/08	2	Alive
138	F	6/24/08	6	Alive
139	M	7/1/08	14	Alive
140	M	7/3/08	11	Alive
141	M	7/3/08	11	Dead
142	M	6/12/08	7	Alive
143	F	9/22/08	8	Alive

Table 5. Information-theoretic results for models to estimate survival of elk at Great Smoky Mountains National Park, 2001–2008.

Model	AICc	ΔAICc	AICc weights	Model likelihood	Number of parameters	Deviance
{year pooled; ages 1, 2–9, 10–14; by sex}	598.028	0.0000	0.53969	1.0000	5	588.015
{year pooled; ages 1, 2–9, 10–14}	598.528	0.5005	0.42020	0.7786	4	590.52
{years 2001–2005, 2006–2008; ages ≥1yo}	603.241	5.2133	0.03982	0.0738	3	597.236
{by year; ages 1, 2–9, 10–14; by sex}	613.925	15.8978	0.00019	0.0004	26	561.639
{by year; ages 1, 2–9, 10–14}	615.1624	17.1348	0.00010	0.0002	25	564.8972

Table 6. Information-theoretic results for models to estimate survival of elk calves at Great Smoky Mountains National Park, 2001–2008.

Model	AICc	ΔAICc	AICc weights	Model likelihood	Number of parameters	Deviance
{calf, by year}	598.7613	0.0000	0.27182	1.0000	9	580.7245
{calf, by year, age of mother as covariate}	599.0124	0.2511	0.23975	0.8820	10	578.9674
{calf, constant time}	599.9425	1.1812	0.15059	0.5540	2	595.9400

Table 7. Calf production for female elk, by age class, in the Great Smoky Mountains National Park, 2006–2008.

Parameter	Mean	Temporal process SE	Total SE
Calf production age 2	0.429	<0.001	0.187
Calf production age 3–9	0.800	<0.001	0.068
Calf production age 10–14	0.923	0.002	0.074
Calf production age 15–20[1]	0.265	0.040	

[1]Data from Raithel et al. (2007).

Table 8. Sub-adult and adult elk mortalities in Great Smoky Mountains National Park, 2006–2008.

Age class	Meningeal worm	Vehicle collision	Injured by other elk	Poached	Unknown
Sub-adult males	2	0	1	0	0
Sub-adult females	0	0	0	0	2
Adult males	1	2	1	1	2
Adult females	0	0	0	0	1
Total	3	2	2	1	5

Table 9. Adult elk survival, by sex and age group, in Great Smoky Mountains National Park, 2006–2008.

Parameter	Mean	Temporal process SE	Total SE
1-year-old male survival	0.846	0.004	0.006
2–9-year-old male survival	0.918	0.005	0.020
10–14-year-old male survival	0.947	<0.001	<0.001
15–20-year-old male survival[1]	0.724	0.077	
1-year-old female survival	0.910	<0.001	<0.001
2–9-year-old female survival	0.953	<0.001	0.016
10–14-year-old female survival	0.970	<0.001	<0.001
15–20-year-old female survival[1]	0.724	0.077	

[1] Data from Raithel et al. (2007).

Table 10. Adult elk survival, by sex and age group, in Great Smoky Mountains National Park, 2001–2005 (From Murrow et al. 2009).

Parameter	Mean	Temporal process SE	Total SE
1-year-old male survival	0.813	0.024	0.035
2–9-year-old male survival	0.912	0.003	0.027
10–14-year-old male survival	0.689	<0.001	<0.001
15–20-year-old male survival[1]	0.724	0.077	
1-year-old female survival	0.842	<0.001	<0.001
2–9-year-old female survival	0.926	<0.001	0.017
10–14-year-old female survival	0.934	0.025	<0.001
15–20-year-old female survival[1]	0.724	0.077	

[1] Data from Raithel et al. (2007).

Table 11. Proportional influences of each parameter change on total change of GSMNP elk herd growth rate.

Parameter	Adjusted growth rate	Rate change	Rate change/total rate change
Proportion male calves	0.9923	0.0048	0.0175
Calf survival	1.0220	0.0345	0.1261
Calf production 2yo	1.0068	0.0193	0.0705
Calf production 3–9 yo	1.0453	0.0578	0.2114
Calf production 10–14	1.0152	0.0277	0.1013
1yo male survival	1.0017	0.0142	0.0519
2–9 yo male survival	1.0016	0.0141	0.0515
10–14yo male survival	1.0046	0.0171	0.0625
1yo female survival	1.0103	0.0228	0.0833
2–9 yo female survival	1.0139	0.0264	0.0965
10–14yo female survival	1.0224	0.0349	0.1276

Table 12. Recruitment rates for female elk, by age class, in Great Smoky Mountains National Park, 2001–2008.

Parameter	2001- 2005 mean	2006- 2008 mean
Recruitment age 2	0.148	0.296
Recruitment age 3–9	0.304	0.552
Recruitment age 10–14	0.395	0.637
Recruitment age 15–20	0.157	0.157

APPENDIX B: FIGURES

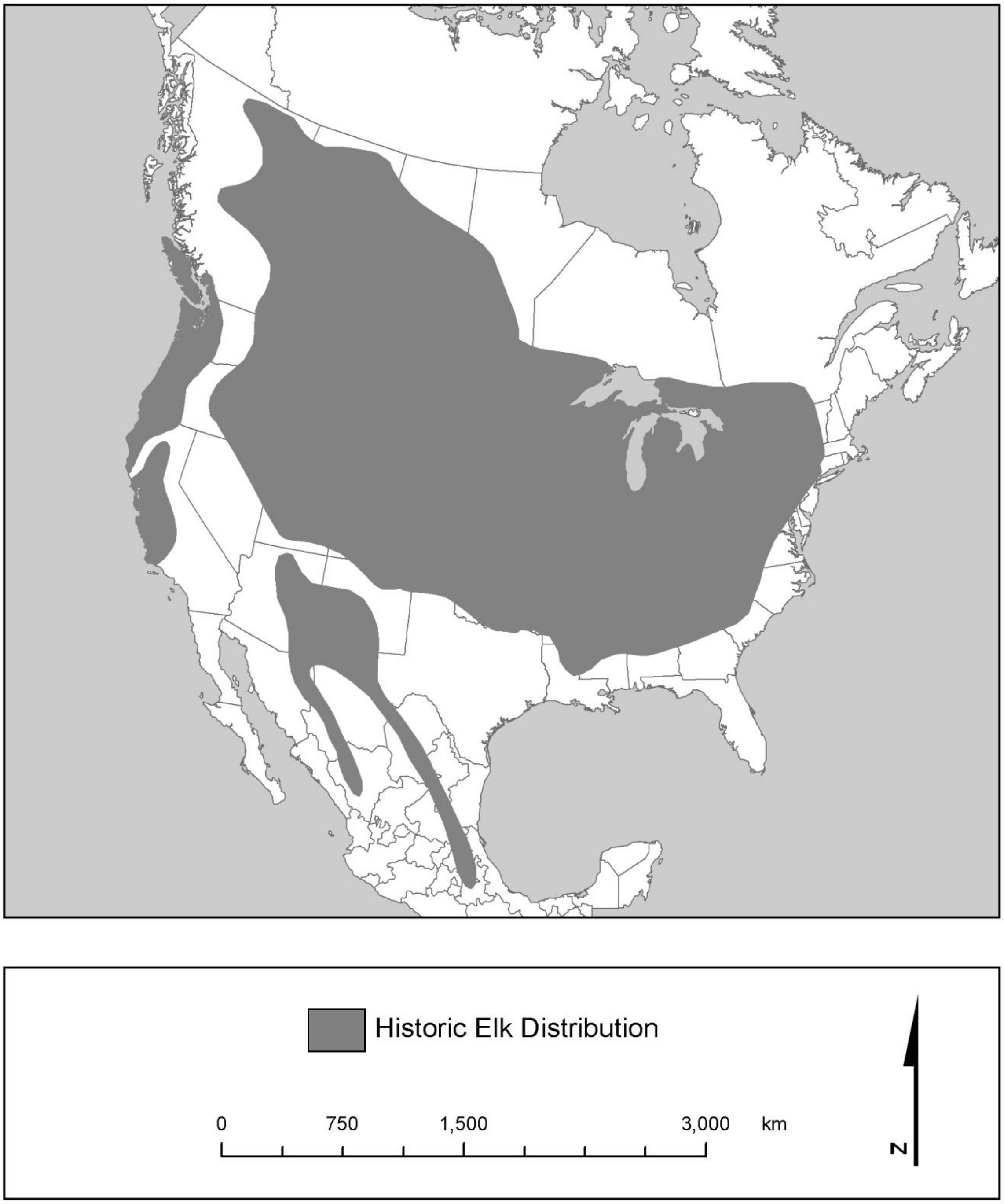

Figure 1. Historic distribution of North American elk (updated from Bryant and Maser 1982).

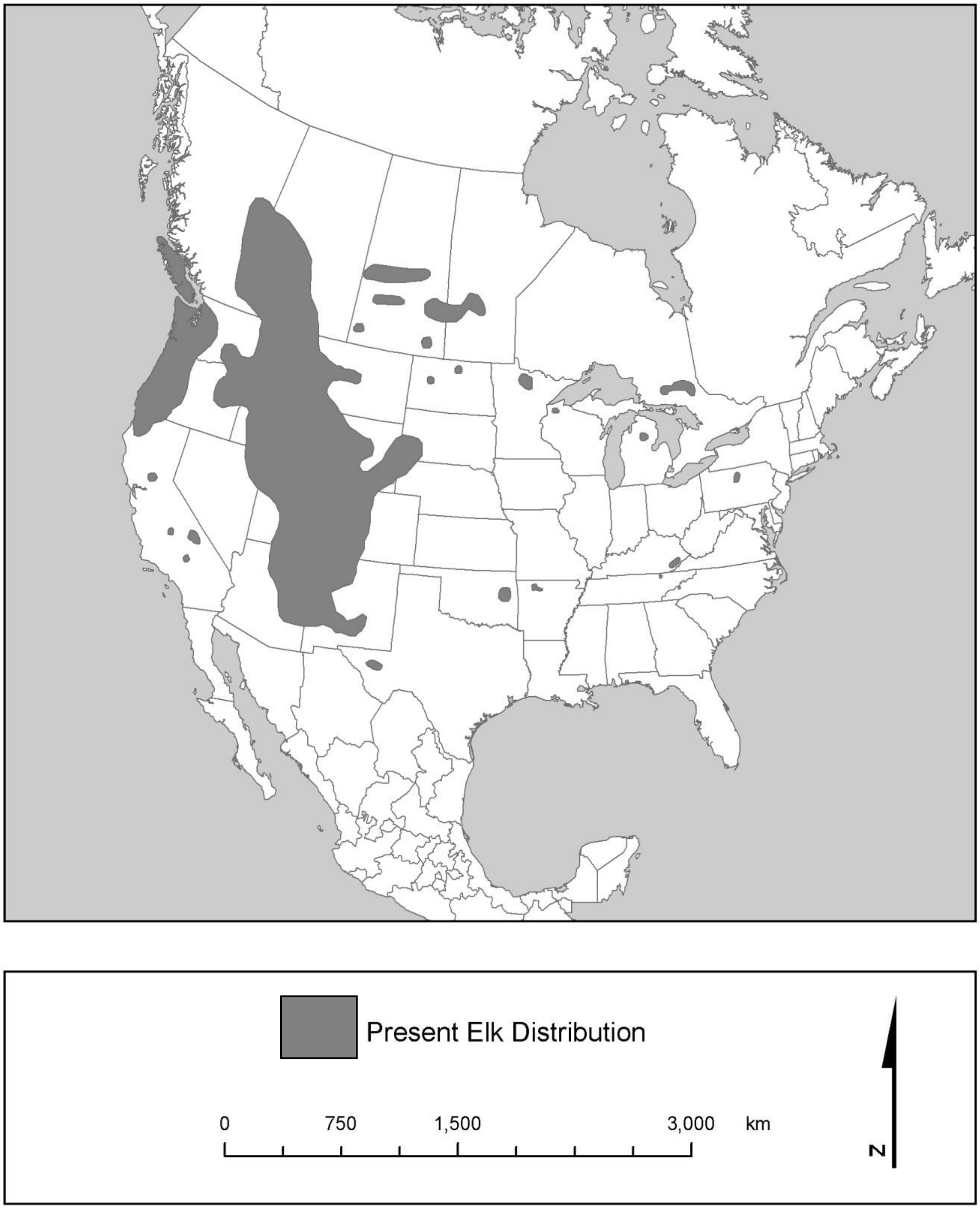

Figure 2. Present distribution of North American elk (updated from Bryant and Maser 1982).

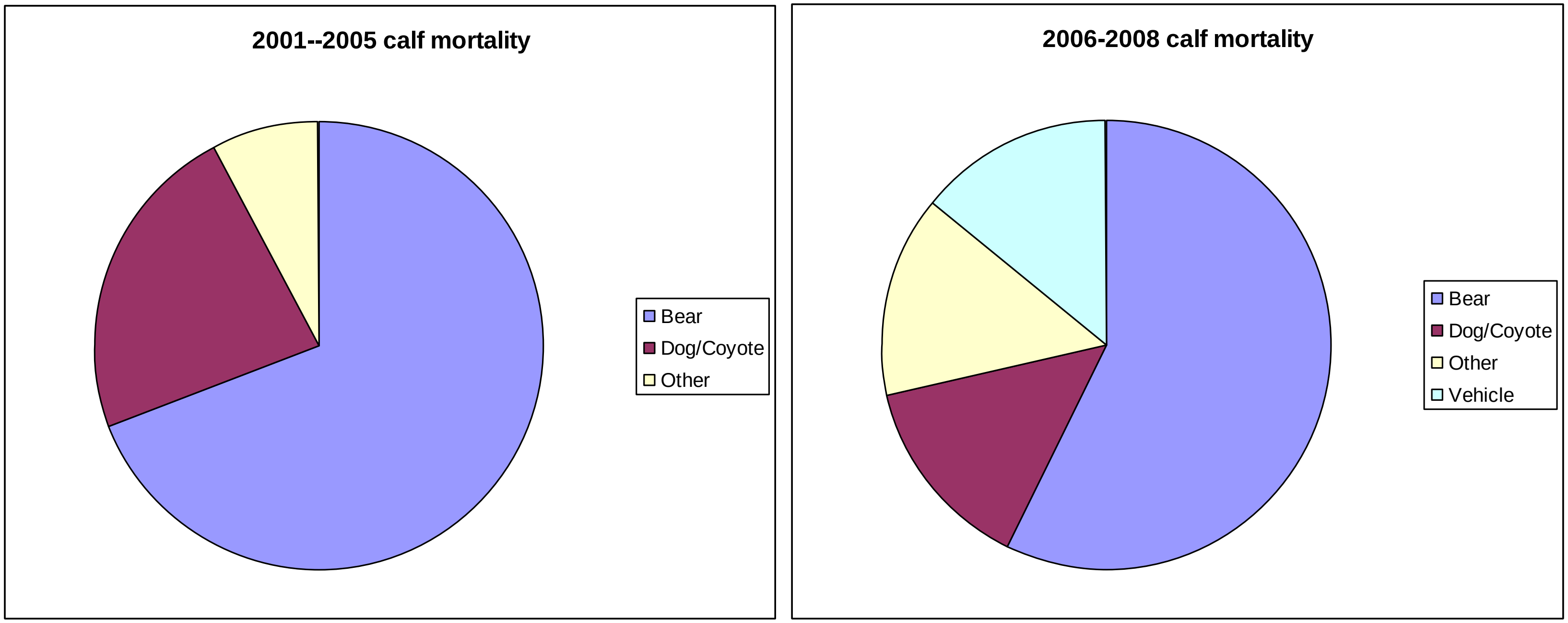

Figure 3. Relative sources of elk calf mortality in Great Smoky Mountains National Park, 2001–2005, 2006–2008.

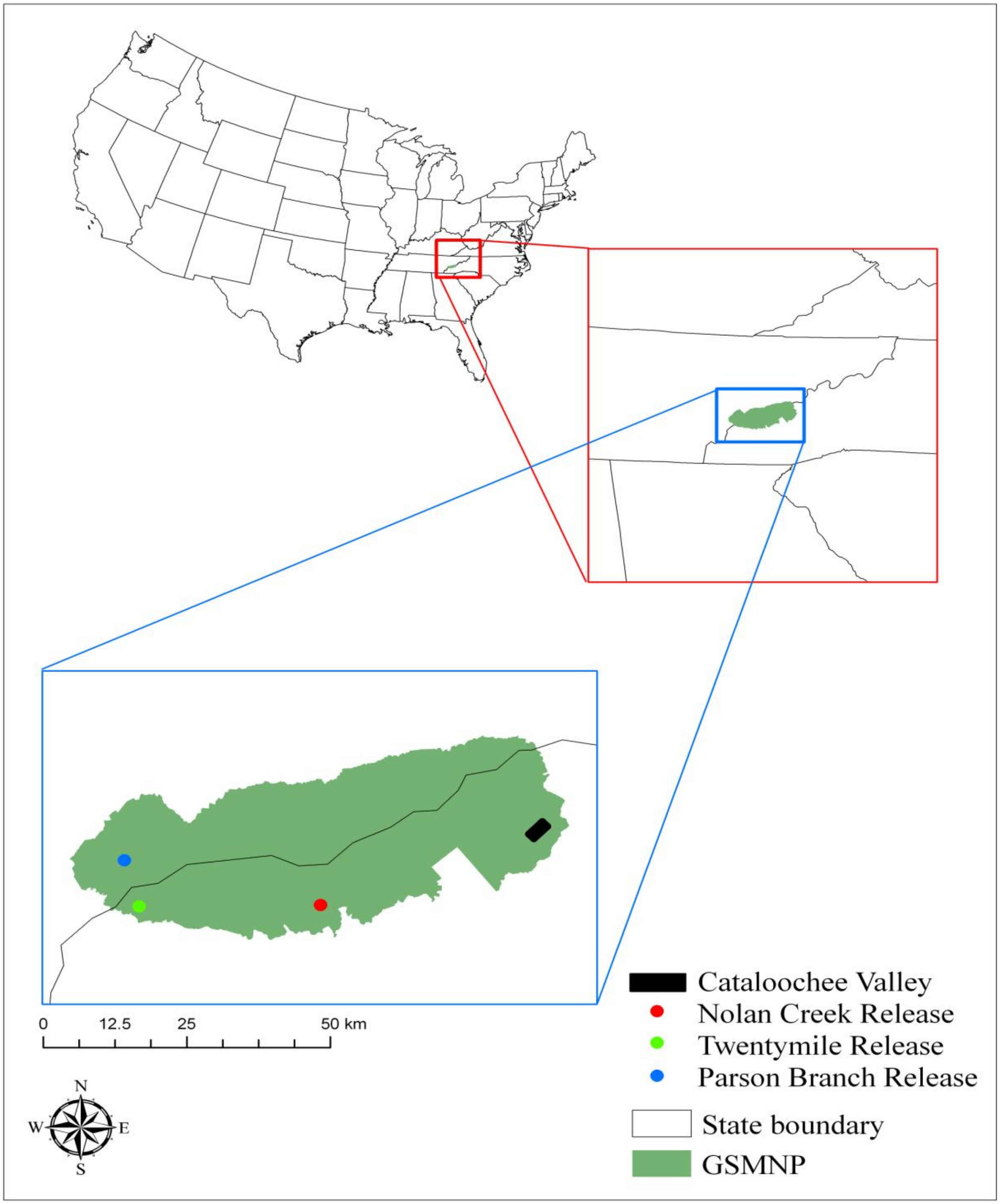

Figure 4. Cataloochee Valley study area and release sites for translocated bears in Great Smoky Mountains National Park, 2006–2008.

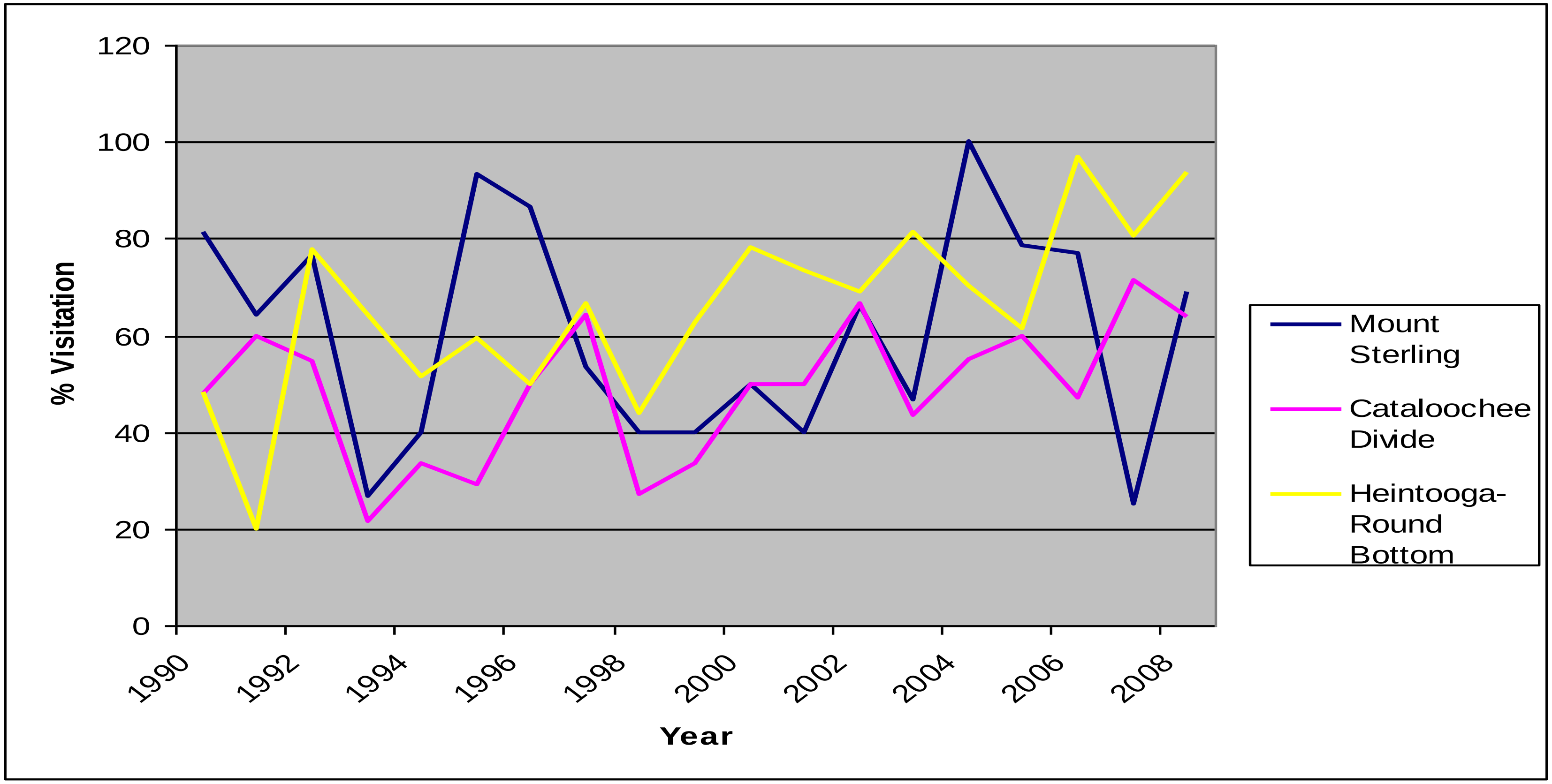

Figure 5. Bait station trend data for routes surrounding Cataloochee Valley study area, Great Smoky Mountains National Park, 1990–2008

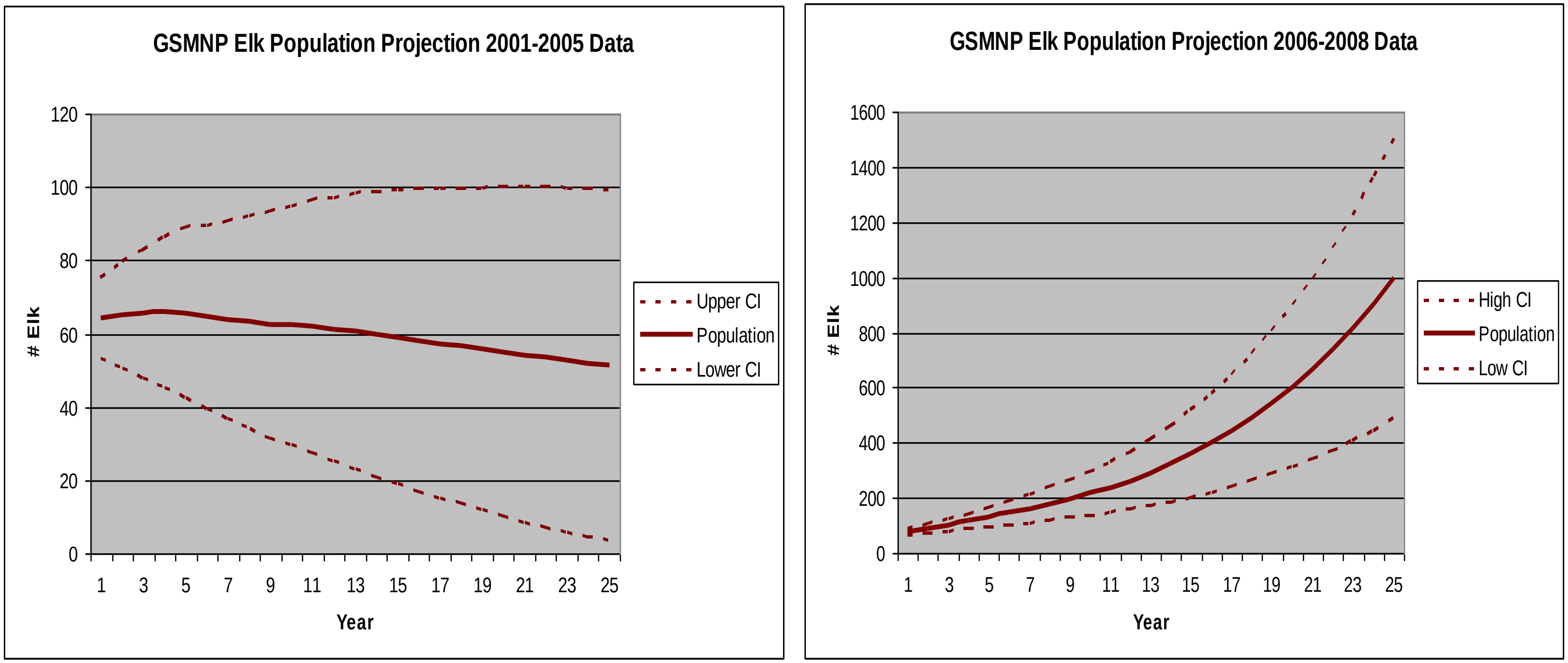

Figure 6. Comparison of population projections for elk in Great Smoky Mountains National Park before and after experimental predator management.

VITA

Joseph Yarkovich was born in Jeannette, Pennsylvania on 5 October 1980. He grew up with his mother and brother in Herminie, Pennsylvania and graduated from Greensburg Central Catholic High School in 1999. He received his Bachelor of Arts degree in Environmental Studies from Allegheny College in May 2003 and spent several years working with bears and non-native animals around the United States before returning to school for his Master of Science degree. His career interests lie in large mammal research and management.