Assessing the Feasibility of a Sustainable, Huntable Elk Population in North Carolina

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Abstract: Elk were introduced in 2001 to the Cataloochee Valley area of Great Smoky Mountains National Park (GRSM). In 2008, the National Park Service transferred responsibility for elk management outside GRSM to the North Carolina Wildlife Resources Commission (NCWRC). Expansion of elk outside of GRSM boundaries presents recreational opportunities for residents and tourists but also increases human-elk conflict and associated property damage, cost of preventive action, and administrative burden for NCWRC staff. Therefore, NCWRC commissioned an integrated biological, economic, and social assessment of the feasibility and value of maintaining a sustainable, hunted elk population outside GRSM in North Carolina. Biologically, we found that the projected population of elk would likely grow in areas where they currently exist, even with modest harvest rates of 4 to 6 males per year. This is probably because of a nearby source herd and large, less developed landscapes. However, even without hunting, establishing additional elk herds in areas remote from the current population would likely fail if herds experience even slightly lower survival and recruitment because of potentially higher levels of elk/human conflict, reduction in quality of habitat, or higher disease rates. Economically, the elk herd would generally continue to be positive for North Carolina's economy, increasing tourism, and conveying net benefits that could total millions of dollars per year, depending on the realized scenario.

Key words: North Carolina, elk, *Cervus canadensis*, RISKMAN, population modeling, hunting, wildlife tourism, economic impact, benefit-cost analysis

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Elk historically existed in the Southern Appalachian Mountains and throughout much of the eastern United States. O'Gara and Dundas (2002) presented a distribution map of elk based on previous work by Murie (1951) that indicated the general presence of elk in North Carolina and Tennessee. One author stated that elk were plentiful in the Carolinas as late as the early 1700s (Brickell 1737). Loss of habitat and excessive hunting were thought to have resulted in the elimination of any significant populations of elk from North Carolina by the late 1700s. However, elk antlers were discovered in the spruce-fir forests of the Black Mountains in North Carolina in the mid-1800s (Cope 1870).

In 2001, the National Park Service imported 25 elk into the Cataloochee Valley area of Great Smoky Mountains National Park (GRSM) in Haywood County, North Carolina, and in 2002, 27 more elk were added. The GRSM elk herd has become established, and it has been studied extensively (Murrow 2007, Murrow et al. 2009, Yarkovich et al. 2011, Yarkovich and Clark 2013, Hillard and Dewald 2014). Over time, the GRSM elk herd has increased, reaching more than 150 in 2014 (McVey, RTI International, personal communication). As the herd has grown, some individual elk have moved out of the Park into surrounding areas. In 2008, the National Park Service declared the experimental phase of the project over and a success. In doing so, they transferred responsibility for elk management outside of GRSM to the North Carolina Wildlife Resources Commission (NCWRC).

The expansion of elk outside of the GRSM boundaries presents additional recreational opportunities for residents and tourists but also increases human-elk conflicts and associated property damage, cost of preventive action, and administrative burden for NCWRC staff. To better understand and address the challenges and responsibilities associated with elk management most effectively, the NCWRC surveyed landowners in 2014 (Linehan and Palmer, NCWRC, personal communication) to understand their attitudes toward and experiences with elk. At the same time, NCWRC commissioned North Carolina State University (Williams et al. 2015) to examine and rank the suitability of elk habitat throughout North Carolina. As a final step in their initial assessment of elk management goals, NCWRC contracted RTI International to assess the biological and socioeconomic feasibility of establishing a sustainable, huntable elk population outside GRSM biological and economic methods to illustrate possible outcomes under various scenarios. After identifying the appropriate study areas, we (1) projected elk populations in each of the areas under no hunting and hunting scenarios, (2) predicted the number of positive and negative social and economic impacts associated with these projected elk populations, and (3) used monetary values from the economics literature and other sources to estimate the benefits and costs associated with these projected elk populations and their associated human impacts.

Study Area

We conducted our analyses in 2014 and limited them to Western North Carolina (WNC) counties (Figure 1), including all counties west of Surry, Wilkes, Caldwell, Burke, and Rutherford. For this area, we reviewed NCSU's 2014 Habitat Suitability Index (HSI) (Williams et al. 2015) in tandem with maps of land use, human population, and infrastructure (e.g., roadways). The NCSU study examined the suitability of habitats throughout all of North Carolina and ranked areas of the state using an HSI value ranging from 0 (very poor habitat) to 1 (highly suitable habitat). The HSI results found that currently unoccupied WNC counties were generally lower-valued elk habitat ($n = 0.29$, $SD = 0.21$). The HSI values of currently-occupied areas of Madison, Haywood, and Jackson counties were 0.38, 0.23, and 0.11, respectively. The HSI relied heavily on hay/pasture and scrub-shrub to predict quality habitat. Elk depend on grasses and forbs and are typically considered mixed feeders that will vary from eating a grass-dominated diet to eating a browse-dominated diet (Christianson and Creel 2009). Grasslands in North Carolina are primarily in the form of private, small holdings of hay/pasture land. Although hay/pasture land may increase the biological carrying capacity of elk, hay/pasture may also increase the risk of human-elk conflict. Although elk readily use scrub/shrub land cover for food and refuge, only about 1% of the total land cover is scrub/shrub. After considering the

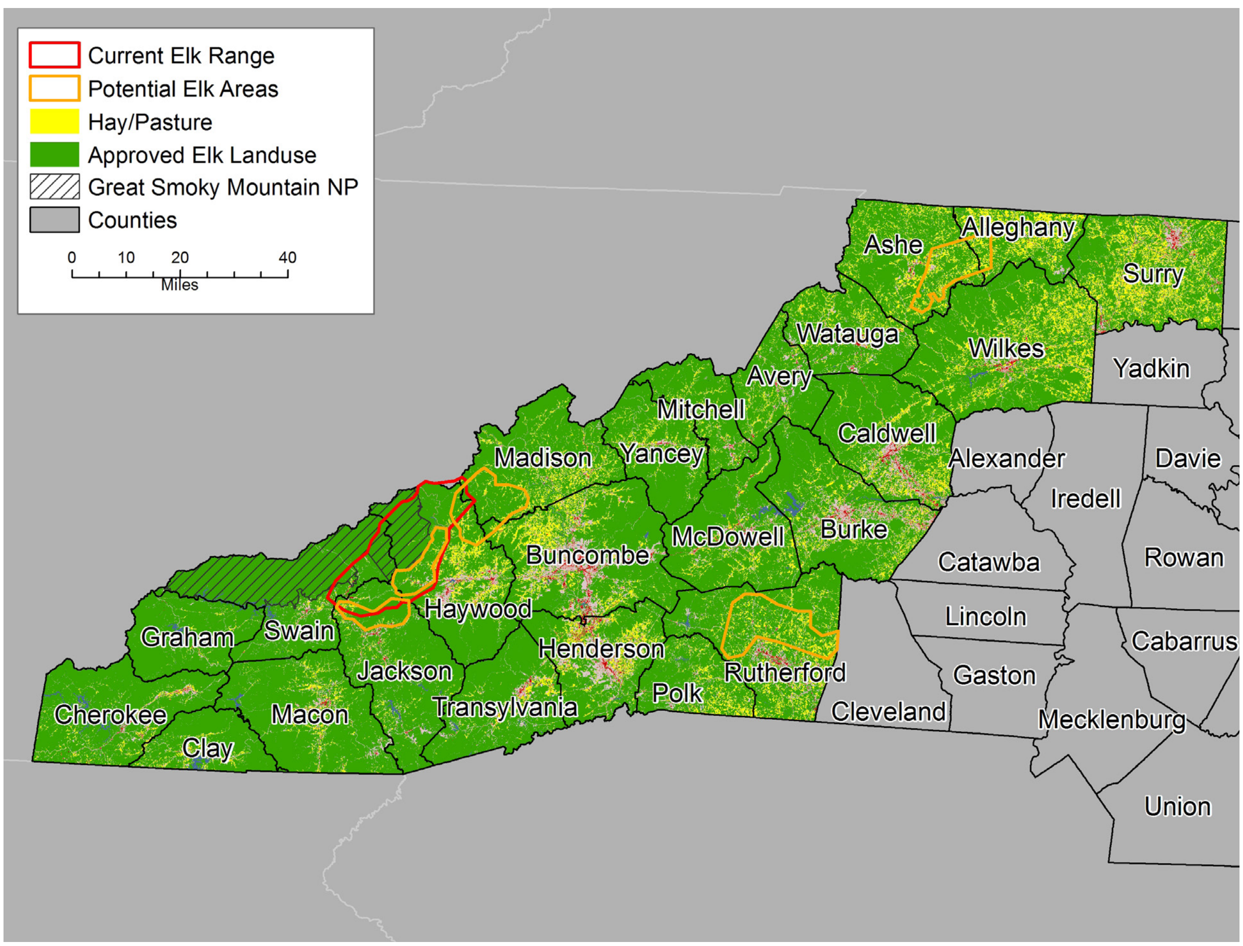

Figure 1. Selected study areas, Western North Carolina (WNC), showing agricultural land uses (hay/pasture and row crops) in yellow, land uses thought to be socially acceptable for elk in green, and unacceptable urban land uses in shades of pink and red. Acceptable landuse includes deciduous forest, emergent herbaceous wetlands, evergreen forest, herbaceous, mixed forest, shrub-scrub, and woody wetland classifications from the National Land Cover Database 2011 (MRLC 2014). Unacceptable land uses (shown in shades of pink and red) include urban and suburban land uses such as residential, industrial, or commercial classifications. Current elk range is outlined in red, and the study areas for this analysis are outlined in gold. Great Smoky Mountain Natural Park is crosshatched in black.

HSI analysis for WNC, we included areas for initial consideration if they were in the top 40% of the NCSU HSI values (i.e., HSI values greater than 0.60) and areas that are currently occupied by elk.

To consider the influence of humans on elk, we combined information on benefits and concerns identified in the NCWRC Human Dimension Survey (Linehan and Palmer 2014), with supplemental data including population density, linear miles of roads, land use/land cover, and secondary roads. We defined commercial, industrial, and residential land uses to be unacceptable land cover types for elk. We identified deciduous and evergreen forests, mixed forest, emergent herbaceous wetlands, herbaceous, shrub/scrub, and woody wetland classifications as acceptable land cover types for elk.

We selected five study areas for further analysis, including two currently unoccupied by elk and three currently occupied (Figure 1). The currently occupied areas are referred to as the Haywood, Jackson, and Madison study areas. The Haywood study area is a contiguous area within portions of Swain, Haywood, and Jackson counties where elk currently exist, adjacent to GRSM. Two areas adjacent to the Haywood study area and having transient elk are the Jackson study area (a contiguous area within Jackson County) and the Madison study area (a contiguous area within Madison, Haywood, and Buncombe counties).

To examine the likelihood of successfully introducing elk into currently unoccupied areas of North Carolina, we chose two elk-uninhabited areas remote from GRSM that had relatively high HSI scores and a considerable amount of potentially suitable land as well as the best available socioeconomic circumstances to support elk: the Rutherford study area (one contiguous area in Rutherford County) and the Alleghany-Ashe study area (one contiguous area covering portions of Alleghany and Ashe counties).

Methods

Projecting Elk Populations

Elk Demographics.—For modeling the growth of elk populations, we had to determine starting population sizes and structures for the five study areas. We obtained 2014 estimates of elk herd population size and age and sex structure in the three occupied study areas adjacent to GRSM (J. Yarkovich, GRSM, personal communication). The 2014 estimates were based on a subset of radio-collared animals and visual elk counts (J. Yarkovich, GRSM, personal communication). We selected the population size and structure of elk currently estimated to be living outside of GRSM in the Haywood study area as of 2014 as our starting population size and structure for the two unoccupied areas (J. Yarkovich, GRSM, personal communication).

Also for modeling, we had to determine the demographic rates of elk in the five study areas. We assigned existing estimates of elk survival and reproduction from the entire GRSM population to the three currently occupied study areas (Yarkovich and Clark 2013). The Yarkovich and Clark (2013) data were collected via weekly radio tracking of elk (greater than 67 adult elk and greater than 42 calves) throughout western North Carolina from 2006 to 2012. Then they calculated survival and recruitment estimates using known-fate analysis in Program Mark (White and Burnham 1999). We assumed that the demographics for our three study areas would be similar to the GRSM elk demographics because the reported numbers included data from elk that moved in and out of the herds in our three study areas and the study areas are all closely connected on the landscape. These rates were also similar to the rates documented in the reintroduced elk population in Kentucky (Larkin et al. 2003).

A general evaluation of the unoccupied study areas reflected a potentially higher likelihood of human-elk conflict via higher human population and higher concentration of agriculture. Additionally, based on data collected by NCWRC, the unoccupied study areas had higher deer densities (and thus, increased likelihood of meningeal worm infestation) than currently occupied areas. We therefore considered that the demographic parameters would likely be slightly lower than that observed for the GRSM herd, especially after a reintroduction event. There is ample literature documenting the impact meningeal worm has on elk in the eastern United States. Meningeal worm has been estimated to kill 1% of the population each year in Pennsylvania and Michigan (Witmer and Cogan 1989, Pils 2000) and caused almost 50% of the documented sub-adult and adult mortalities in GRSM from 2001–2006 (Murrow et al. 2009). Meningeal worm can impact elk population growth, and has been a potential factor in the failure of elk reintroductions in the east (Anderson et al. 1966, Carpenter et al. 1973, Severinghaus and Darrow 1976, Witmer 1990, Raskevitz et al. 1991, Samuel et al. 1992). Furthermore, adult females with high parasite infestations may be incapable of carrying a fetus to term, nursing effectively, or defending calves from predators. We reviewed literature on resource conflict, human impact, and habitat effects (Stussy et al 1994, Larkin et al. 2003, Smallidge et al. 2003, Sawyer et al. 2007, Stankowich 2008, Hebblewhite and Merrill 2011, Webb et al. 2011). After extensive literature search and consultation with elk biologists, we reduced the hypothetical demographic rates in the unoccupied study areas to illustrate the likely impact of these slightly less-favorable conditions. Based on the various changes in demographics seen in the literature (Hebblewhite and Merrill 2011, Stussy et al. 2004), we reduced survival by 10% in the Alleghany-Ashe study area relative to Jackson, Haywood, and Madison study areas (Table 1). Compared to the

Table 1. Modeling parameters and values assigned for elk study areas in western north carolina based on averages of yearly estimates from 2006 to 2012 (Yarkovich and Clark 2013).

RISKMAN inputs	Haywood, Jackson, and Madison study areas	Alleghany-Ashe study area	Rutherford study area	SE
Calf sex ratio	0.595	0.595	0.595	0.057
Calf recruitment 2 YOA[a]	0.031	0.031	0.031[b]	0.042
Calf recruitment 3–9 YOA	0.226	0.226	0.126	0.103
Calf recruitment ≥10 YOA	0.668	0.668	0.568	0.083
Calf survival	1.000[c]	1.000	1.000	0.000
Male yearling survival	0.852	0.752	0.752	0.051
Female yearling survival	0.870	0.770	0.770	0.043
Male adult survival 2–9 YOA	0.935	0.835	0.835	0.018
Female adult survival 2–9 YOA	0.943	0.843	0.843	0.015
Male adult survival ≥10 YOA	0.888	0.788	0.788	0.036
Female adult survival ≥10 YOA	0.901	0.801	0.801	0.028

a. Years of age

b. Because of the low level of documented calf recruitment from young elk, this rate was not adjusted.

c. For purposes of modeling, calf survival is set to 100%, but recruitment values (i.e., survival to next age level) incorporate calf mortality and female reproduction.

Table 2. RISKMAN modeling results for elk population projections assuming no harvesting, no immigration, no major changes in demographic parameters, and assuming starting herds in 2014 of 55 animals are introduced into the Alleghany-Ashe and Rutherford study areas.

	Initial (2014) elk population		2019		2029		2039	
	M	F	M	F	M	F	M	F
Study area	(SE)	(SE)	(SD)	(SD)	(SD)	(SD)	(SD)	(SD)
Haywood	26	29	43	38	73	55	110	82
	(5)	(5)	(7.5)	(8.8)	(18.2)	(18.4)	(34.9)	(34.8)
Jackson	3	5	6	6	13	10	21	16
	(0)	(0)	(2.1)	(2.8)	(6.4)	(6.0)	(12.8)	(11.7)
Madison	1	4	4	5	10	8	17	13
	(0)	(0)	(1.8)	(2.4)	(5.3)	(5.3)	(11.0)	(10.0)
Alleghany-Ashe	26	29	26	23	16	12	9	6
	(5)	(5)	(6.1)	(6.6)	(6.6)	(6.2)	(5.8)	(5.2)
Rutherford	26	29	22	20	11	8	5	4
	(5)	(5)	(5.3)	(5.8)	(4.8)	(4.6)	(3.6)	(3.4)

Table 3. Haywood Study Area: Total Elk Population Projections Under Alternative Hunting Scenarios, assuming a Starting Elk Population (2014) of 55.

Hunting regime	2019	2029	2039
No Hunting	82	128	192
4 quota: all M	65	90	142
4 quota: 80%M	61	67	90
4 quota: 50%M	57	37	30
6 quota: all M	56	71	120
6 quota: 80%M	53	61	95

Alleghany-Ashe study area, the Rutherford study area had similar risks of human-elk conflict and higher rates of white-tailed deer but also had fewer contiguous blocks of forest; thus, both survival and adult recruitment, which incorporates calf survival, were assumed to be 10% lower in the Rutherford study area relative to Jackson, Haywood, and Madison study areas. This recruitment reduction was based primarily on less contiguous forest reducing parturition sites and escape cover.

RISKMAN.—We used the computer simulation program RISKMAN to project elk population size and variability in each of the five study areas 25 years into the future under no-hunting and several hunting scenarios (Taylor et al. 2006). RISKMAN is an individual-based model that requires estimates of a starting population size, maximum species age, standing age distribution, calf survival, age-specific and sex-specific survival, calf sex ratio, and age-specific recruitment. The program can perform stochastic growth projections by exposing individuals in the population to a series of Bernoulli trials, whereby they age or die, reproduce or not, etc., according to random normal deviations of vital rate means based on standard errors provided by the user. The program uses Monte Carlo techniques to estimate the uncertainty of output parameters. For this elk analysis, each RISKMAN model scenario was replicated 1,500 times to estimate metrics annually over the period 2015 through 2039. Each model replicate applied the previously mentioned demographic rates (calf sex ratio, elk survival, and recruitment) along with a measure of variability to the starting elk population size and structure (Table 1). We allowed variances in parameter estimates to covary to simulate the condition wherein annual environmental variability affects multiple parameters and demographic classes. We did not include density effects (Taylor et al. 2006). Modeling results for elk population projections over 25 years in each study area, assuming no harvesting, no immigration, and hypothetical starting herds of 55 in Alleghany-Ashe and Rutherford study areas are shown in Table 2. Modeling results for elk population projections under alternative hunting scenarios for the Haywood study area are shown in Table 3. Last, we conducted a simple sensitivity analysis to evaluate the population response of elk to the overall demographic rates and to our self-imposed survival and recruitment reductions of the unoccupied study areas. We systematically increased and decreased each starting demographic by 5% and recorded the mean population size at year 25 (see Mills and Lindberg 2002).

Projecting the Benefits and Costs of Elk

Overall approach.—Economists use benefit-cost analysis to measure the overall impact of a resource policy on society's well-being. Almost always, the benefits and costs of a resource policy are experienced by different members of society. Benefit-cost analysis provides an objective way of evaluating the policy's overall effect, aggregating across all stakeholders. If net benefits of the policy (benefits minus costs) are projected to be positive, the benefits experienced by some members of society would exceed the costs experienced by others; on balance, the policy would increase society's well-being. Conversely, if net benefits are projected to be negative, the costs experienced by some individuals would exceed the benefits received by others; on balance, the policy would reduce society's well-being.

All benefit-cost analyses follow four basic steps, which were applied in our assessment of the potential future elk scenarios: (1) identify and describe potential positive and negative impacts; (2) to the extent possible, quantify the positive and negative impacts; (3) when possible, estimate a per-impact dollar value for all positive and negative impacts; and (4) combine estimated quantitative impact estimates with value information to estimate total quantified costs and benefits. Then, the net benefit of the elk in each location is computed by subtracting total benefits minus total costs. Using the identified five study areas and the elk population projections in each study area under no-hunting and hunting scenarios, we predicted the number of positive and negative social and economic impacts in each area. We used monetary values from the economics literature and other sources to estimate the benefits and costs associated with these projected elk populations and their associated human impacts and computed net benefits to assess whether elk would improve or reduce North Carolinians' well-being.

Identifying and Describing Potential Impacts of Elk.—We projected the number of positive and negative elk-related human impacts by gathering data on the number of reported impacts of each type over several years and then projected future impacts based on elk populations or other factors. We identified three classes of positive impacts: increased wildlife-viewing tourism, hunting, and enjoyment of elk viewing by residents. Similarly, we identified three classes of negative impacts: property damage (gardens, fences, crops), livestock or pet injury or death, and vehicle-elk collisions. We reviewed the results of the NCWRC Human Dimension Survey of landowners in WNC to identify homeowners' views of different types of elk-human interactions, which guided further data collection. We conducted semi-structured interviews of eight stakeholders representing different interests to get information about specific elk impacts about which they had concerns or positive views, and obtained records of complaints received by NCWRC about elk impacts from 2012 to mid-2014.

Quantifying Impacts of Elk.—For most impact categories, we projected a range of impacts (Tables 4 and 6–8). Due to data limitations, we were unable to estimate statistical relationships between the projected number of positive or negative elk impacts and future values of dependent variables such as future elk population or future human population. Instead, we assume a simple proportional relationship between the projected number of impacts and dependent variables. For example, we estimated tourism impacts using visitation to two state parks as proxies for nature-viewing tourism in the study areas and assuming a 1% increase in tourism because of elk. Because the 2011 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (USFWS 2014) shows that more than 70% of away-from-home wildlife watchers are North Carolina residents, we projected future tourism growth as a func-

Table 4. Estimated number of positive and negative impacts, summed across all five study areas. Includes impact estimates for Alleghany-Ashe, Haywood, Jackson, Madison, and Rutherford study areas, with Haywood results representing the 6 all-male quota hunting scenario. For study-area specific results, please see tables 6-8.

Year of Projection	2019		2029		2039	
	Estimated positive impact incidents					
Wildlife-viewing tourism trips	7,220		6,101		5,630	
Hunting trips	6		6		6	
	Estimated negative impact incidents					
	Low	High	Low	High	Low	High
Property or lawn damage	3	7	1	7	3	9
Garden damage	3	7	1	7	3	9
Hay crop damage	0	7	0	7	1	9
Row crop damage	3	12	1	11	3	14
Livestock injury or death	0	12	1	11	1	16
Fence damage	3	4	1	6	3	5
Human risk	0	4	0	6	1	5
Pet injury or death	0	7	0	6	1	9
Vehicle collisions	3	3	1	2	3	4
Total of estimated negative impact incidents	15	63	6	63	19	80

Table 6. Estimated elk population, impacts, benefits and costs of elk for Haywood study area under two scenarios: no hunting and 6 elk quota, all male.

	No hunting scenario			6 elk quota, all male		
Year	**2019**	**2029**	**2039**	**2019**	**2029**	**2039**
Estimated number of elk	82	128	192	56	71	120
Estimated tourism	1,258	1,380	1,513	1,258	1,380	1,513
Elk permits	0	0	0	6	6	6
Low estimated elk benefits	$132.1[a]	$144.9	$158.8	$134.1	$146.8	$160.8
High estimated elk benefits	$226.5	$248.3	$272.3	$231.0	$252.8	$276.8
Low adverse impacts	6	14	19	5	6	14
High adverse impacts	29	48	72	21	28	46
Low estimated elk costs	$19.8	$40.0	$59.6	$19.5	$19.8	$40.0
High estimated elk costs	$73.4	$116.8	$161.7	$45.7	$72.0	$111.9
Low estimated net benefits	$58.7	$28.0	–$2.8	$88.4	$74.9	$48.9
High estimated net benefits	$206.7	$208.3	$212.7	$211.5	$233.1	$236.8

a. Units for estimated benefits, costs, and net benefits are thousands of 2014 dollars.

Table 7. Estimated elk population, impacts, benefits and costs of elk for transiently occupied Jackson and Madison study areas, no hunting.

	Jackson study area			Madison study area		
	2019	2029	2039	2019	2029	2039
Estimated number of elk	12	24	37	9	18	30
Estimated tourism	1,258	1,380	1,513	1,258	1,380	1,513
Low estimated elk benefits	$132.1[a]	$144.9	$158.8	$132.1	$144.9	$158.8
High estimated elk benefits	$226.5	$248.3	$272.3	$226.5	$248.3	$272.3
Low adverse impacts	0	0	5	0	0	0
High adverse impacts	6	10	16	2	8	10
Low estimated elk costs	$0.0	$0.0	$19.5	$0.0	$0.0	$0.0
High estimated elk costs	$5.0	$12.2	$37.6	$2.3	$9.9	$12.2
Low estimated net benefits	$127.2	$132.7	$121.2	$129.9	$135.0	$146.7
High estimated net benefits	$226.5	$248.3	$252.7	$226.5	$248.3	$272.3

a. Units for estimated benefits, costs, and net benefits are thousands of 2014 dollars.

Table 8. Estimated elk population, impacts, benefits and costs of elk for 2014 elk-unoccupied Alleghany-Ashe and Rutherford study areas, no hunting, if 55 elk are introduced in each study area in 2014.

	Alleghany-Ashe Study Area			Rutherford Study Area		
	2019	2029	2039	2019	2029	2039
Estimated number of elk	49	28	15	42	19	9
Estimated tourism	1,872	1,166	702	1,573	796	390
Low estimated elk benefits	$196.5[a]	$122.5	$73.7	$165.2	$83.5	$41.0
High estimated elk benefits	$336.9	$209.9	$126.3	$283.2	$143.2	$70.3
Low adverse impacts	5	0	0	5	0	0
High adverse impacts	17	10	6	17	8	2
Low estimated elk costs	$19.5	$0.0	$0.0	$19.5	$0.0	$0.0
High estimated elk costs	$38.5	$12.2	$5.0	$38.5	$9.9	$2.3
Low estimated net benefits	$158.0	$110.3	$68.7	$126.7	$73.6	$38.7
High estimated net benefits	$317.3	$209.9	$126.3	$263.6	$143.2	$70.3

a. Units for estimated benefits, costs, and net benefits are thousands of 2014 dollars.

tion of projected North Carolina state population growth in areas where elk populations are projected to be stable or increase. In the Alleghany-Ashe and Rutherford study areas, where elk populations are projected to decline, we assumed that elk-related tourism would also decline and will fall to zero when estimated elk herd size falls below 10 animals in the study area. We did not attempt to quantify or value the enjoyment by local residents of viewing elk, and in our simulations, elk hunting benefits were limited to the four to six permits determined to be sustainable.

Except for elk-vehicle collisions (quantified based on two years' collision data from WNC), we characterized negative impacts using data on complaints received by NCWRC from 2012 through mid-2014. With only two and a half years of data on adverse elk impacts, we were unable to statistically project future adverse impact frequencies. We assume a proportional relationship between the number of elk living in a study area and the number of adverse impact incidents that would be incurred. We classified the complaints into categories and scaled the 2014 complaints up to estimate the number of complaints for the entire 2014 year. Then, using the estimated 68 elk living outside GRSM in the Haywood, Jackson, and Madison study areas, we computed the number of complaints of each type per elk and used these ratios to estimate the number of complaints per year as a function of the projected number of elk in each study area. Similarly, future elk-vehicle collisions were projected based on the two to three elk collisions reported per year, and projected as a function of future elk populations.

Identifying Per-Impact Dollar Values.—We obtained high and low dollar values for each category of positive and negative impact from the literature, vendors, federal, and North Carolina databases, and industry experts. Dollar values used in the study, adjusted to 2014 using the consumer price index, are shown in Table 5.

Estimating Costs and Benefits of Elk in Specific Study Areas.—Having projected annual numbers of positive and negative impacts of elk through 2039 and in each study area, the estimation of benefits and costs is a process of multiplying the estimated number of impacts of a particular type in a given year, times its 2014 estimated per-impact dollar value. Results are shown in Tables 6, 7, and 8. To reflect the uncertainties associated with the projections and the range of potential per-impact values, we present a range of benefit and cost estimates. High estimated benefits result from multiplying projected numbers of visitors and hunters times high

Table 5. Dollar values per positive and negative impact incident (2014).

Type of impact	Low value	High value
Dollar values for positive impacts		
wildlife viewing day[a]	$35	$60
hunting day[a]	$110	$250
Dollar values for negative impacts		
Residential ornamental, or lawn damage[b]	$100	$400
Garden damage[c]	$250	$900
Hay crop damage[d]	$297	$594
Row crop damage[d]	$429	$858
Livestock injured or killed[e]	$175	$1,400
Fence damage[f]	$2,987	$4,967
Human chased	None	None
Pet injured or killed[e]	$400	$800
Vehicle collisions[g]	$15,777	$21,345

a. Boyle et al. 1996
b. Prices of supplies at several home stores and local nurseries
c. Oregon State University 2013
d. USDA 2014
f. Edwards and Chamra 2012
e. Veterinarian cost of care estimates (K. Dahms) Dahms Veterinary Service, personal communication, North Carolina Department of Agriculture 2014 (cattle prices), Equine.com 2014 (horse prices).
g U.S. Department of Transportation 2008

dollar values, while low estimated benefits result from multiplying projected numbers of visitors and hunters times low dollar values. High cost estimates are computed by multiplying high quantitative estimates of negative impacts times high dollar values, while low cost estimates are computed by multiplying low quantitative estimates of negative impacts times low dollar values. Finally, we computed high net benefits by subtracting low cost estimates from high benefit estimates, and low net benefit estimates were computed by subtracting high cost estimates from low benefit estimates.

Results

Elk Population Projections

Alleghany-Ashe and Rutherford Study Area.—The Alleghany-Ashe and Rutherford study areas are used to illustrate likely outcomes in situations where conditions are slightly less favorable for elk as reflected in lower survival (Alleghany-Ashe) and lower survival and recruitment (Rutherford study area) parameters. In these two areas, hypothetical introduced elk populations were projected to decline steadily, with the herd posited in Rutherford county declining at a slightly faster rate than the herd in Alleghany-Ashe (Table 2). In both study areas, the newly-introduced elk herd would be expected to attract thousands of elk-viewing visitors each year and thus would convey considerable net benefits to society. Over time, however, as the size of the elk herds decline, both benefits and costs of the elk also are predicted to decline and are projected to fall to zero after 2039. It should be noted that increasing the number of elk introduced did prolong the presence of elk in these study areas, but herd populations still declined because of the assumed underlying habitat and landscape conditions and the potential elk-human conflicts that we assumed would result. Specifically, RISKMAN simulations for these study areas predicted that by 2039 elk populations would fall from 55 to 15 (SD = 10) in the Alleghany-Ashe study area and from 55 to 9 (SD = 6) in the Rutherford study area. These simulations illustrated the vulnerability of elk populations if survival and recruitment were even slightly reduced because of human-influenced land uses (agriculture, highways) and the resulting risks of increased human-elk conflict and the risk of higher exposure to meningeal worm.

Jackson and Madison Study Areas.—Elk population, elk-related benefits, and elk-related costs were estimated to increase slowly over time (Table 7). RISKMAN simulations indicated that elk populations would not reach a sufficient size by year 25 for hunting to be sustainable.

Haywood Study Area with Hunting Scenarios.—RISKMAN modeling results showed that the population of 55 elk in the Haywood study area could sustain a low level of hunting over 25 years. RISKMAN simulations of scenarios with harvests limited to only male or 80% male/20% female with total annual harvest of 4 or 6 elk predicted elk populations that were approximately stable or slightly increasing over time. Table 3 illustrates projected elk populations for Haywood study area under the no-hunting scenario and several hunting scenarios. With no hunting, the Haywood study area herd was projected to reach 192 (SD = 67) by 2039. Harvesting six male elk per year reduced the rate of population growth such that the Haywood study area herd size was projected to reach 120 (SD = 76) in 2039.

Over time, both benefits and costs of elk were projected to increase (Tables 6 through 8). With a hunting quota of 6 elk, all male, net benefits of elk in the Haywood study area were projected to be between US $49,000 and $237,000 in 2039. Under the no-hunting scenario, the low estimated net benefits for the Haywood study area in 2039 are projected to be negative, illustrating that as elk populations grow, the potential exists for costs of elk to exceed benefits. Other scenarios with quotas greater than 6 elk or a larger share of female elk projected that the elk population might not be sustainable. (See results in Table 3 for 4 quota, 50% male, 50% female; elk population in the Haywood study area is projected to decline to 30 animals in 2039.)

Sensitivity Analysis

Our sensitivity analysis determined that adult female survival is the main driver of the changes in population growth. When survival is decreased, even by just a few percentage points, adult survival of 2- to 9-year-old females is the driver of the population growth. If survival and recruitment are decreased, adult survival of 2- to 9- and 10+-year-old females are the drivers. Returning these sole demographics to the original value enabled many population projections to stabilize. Therefore, potential differences in habitat, as reflected by assumed adjustments to population parameters, caused very different elk population projections in the five study areas.

Discussion

We have presented a quantitative simulation to illustrate potential benefits and costs associated with elk. Additionally, our analysis illustrates that the current demographic rates documented for GRSM, while sustainable and leading to slow growth of the overall elk population, are still sensitive to slight changes in survival. Limited hunts of males could likely be supported in areas with a well-established elk population (>55), such as the Haywood study area. However, even in the Haywood study area, harvesting more than 6 elk per year, or harvesting more than 2 female elk per year, results in a swiftly declining population. Jackson and Madison study areas, where a few elk have recently been observed and where habitat and land use are similar to Haywood, will likely see a slowly increasing population of elk.

Our results support the idea that if different landscapes and human land use conditions impact the documented GRSM elk demographic parameters, vastly different long-term elk populations could result. However, it is worth noting that our modeling efforts did not include any potential immigration of elk from GRSM, and we know that these are not closed populations.

The illustrations of hypothetical introductions of elk into Alleghany-Ashe and Rutherford study areas, which assume that conditions in those locations result in lower herd survival and recruitment, highlight the importance of carefully evaluating conditions in potential introduction areas. For our study, the assumptions were postulations based on information from the literature and a general assessment of habitat conditions. The two unoccupied study areas (Alleghany-Ashe and Rutherford) have more agricultural land or more development and have higher deer populations. Even small reductions in survival and recruitment relative to those estimated for the GRSM herd will result in population declines or extinction, even in the absence of hunting. For example, if survival is even 5% lower than those estimated for the GRSM herd, elk herd growth rates drop below 1.0 by the tenth year of projections and are not sustainable. This is not unexpected given the relatively small starting population sizes and their vulnerability to chance events. Large areas of contiguous natural landscapes with relatively low levels of human influence have allowed elk populations to grow in areas near the existing source herd in GRSM. For elk to be sustainably introduced elsewhere, similar landscapes that minimize the potential for elk-human conflict would be a critical factor for sustainability. These analyses illustrate the need for in-depth investigation into all parameters that might impact elk survival, such as roads, predators, disease, and human-conflict via pilot projects geared toward elk habitat and human-elk conflict prior to any potential elk reintroductions. With such studies, properly located and properly managed elk herds have the potential to increase the overall welfare of North Carolina citizens.

Our estimated benefits are driven by the projected increase in wildlife-watching tourism. While per-hunter benefits exceed per-tourist benefits, the projected number of visitors who would value viewing elk far exceeds the small number of elk permits that would be sustainable. Our estimate of elk-related tourism predicted thousands of visitors would be attracted by elk. Estimated tourism benefits reflect relatively low per-visitor values ($35/person/day) experienced by thousands of visitors. In contrast, we projected only a relatively small number of individuals would experience adverse impacts due to elk (currently about a dozen incidents per year); however, the per-incident value for these individuals could be quite high. For individuals experiencing fence damage, injured or euthanized livestock, or an elk-vehicle collision, the cost for a single incident could be thousands of dollars. There is also the possibility that some individuals, whose homes or farms are located in areas that elk frequent, may experience repeated incidents of elk-related damage.

Further research into elk-viewing tourism will allow a more refined estimate of these benefits. In addition, collection of additional data on adverse impacts associated with elk in relatively populous areas may enable a statistical analysis of the relationship between damages of various types and elk population and other variables. Together, these data would enable better estimation of potential conflicts and permit a more accurate estimate of the elk herd's costs, benefits, and social carrying capacity in each study area. On balance, however, our analysis shows that allowing elk herds to grow, with limited hunting, could provide positive net benefits of more than a $1 million per year. Because most away-from-home wildlife watchers in North Carolina are North Carolina residents (72% in 2011; USFWS 2014), most of the estimated net benefits would accrue to the people of North Carolina.

Management Implications

It will be important to monitor elk herd demographics to ensure that sufficient females survive and reproduce, to ensure that the elk population is stable or increasing, and to consider depredation permits and other sources of mortality in setting hunting quotas. More specifically, if hunting is considered in the Haywood study area, any elk taken under depredation permits or in the act of doing damage or in a vehicular incident should be included in the harvest rate, and the number harvested through hunting be correspondingly reduced until the elk population reaches a larger size. While the current elk populations in the Jackson and Madison study areas are too small to allow hunting, we recommend that wildlife officials continue to monitor these herds to determine if and when they become large enough to allow sustainable hunting.

Conversely, the low estimates of net benefit presented in Table 6 for the Haywood study area illustrate an important consideration: in addition to ensuring that hunting and other sources of elk mortality do not result in an unsustainable drop in elk survival, wildlife officials should also monitor to ensure that elk herds do not become too large. This scenario illustrates that under some conditions, costs of elk may grow faster than benefits; as the elk population grows, costs may exceed benefits (net benefits may become negative). Negative net benefits would indicate that the elk population had exceeded its social carrying capacity. That is, the herd size would have become large enough that the costs borne by individuals incurring damages exceeded the benefits experienced by elk-viewing tourists and elk hunters; under this scenario, the presence of elk in the Haywood study area would be estimated, on balance, to reduce the welfare of state residents. In situations where the elk herd approaches or exceeds its biological or social carrying capacity, more liberal hunting quotas could be considered.

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