POPULATION MODELS FOR WHITE-TAILED DEER IN THE BLACK HILLS OF SOUTH DAKOTA

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ABSTRACT

Models were developed for the white-tailed deer (*Odocoileus virginianus*) population inhabiting the Black Hills of western South Dakota. Three sets of models were created using harvest data from 1997 through 2003 provided by South Dakota Department of Game, Fish and Parks. Initial population size was estimated using harvest mortality rates, survival rates, and total harvest, which resulted in starting populations of 43,186 (Set 1 and 3) and 45,355 (Set 2). Models for Set 1 were based upon a maximum recruitment rate of 0.9. Set 1 models were structured in three ways: A) linear density dependence; B) using a constant fecundity rate of 1.5 fawns/female up to 75% of carrying capacity (K) and then converting fecundity to a linear density dependent model; and C) nonlinear density dependence weighting the nonlinear function at 75% and the linear function at 25% with carrying capacities of 40,000, 50,000 and 60,000 deer. Set 2 models were based upon a maximum fecundity of 2 fawns/female and were structured in two ways: A) maximum fecundity of 2 fawns/female up to 75% of K and then linear density dependence; and B) nonlinear models weighting the nonlinear function at 75% and the linear function at 25% (Ks of 35,000, 45,000, and 55,000 deer). Models for Set 3 were structured the same as Set 1 using a 0.65 recruitment rate. A Pearson correlation matrix was created to compare model output to total harvest. The linear density dependent model (A) at carrying capacity of 40,000 deer was the most highly correlated model for Set 1 ($r = 0.810$, $p=0.027$). The nonlinear/linear density dependent model (B) at carrying capacity of 35,000 deer was the most highly correlated for Set 2 ($r = 0.826$, $p=0.022$). The linear density dependence model (A) at carrying capacity of 40,000 deer ($r=0.801$, $p=0.030$), and the nonlinear/linear density dependence model (C) at carrying capacity of 40,000 deer ($r=0.803$, $p=0.030$) were the most highly correlated models for Set 3. Our population model results supported conclusions of SDGFP personnel and can be used as a tool to aid managers of white-tailed deer in the Black Hills, South Dakota.

Keywords

Black Hills, Odocoileus virginianus, population model, South Dakota, white-tailed deer.

INTRODUCTION

Abundance and diversity of wildlife in the Black Hills make it a popular destination for hunters and tourists, and add to the quality of life for the people residing there. White-tailed (*Odocoileus virginianus*) and mule (*O. hemionus*) deer make up a significant portion of this wildlife with an estimated population between 40,000 to 45,000 animals (Huxoll 2004). Applications for deer licenses in 2003 were 11,156 for residents and 1,335 for non-residents, who applied for 5,970 resident and 471 non-resident licenses (Huxoll 2004). South Dakota deer hunters spent an average of $1,581 per year on deer hunting alone, and spent an average of 13 days hunting deer per year (U.S. Fish and Wildlife Service 2003). Non-consumptive wildlife watching also is popular with 45% of South Dakotans participating and spending an average of $738 per year on these activities (U.S. Fish and Wildlife Service 2003).

Population models are important tools that aid management of this resource. Population models can help define problems, organize thoughts, understand available data, show gaps in data, show research needs, communicate and test our understanding, and make predictions (Starfield and Bleloch 1991). Models of populations also allow managers to evaluate hypotheses inherent in management plans and gain important insight into changing management strategies before costly manipulations are undertaken (Vandermeer and Goldberg 2003). Currently, the South Dakota Game, Fish and Parks department (SDGFP) does not use a population model to manage the Black Hills white-tailed deer herd. Our objective was to create a population model for the white-tailed deer herd in the Black Hills of South Dakota that could be used as a tool to aid wildlife managers.

STUDY AREA

The Black Hills are located in western South Dakota and northeastern Wyoming and are an isolated eastern extension of the Rocky Mountains. The Black Hills extend about 190 km north to south and 95 km east to west (Petersen 1984) and occupy 8,400 km^2 of area (Fecske and Jenks 2002). Elevation in the Black Hills ranges from 973-2,202 m above mean sea level (Orr 1959). Annual temperatures range from 5 to 9° C with extremes ranging between -40 to 44° C (Thilenius 1972). Mean annual precipitation ranges from 45-66 cm (Orr 1959).

The Black Hills deer unit boundaries begin at the junction of Interstate 90 (I-90) and the South Dakota-Wyoming border and continue south along I-90 to the Rapid City Limits. The unit boundary continues west and south along the Rapid City limits to US Highway 16 (US 16). The boundary follows US 16 southwest to the eastern boundary of Black Hills National Forest, then south along the eastern border of the Black Hills National Forest, Custer State Park, and Wind Cave National Park (Custer State Park and Wind Cave National Park are excluded from the unit). The unit boundary continues south along the section line to Custer County Rd. 101, then west along 101 to US Highway 385

(US 385). The study unit then follows US 385 to Fall River Co Rd 18, then northwest along 18 and Custer Co Rd 333 to SD Highway 89 (US 89) at Argyle, then south along SD 89 to Fall River Co Rd 317, then west along 317 to Custer Co Rd 319, then west along 319 to Custer Co Rd 715, then west along 715 to Custer Co Rd 769, then west along 769 through Dewey to the Wyoming state line. The western border of the unit is the South Dakota-Wyoming State Line.

Overstory vegetation in the Black Hills is dominated by ponderosa pine (*Pinus ponderosa*) interspersed with white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and quaking aspen (*Populus tremuloides*); burr oak (*Quercus macrocarpa*) occurs at lower elevations (Thilenius 1972). Understory vegetation consists of snowberry (*Symphorocarpus albus*), serviceberry (*Amelanchier alnifolia*), common juniper (*Juniperus communis*), Oregon grape (*Berberis repens*), bearberry (*Arctostaphylos uva-ursi*), and various grasses and forbs (Thilenius 1972, Severson and Thilenius 1976).

The Black Hills deer herd is a mix of white-tailed deer (70%) and mule deer (30%) (Huxoll 2004). Elk (*Cervus elaphus*), Rocky mountain bighorn sheep (*Ovis canadensis*), mountain goat (*Oreamnos americanus*), and pronghorn (*Antilocapra americana*) occur sympatrically with deer within the Black Hills.

METHODS

Spread sheet models were created in Excel (Microsoft Corp., One Microsoft Way, Redmond, WA) with initial parameters based upon harvest data from 1997 to 2003 provided by the SDGFP and previous studies on deer conducted in the Black Hills (DePerno 1998, S. L. Griffin, South Dakota Game, Fish and Parks, Rapid City, South Dakota, unpublished data). Three sets of models were created and analyzed using different carrying capacities and model equations.

Initial population estimates for Set 1 and Set 3 were calculated using male (0.60) and female (0.83) survival rates (DePerno 1998) and unpublished data (S. L. Griffin, South Dakota Game, Fish and Parks, Rapid City, South Dakota, unpublished data). Cause specific mortality (DePerno 1998, S. L. Griffin, South Dakota Game, Fish and Parks, Rapid City, South Dakota unpublished data) (female mortality: natural mortality = 0.78, harvest mortality = 0.22; male mortality: natural mortality = 0.33, harvest mortality = 0.67) also was used to calculate an initial population size of 8,906 males and 34,280 females for a total population of 43,186. Initial population estimates for Set 2 were calculated using harvest data provided by SDGFP and harvest mortality rates of females of 0.04 and males of 0.20 (S. L. Griffin, South Dakota Game, Fish and Parks, Rapid City, South Dakota, unpublished data). Adult natural mortality for Set 2 was fixed at 0.20 for males and 0.32 for females with fawn mortality fixed at 0.60 for males and 0.48 for females (S. L. Griffin, South Dakota Game, Fish and Parks, Rapid City, South Dakota, unpublished data). Initial population size for Set 2 was 11,880 males and 33,475 females for a total population of 45,355.

Fawn sex ratios were fixed at 50:50 and immigration and emigration were fixed at zero for all three sets of models. Carrying capacities (K) of 40,000, 50,000, and 60,000 deer were used for Sets 1 and 3, whereas carrying capacities of 35,000, 45,000, and 55,000 deer were used for Set 2 models. Stochastic events where included in models every ten years to simulate severe weather conditions. Starting in year 2007 for Sets 1 and 3, mortality rates were doubled. Starting in year 2006, Set 2 adult mortality was doubled and fawn mortality rates increased to 0.90 for males and 0.80 for females. Female harvest for Set 1 and 3 was fixed at 14% of male harvest. Female harvest was increased to 33% of male harvest in 2014 to simulate an increased female harvest strategy.

Set 1 contained three different model types. Model A calculations were structured around a maximum recruitment rate of 0.90 declining linearly to zero as the population reached carrying capacity. Equations for each of the three carrying capacities were generated using linear density dependence ($Y = 0.90 - 2.25*10^{-5} X$ [40,000 K], $Y = 0.90 - 1.8*10^{-5} X$ [50,000K], and $Y = 0.90 - 1.5*10^{-5} X$ [60,000 K] for the three carrying capacities). Model B of Set 1 used a constant 1.5 fawns/adult female fecundity rate up to 75% of K and then declined linearly using the previous linear density dependent model. Model C used a maximum 0.90 recruitment rate and incorporated nonlinear density dependence into the model equation. The nonlinear portion of the equation was weighted 75% nonlinear and 25% linear ($Y = 0.90 - 3.75*10^{-6} X - 1.875*10^{-10} X^2$ [40,000 K], $Y = 0.90 - 4.5*10^{-6} X - 2.7*10^{-10} X^2$ [50,000 K], $Y = 0.90 - 5.625*10^{-6} X - 4.21875*10^{-10} X^2$ [60,000 K] for the three carrying capacities).

Set 2 contained two different models. Model A used a maximum fecundity rate of 2 fawns/adult female up to 75% of carrying capacity, then declined linearly using equations $Y = 2 - 5.714*10^{-5} X$ (35,000 K), $Y = 2 - 4.444*10^{-5}X$ (45,000 K), $Y = 2 - 3.636*10^{-5} X$ (55,000 K) for the 3 carrying capacities. Model B for Set 2 used a maximum fecundity rate of 2 fawns/adult female and incorporated nonlinear and linear density dependence into the model. The nonlinear portion of the model was weighted 75% and the linear portion 25% ($Y = 1.429*10^{-4} X - 1.224*10^{-9} X^2$ [35,000 K], $Y = 1.111*10^{-4} X - 7.407*10^{-10} X^2$ [45,000 K], $Y = 9.09*10^{-5} X - 4.959*10^{-10} X^2$ [55,000 K] for the three carrying capacities).

Set 3 contained three different models that were calculated in the same manner as Set 1 models except that recruitment rate was fixed at 0.65 (J. Wrede, South Dakota Game, Fish and Parks, Rapid City, South Dakota, pers. comm.). Equations for the linear density dependent model (A) were $Y = 0.65 - 1.625*10^{-5} X$ (40,000 K), $Y = 0.65 - 1.3*10^{-5} X$ (50,000 K), $Y = 0.65 - 1.08*10^{-5} X$ (60,000 K) for the 3 carrying capacities. Model B of Set 3 used a constant 1.5 fawns/adult female fecundity rate up to 75% of K and then declined linearly using the previous linear density dependent model. Equations for the nonlinear and linear density dependent model (C) were $Y = 0.65 - 4.0625*10^{-6} X - 3.04688*10^{-10} X^2$ (40,000 K), $Y = 0.65 - 3.25*10^{-6} X - 1.95*10^{-10} X^2$ (50,000 K), $Y = 0.65 - 2.7083*10^{-6} X - 1.35417*10^{-10} X^2$ (60,000 K) for the 3 carrying capacities.

Population estimates generated from the model were correlated with total harvest using a Pearson correlation matrix. We assumed that the highest positive correlation coefficient would represent the best model for each set (Jenks et al. 2002).

RESULTS

From 1997 to 2003, 21,360 white-tailed deer were harvested in the Black Hills. Total harvest ranged from 2,711 in 2002 to 3,715 in 1997 with harvest generally stable (Figure 1). Models using carrying capacities of 35,000 to 40,000 deer had the highest correlation coefficients with harvest. Set 1 Model A using linear density dependence with a carrying capacity of 40,000 deer had a correlation coefficient of 0.810 (p= 0.027) (Table 1). Set 2 Model B using the nonlinear/linear model had a correlation coefficient of 0.826 (p=0.022) (Table 1). Set 3 had two models with correlation coefficients greater than 0.80 (Table 1). Model A using only linear density dependence had a correlation coefficient of 0.801 (p=0.030) and Model C using the nonlinear/linear equation had a correlation coefficient of 0.803 (p=0.030). Models that used the constant fecundity rate up to 75% of carrying capacity then switching to a linear density dependent model (Model B for Set 1 and 3, and Model A for Set 2) resulted in large variations in estimated population size from one year to the next and had low or negative correlation coefficients (Tables 1).

Population models were run from 1997 to 2025 to evaluate model performance over an extended period (Figure 2). Set 1 Model A using linear density dependence and Set 3 Model C using nonlinear and linear density dependence were similar and both stabilized at a population of approximately 33,000 deer. Set 2 Model B using nonlinear and linear density dependence approached a similar population size, but was reduced due to stochastic events (Figure 2). Set 3 Model A using only linear density dependence resulted in a decline in the population while stabilizing at about 21,000 deer (Figure 2).

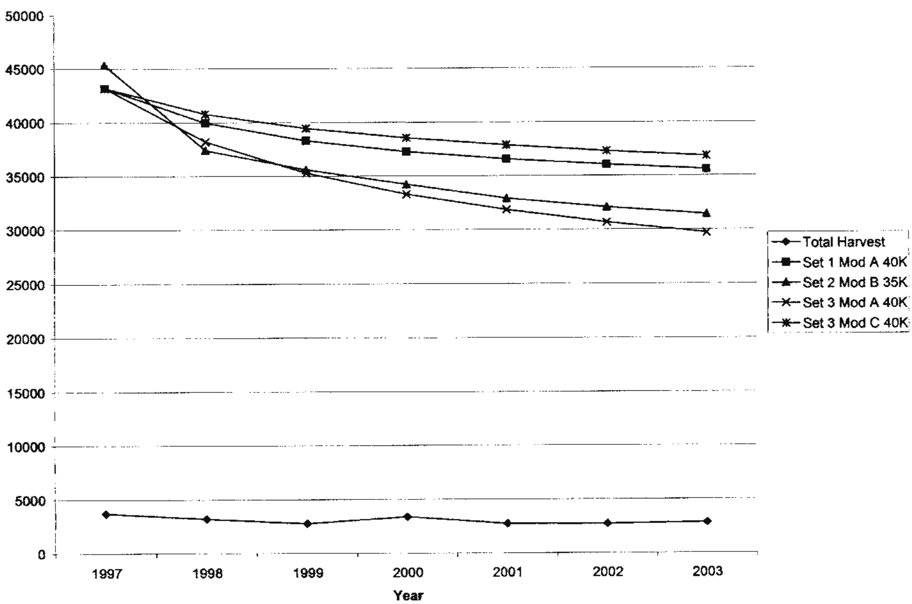

Figure 1. Population model projections and total harvest from 1997 to 2003 for models with highest positive correlation coefficients from three sets of models for white-tailed deer in the Black Hills, South Dakota.

Table 1. Correlation coefficients (p-value) from three sets of models at different carrying capacities for modeling white-tailed deer in the Black Hills, South Dakota.

Set	Carrying capacity	Model A	Model B	Model C
1	40,000	**0.810[1] (0.027)**	-0.483 (0.27)	-0.777 (0.04)
	50,000	-0.149 (0.75)	-0.661 (0.106)	-0.808 (0.28)
	60,000	-0.808 (0.28)	-0.427 (0.340)	-0.800 (0.031)
2	35,000	0.122 (0.794)	**0.826 (0.022)**	
	45,000	0.339 (0.457)	0.678 (0.094)	
	55,000	-0.647 (0.116)	-0.648 (0.115)	
3	40,000	**0.801 (0.03)**	-0.582 (0.171)	**0.803 (0.030)**
	50,000	0.774 (0.041)	-0.654 (0.111)	-0.648 (0.116)
	60,000	0.692 0.085	-0.538 (0.213)	-0.807 (0.028)

[1] Bold values indicate the highest positive correlation coefficients for each of the sets of models.

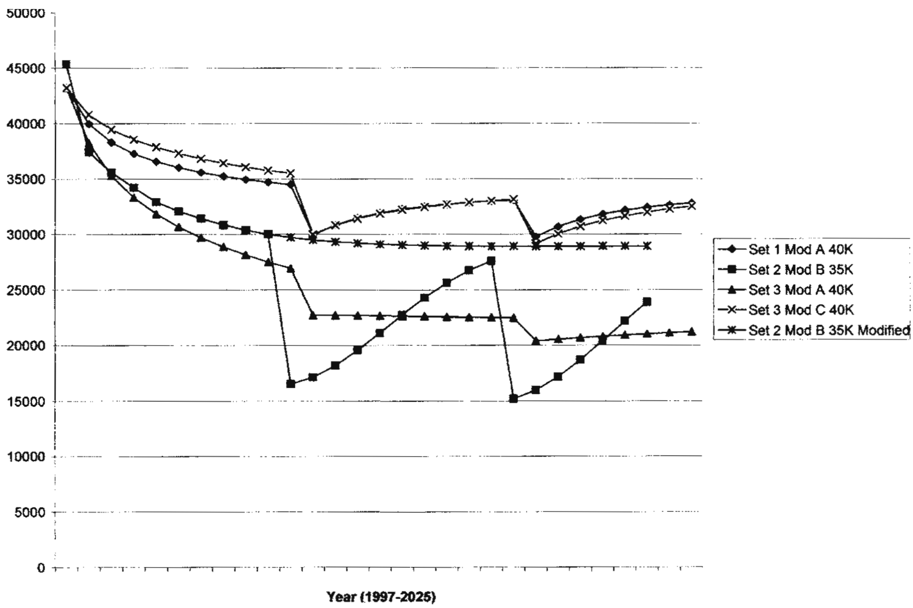

Figure 2. Population model projections from 1997 to 2025 for models with highest positive correlation coefficients and one modified model for three sets of models for white-tailed deer in the Black Hills, South Dakota.

DISCUSSION

Wildlife managers are faced with an increasing complexity of issues that compete for wildlife management resources. Managers are asked to objectively outline multiple management plans to deal with controversial issues, or generate arguments against activities that could endanger or compromise valuable wildlife assets (Walters and Gross 1972). Models have been developed to aid this process by simulating multiple management strategies in a short period of time using available data. Walters and Gross (1972) developed models based upon interactions of density, natality rates, and mortality rates. Models were able to simulate effects of changing harvest strategies, identify which parameters most strongly control population behavior over time, and examine the consequences of different management strategies to uncontrolled population catastrophes (Walters and Gross 1972). Williams (1981) reported the successful use of simulation models to manage the elk herd at the Wichita Mountain Wildlife Refuge in Oklahoma. Reproduction, natural mortality, and harvest characteristics were used to analyze management alternatives to maintain a target population of elk on the refuge while meeting the demands of the public for increased elk harvest (Williams 1981).

We generated population models for white-tailed deer in the Black Hills of South Dakota using preexisting harvest data from SDGFP and previous studies conducted in the Black Hills (Huxoll 2004, DePerno 1998, S. L. Griffin, South Dakota Game, Fish Parks, Rapid City, South Dakota, unpublished data). However, some of the assumptions that we used to define parameters in our models may have influenced our conclusions. Initial population estimates that we used in our analysis of 43,186 deer for Sets 1 and 3, and 45,355 deer for Set 2, correspond to estimates of deer populations in the Black Hills reported by Huxoll (2004) of between 40,000 and 45,000 deer. Male survival rates used for Sets 1 and 3 were based upon a sample size of 10 animals (DePerno 1998). Further study of survival and mortality rates and additional harvest data could produce stronger estimates of parameters for use in models.

Fawn data for the white-tailed deer herd in the Black Hills is limited. Griffin (S. L. Griffin, South Dakota Game, Fish Parks, Rapid City, South Dakota, unpublished data) estimated the October doe fawn ratio as 1 doe/0.96 fawns. Fecundity data for the time of parturition would benefit the model. Accurate sex ratios of fawns born in the Black Hills would strengthen the model as well. We assume a 50:50 sex ratio of fawns in the models. Benzon (1998), however, documented a male:female sex ratio in the Black Hills of 56:44 for the years 1994 through 1997 with a range of 40:60 to 71:29. These data could be used to adjust the fawn sex ratios in the model.

Population models using a constant fecundity up to 75% of carrying capacity and then switching to a linear density dependent equation had low or negative correlation coefficients with harvest data (Tables 1). This was due to the rigidity of these models. One deer over or under the 75% carrying capacity value drastically changes the behavior of these models. This drastic change led to sharp increases or decreases in the projected population between years.

Stochastic events that would simulate a severe winter were included into the model every ten years. Events, such as fire, also can influence the dynamics of deer populations. Zimmerman (2004) documented changes in recruitment following the Jasper fire in the central Black Hills. Deer recruitment in year one and two post-fire was lower, year three was equal, and in year four post-fire there was an increase in recruitment based on fetal counts in collected adult deer in the southern Black Hills (Zimmerman 2004). Effects of fire on recruitment could be added to the model as they arise to increase model effectiveness.

Population models most positively correlated with known harvest data for white-tail deer in the Black Hills were those using carrying capacities of between 35,000 to 40,000 deer (Tables 1). These carrying capacity estimates seem to support the conclusions of SDGFP personnel (J. Wrede, South Dakota Game, Fish and Parks, Rapid City, South Dakota, pers. comm.). Set 1 linear density dependent model (A) and Set 3 nonlinear and linear density dependent model (C) resulted in similar patterns in the population and stabilized just below 33,000 deer. Set 2 nonlinear and linear density dependent model (B) approached this level, but was significantly reduced by programmed stochastic events. When we ran this model without the stochastic events, this model approached a population level of about 29,000 deer (Figure 2). These population levels equate to deer densities between 3.4 and 3.9 deer/km^2. The 2002 County Wildlife Assessments indicate a range in deer densities of 0.44 deer/km^2 in Fall River County to 4.8 deer/km^2 in Mead County (Huxoll 2003). Deer densities reported in the county wildlife assessments indicate lower deer densities than our population models. Those data contain observational effects and should not be interpreted as absolute abundance measures, but rather as relative measures that are used to detect trends in populations over time (Huxoll 2003).

Our models can be used as tools for managing the white-tailed deer population in the Black Hills. The addition and updating of model parameters through ongoing research will only strengthen the model and add to its value as a tool for managers of the deer resource in this region.

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