DISTRIBUTION AND ABUNDANCE OF AMERICAN MARTENS AND COUGARS IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING

BY

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This dissertation is approved as a creditable and independent investigation by a candidate for the Doctor of Philosophy degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this dissertation does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

DISTRIBUTION AND ABUNDANCE OF AMERICAN MARTENS AND COUGARS IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING

Dorothy Marie Fecske

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American martens (*Martes americana*) and cougars (*Puma concolor*) are 2 carnivores that have become reestablished in the Black Hills of South Dakota and Wyoming. I predicted current distributions and estimated population sizes for both species in the Black Hills. Using geographical information system technology, I constructed and tested ranked habitat-relation models for martens and cougars in the Black Hills National Forest to predict their current distributions. For martens, I modeled the population and spatial structure using data derived from a marten habitat-relation model a track-plate box population survey, a sample of radiocollared martens (n = 13), and a marten Habitat Suitability Index model. I estimated the resident adult population size of martens based on mean home range size of radiocollared martens in high-quality habitat patches. Cougar population size was estimated using a population program, incorporating parameters obtained from radiocollared cougars (n = 12), the literature, and habitat quality derived from the cougar habitat-relation model. Results indicated the American marten distribution in the Black Hills coincided with white spruce-dominated (*Picea glauca*) forests and associated contiguous forests of other types (predominantly ponderosa pine, *Pinus ponderosa*). High-quality marten habitat consisted of mature, dense canopied (>50%), spruce-dominated forests, in riparian areas, and at relatively high elevations. The marten population in the Black Hills was distributed in a metapopulation structure, containing 2 subpopulations; a 246-km^2 area in the northern Black Hills and a 121-km^2 area that included the Norbeck Wildlife Preserve and vicinity in the central Black Hills; marten presence was lower intermediate to the 2 subpopulations where spruce-dominated forests were more fragmented. Based on mean home range sizes (15.8 km^2 for males, and 5.8 km^2 for females) of radio-collared martens, 124 resident adult martens were estimated to occur in 492 km^2 of high-quality habitat patches. High-quality cougar habitat (6,702.9 km^2; based on macro-habitat characteristics of prey, stalking topography, and concealment habitat) occurred throughout the Black Hills. However, the distribution of the highest ranked habitats was not uniformly distributed, suggesting densities of cougars varied locally within the Black Hills National Forest. Mean annual home-range size of 3 established adult male cougars (n = 9 annual ranges) was 809.2 km^2, and was significantly larger (P = 0.001) than that of adult females (n = 7 annual ranges, 182.3 km^2). Three and 5 females were documented in home ranges of 2 adult male cougars. Total number of cougars in the Black Hills was estimated as 127–149, with an estimated carrying capacity of 152 cougars. A minimum of 5,277 km^2 of high-quality habitat was necessary to maintain the cougar population long-term.

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CHAPTER 1: INTRODUCTION

American martens (*Martes americana*) and cougars (*Puma concolor*) are 2 carnivores that have become reestablished in the Black Hills of South Dakota. Martens likely were native to the Black Hills (Turner 1974, Negus 1980, Fredrickson 1993), and were reintroduced to the region, beginning in the early 1980s (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data). Cougars historically occurred throughout South Dakota but were extirpated from the state during the bounty period (Young 1946). Since protected as state threatened, beginning in 1978, cougars have naturally become reestablished in the Black Hills. The objective of my research was to determine the current distributions and estimate population sizes of American martens and cougars in the Black Hills.

AMERICAN MARTENS: HISTORICAL AND CURRENT STATUS

Although there are no known historical records of American martens in South Dakota, marten specimens dating back to the late Pleistocene period and 10,000–13,500 years ago were collected in Cherry, Nebraska and Albany, Wyoming, respectively (Graham and Graham 1994). In South Dakota, Hoffman (1877) reported seeing several martens in the early 1800s, approximately 13 km west of the Grand River Indian Agency (Carson County). In the more recent past, the species was documented in the Black Hills. In the late 1800s or early 1900s, a trapper named Dan Ruland was reported to have received $2.50 per pelt for trapping marten in the Black Hills, near Crow Creek and between Deadwood and Newcastle, Wyoming (Fredrickson 1993). Moreover, during the 1929–1930 trapping season, Wayne Negus (1980) described trapping 17 martens from the Black Hills, in the Beaver Creek Drainage, near the South Dakota-Wyoming border (Lawrence County). Additionally, one marten was trapped on 4 January 1930 near Pringle, South Dakota (Custer County; Turner 1974). However, between 1930 and 1979, there is no record of martens being harvested from the Black Hills.

American martens probably were extirpated from the Black Hills due to a combination of unregulated trapping combined with the low reproductive output of this carnivore. Factors contributing to their decline likely were exacerbated by limited suitable habitat for the species. In the western United States, martens inhabit late-successional, mesic coniferous forests (Buskirk and Powell 1994). In the Black Hills, these conditions are met in mature, white spruce (*Picea glauca*) -dominated forest types. Spruce forests are limited to relatively high elevations and in canyon lands in the northern and central Black Hills, whereas ponderosa pine (*Pinus ponderosa*) forests dominate the mountain range (Hoffman and Alexander 1987). In the early 1700s and then again in the late 1700s, it is believed that most of the Black Hills was burned by a series of fires (Turner 1974); smaller-scale fires occurred locally in the mid to late 1800s. Since the late 1800s, spruce forests have increased in extent in the Black Hills (U.S. Forest Service 1996), although it is not known whether the forests have expanded to their historic range prior to the large-scale fires of the 1700s. Nevertheless, martens were returned to the region in the early 1980s through a reintroduction effort by the South Dakota Department of Game, Fish and Parks (SDGF&P).

American martens were reintroduced primarily to provide future trapping opportunities for sportsmen, but also for their ecological and aesthetic value (Fredrickson 1993). Forty-two martens (25 males, 17 females) from Idaho were released into the northern Black Hills in 1980 and 1981. Additionally, between 1990 and 1993, 83 martens from Colorado (22 males, 21 females) and Idaho (31 males, 9 females) were released into the central Black Hills (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD unpublished data). From 1982–1995, SDGF&P and Black Hills National Forest employees documented evidence of 115 marten sightings, sign (snow tracks), and road-killed martens without ear tags, indicating the population had become successfully established (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data).

COUGARS: HISTORICAL AND CURRENT STATUS

Historically, cougars occurred in South Dakota and in the late 1800s, were documented throughout the state (Young and Goldman 1946, Turner 1974). Regarding cougars in South Dakota, Theodore Roosevelt (1893) wrote: "Though the cougar prefers woodland it is not necessarily a beast of dense forests only, for it is found in all the plains country, living in the scanty timber belts which fringe the streams, or among the patches of brush in the Bad Lands." Hoffman (1877) noted "occasional specimens are captured in the oak groves in Oak Creek" (where the Grand River joins the Missouri River in Corson County). In the Black Hills of South Dakota and Wyoming, cougars were sighted during expeditions to the region (Ludlow 1875, Turner 1974, Dodge 1998), and were considered abundant at that time (Ludlow 1875, Hallock 1880).

In 1899, a bounty on cougars in South Dakota was initiated to eradicate the species (SDGF&P 1998); by the early 1900s, cougars were extirpated from the state. No official reports of cougars in South Dakota occurred after 1906 until the early 1930's when 2 cougars were killed in the western Black Hills (Turner 1974); a cougar (sex unknown) was killed in 1930 at the headwaters of Stockade Beaver Creek, Weston County, Wyoming, and a female cougar was killed in 1931, 8 km south of Hardy Ranger Station in Pennington County, South Dakota near the South Dakota-Wyoming border. In 1958, the last cougar was killed during the bounty period; a male was shot on Elk Mountain in western Custer County (Turner 1974). Although no reports of cougar killings occurred after 1958, several sightings confirmed their occasional presence in the Black Hills. Between 1964 and 1965, 4 sightings of cougars were documented in Wind Cave National Park. In 1965, tracks west of Custer, South Dakota were positively identified as those of a cougar, and a sighting was reported southwest of Hot Springs, South Dakota (Fall River County). Furthermore, in 1968, a cougar was sighted near Crow Peak (Lawrence County, South Dakota) (Turner 1974).

Cougars were not legally protected in South Dakota until 1978 when the species was classified as state threatened (E. Dowd Stukel, South Dakota Department of Game, Fish and Parks, Pierre, SD, personal communication). It is unclear if cougars sighted in the 1960s were animals that had immigrated to the Black Hills or were descendants from individuals from a remnant population (Turner 1974). The nearest viable cougar populations to the Black Hills occur in the Bighorn Mountains (200 km to the west) and the Laramie Mountains (160 km southwest). Berg et al. (1983) believed transient cougars originating from established populations in the Bighorn Mountains recolonized the Black Hills. However, other evidence supports the hypothesis that cougars may have immigrated to the region from the Laramie Mountains, initially establishing in the southern Black Hills. For example, in the mid 1980s, SDGF&P staff began collecting information on cougar sightings (T. Benzon, South Dakota Department of Game, Fish and Parks, Rapid City, SD, personal communication), and in 1995, they maintained more formal reports. From January 1995 to October 1999 there was an overall increase in the number of sightings of cougars, but sightings were not equally represented throughout the Black Hills. When numbers of reported sightings were adjusted for human population size by county, more reports were obtained from southern counties (Custer and Fall River counties) than northern counties (Lawrence and Pennington counties). Additionally, from 1996 to 1999, more reported cougar deaths occurred in southern counties (58%) than northern counties (42%). Nevertheless, after receiving protection, cougar sightings increased in the Black Hills.

STUDY AREA

The Black Hills are located in west-central South Dakota and northeastern Wyoming, and represent the easternmost extension of the Rocky Mountains. The mountains average about 900–1,200 m above the surrounding Northern Great Plains, and the highest peak is 2,173 m. Topography is variable, characterized by steep ridges, canyonlands and gulches, with large boulders, rock outcrops and caves, and rolling hills, valleys, upland prairies, and tablelands (Froiland 1990).

The climate of the Black Hills is predominantly semi-arid continental. However, due to the rise in elevation of the mountains above the plains, the region is influenced by a mountain climate type (Froiland 1990). Precipitation ranges from 72 cm at high elevations in the northwestern Black Hills to less than 33 cm in the southern foothills. Temperatures also are variable, due to changes in elevation and aspect (Larson and Johnson, 1999). Mean daily temperatures in the Northern Black Hills, ranged from -0.8 to13.8^{o}C. Mean daily temperatures in the Southern Black Hills ranged from 0.5 to 6.9 ^{o}C (Froiland 1990).

Forests of the Black Hills, dominated by ponderosa pine (*Pinus ponderosa*) trees, cover about 84% of the forested landscape (Rumble and Anderson 1996). Additional dominant tree species include white spruce (*Picea glauca*) forests, intermixed with pine in the northern and central Black Hills

(Ludlow 1875, Froiland 1990, Dodge 1998), aspen (*Populous tremuloides*) groves are interspersed throughout pine and spruce forests, and burr oak (*Quercus macrocarpa*) forests occur along the periphery of the mountain range. Other tree species, including American elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica*), box elder (*Acer negundo*), eastern hop-horn-beam (*Ostrya virginiana*), and paper birch (*Betula papyrifera*), occur along drainages throughout the Black Hills (Hoffman and Alexander 1987). Interspersed among the forests are mixed grass prairie, montane grasslands, and willow (*Canix* spp.) and sedge (*Salix* spp.) meadows (Froiland 1990). Mountain mahogany (*Cercocarpus montanus*) and sagebrush (*Artemisia spp*.) steppe are the dominant shrubland communities and occur in drier, lower elevations of the mountain range.

Major natural disturbances that historically diversified the Black Hills landscape were forest fires from thunderstorms and strong winds (Progulske and Shideler 1974), and beaver (*Castor canadensis*) activity (Froiland 1990). Shaped by fire, much of the Black Hills regenerated into a diverse landscape of shrubs and small deciduous trees, intermixed among large old trees that escaped burning (Ludlow 1875, Progulske and Shideler 1974, Dodge 1998). Structure of ponderosa pine stands was variable, with trees ranging from pole-size to more than 26 cm in diameter, with some occurring in dense stands, but mostly, trees were sparsely distributed (Ludlow 1875, Dodge 1998). Spruce trees averaged 20 cm in diameter, but some over 26 cm diameter and more than 30 m high were documented (Dodge 1998). Quaking aspen stands were associated with areas disturbed by windfalls and fire (Ludlow 1875) and were distributed throughout the Black Hills (Dodge 1998). In addition, beavers were numerous in the region, and dams along many of the tributaries converted the valleys into bogs with dense riparian vegetation (Ludlow 1875, Dodge 1998). Numerous deciduous trees were documented along drainages as well as an abundance of soft mast-producing shrubs that were distributed throughout the region (Ludlow 1875, Dodge 1998).

Since 1875, forests, grasslands, and meadows have retained a similar character to their historic state, and many of the same species still occur in the Black Hills (Larson and Johnson 1999). However, the distribution and abundance of vegetation has changed. In general, the composition and structure of native vegetation is less diverse, the water regime of the region is altered, and the landscape is invaded by introduced exotic species (Larson and Johnson 1999). In the last century, fire suppression and silvicultural treatments were practiced by the USDA Forest Service to enhance growth of ponderosa pine for timber production; fire suppression also was practiced for human safety concerns. As a result, ponderosa pine forests today are more regularly distributed, have increased in density and extent throughout the region, and many of the stands contain little or no understory vegetation. In addition, much of the riparian vegetation was cleared for grazing purposes, agriculture, and development. Not only did the vegetation structure change along many tributaries, but also the lack of vegetation warmed stream temperatures causing higher evaporation rates and decreasing stream flow (Froiland 1990). That, in conjunction with decreased soil moisture penetration (from the regular-spaced, closed canopied pine stands) and a lack of beaver activity to maintain the water table (from intensive beaver trapping), has resulted in a drier Black Hills landscape than that described by Ludlow (1875) and Dodge (1998) (Froiland 1990, Larson and Johnson 1999). Moreover, the extent of grasses and forbs, and extensive fruiting shrubs that were reported by Ludlow (1875) and Dodge (1998) have declined due to cattle grazing that occurs throughout the National Forest. Finally, to what extent extirpations of the predator guild [e.g., grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), lynx (*Lynx canadensis*) (Turner 1974)] had and is continuing to have on the subsequent modification of existing vegetation is undocumented in the Black Hills. However, it is hypothesized that mammalian carnivores help shape the landscape by acting as long-distance seed dispersers of fruits and could influence vegetation indirectly by limiting herbivore numbers and distribution (Murphy et al. 1999).

The South Dakota GAP Analysis Project categorized land in the Black Hills, South Dakota into status codes to represent land ownership and management (Smith et al. 2002). Status 1 lands have permanent protection from conversion of natural land cover and a mandated management plan to maintain a natural state within which natural disturbance events are allowed to proceed without interference or are mimicked through management; in the Black Hills, natural disturbances (fire) are not allowed to proceed without interference in these areas. Status 2 lands are similar, maintaining a primarily natural state, but may receive use or management practices that degrade the quality of existing natural communities. Status 3 lands have permanent protection from conversion of natural land cover for the majority of the area, but are subject to extractive uses of either a broad, low-intensity type or localized intense type; status 3 lands do require protection for federally listed endangered and threatened species (Smith et al. 2002). In the Black Hills, lands receiving the highest protection status (Status 1) are the Black Elk Wilderness (54.3 km^2), Beaver Creek area (20.2 km^2), Wind Cave National Park (114.1 km^2), Mount Rushmore National Monument (5.0 km^2), and Jewel Cave National Monument (5.0 km^2), totaling 198.6 km^2. Status 2 lands include Norbeck Wildlife Preserve (137.6 km^2) and Custer State Park (267.2 km^2) for a total of 603.4 km^2 of status 1 and 2 lands. The remaining Black Hills National Forest (4,386 km^2) covers just over half of the Black Hills, and is classified as Status 3.

CHAPTER 2: FIELD EVALUATION OF A HABITAT-RELATION MODEL FOR THE AMERICAN MARTEN

ABSTRACT

Monitoring programs aimed at indicator species like the American marten (*Martes americana*) may index ecosystem conditions throughout the animal's range. Habitat-relation models may be useful to monitor indicator species and their habitats temporally. I constructed and field-tested a habitat-relation model for American martens to determine current distribution of the species in the Black Hills, South Dakota, and establish baseline data for the population. I conducted a track-plate-box survey, selecting survey quadrats using the model, field reconnaissance, and area used by radio-collared martens. I performed stepwise logistic regression to test the model and predict marten presence in random quadrats throughout the study area and in quadrats surveyed by the United States Department of Agriculture (USDA) Forest Service. Of 46, 10.2-km^2 quadrats surveyed, 14 (30%) had boxes visited by martens. High-quality habitat was positively and low-quality habitat negatively correlated with marten presence. Logistic model coefficients predicted martens would be detected in 6 of 68 (9%) random quadrats. When field-tested (post analysis) the model correctly predicted outcomes for 3 (60%) of 5 quadrats surveyed.

INTRODUCTION

Throughout its range in the western United States, the American marten (*Martes americana*) inhabits late-successional, mesic coniferous forests (Buskirk and Powell 1994). Such specific habitat requirements make this species vulnerable to extirpation from habitat alterations (Minta et al. 1999). Thus, the marten has been called an indicator species; within its range, its presence indicates ecosystem integrity, whereas declines in distribution or numbers foreshadow ecosystem deterioration (Minta et al. 1999). Federal law mandates that national forest planning account for needs of indicator species (Morrison et al. 1998). Monitoring programs focused on indicator species, like martens, could index ecosystem conditions throughout their range. Single-species habitat-relation models may be useful to monitor indicator species and their habitats temporally. Morrison et al. (1998) advocated using habitat-relation models to generate and test research hypotheses and to update models accordingly as part of an adaptive management scheme. Equally important are field validations of habitat-relation models.

I constructed and field-tested a habitat-relation model for the American marten to determine current distribution of the species and establish baseline data for the population. In the western United States, martens are found at relatively high elevations in mature spruce (*Picea* spp.) or fir (*Abies* spp.)-dominated forests (Campbell 1979, Thompson and Colgan 1987) with >50% canopy cover (Hargis and McCullough 1984, Thompson 1994). Martens prefer riparian habitat (Martin 1987, Buskirk et al. 1989) and often are associated with red squirrel (*Tamiasciurus hudsonicus*) middens (Ruggiero et al. 1998). I hypothesized that martens would be detected more often in areas containing these habitat characteristics (i.e., high-quality habitat) and the probability of detecting martens would increase as the amount of high-quality habitat increased.

METHODS

To create the habitat-relation model for American martens, I acquired digital databases from the South Dakota Gap Analysis Project containing macro-habitat characteristics. Databases included a USDA Forest Service geographical information system (GIS) of the Black Hills containing dominant overstory species, percentage canopy cover, and stand size; a digital line graph stream database; and a digital elevation model (30-m resolution) database. The model was developed using ARC/INFO and ArcView (Environmental Systems Research Institute, Inc., Redlands, Calif.) software and was limited to national forest land within the Black Hills.

The model was constructed by recoding each database with ranks associated with their suitability to American martens. Databases were projected to the Universal Transverse Mercator coordinate system (Datum NAD 27) and converted to 30-m cell grids to match the digital elevation model data and enable the layers to be overlaid and added. For example, the coverage containing dominant overstory species was recoded to values 3, 2, and 1, representing white spruce, ponderosa pine, and deciduous forests, respectively (Table 1). Spruce forest was assigned the greatest value (3) because data for western states indicated it was selected by martens over other forest types (Buskirk and Powell 1994). The 5 databases were overlaid and cells summed to create the habitat-relation model. Mature, spruce-dominated stands with >50% canopy, within 100 m of streams, and at elevations $\geq$1,585 m received the greatest rank (i.e., Rank 9, high quality habitat) for martens.

I conducted a population survey to determine the distribution of American martens in the Black Hills. I chose the track-plate-box survey method (Zielinski and Kucera 1995) because of its relatively low cost and because the technique does not depend on snow conditions. Following Zielinski and Kucera (1995) the sampling unit was a 10.2-km^2 (4-mi^2) quadrat. This quadrat size was large enough to include the home range of a marten and enabled results to be compared easily to other marten populations (Zielinski and Kucera 1995).

I conducted the survey from 18 April to 1 December 1999. I chose quadrats using the habitat-relation model identifying high-ranked habitat (Figure 1) and from field reconnaissance. The survey area included the Black Hills, South Dakota lands north of U.S. Route 16, encompassing Lawrence, Pennington, and Custer counties. Land south of U.S. Route 16 in Custer County was not considered suitable for American martens. I placed 6 baited track-plate-boxes in each quadrat and checked and rebaited every 4 days for a 12-day period or until they were visited by martens. I placed boxes approximately 0.8

km (0.5 mi) apart in a loosely shaped grid; I placed boxes in several of the initial quadrats surveyed in linear transects. Skunk (*Mephitis mephitis*) essence was used as an attractant to the wooden track-plate-box, accompanied by chicken, to lure the animal across the tracking medium (carbon-sooted aluminum plate). To determine if the technique was effective at detecting presence of martens, I surveyed 2 quadrats that included portions of home ranges of 3 radio-collared martens.

Using results of the track-plate-box survey, I tested the habitat-relation model for its ability to predict American marten occurrence. I determined percentages for each of the ranked habitats per quadrat for all quadrats surveyed. I incorporated the data into a stepwise (backward) logistic regression analysis (Program Systat 9.0, SPSS Science Marketing, Chicago, Ill.); factors included in the model were percentages of Rank 1–9 habitats in quadrats surveyed for martens. Next, I determined the probability of detecting martens in 100 random quadrats throughout the Black Hills using results of the logistic analysis. I made predictions based on the model as to which of 10 quadrats surveyed by USDA Forest Service personnel using similar methodology would contain martens.

RESULTS

The habitat-relation model ranked National Forest land in the Black Hills, South Dakota according to suitability to American martens. No quadrats surveyed contained >6.0% of the greatest quality (Rank 9) habitat. Of 46 quadrats surveyed (476.3 km^2, Figure 2), 14 (144.9 km^2, 30%, Figure 3) had track-plate-boxes visited by martens, including the 2 quadrats placed within home ranges of radio-collared animals. All quadrats that detected martens had boxes visited between days 1 and 8 after placement. Eight of 15.5 quadrats surveyed in Lawrence county (52%) had boxes visited by martens, whereas only 6 of the 30.5 quadrats surveyed in Pennington and northern Custer counties combined (20%) had boxes visited by martens.

Because private land was not classified in the GIS, I could not determine the relationship between American marten detection and percentage of each of the ranked habitats per quadrat for all quadrats surveyed. To minimize effects of unclassified private lands, I omitted quadrats with >12% private land (4 quadrats) from analyses. Stepwise logistic regression analysis of remaining quadrats (42) resulted in 2 habitat ranks remaining in the model: Rank 3 habitat, which in the majority of the quadrats surveyed was the least-ranked habitat, and Rank 9 habitat, the greatest rank (Table 2). At least 2.0% of Rank 9 habitat and not more than 5.0% of Rank 3 habitat per quadrat was necessary to predict ($P \geq 0.5$) presence of martens (Figure 4). Probability of detecting martens increased as amount of Rank 9 habitat increased. The logistic model used to predict marten detection was:

$$P = e^{-0.323 - 0.254 \text{ (Rank 3)} + 0.758 \text{ (Rank 9)}} / 1 + e^{-0.323 - 0.254 \text{ (Rank 3)} + 0.758 \text{ (Rank 9)}}$$

The habitat-relation model was satisfactory ($Rho^2 > 0.20$, [Hensher and Johnson 1981]) at predicting American marten presence ($P = 0.004$, McFadden's

$Rho^2 = 0.245$, $\chi^2 = 11.28$). However, it performed better at predicting where martens would not be found than where they would be detected (Table 3, specificity = 0.82, sensitivity = 0.47).

I calculated percentages of Rank 3 and Rank 9 habitat in 100 random quadrats throughout the Black Hills and estimated probabilities of occurrence using the logistic model. Thirty-two of those quadrats had >12% of the area privately owned. Of the remaining 68 random quadrats, 6 (9%) had probabilities $\geq$0.5, indicating martens would be detected in those quadrats. Of 10 quadrats surveyed by the USDA Forest Service, 5 quadrats had >12% of the area privately owned, leaving 5 for the analysis. The logistic model correctly predicted one (33%), of 3 quadrats in which martens were detected, and 2 (100%) of 2 quadrats where martens were not detected by the USDA Forest Service.

DISCUSSION

In the Black Hills, American martens are associated with habitats similar to those reported in other western states, in and near mature spruce-dominated forests, with dense canopy cover, in riparian areas, and at relatively high elevations. Dense canopy in these forest types offer martens protection from predators and increased thermal cover (Hargis and McCullough 1984, Thompson 1994). In addition, riparian habitats are important to American martens as foraging and resting sites (Martin 1987, Buskirk et al. 1989). Spruce stands and the distribution of red squirrels in the Black Hills are associated with high elevations. Squirrel middens provide resting sites and the red squirrels provide prey to martens (Ruggiero et al. 1998). The track-plate-box survey method detects presence of martens when densities are high (Ivan and Foresman 1999). Thus, results indicate that greater densities of martens occur in the northern Black Hills than in the central Black Hills because Rank 9 habitat is found more commonly in the northern Black Hills.

The American marten distribution coincides with prior release locations of reintroduced animals (Figure 3). Forty-two martens were released by the SDGF&P into the northern Black Hills in 1980 and 1981, and 83 martens in the central Black Hills between 1990 and 1993 (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data). De Vos (1951) determined that the rate martens colonize vacant habitat from a refuge is about 6–8 km/decade. Based on locations of release sites and rate of colonization (De Vos 1951), martens would have had time to colonize all suitable habitat in the Black Hills. It is possible colonization could take longer due to high mortality of dispersing martens through thinned stands (DeVos 1951). Nevertheless, at least some of these animals had the ability to exploit available habitats throughout the Black Hills based on my observations of a male dispersing from the central to the northern Black Hills (D. M. Fecske, unpublished data), and that adult and juvenile females have moved comparable distances (Thompson and Colgan 1987, Latour et al. 1994). By creating and field-testing the habitat-relation model, not only did I document current distribution of martens, but I also identified quadrats with mature spruce-dominated stands where martens were either at low densities or did not occur.

Results indicated there was a critical percentage of high-quality habitat required for American marten presence within a given 10.2-km^2 area. Martens were detected more often in quadrats containing high-ranked (Rank 9) habitat. Also, the probability of detecting martens in quadrats increased as percentage of Rank 9 habitat increased (from 2% [0.20 km^2] to 6% [0.61 km^2], where at 6%, there was a 92% chance of detecting the animal), and as amount of Rank 3 habitat decreased (from about 5% to <1%). Potvin et al. (1999) analyzed habitat use of radio-collared martens in Quebec and made management recommendations. They suggested that $\geq$50% (5.0 km^2) uncut forest be preserved inside 10-km^2 units and that <30% (3.0 km^2) of the area be clear-cut over a 30-year period. Allen (1982) reported 2.59 km^2 as the minimum amount of contiguous suitable habitat required before an area would be occupied by martens. Both reports relied on winter habitat use as a limiting factor for martens.

Mature stands of spruce-dominated forest are required during winter to provide adequate protective and thermal cover for American martens (Allen 1982). The habitat-relation model was created from data collected during spring, summer, and fall. In theory, had the survey been conducted in winter, a larger amount of high-quality habitat might have been required by the species. However, in quadrats I surveyed, Rank 9 habitat (i.e., mature white spruce stands within 100 m of streams) composed ≤6% (0.61 km^2) of quadrats and in the random quadrats analyzed, maximum percentage of Rank 9 habitat was 7% (0.72 km^2). Consequently, martens in the system were using the greatest quality habitat available in the Black Hills.

Overall, the habitat-relation model was satisfactory at predicting American marten detection, suggesting macro-habitat characteristics were good predictors of marten presence. The model, however, performed better at predicting where martens would not occur than where they would be detected. There were 2 reasons for the low sensitivity of the model. The first was that portions of many quadrats surveyed included private land. Therefore, if a particular quadrat had a low amount of Rank 3 habitat and a relatively large amount of Rank 9 habitat, but those habitats were not reflected in the database due to private ownership, the model would not predict marten occurrence. The second reason was that some white spruce stands were classified incorrectly as ponderosa pine stands in the USDA Forest Service GIS. Therefore, the logistic model predicted martens would not occur in those quadrats when martens were detected in the track-plate-box survey and 10 martens, including adult, breeding females, were live-trapped in this region. Through the field validation process I were able to identify sources of error in the GIS that can be corrected in future modeling efforts and, thus, improve performance of the habitat-relation model.

MANAGEMENT IMPLICATIONS

Using information obtained from the field evaluation of the habitat-relation model, new hypotheses can be developed and tested to understand why American martens were not detected in particular white-spruce dominated stands. I identified forested ecosystems that were potentially declining in quality from thinning, fragmentation, or isolation from a water source (Figure 5). Integrity of declining white spruce forests could be enhanced by allowing young spruce or mixed conifer stands (naturally or through plantings) to reach maturity and maintaining moderately ranked habitat surrounding those stands. Protection or enhancement of riparian zones could make otherwise high-quality stands more attractive to martens and also would offer connectivity between forest patches (Potvin et al. 1999). The habitat-relation model could be used to predict potential corridors to maintain connectivity in the intermediate region between the 2 regions that have greater densities of martens. For example, percentages of Rank 3 and Rank 9 habitat could be calculated and suitability to martens determined using the logistic model (Chapter 4). Areas most suitable could be given priority in conservation efforts. Habitat could be maintained or enhanced to enable colonization of formerly unoccupied or unsuitable habitats or provide increased connectivity throughout the marten distribution.

Table 1. Macro-habitat characteristics ranked by suitability to American martens; greater values indicate greater suitability. Individual gridded databases for 5 characteristics were overlaid and summed to create a habitat-relation model for martens in the Black Hills, South Dakota (1998–2001). Rank 9 represented the most suitable marten habitat [white spruce dominant overstory (3); canopy cover >50% (2); tree size >22.9 cm diameter-breast-height (dbh) (2); ≤100 m from a stream (1); and at elevations >1585 m (1)].

Habitat Characteristics		Rank
1. Overstory Cover	White spruce	3
	Ponderosa Pine	2
	Deciduous spp. / Other	1
2. Percent Canopy Cover	>50%	2
	30–50%	1
	<30%	0
3. Tree Size	>22.9 cm dbh	2
	2.7–22.9 cm dbh	1
	12.7 cm dbh	0
4. Riparian Habitat	≤100 m from stream	1
	>100 m from stream	0
5. Elevation	≥1,585m elevation	1
	<1,585m elevation	0

Table 2. Logistic regression (*n* = 42) results from a track-plate-box survey to detect American marten presence in the Black Hills, South Dakota (1998–2001).

Variable	Coefficient	*P*-value	*t*-ratio	S. E.
Constant	-0.323	0.694	-0.393	0.821
Habitat				
Rank 3	-0.254	0.092	-1.687	0.150
Rank 9	0.758	0.041	2.045	0.371

Table 3. Prediction success table of the American marten habitat-relation logistic regression model developed for the Black Hills, South Dakota (1998–2001).

Actual Choice	Predicted Response	Choice Reference	Total
Response	4.467	5.533	10.000
Reference	5.533	26.467	32.000
Predicted Total	10.000	32.000	42.000
Correct	0.447	0.827	
Success Ind.	0.209	0.065	
Total Correct	0.737		

Sensitivity: 0.447 Specificity 0.827
False Reference 0.553 False Response 0.173

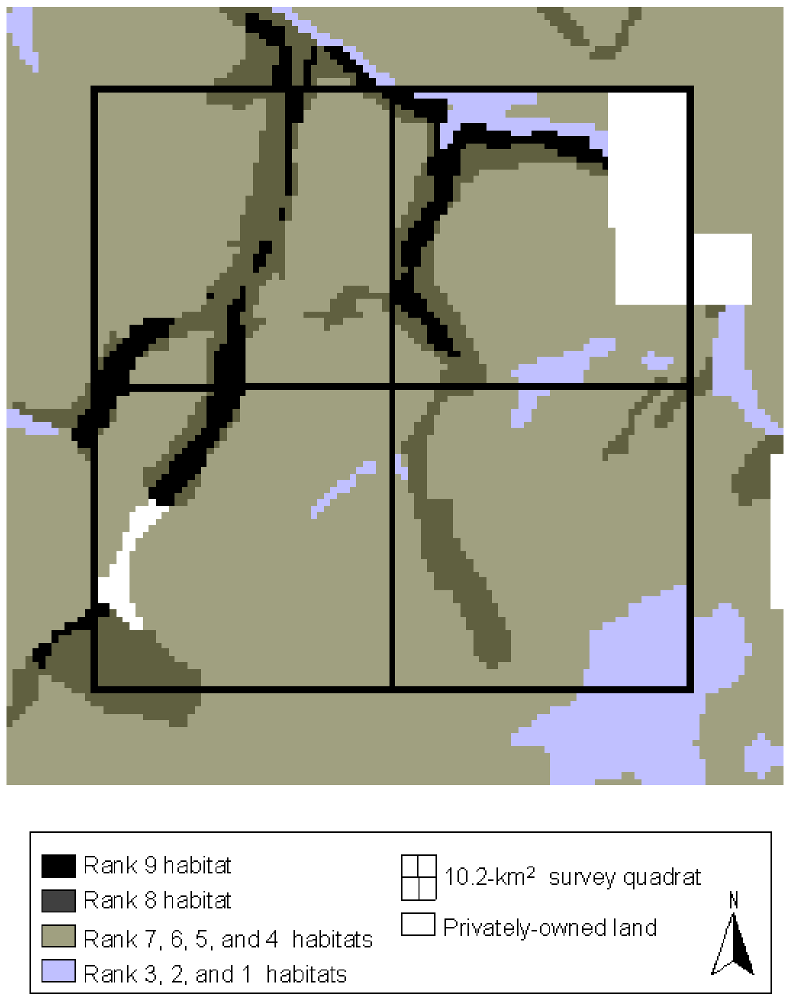


Figure 1. Survey quadrat (10.2 km^2) overlaid on the American marten habitat-relation model for the Black Hills National Forest, South Dakota (1998–2001).

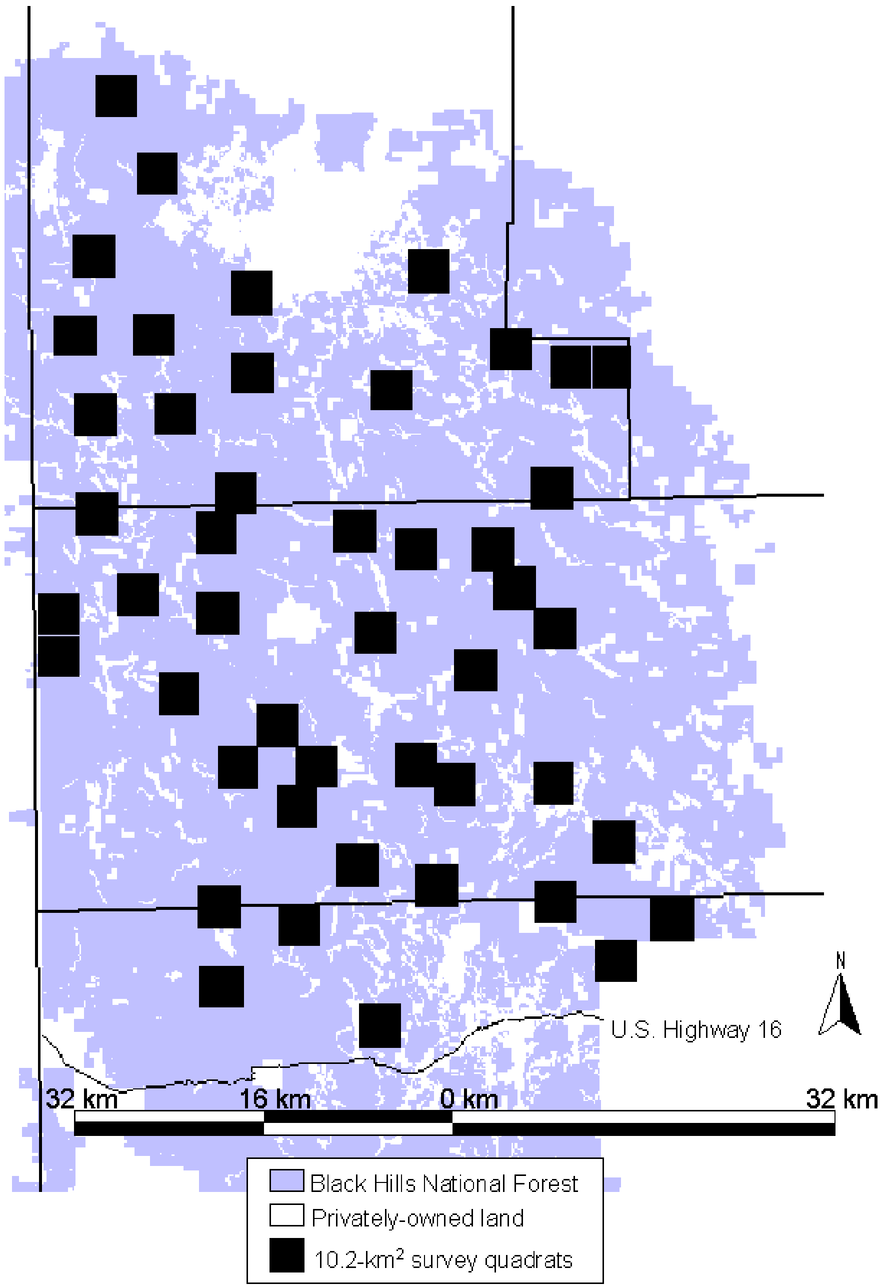


Figure 2. Forty-six 10.2 km2 quadrats surveyed to determine known distribution of American martens in the Black Hills, South Dakota (1998–2001).

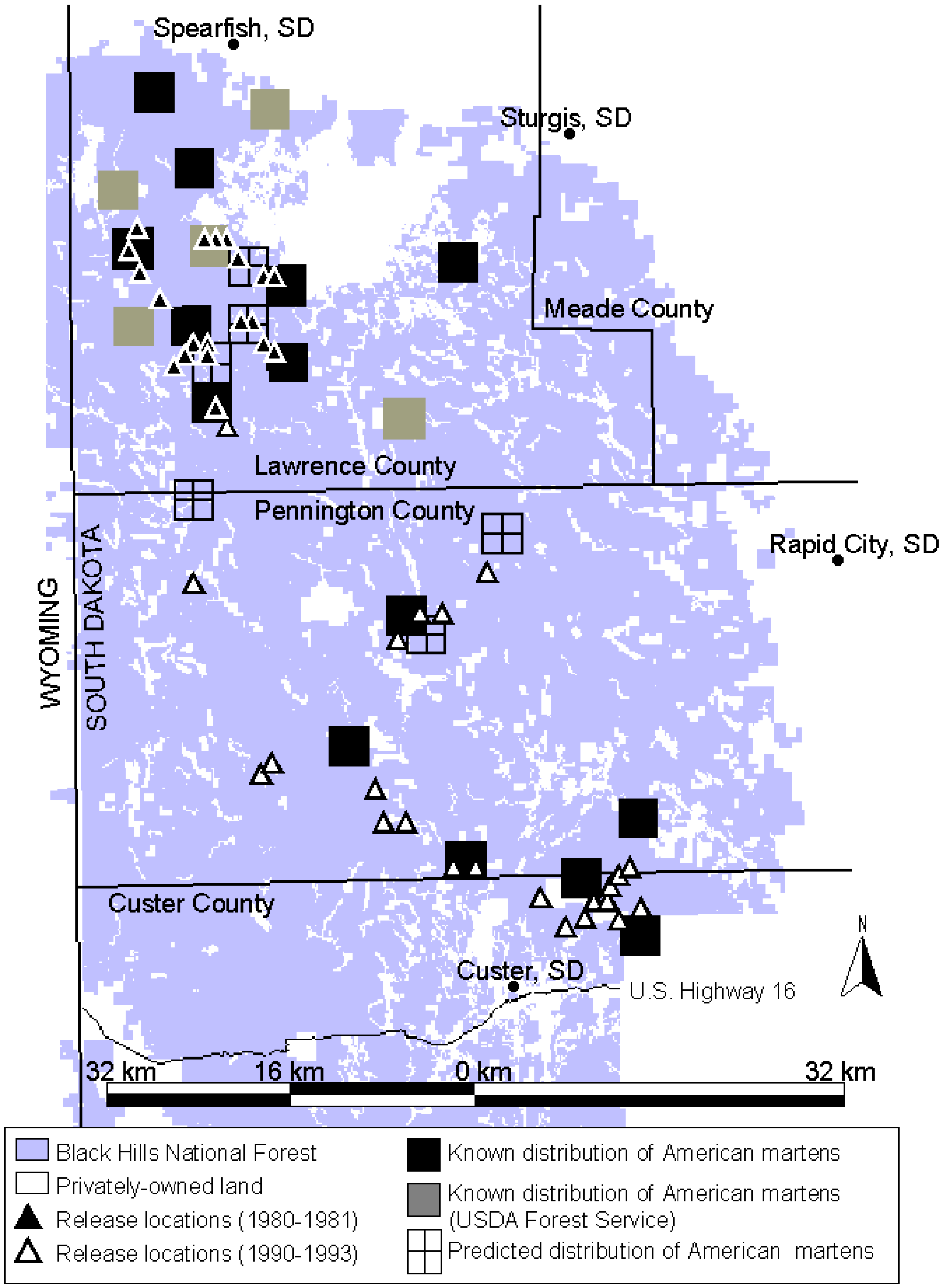


Figure 3. Known and predicted American marten distribution in the Black Hills, South Dakota (1998–2001).

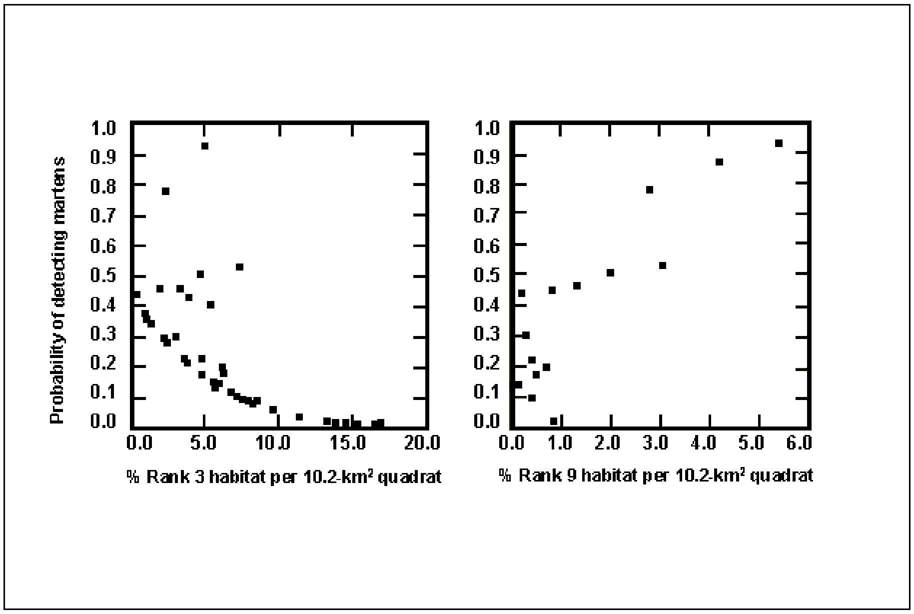


Figure 4. Logistic regression (*n* = 42) results from a track-plate-box survey to detect American marten presence in the Black Hills, South Dakota (1998–2001). Rank 3 habitat was correlated negatively, and Rank 9 habitat correlated positively to marten detection.

Figure 5. The habitat-relation model identified white spruce stands in the Black Hills, South Dakota (1998–2001) that were declining in quality from thinning, fragmentation, or isolation from a water source.

CHAPTER 3: A LANDSCAPE ANALYSIS FOR AMERICAN MARTENS (*Martes americana*) IN THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

Determining spatial relationships among habitat patches, corridors, and background matrixes are important for understanding population parameters of species in fragmented landscapes. I conducted a landscape analysis for American martens (*Martes americana*) in the Black Hills. High-quality habitat patches were identified throughout National Forest lands, based on a habitat-relation model. Thirteen adult martens were captured, fitted with radiocollars, and monitored using aerial telemetry techniques. Mean home range sizes (15.8 km^2 for males, and 5.8 km^2 for females) were used to estimate the number of resident animals in high-quality habitat. Habitat selection analyses were conducted for study animals. Additionally, based on a U.S.D.I. Marten Habitat Suitability Index (HSI) Model, micro-habitat characteristics at track-plate-boxes used in a population survey were measured and compared to calculated HSI values where martens were and were not detected. I identified potentially suitable and corridor habitat within a matrix of contiguous forest cover. Results indicated the Black Hills marten population was distributed in a metapopulation structure, containing 2 subpopulations, with an estimated resident adult population of 124 martens occurring in 492 km^2 of high-quality habitat. The modeling facilitated identification of subpopulations that should be protected,

additional marten habitat outside of known subpopulations where martens were detected and where more information was needed, connective corridor habitat to maintain the species long-term, and future habitat potential for martens on National Forest lands. Calculated HSI values at baited boxes allowed us to provide a modest test of the HSI Model, and gain important insight on habitat requirements at the stand level.

INTRODUCTION

Landscapes are heterogeneous expanses of land composed of a cluster of interacting ecosystems, or landscape elements, that occur repeatedly across the land area (Forman and Godron 1986). At the landscape scale, habitat patches, corridors, and the background matrix are the units of measure and interest (Bissonette et al. 1991). Determining the spatial relationships among these components is important for understanding population parameters of species in fragmented landscapes (Fahrig and Merriam 1994). Bissonette et al. (1991) argued that to appropriately protect habitat for American martens (*Martes americana*) long-term, requires managing forests at the landscape level. Their work was based on a protected population of martens in Newfoundland, where logging was a major activity and habitat fragmentation limited marten population size. They provided guidelines for management of the landscape for martens including: 1) mature forest should dominate the matrix of the landscape, 2) clearcut patches should be kept within specified sizes; 3) residual forest patches resulting from timber harvests should be kept within specified sizes and shapes, and 4) corridors along riparian areas should be maintained to allow movement between patches.

In the Black Hills of South Dakota, where 69% of the National Forest is considered suitable for timber harvest, either for wood production or management for big game (USDA Forest Service 1996), a protected, reintroduced population of American martens exists. Forty-two American martens (25 males, 17 females) from Idaho were released into the northern Black Hills in 1980 and 1981 by the South Dakota Department of Game, Fish and Parks (SDGF&P). Additionally, between 1990 and 1993, 83 martens from Colorado (22 males, 21 females) and Idaho (31 males, 9 females) were released into the central Black Hills (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data). Records (n = 115) of marten sightings, sign (snow tracks), and vehicular mortalities of animals without ear tags from 1982 to 1995 indicated the population had become established (L. F. Fredrickson, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data). I determined that the current distribution of martens in the Black Hills was fragmented (Chapter 2), and identified factors that could be contributing to relatively low densities, locally. The goal for this analysis was to provide a broad-scale examination of the Black Hills landscape in relation to its suitability to martens, and thereby contribute to developing a strategy for long-term conservation of this population. However, in doing so, I obtained data that revealed insights into habitat needs of martens at the stand level. My work represents a paradigm for incorporating the adaptive management approach to better manage habitat for a species long-term in light of new information (Morrison et al. 1998).

METHODS

I modeled the population and spatial structure of the Black Hills landscape for American martens using data derived from a marten population survey and habitat-relation model (Chapter 2), a sample of radiocollared martens, and a marten Habitat Suitability Index (HSI) model (Allen 1982). I identified subpopulations in high-quality habitat patches and estimated resident adult population size. Based on the South Dakota Gap Analysis (SD-GAP) land cover map containing broad land cover classes of the Black Hills, I identified potentially suitable and corridor habitat occurring within a matrix of contiguous forest throughout the mountain range. All spatial data were processed using Arc/Info, Arc/View 3.2 (Environmental Systems Research Institute, Inc., Redlands, CA 92373); and IMAGINE (Leica Geosystems, Atlanta, GA 30329) geographic information system (GIS) software. Statistical analyses were conducted using Program Systat 9.0 (SPSS, Inc. Chicago, IL 60606) or with Microsoft Excel 97 (Microsoft Corp. Bellvue, WA 98004).

I created and tested a ranked habitat-relation model for American martens in the Black Hills (Chapter 2). The model was based on digital, gridded (30-m^2 cells) databases of habitat characteristics (overstory species, tree size, percent canopy cover, proximity to streams, and elevation), that were recoded in a GIS with ranks according to suitability to martens and summed to create a final model. The highest ranked (high-quality) marten habitat (Rank 9) contained mature forest (>22.9 cm dbh), a dense canopy (>50%), was dominated by spruce trees, was within 100 m of a stream, and occurred at elevations $\geq$1585 m (based on the distribution of red squirrels, *Tamiasciurus hudsonicus*, [Higgins et al. 2000]); lower-quality habitat was associated with younger forests of other types and open habitats. The model was tested using results of a track-plate-box presence/absence survey for the species (Zielinski and Kucera 1995). The test was based on a logistic regression analysis of the percentages of habitat ranks in 10.2-km^2 survey quadrats where martens were detected (n = 14), and those where martens were not detected (n = 32). I noted the sensitivity of the model could be improved by correcting classification errors in the database. Further, high-quality habitat throughout the National Forest could be identified from results of the logistic model to predict corridors between 2 regions where greater densities of martens occurred within the documented range. As part of an adaptive management scheme (Morrison et al. 1998), I corrected known classification errors in the marten habitat-relation model that were identified based on field observations. Then, I determined areas throughout the Black Hills National Forest that met the requirements for marten detection.

Based on the resulting logistic analysis test of the habitat-relation model, within a given 10.2-km^2 survey quadrat in the National Forest, $\geq$2% of high-quality habitat (Rank 9), and $\leq$5% of Rank 3 habitat (low-quality habitat) was necessary to predict ($P \geq 0.5$) presence of martens (Chapter 2). I queried the model and created 2 binary grids, one containing only Rank 9 habitat and the other Rank 3 habitat. I conducted focal sum analyses (square search distance of 5.18 km) on the 2 grids to determine, for each 30-m cell, the number of cells per 10.2 km^2 that contained either Rank 3 or Rank 9 habitat. These databases then were combined to identify high-quality marten habitat, based on land that met the proportion criteria ($\geq$2% Rank 9 and $\leq$5% Rank 3 habitat per 10.2 km^2). From this grid, I identified and determined the area of high-quality habitat patches for martens in the Black Hills. Also, I mapped 10.2 km^2 regions that contained any amount of Rank 9 habitat, to represent future habitat potential for martens in the Black Hills, should landscapes surrounding current Rank 9 habitat be enhanced for the species.

I captured and radiocollared a sample of adult American martens in high-quality habitat patches. Martens were captured with enclosed, wire live traps (Tomahawk Livetrap Co., Tomahawk, WI 54487) baited with venison, and using skunk essence (Murray's Lures, Elizabeth, WV 26143) as a lure. Traps were placed under spruce trees and covered with branches to provide security and thermal cover to captured martens, and checked daily. Upon capture, a flexible funnel (Bull et al. 1996) was attached (via duct tape) to the trap and a restraining device (Handcock Trap Co., Custer, SD). Afterwards, the trap was opened and the animal was allowed to travel through the funnel into the restraining device, where it was injected with ketamine hydrochloride (10 mg/454g body weight; Fort

Dodge Labs, Inc., Fort Dodge, IA 50501). After injected, martens were allowed to back out of the restraining device into the canvas funnel or into the trap, until they became unconscious. Immobilized animals were aged based on the degree of tooth wear (Strickland et al. 1982), and fitted with 34-g radiocollars programmed with a 12-hour duty cycle and expected battery life of 8.9 months (Telonics, Inc., Mesa, AZ 85204). Recovering animals were placed back into the trap until visible effects of the drug were no longer apparent. All martens were released at capture locations.

Radiocollared Americans martens were located weekly from fixed-wing aircraft (Cessna 172 or Cessna 205) during daylight hours using aerial telemetry techniques (Quigley and Crawshaw 1989). Altitude at which locations were obtained ranged from 500 to 1000 m. Mean telemetry error was 152 m (min., max. = 40m, 500m; Chapter 4).

Location coordinates for radiocollared American martens were incorporated into a GIS to estimate annual home range and determine habitat requirements. Home ranges of martens were determined using the Minimum Convex Polygon (MCP) method (100%). Similar to Bissonette et al. (1991), I estimated the resident adult population size of martens within the Black Hills using mean home ranges of male and female study animals that were located in high-quality habitat patches.

I mapped potential American marten habitat and corridors within a contiguous forest matrix for the Black Hills mountain range. Because the habitat-relation model was limited to National Forest land, for this analysis, I used a grid derived from the SD-GAP land cover map of the Black Hills (Smith et al. 2002), recoded to 4 broad habitat types: 1) ponderosa pine forest, 2) spruce forest, 3) deciduous forest, and 4) open habitats. I analyzed second and third-order habitat selection (Johnson 1980) of radiocollared martens. Home ranges of martens were estimated and an equal number of random circular "home ranges" in the central and northern Black Hills were generated (Kie et al. 2001), based on the mean home-range size of radiocollared martens. All home ranges were overlaid onto the SD-GAP Black Hills land cover map to determine proportions of dominant land cover classes comprising marten and random home ranges. Proportions were compared using Manly's (1972) Alpha Preference Index.

Third-order habitat selection was determined by analyzing land cover classes at locations of radiocollared American martens, and quantifying habitat variables at a sample of track-plate-boxes used during a track-plate box survey for the species (Chapter 2). Due to the relatively high error (500 m) associated with locations, landscapes selected by 11 martens were analyzed based on 1000-m diameter error circles (0.78 km^2) surrounding marten locations and an equal number of random locations within annual home ranges. Proportions of dominant land cover classes comprising marten and random buffered locations were determined, and compared using Manly's (1972) Alpha Preference Index. Additionally, micro-habitat characteristics were measured opportunistically at locations of a sample of track-plate-boxes used during the population survey to detect marten presence in the central and northern Black Hills (Chapter 2). Habitat characteristics were based on an HSI model, designed to rapidly assess habitat for martens in western states (Allen 1982). The model incorporated 4 variables: 1) percent canopy cover, 2) percent canopy cover comprised of spruce trees, 3) percent ground cover (woody debris >7.6 cm diameter), and 4) stand age. The first 3 variables were determined with a GRS densiometer (Forestry Suppliers, Inc., Jackson, MS 39284) at 1-m intervals along 4, 15-m transects arranged in the 4 cardinal directions from baited boxes. Stand age was estimated from mean diameter at breast height (dbh) of trees, determined by standing at baited boxes, and identifying a sample of trees using a Jim-GEM Cruz-All, (Forestry Suppliers, Inc., Jackson, MS 39284) with a basal area factor of 10. Mean diameters were categorized into 4 classes defined in the HSI model and based on criteria used by USDA Forest Service: 1) shrub-seedling (<2.5 cm), 2) pole sapling (2.6–12.6 cm), 3) young (12.7–22.9 cm), and 4) mature or old growth (>22.9 cm) forest. Measurements of variables were converted to HSI scores, ranging from 0 to 1.0, where a 1.0 indicated highest suitability to martens, and was used to obtain a final HSI score with the equation $(V_1xV_2xV_3xV_4)^{1/2}$ (Allen 1982).

Mean HSI scores measured in habitat where martens were detected at boxes were compared to those where martens were not detected using *t*-tests. Additionally, HSI values of habitat at boxes were coded into 3 habitat categories for martens 1) marginal (0.1–0.3), 2) suitable (0.4–0.6), and 3) optimal (0.7–1.0)

(Laymon and Barrett 1986). A Chi-Square test was used to determine if the frequency of habitat at track-plate-boxes occurred in 3 HSI categories differed from what would be expected. Bonferroni multiple comparison tests (Rao 1998) were used to determine significant differences between the 2 categories among 3 HSI categories.

I identified potentially suitable American marten habitat and travel corridors throughout the Black Hills mountain range using additional information gleaned from the HSI model and results from habitat analyses of radiocollared martens. First, using the SD-GAP Black Hills land cover map, I created a matrix of contiguous forest cover, based on criteria in the HSI model for martens (Allen 1982). According to the model, 2.59 km^2 of contiguous forest cover (regardless of tree species) was required for habitat to be considered suitable for martens. I queried the land cover map and created a binary grid containing only forest habitat. I conducted a focal sum analysis on the grid to determine, for each 30-m cell, the number of cells per 2.59 km^2 that contained forest cover. Cells were subsequently recoded into 3 categories: 100% forest cover, 90–99% forest cover, and <90% forest cover per 2.59 km^2.

Within the matrix, I categorized potential American marten habitat and connecting corridor habitat based on density of selected forest types observed within home ranges of radiocollared male martens. I determined the mean percentage of selected forest type(s) that occurred in home ranges of study animals. Then, I conducted a focal sum analysis on a binary grid that contained only selected forest type(s). The result was a gridded database that identified for each cell, the number of cells per mean circular male home range size that contained the selected forest type(s). To identify potential and corridor habitat, I queried cells in the selected forest type(s) density and contiguous forest grids that met desired criteria. For example, potential marten habitat was determined by querying cells that occurred within the contiguous forest cover matrix and that had forest density grid cell values that included the mean percent selected forest type(s) per male range ± 1 SD. To identify corridor habitat I queried cells that were contained within the contiguous forest cover matrix and had forest density grid cell values within a range beginning with the minimum percent of selected forest type(s) by martens and ending with the value just less than the mean - 1 SD.

RESULTS

A total of 492 km^2 of habitat in the Black Hills met the conditions for American marten detection, representing high-quality habitat for the species (Figure 6). Largest patches of high-quality habitat occurred in 2 distinct regions of the Black Hills: 1) a 246-km^2 region in Northern Black Hills (NBH), and 2) a 121-km^2 area (Norbeck Wildlife Preserve and vicinity) in the Central Black Hills (CBH). Four smaller high-quality habitat patches (from north to south, 21 km^2, 36 km^2, 20 km^2, and 47 km^2) were contained near and between the 2 larger patches. An additional 514 km^2 of habitat contained any amount of Rank 9 habitat per 10.2-km^2, representing future habitat potential, should forests and riparian habitat be enhanced in these areas for the species. Thus, the total potential range of marten habitat based on the habitat-relation model could be as large as 1,006 km^2.

A total of 13 adult ($\geq$1 year) American martens (10 male, 3 female) in 2 large habitat patches of highest-quality habitat were captured, fitted with radio-collars, released, and monitored (Table 4). Martens were trapped from the Norbeck Wildlife Preserve in the CBH (-103^o 33' 10.7" N, 43^o 51' 3.5" W), and in the NBH, along Spearfish Creek (-103^o 54' 50.4" N, 44^o 15' 50.4" W). Duration of monitoring ranged from 1–61 weeks. Five male martens and 1 female died while being monitored; 4 were killed by predators (1 coyote (*Canis latrans*) and 4 unknown predators) and 2 died from unknown causes. One female marten chewed through her radio-collar and it was retrieved from a cavity of a mature (>22.9 cm dbh) ponderosa pine tree. Two martens were recaptured after their collars malfunctioned, were fitted with new transmitters, and released for subsequent monitoring. Four martens were monitored until I lost track of their signal from unknown causes. One marten was monitored for 61 weeks.

Mean home range size of 9, male American martens was 15.8 ± 13.6 km^2 (SD), and of 2 females, 5.8 ± 1.6 km^2 (SD) (Table 4). Based on mean home range sizes of males and females, a total of 124 adult resident martens (85 females, 39 males) were estimated to occur within high-quality habitat patches. Radiocollared martens established home ranges in landscapes dominated by spruce forest habitat (Alpha = 0.530 > Manly's Alpha [0.25]) (Table 5).

Individually, 7 of 11 martens selected landscapes (Alpha > Manly's Alpha 0.25) that had relatively high proportions of spruce forest (Table 6).

Habitat Suitability Index values were determined at locations of 74 track-plate-boxes from 15, 10.2 km^2 quadrats surveyed for American martens (10 quadrats in the CBH and 5, in the NBH) (Table 7). Twenty-three boxes were visited by martens; of those, 12 boxes occurred in quadrats in the CBH, and 11 occurred in quadrats in the NBH. When the HSI values from individual boxes were averaged across 10.2 km^2 survey areas, HSI values of quadrats where martens were detected (n = 10, mean ± SD = 0.0.617 ± 0.130) were not different from values in quadrats where martens were not detected (n = 5, mean ± SD = 0.603 ± 0.158) (t = -0.181, d.f. = 13, P = 0.859). However, HSI values at individual boxes where martens were detected (n = 23, mean ± SD = 0.728 ± 0.271) were significantly greater than values where martens were not detected (n = 51, mean ± SD = 0.548 ± 0.330) (t = -2.280, d.f. = 72, P = 0.026). Distribution of HSI values (n = 74) categorized as either marginal, suitable, and optimal differed between boxes where martens were detected, and those where martens were not detected (Calculated χ^2 = 6.897) (Table 8); boxes where martens were detected had fewer marginal HSI values than those were martens were not detected.

Based on the results of habitat selection analyses of radiocollared American martens and microhabitat characteristics at track-plate-boxes, potentially suitable and corridor habitat within the contiguous forest matrix was identified throughout the mountain range (Figure 7). Only 81 km^2 of habitat in the Black Hills had 100% contiguous forest cover per 2.59 km^2 and was not representative of all landscapes known to be used by martens in the Black Hills. Therefore, habitat that had 90–99% contiguous forest per 2.59 km^2 (3,069 km^2) was added to the matrix, totaling 3,150 km^2 of contiguous forest matrix habitat. Habitat analyses of radiocollared martens and at track-plate-boxes visited by martens indicated spruce forests were important to the species. Therefore, the SD-GAP Black Hills land cover map was recoded to a binary grid containing only spruce forest. Then, because the mean home range size of an adult male marten was 15.8 km^2, the focal sum analysis was conducted on the recoded grid using a circular search area of 15.8 km^2. Mean percent of spruce forest that comprised a males territory was 22.48% ± 10.36%. Minimum percent of spruce contained within a male's home range was 3.75%. Thus, within the contiguous forest matrix, 853 km^2 of potentially suitable marten habitat and 1,374 km^2 of connecting corridor habitat were identified.

DISCUSSION

Radiocollared American martens used landscapes dominated by spruce forest at both second and third-order habitat selection. Additionally, higher HSI values at track-plate-boxes where martens were detected indicated that the presence of mature spruce trees were important to the species at the stand level. Moreover, habitat that contained 90 to 100% contiguous forest cover per 2.59 km^2 provided a matrix where potentially suitable habitat and connecting corridors could be identified based on density of spruce forest that occurred in home ranges of study animals. Presence of contiguous forest likely enhanced habitat for an individual adult male marten (No. 325) that established a home range in habitat where spruce stands occurred at relatively low densities (D. M. Fecske, unpublished data). Thus, based on the analyses, the distribution and productivity of the marten population in the Black Hills is likely tied to the quality of spruce-dominated stands and associated contiguous forest. In the Black Hills, ponderosa pine is the dominant forest type providing contiguous cover; according to the HSI model, martens used pine forests when they were adjacent to mature spruce stands (Allen 1982).

Hanski and Gilpin (1997) defined a metapopulation as a set of local 'subpopulations' within some larger area, where typically migration from 1 local population to at least some other patches was possible. Findings suggested the American marten population in the Black Hills was distributed in a metapopulation structure, with 2 dominant subpopulations. The test of the habitat-relation model predicted 2 relatively large patches of high-quality habitat, one in the CBH and the other in the NBH. Based on an adult radiocollared male marten (No. 325) that dispersed from the central to northern Black Hills (Chapter 4) it was possible for individual martens to migrate between the 2 regions. Also, additional track-plate box survey work confirmed consistent detection in these areas among years and throughout seasons (D. M. Fecske, unpublished data). For example, of 2, 10.2-km^2 quadrats surveyed in the NBH subpopulation, martens were detected in 1999, 2001, and 2002 during repeated track-plate-box surveys. Moreover, during spring, summer, and fall of 2002, martens were detected all seasons at 1 of the quadrats, and during spring and fall of the other quadrat. Additionally, in 2 quadrats surveyed in the CBH subpopulation, martens were detected during 1999, 2001, and 2002, and during the spring, summer, and fall of 2002 (D. M. Fecske, unpublished data). Finally, 3 adult females were captured in the CBH subpopulation, further confirming breeding-age females existed in this subpopulation. Although I did not capture any adult females in the NBH subpopulation, the duration of trapping was limited to March and early April 2001 for this region. Consequently, it was possible that movements of pregnant females were more limited at this time, thus minimizing the likelihood of their capture. However, based on relatively small marten tracks made during winter, at least 1 female was suspected to have been detected on a sooted track-plate in the NBH, (D. M. Fecske, unpublished data).

Additional supportive evidence that the 2 subpopulations contained the highest population densities in the Black Hills was based on road-killed martens documented by SDGF&P. Of 6 road kills of uncollared males, all occurred within the regions encompassing the 2 subpopulations (D. M. Fecske, unpublished data).

Four smaller regions of high-quality marten habitat predicted by the model did not represent connecting corridor habitat to the 2 subpopulations (Chapter 2). Instead, they represented isolated patches of habitat for the species. However, the available evidence did not support classifying these regions as productive subpopulations. Two quadrats from 2 of the smaller regions of highest-quality habitat were surveyed for 2 years (1999 and 2002; and 1999 and 2001). In both cases, martens only were detected the first year surveyed. Additionally, 1 of the quadrats was surveyed during spring, summer, and fall in 2002, but martens were not detected during any season. It is possible these smaller areas provided high-quality habitat patches within the forest matrix that supported lower numbers of individuals or dispersing subadults.

Not all habitat predicted by the original habitat-relation model likely contained high marten densities. I surveyed 2 of 4 quadrats in the Northern Black Hills subpopulation originally predicted to contain martens based on the model; only in 1 quadrat did I detect martens (D. M. Fecske, unpublished data). Therefore, although the model identified high-quality habitat, it may be that some quadrats predicted by the model to detect marten presence could be influenced by other factors (i.e., amount, or contiguity of Rank 9 habitat per 10.2 km^2), rendering them less suitable to martens. For example, in the logistic equation, habitat patches containing the minimum amount of Rank 9 habitat to detect martens (2%) only resulted in a 0.5 probability of detection, whereas higher amounts of Rank 9 habitat had a greater probability of detection (Chapter 2). In Chapter 2, I hypothesized potential factors that could be impacting use of habitat by martens in the Black Hills, such as fragmented and thinned spruce stands, and isolation of spruce stands from a former water source, caused by past clearing of streamside vegetation. These findings indicated that additional evidence should be examined before categorizing all predicted high-quality areas as productive marten habitat.

Based on the area containing high-quality habitat, I estimated a resident population totaling 124 adult animals. However, predicting the effective breeding population is difficult without a thorough understanding of the structure of sex and age classes (Bissonette et al. 1988), which are unknown for this population. Consequently the effective breeding population could be lower than estimated. My estimate also was based on home ranges generated from relatively small numbers of locations, which should be considered minimum estimates of home range. Home ranges based on MCP method are sensitive to sample size. Therefore, larger samples could have resulted in larger home ranges of martens and, subsequently a lower population estimate for high-quality habitat. Conversely, results should not be interpreted that martens did not occur, or were not breeding outside of what was identified as high-quality habitat. My estimate was limited to high-quality habitat where radiocollared martens were trapped. However, during the track-plate-box survey (Chapter 2), 5 of 14 quadrats where martens were detected occurred outside of what was considered high-quality habitat. Also, Male No. 325 established a home range in poor-quality habitat until it was killed by a coyote (Chapter 4). It is likely that productivity and survival is lower in these regions due to poorer quality habitat. Even in areas of overall high-quality habitat, the 4 martens that died during respective monitoring periods selected landscapes that had relatively high proportions of grassland and open habitats, which are considered less suitable to martens.

Using the SD-GAP Black Hills land cover map, I modeled a matrix of contiguous forest cover and habitat where spruce forests occurred at densities similar to those of radiocollared animals. Relatively little of the landscape contained 100% of contiguous forest cover per 2.59 km^2 and did not represent a suitable forest matrix for martens as predicted by the marten HSI model (Allen 1982). Thus, the 100% contiguous forest cover requirement was not realistic for predicting the occurrence of martens in the Black Hills. This could be due, in part, to the fact that the Black Hills evolved into a landscape of forests interspersed with parklands and meadows (Dodge 1998). However, mapping a habitat matrix containing 90–100% forested cover per 2.59 km^2 enabled identification of potentially suitable and connecting corridor habitat in relation to high-quality habitat patches and the 2 subpopulations (Figure 7). Potentially suitable marten habitat included regions where the 2 subpopulations occurred and 3 of 4 smaller highest-quality habitat patches predicted by the habitat-relation model. But, in the CBH, where a 36.1 km^2 habitat patch was predicted to occur, potentially suitable habitat increased the extent of this area substantially, to 122.7 km^2. Also, the map of potentially suitable marten habitat allowed identification of regions in the Black Hills not documented to contain high-quality habitat, most notably in the western and north-eastern edges of the mountain range.

The higher amount of potential marten habitat identified by the SD-GAP Black Hills land cover map was due to 1 or a combination of the following factors: 1) general land cover categories encompassed all spruce dominated habitat, regardless of the age of the stand; 2) high-quality marten habitat identified by the habitat-relation model occurred at ≥1,585 m (based on the distribution of red squirrels); thus, mature spruce forests at lower elevations only would be represented by the SD-GAP map; and 3) spruce forest in the SD-GAP map could have been overestimated due to the inherent error in classifying spectral images using training data. Regardless, the analysis using the SD-GAP land cover map supported results based on the habitat-relation model. Moreover, it identified connecting corridor habitat that could be maintained for the species. For example, corridor habitat falling along drainages could be given high priority in conservation for martens (Bissonette et al. 1991). Finally, the map of potential marten habitat identified regions where additional research is needed. There is a possibility that martens may not have colonized, or occurred at low densities in more isolated mature spruce-dominated forests in the northeastern and western Black Hills.

The main focus of the analysis was broad-scale. However, based on micro-habitat data collected at a sample of track-plate-boxes where martens were and were not detected, I provided more specific information on habitat needs at the stand level. For example, measurements taken on the 4 HSI variables at individual stands can aid in determining if those areas are suitable habitat to martens. Also, the data were used to evaluate a HSI model for the species. Brooks (1997) reported the need to test and improve current HSI models because they are widely used to make management decisions. He further stated that any reliable population data for the region should be considered for testing such models. Not only did analysis of the data provide additional insight into the habitat needs of this species, but also, it provided a modest test of the HSI model for martens. Although the sample was small, higher HSI scores seemed to be predictive of marten detection.

I identified 2 productive subpopulations of American martens. Currently, 54.3 km^2 of the CBH subpopulation has protection from human-caused mortality due to its location within the Black Elk Wilderness area, which is contained within the 107-km^2 Norbeck Wildlife Preserve. However, the remaining area of Norbeck Wildlife Preserve and Custer State Park contained within portions of this subpopulation are subjected to current and future logging activity. Moreover, none of the NBH subpopulation has complete protection. To sustain productive breeding populations long-term, my data indicated that forests in the 2 regions should be protected from further logging activity to maintain source populations of martens. Additionally, potential habitat identified by the landscape analysis should be examined more closely to determine if additional subpopulations exist, or to identify factors limiting presence of martens. Further, long-term plans for the Black Hills should include a means to protect connecting habitat among the high-quality habitat patches. Finally, I mapped future habitat potential for martens in the Black Hills National Forest based on all quadrats that had any high-quality habitat. Through long-term planning, habitat could be enhanced for the species in quadrats that historically contained mature spruce stands, thus facilitating range expansion of the species.

Table 4. Home range estimates (Minimum Convex Polygon [MCP]) of American martens in 2 regions of the Black Hills, South Dakota (1998–2001): Central Black Hills [CBH] and Northern Black Hills [NBH]). N = number of locations used to generate home-range estimates.

MARTEN ID	SEX	LOCATION TRAPPED	DURATION MONITORED	N	HOME RANGE (KM^2)
275.801	M	CBH	61 weeks; 1/15/99–3/22/00	57	13.1
187.781	M	CBH	33 weeks; 9/6/99–5/10/00	37	29.6
323.830	M	CBH	1 week; 4/1/99 37 weeks; 1/11/00–10/23/00**	30	5.1
248.841	M	CBH	27 weeks; 12/18/98–7/4/00	15	11.8
247.761	M	CBH	1 week; 12/18/99–12/20/98 1 week; 4/7/99–4/17/99**	4	---
300.920	F	CBH	28 weeks; 2/24/99–9/23/99 29 weeks; 3/26/00–10/30/00	53	7.0
159.951	F	CBH	34 weeks; 9/26/99–6/6/00**	32	4.7
019.910	F	CBH	1 week; 1/11/00–1/18/00	3	---
325.771	M	NBH*	32 weeks; 4/1/99–11/30/99**	32	40.3
M801	M	NBH	26 weeks; 3/22/01–10/8/01	18	28.6
M761	M	NBH	22 weeks; 3/24/01–9/02/01**	20	3.4
M771	M	NBH	30 weeks; 4/13/01–11/30/01**	18	3.6
M921	M	NBH	24 weeks; 4/8/01–10/8/01	15	6.5

* This marten was originally captured in the CBH but dispersed, and established a home range in the NBH.

** Marten died during the monitoring period.

Table 5. Second-order habitat selection by American martens (n = 11) in the Black Hills, South Dakota (1998–2001) using Manly's (1972) Alpha preference index. Land cover classes with Alpha values greater than Manly's Alpha (0.25) were selected at the home range level by martens.

DOMINANT LAND COVER	% USED	% AVAILABLE	ALPHA
Ponderosa pine forest	69.40	76.78	0.170
White spruce forest	16.46	5.86	0.530 *
Deciduous forest	10.16	9.23	0.207
Grassland/open habitats	3.98	8.12	0.092

Table 6. Third-order habitat selection by American martens (n = 11) in the Black Hills, South Dakota (1998–2001) using Manly's (1972) Alpha Preference Index. Land cover classes with Alpha values greater than Manly's Alpha (0.25) are selected for by martens.

MARTEN		PONDEROSA PINE			WHITE SPRUCE			OPEN HABITATS			DECIDUOUS		
ID # SEX	LOC.	% USE	% AVAIL.	ALPHA	% USE	% AVAIL.	ALPHA	% USE	% AVAIL.	ALPHA	% USE	% AVAIL.	ALPHA
248.841 M	CBH	77.1	82.4	0.262 *	21.1	14.4	0.409 *	0.87	1.31	0.186	0.93	1.83	0.142
323.830 M	CBH	75.9	77.6	0.201	21.6	20.3	0.218	0.81	0.46	0.363 *	1.68	1.60	0.216
159.951 F	CBH	67.8	67.2	0.185	31.5	40.4	0.143	0.61	0.32	0.350 *	0.07	0.04	0.321 *
275.801 M	CBH	63.0	63.8	0.302 *	36.4	35.2	0.317 *	0.36	0.59	0.187	0.24	0.38	0.193
187.781 M	CBH	80.5	81.9	0.221	17.6	16.5	0.240	0.59	0.60	0.221	1.35	0.96	0.317 *
300.920 F	CBH	75.5	78.3	0.234	23.0	20.2	0.277 *	0.46	0.41	0.272 *	0.94	1.05	0.217
761 M	NBH	54.2	56.9	0.217	42.3	39.5	0.244	1.07	0.71	0.343 *	2.52	2.91	0.197
921 M	NBH	58.8	65.0	0.250	36.1	28.0	0.356 *	1.82	3.03	0.166	3.26	3.96	0.227
801 M	NBH	58.8	73.7	0.151	26.2	10.9	0.456 *	6.7	5.4	0.237	8.2	10.0	0.156
325.771 M	NBH	71.8	60.9	0.184	12.2	2.8	0.678 *	3.3	7.5	0.069	12.7	28.8	0.069
771 M	NBH	56.6	63.8	0.203	36.9	33.4	0.253 *	3.17	2.15	0.338 *	3.3	3.7	0.204

Table 7. Habitat Suitability Index (HSI) values determined at locations of 74 track-plate-boxes placed in 15, 10.2 km^2 quadrats during a population survey of American martens in the Black Hills, South Dakota (1998–2001). HSI values were based on 4 variables [percent canopy cover (%C), percent canopy cover comprised of spruce trees (%CS), stand age (C = young, D = mature), and percent ground cover (woody debris >7.6 cm diameter) (%WD)]. HSI values were reclassified into 3 categories 1) Marginal (0.1–0.3); 2) Suitable (0.4–0.6), and 3) Optimal (0.7–1.0) for martens.

BOX ID	SITE, REGION	MARTENS DETECTED	% C	% CS	STAND AGE	% WD	HSI VALUE	HSI CATEGORY
1	1, CBH	YES	50	77	C	27	0.894	O
2	1, CBH	NO	32	0	D	7	0.114	M
3	1, CBH	NO	32	0	C	8	0.123	M
4	1, CBH	NO	67	100	D	25	1.000	O
5	2, CBH	NO	22	23	D	27	0.000	M
6	2, CBH	NO	50	0	D	23	0.316	M
7	2, CBH	YES	73	100	C	37	0.894	O
8	2, CBH	NO	71	0	D	15	0.296	M
9	2, CBH	NO	65	36	C	33	0.852	O
10	2, CBH	YES	58	14	D	33	0.648	S
11	3, CBH	YES	50	50	D	5	0.791	O
12	3, CBH	NO	77	0	D	15	0.296	M
13	3, CBH	NO	42	0	D	18	0.253	M
14	3, CBH	NO	58	71	D	7	0.817	O
15	3, CBH	YES	65	59	C	12	0.796	O
16	3, CBH	YES	40	0	D	10	0.212	M
17	4, CBH	NO	52	78	C	28	0.894	O
18	4, CBH	NO	30	0	D	18	0.138	M
19	4, CBH	NO	72	95	C	25	0.894	O
20	4, CBH	NO	52	87	D	55	1.000	O
21	4, CBH	NO	67	68	D	13	0.912	O
22	4, CBH	NO	33	25	D	27	0.460	S
23	5, CBH	NO	70	43	D	23	1.000	O
24	5, CBH	YES	58	100	D	25	1.000	O
25	5, CBH	NO	40	100	D	25	0.775	O
26	6, NBH	NO	48	100	D	27	0.965	O
27	6, NBH	NO	57	94	D	12	0.890	O
28	6, NBH	NO	55	21	D	0	0.537	S
29	6, NBH	NO	77	15	C	15	0.556	S

Table 7. (Cont.)

BOX ID	SITE	MARTENS DETECTED	% C	% CS	STAND AGE	% WD	HSI VALUE	HSI CATEGORY
30	6, NBH	NO	35	29	D	5	0.431	S
31	6, NBH	NO	85	59	D	3	0.763	O
32	7, CBH	YES	58	69	D	10	0.866	O
33	7, CBH	YES	75	87	D	15	0.935	O
34	7, CBH	NO	48	86	D	30	0.965	O
35	7, CBH	YES	60	83	D	23	1.000	O
36	7, CBH	NO	40	0	C	20	0.219	M
37	7, CBH	NO	57	0	C	18	0.277	M
38	8, CBH	NO	82	0	D	5	0.250	M
39	8, CBH	NO	82	0	C	8	0.238	M
40	8, CBH	NO	62	76	D	18	0.978	O
41	8, CBH	NO	68	68	D	25	1.000	O
42	8, CBH	NO	80	0	C	2	0.208	M
43	8, CBH	NO	92	0	C	8	0.238	M
44	9, CBH	NO	70	81	D	23	1.000	O
45	9, CBH	NO	33	0	D	7	0.149	M
46	9, CBH	NO	62	0	D	28	0.316	M
47	9, CBH	NO	55	0	D	12	0.281	M
48	9, CBH	NO	52	0	C	27	0.283	M
49	9, CBH	NO	70	0	C	42	0.283	M
50	10, NBH	YES	60	14	D	13	0.586	S
51	10, NBH	YES	53	22	D	30	0.770	O
52	10, NBH	NO	28	18	D	2	0.188	M
53	10, NBH	YES	37	77	D	32	0.684	S
54	10, NBH	YES	57	20	D	13	0.685	S
55	11, NBH	NO	68	100	D	17	0.958	O
56	11, NBH	YES	53	19	D	0	0.510	S
57	11, NBH	NO	62	3	D	12	0.357	M
58	11, NBH	NO	68	5	D	12	0.408	S
59	11, NBH	YES	62	68	D	28	1.000	O
60	11, NBH	YES	65	56	D	8	0.841	O
61	12, NBH	NO	45	7	D	20	0.448	S
62	12, NBH	NO	5	53	D	38	0.000	M
63	12, NBH	NO	70	93	D	13	0.912	O
64	12, NBH	NO	82	24	D	23	0.807	O
65	12, NBH	YES	65	56	D	22	1.000	O
66	12, NBH	YES	35	81	C	30	0.565	S
67	13, CBH	YES	65	0	D	12	0.281	M
68	13, CBH	YES	40	60	D	28	0.775	O
69	13, CBH	NO	82	22	C	52	0.689	C
70	14, NBH	YES	13	100	D	48	0.000	M
71	14, NBH	YES	50	90	D	30	1.000	O
72	15, CBH	NO	40	95	D	25	0.775	O
73	15, CBH	NO	55	39	D	8	0.835	O
74	15, CBH	NO	40	100	C	10	0.600	S

Table 8. Bonferroni multiple comparisons test to evaluate frequency that habitat at track-plate-boxes occurred in 3 HSI categories in the Black Hills, South Dakota (1998–2001): 1) Marginal (HSI value = 0.1–0.3); 2) Suitable (HSI value = 0.4–0.6), and 3) Optimal (HSI value = 0.7–1.0).

GROUP	N	HSI CATEGORY	PROPORTION EXPECTED	PROPORTION OBSERVED	BONFERONI CI
Martens detected	24	Marginal	0.33	0.13	-0.01–0.26 *
		Suitable	0.19	0.25	0.08–0.42
		Optimal	0.50	0.63	0.43–0.82
Martens not detected	51	Marginal	0.33	0.43	0.30–0.57
		Suitable	0.19	0.16	0.06–0.26
		Optimal	0.48	0.41	0.28–0.55

Calculated χ^2 = 6.8973, α = 0.05

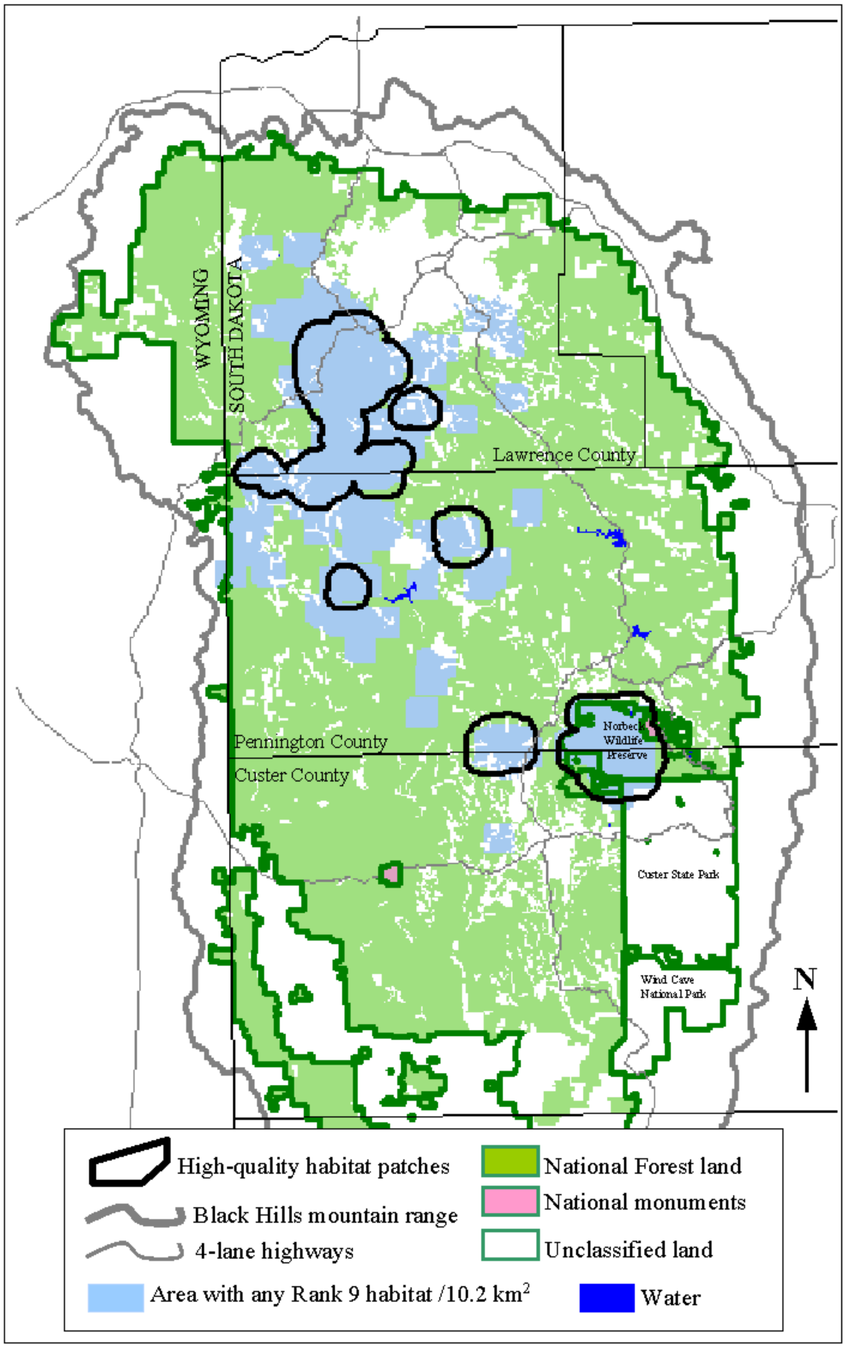


Figure 6. High-quality habitat patches for American martens in the Black Hills, South Dakota (1998-2001). The 2 large regions indicate subpopulations of martens.

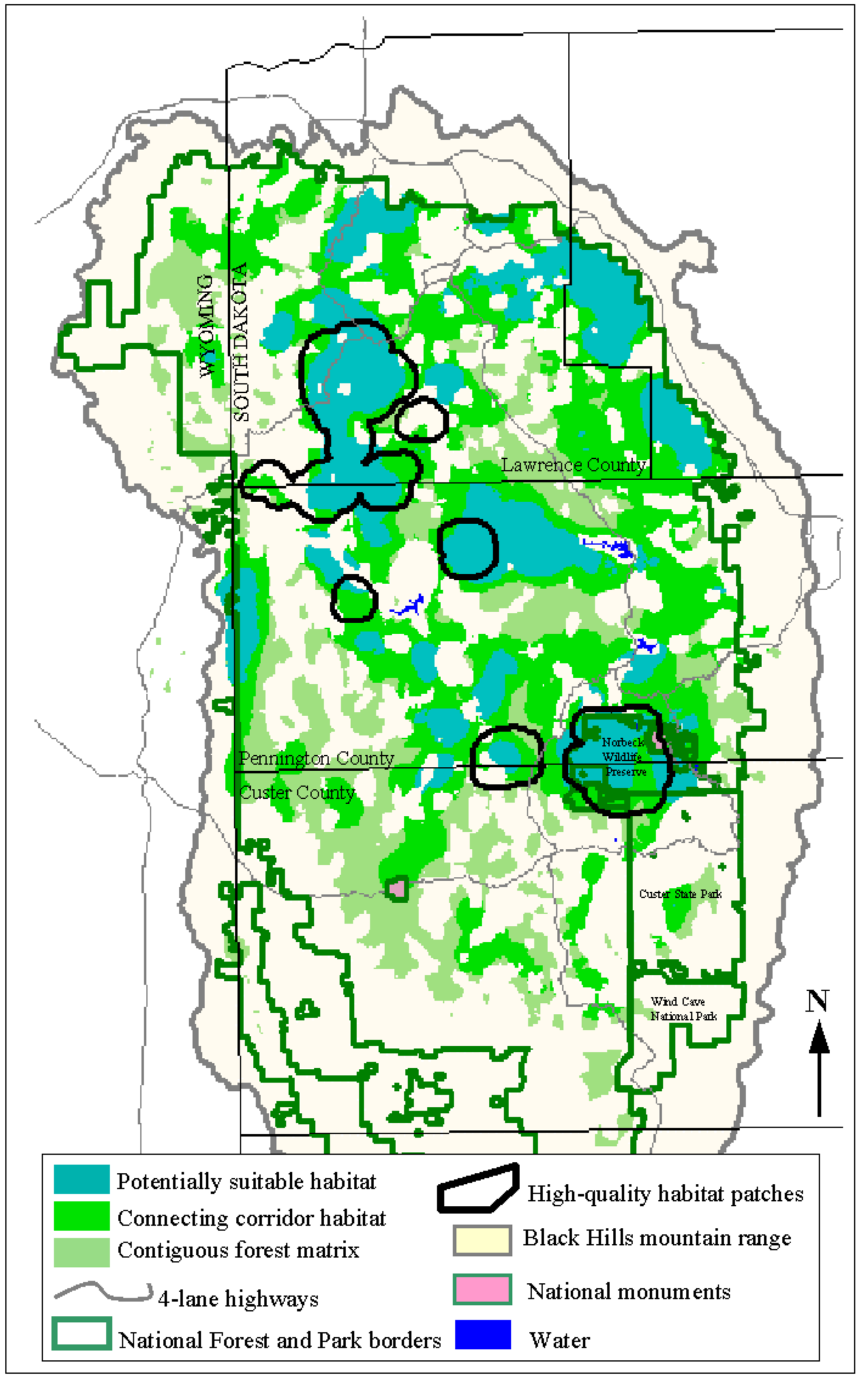


Figure 7. Potentially suitable American marten habitat and connecting corridor habitat within a contiguous forest matrix in the Black Hills, South Dakota and Wyoming (1998-2001).

CHAPTER 4: DISPERSAL BY A MALE AMERICAN MARTEN

ABSTRACT

A radio-collared adult male American marten (*Martes americana*) in an unharvested population in the Black Hills of South Dakota was initially captured 1 April 1999 and relocated 32 times until found dead 7 December 1999. Over a 21 to 56-day period (5–26 May to 18 April–12 June) it traveled 74 km (straight-line distance between capture site to location at death). The 2 farthermost locations were 82 km apart.

INTRODUCTION

Dispersal is the movement of an animal from its natal range to its first or subsequent breeding range, or where it would have reproduced had it survived (Shields 1987). American martens (*Martes americana*) are born in spring (Mead 1994), attain adult size by autumn (Brassard and Bernard 1939) and are able to disperse at that time (Strickland 1994). Dispersal may occur, however, as late as February through the following September (Slough 1989), or possibly, not at all, under conditions of high prey densities (Powell 1994). Transient or resident martens have dispersed ≤20 km from capture sites or previous home ranges (Bateman 1986, De Vos and Gunther 1952). Thompson and Colgan (1987), however, reported longer dispersal distances of 3 resident adult martens during years of scarce prey. Two males, ages 3 and 4 years, were trapped 48 and 40 km, respectively, from home ranges they occupied for 2 years; and 1, 5-year-old female was captured 80 km from her home range of 28 months. I describe long-distance dispersal of an adult male American marten in an unharvested population in the Black Hills of South Dakota and Wyoming.

Historically, American martens occurred in South Dakota (Turner 1974, Negus 1980, Graham and Graham 1994) and were documented in the Black Hills in the late 1800s and early 1900s (Fredrickson 1993, Turner 1974). Nonetheless, between 1930 and 1979, no martens were harvested from the Black Hills. In 1980 and 1981, a reintroduction effort was initiated by the South Dakota Department of Game, Fish and Parks (Fredrickson 1993). Forty-two martens were released into the northern Black Hills. Additionally, between 1990 and 1993, 83 martens were released in the central Black Hills. In 1998, a study was initiated to estimate population size and document the current distribution of American martens within the Black Hills of South Dakota.

METHODS

A male American marten (marten No. 325) was live-trapped (Tomahawk Live Trap Co., Tomahawk, Wisconsin) on 1 April 1999 in Black Elk Wilderness Area (Central Black Hills (103^{o} 33' 06'', 43^{o} 51' 00''). The marten was immobilized with ketamine hydrochloride (10.0 mg / 454 g body weight), weighed, aged, and fitted with a radio-collar (Telonics, Inc., Mesa, Arizona). At the time of capture, the animal weighed 1,020 g and was categorized as an adult (Poole et al. 1994). I conducted weekly flights from a fixed-wing aircraft to locate the animal. Mean telemetry error was 152.0 m (n = 8), which was determined by placing radio-collars throughout the study area and having the pilot locate the transmitters. The marten was not relocated every week due to the limited range of the radio-transmitter, relatively large distances moved between some locations, and inclement weather. I classified the status of the marten according to that described in Hawley and Newby (1957); martens that occupied a home range for >3 months were considered resident, those that occupied a home range ≥ 1 week but ≤ 3 months were considered temporary residents, and those present in an area for <1 week were transients. I considered a movement greater than 3.6 km indicative of a dispersal event because it surpassed the length of the radius of the mean home range size (10.2 km^2, Zielinski and Kucera 1995) for the species (Kernohan et al. 1994). After the marten died, age was confirmed using the temporal muscle coalescence (Poole et al. 1994). The estimated age of the animal at the time of its death was $\geq$ 3 years. Puncture holes in the skull indicated that the marten was likely killed by a coyote (*Canis latrans*) (S. W. Buskirk, University of Wyoming, Laramie, personal communication), and partially consumed.

RESULTS AND DISCUSSION

American Marten No. 325 was relocated 32 times between the date of capture on 1 April and the date it was located dead, on 7 December 1999. Initially, on 6, 7, and 17 April 1999, it was located approximately 9.8 km southeast of its capture location in Black Elk Wilderness Area. Then, on 7 May 1999, the animal was located about 16.2 km west of its capture location.

Between 7 May and 25 May, the marten continued traveling north and west, not remaining at any one location for more than one week until it reached the northern Black Hills, between 25 May and 13 June 1999. Over a 21 to 56-day period (5–26 May to 18 April–12 June), it traveled 74 km (straight-line distance from the capture site to the location of death); the 2 furthermost locations were 82 km apart. The marten was relocated 23 times after it was considered resident (13 September) in the northern Black Hills. The marten remained in the northern Black Hills until its death, sometime between 17 November and 7 December 1999.

Adult American martens are known to disperse in response to low prey abundance (Thompson and Colgan 1987) and due to intraspecific encounters in high-density, unharvested populations (Davis 1983, Phillips et al. 1998). The Black Elk Wilderness and surrounding area was one of several reintroduction sites for martens. At the rate martens colonize vacant habitat (8–16 km per decade, De Vos 1951) the marten population in the Black Hills could be at carrying capacity. Marten No. 325 may have dispersed due to interactions with other males or competition for limited high-quality marten habitat (Chapter 4).

Marten No. 325 traveled a long distance before becoming a resident in the northern Black Hills. The long distance traveled could be due to a fragmented distribution of potential foraging areas (Thompson 1994, Soutiere 1979). Survey work suggests the current American marten distribution in South Dakota occurs in the northern Black Hills, and extends southeast approximately 90 km to Black

Elk Wilderness area and the vicinity (Chapter 2). Marten presence is highest in the northern Black Hills, and lowest in the intermediate region, where marten No. 325 traveled, but did not remain. Spruce stands in the intermediate region are scattered and fragmented. The information obtained on marten No. 325 reveals potential factors regulating marten populations in the Black Hills including low prey abundance, population saturation, a fragmented distribution of high-quality habitat and/or high predator abundance.

CHAPTER 5: DISTRIBUTION AND ABUNDANCE OF COUGARS (*Puma concolor*) IN THE BLACK HILLS OF SOUTH DAKOTA AND WYOMING

ABSTRACT

Since removal of a bounty and subsequent legal protection as a state threatened species in 1978, cougars (*Puma concolor*) have recolonized a portion of their former range in South Dakota and Wyoming. I determined the current distribution and estimated abundance of cougars in the Black Hills. A ranked habitat-relation model for cougars was constructed based on macro-habitat characteristics of prey, stalking topography, concealment habitat, and anthropogenic influences. During the winters of 1998–2001, 12 cougars were captured, radiocollared, and monitored weekly using aerial radio-telemetry techniques. Annual home ranges were estimated for cougars monitored $\geq$8 months and percent home-range overlap was determined for established males. The habitat-relation model was tested with locations of radiocollared cougars. Cougar population size was estimated using program PUMA, incorporating parameters obtained from research animals, the literature, and habitat quality derived from the habitat-relation model. Additionally, population growth was modeled based on population parameters of cougars in an unhunted population and under varying conditions of immigration and habitat loss. Cougars selected high-ranked (high-quality) habitat (ranks $\geq$13), and avoided habitat with lower ranks (ranks $\leq$12). The Black Hills was estimated to be 8,400 km^2 and contained

6,702.9 km^2 of high-quality habitat. Mean annual home-range size of 3 established adult male cougars (*n* = 9 annual ranges) was 809.2 km^2, and was significantly larger (*P* = 0.001) than that of adult females (*n* = 7 annual ranges, 182.3 km^2). Three and 5 females, respectively, were documented in home ranges of 2 adult male cougars. Percent overlap for 3 established cougars averaged 33% (range 18.0–52.0%). Total number of cougars in the Black Hills was estimated as 127–149, with an estimated carrying capacity of 152 cougars. Regardless of number of male (0–9) and female (0–5) immigrants per decade, the population increased to a mean of 166 cougars (range 164–171 cougars). A minimum of 5,277 km^2 of high-quality habitat was necessary to maintain the cougar population for 100 years.

INTRODUCTION

Historically, cougars (*Puma concolor*) occurred throughout South Dakota (Young and Goldman 1946, Turner 1974). In 1899, a bounty was placed on cougars (South Dakota Department of Game, Fish and Parks [SDGF&P] 1998), and by the early 1900s, cougars apparently were extirpated from the state. No official reports of cougars in South Dakota occurred after 1906 until the early 1930's, when 2 cougars were killed in the western Black Hills (Turner 1974). In 1958, the last cougar was killed during the bounty period (1899 to sometime after 1972); a male was shot on Elk Mountain in western Custer County (Turner 1974). Although no reports of cougars killed occurred after 1958, several sightings confirmed their presence in the Black Hills. Cougars were not legally protected in

South Dakota until 1978 when the species was classified as state threatened (E. Dowd Stukel, South Dakota Department of Game, Fish and Parks, Pierre, SD, personal communication). However, after receiving protection, sightings of cougars increased in the Black Hills.

The first objective of my research was to predict the current distribution of cougars in the Black Hills. Landscapes that sustain cougar populations have been characterized as having vegetative communities and topographic characteristics that not only attract prey but also confer hunting advantages to cougars (via concealment and stalking cover) (Seidensticker et al. 1973, Logan and Irwin 1985, Koehler and Hornocker 1991). Landscape elements that provide concealment and stalking cover include dense vegetation, steep slopes, boulder piles, undercut cliffs, and rock outcrops. These elements also provide cougars security cover while feeding and nursery sites for females with young (Logan and Sweanor 2000). Conversely, anthropogenic characteristics are known to negatively impact cougar habitat use and survival. For example, cougars avoid human-dominated landscapes (Dickson and Beier 2002), and 4-lane highways can cause significant mortality from collisions with vehicles (Beier and Barrett 1993, Foster and Humphrey 1995).

White-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*) are important prey items to cougars (Anderson 1983). In the Black Hills, white-tailed deer are associated with dense pine (*Pinus ponderosa*)-aspen (*Populus tremuloides*) stands and dense riparian vegetation (Swenson et al.

1983, Sieg and Severson 1996, Deperno et al. 2001, 2002). Mule deer generally occupy open habitats with rugged and rocky topography (Swenson et al. 1983, Sieg and Severson 1996). In general, mountainous terrain is important to both species of ungulates during winter as exposed south, west, and north (in the northern Black Hills) -facing slopes provide access to food and relatively mild weather conditions (Kennedy 1992, DePerno 1998, Dubreuil 2002). My goal was to construct and test a habitat-relation model for cougars in the Black Hills National Forest based on habitats where deer were predicted to occur and habitat characteristics that would appear to offer advantages to cougars for hunting and that affect habitat use by cougars.

The second objective of my study was to estimate the size of the cougar population in the Black Hills of South Dakota and Wyoming for establishing baseline data to monitor trends and estimate biological carrying capacity for population modeling. Logan and Irwin (1985) suggested that density estimates of resident adult cougars obtained from areas with specific habitat characteristics could be extrapolated to landscapes that are similar. Home ranges have been used to estimate densities of large carnivores (Clark et al. 1993). My goal was to use the habitat-relation model to identify apparent high-quality cougar habitat, and, in conjunction with information collected from a sample of radiocollared cougars, field observations, the literature, and a population program (Program PUMA, Beier 1993), estimate the population size of cougars in the Black Hills. Additionally, I modeled cougar population growth over a 100-year period under varying conditions of immigration and habitat loss, to determine the minimum area of high-quality habitat needed to support the current cougar population.

METHODS

The cougar habitat-relation model was created based on a literature review and available digital databases. The model incorporated 4 landscape-level components considered important to cougars: 1) distribution of prey habitat (white-tailed deer and mule deer), 2) habitat likely to enhance prey-capture success (steep slopes, >50%), 3) concealment habitat (i.e., tributary draws more likely associated with dense vegetation), and 4) anthropogenic characteristics that affect cougar habitat use (i.e., high-density residential areas, habitat adjacent to highways).

I identified high-quality prey habitat, based on research conducted on white-tailed deer (DePerno 1998, Deperno et al. 2001, 2002) and mule deer (Dubreuil 2002) in the Black Hills. Both studies determined macro-habitat characteristics selected by deer, including: 1) dominant overstory vegetation, 2) percentage overstory canopy cover, 3) structural stage of forest stands, 4) elevations, 5) slopes, and 6) aspects. Using results from the 2 studies, I created ranked habitat-relation models for both deer species through the application of digital databases of macro-habitat characteristics acquired from the South Dakota Gap Analysis Project (Smith et al. 2002). Databases included a USDA Forest Service GIS containing dominant overstory species, structural stage, and canopy cover of forested stands, and a USGS 30-m digital elevation model from which slope and aspect were derived. Because the Forest Service GIS only contained data for the Black Hills National Forest, models were limited to National Forest land. Data were processed in a GIS using Arc/Info, Arc/View (Arc/Info and Arc/View, ESRI, Inc., Redlands, CA); and IMAGINE (Leica Geosystems, Atlanta, GA) software. Databases were projected to the Universal Transverse Mercator coordinate system (Datum NAD27) and converted to 30-m cell grids to match the digital elevation model data.

Seasonal habitat-relation models for white-tailed deer and mule deer were constructed by recoding individual databases of macro-habitat characteristics with ranks associated with their suitability to both species (Tables 9 and 10). For example, dominant overstory cover types that were selected by white-tailed deer or mule deer during winter and summer were assigned a rank of 3, cover types used in proportion to availability were assigned a rank of 2, and those avoided, were given a rank of 1. Structural stages of stands, based on tree size (diameter at breast height, dbh; 2 = <2.5 cm dbh, 3 = 12.7–22.9 cm dbh, 4 = >22.9 cm dbh) and percent canopy cover (A = 0–40%, B = 41–70%, C = 71–100%) were recoded, and ranked. Elevation, slope (degrees), and aspect characteristics at white-tailed deer and mule deer locations were ranked based on the distribution of values of those characteristics around respective means. Values for these characteristics within the means of each characteristic ± 1 SD were assigned a rank of 3. Values that ranged from greater than or less than the means of each characteristic ± 1 SD through the means ± 2 SD, were assigned a rank of 2, and remaining values in the distribution were given a rank of 1. Databases were overlaid and cells summed to create winter and summer habitat-relation models for the 2 species. Annual habitat-relation models were constructed by overlaying winter and summer models, maintaining the highest rank for each cell. To create the final digital layer ranking prey habitat for cougars, annual habitat-relation models of white-tailed deer and mule deer were overlaid and the highest rank in each cell was maintained.

I ranked a grid of slopes in the Black Hills according slopes selected by cougars based on reports in the literature. Logan and Irwin (1985) determined that cougars in the Bighorn Mountains, Wyoming selected habitat with slopes >50%, avoided slopes ≤20%, and used other slopes in proportion to availability. Therefore, I assigned slopes >50% a rank of 3, slopes 21–49%, a rank of 2, and slopes ≤20% a rank of 1. Additionally, because cougars were reported to select riparian habitat (Dickson and Beier 2002), I determined the mean distance of cougar locations (n = 175) to streams (340 m ± 241m [SD]), based on verified sightings (1985–1998) of cougars in the Black Hills (T. Benzon South Dakota Department of Game Fish and Parks, Rapid City, SD, unpublished data). I acquired a USGS digital line graph file of streams for the region, and buffered drainages based on the mean distance + 1 SD (581 m). I assigned cells comprising the area within the buffered distance a rank of 2 and area outside the buffered distance a rank of 1. Then, using a population density grid (Center for International Earth Science Information Network data, Columbia University, Palisades, NY) and a USGS digital line graph file of roads, I identified landscape elements that were considered unsuitable to the species. High-density residential/urban areas and areas comprising 4-lane highways (55-m buffer surrounding 4-lane highways) in the Black Hills were given a value of 0. I overlaid and summed the ranked databases of prey habitat, slopes, and buffered streams, and then multiplied the resulting layer by the high-density residential/urban and 4-lane highway databases to create the final cougar habitat-relation model.

During the winters (January–April) 1998–99, 1999–00, and 2000–01, I captured, affixed transmitters to, and released cougars to monitor movements. Capture methods followed guidelines established by the American Society of Mammalogists for care and use of research animals (Animal Care and Use Committee 1998) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (IACUC No. 99-A002). Capture protocol was similar to that used by Anderson (2003). In the mornings after snowfall, from sunrise until about 1200 hrs, field crews in 2–4 vehicles searched for cougar tracks in snow on roads in the Central Black Hills (Custer and Pennington counties). If fresh tracks were located, hounds were unleashed at the site in the direction the cougar(s) traveled to attempt to chase and tree the animal(s). Treed cougars were immobilized with a combination of Telazol ® (2.2 mg/0.45kg) and xylazine hydrochloride (0.45mg/0.45 kg), delivered in a dart propelled from a CO_2 pistil. The effects of the xylazine hydrochloride were reversed using Antagonil® (0.57mg/0.45 kg). Immobilized cougars were weighed. Ages were estimated based on tooth wear and fur color characteristics (Anderson and Lindzey 2000). Adults ($\geq$2 years of age for males, and $\geq$1.5 years for females) (Young and Goldman 1946, Logan and Sweanor 2000) were fitted with radio-collars (Mod-500 transmitters with activity and mortality sensors, Telonics Inc., Mesa, AZ). Kittens (<1 year) were fitted with ear-tag transmitters (M6300 with a 12-hour duty cycle, Advanced Telemetry Systems, Inc., Isanti, MN). All study animals were monitored weekly from fixed-wing aircraft using aerial telemetry techniques (Quigley and Crawshaw 1989). Radio-telemetry location error averaged 0.152 km (n = 8; range 0.040–0.500 km; Chapter 4).

To test the habitat-relation model, locations of radiocollared cougars and an equal number of random locations in the Black Hills National Forest were buffered by maximum telemetry error and overlaid onto the GIS model. Proportions of ranks of habitat were determined in buffered cougar and random locations. Data were analyzed using Manly's (1972) Alpha preference index to test the null hypothesis that cougars select all ranks of habitat equally.

I estimated the population size of cougars in the Black Hills of South Dakota and Wyoming using a cougar population program (Program PUMA, Beier 1993), based on information derived from the habitat-relation model, radiocollared cougars, and the literature when data were limited or unavailable. First, I determined the size of the Black Hills. The area of the Black Hills study site was estimated using a Digital Land Cover Map created from Thematic

Mapper Satellite Imagery (Landsat 5, USGS EROS Data Center, Sioux Falls, SD). The perimeter of the Black Hills, including major topographical features described in Froiland (1990) (Limestone Plateau, Central Core, Hogback Ridge, Red Valley, the Foothills, and Minnekahta Plains), was outlined 3 times and mean area determined. Annual home ranges for cougars (Adaptive Kernal: 90% and 60%, Worton 1987) were estimated with ARC/VIEW 3.2 software (Spatial Movement Analysis extension). When contours representing annual ranges of individual cougars were disjunct, I increased the least squares cross validation score incrementally by 100 until the contour became contiguous (Kie et al. 2001). I calculated the mean home-range size of 3 established adult males (>2.5 years) monitored for 3 years to estimate home range size of territorial males in the Black Hills. Spatial distribution of adult cougars was analyzed using a home range overlap index (Logan and Sweanor 2001). I estimated the number of male territories that occurred in the study area based on mean home-range size and percent overlap of established radiocollared males and percent overlap of cougars in another protected population (Logan and Sweanor 2001).

During the 3-year field season, locations of family groups in the Black Hills were documented from verified reports from SDGF&P (Cougar observation reports 1999–2001, South Dakota Department of Game, Fish and Parks, Rapid City, SD, unpublished data), Custer State Park and USDA Forest Service biologists, sightings and snow tracks observed by field crew members, and radiocollared females. These records were used to document the number of family groups that occurred within home ranges of adult, male radiocollared cougars, and estimate number of kittens born to female cougars. Because male cougars share home ranges with $\geq$1 female, and females may mate with >1 male (Logan and Sweanor 2001), I estimated the number of adult breeding females in the Black Hills using average size of a male home range. Additionally, female cougars are not territorial (Lindzey 1987, Logan and Sweanor 2001) and densities of female carnivores have been predicted to be more dependent on the distribution of available food resources (Sandell 1989). Thus, a higher number of females per male home range should occur in high-quality habitat than in lower-quality habitat. I incorporated this hypothesis into the estimate by classifying the ranked cougar habitat-relation model into 2 categories: 1) high-quality (high-ranked) habitat and 2) low-quality (low-ranked) habitat. To correct for high- and low-quality habitat in the Black Hills outside the Black Hills National Forest, I calculated the area of high and low-quality habitats and, using equivalent proportions, extrapolated those areas to privately owned lands within the Black Hills. Areas comprising high-density residential/urban and 4-lane highways were considered unsuitable to cougars and were not used to generate the estimate.

Densities of males and females/100 km^2 were calculated and entered into program PUMA. Population estimates were derived for likely scenarios of variable female density and male home range overlap (%) within the Black Hills. Then, based on an estimate of carrying capacity and using survival parameters estimated from an unhunted cougar population (Logan and Sweanor 2001)

(Table 15), I simulated population growth for a 100-year period under varying conditions of immigration. Additionally, to simulate habitat loss, I successively decreased the amount of high-quality habitat in the Black Hills by increments of 100 km^2 to determine the minimum area needed to sustain the Black Hills cougar population. I based estimates of projected population size in response to varying levels of immigration and habitat loss on several assumptions: 1) density of female cougars in high-quality habitat was greater than in low-quality habitat (based on the distributions of mule deer and white-tailed deer, riparian habitat, and steep-sloped topography); 2) density of male cougars did not differ between high and low-quality habitat; 3) percent overlap of male territories in the Black Hills was similar to cougars in New Mexico (Logan and Sweanor 2001); 4) initial number of kittens and yearling cougars in the Black Hills was similar to that estimated by Program PUMA (Beier 1993); 5) level of density dependence (moderate for juveniles, mild for adults) remained constant throughout the 100-year time period; 6) no catastrophes occurred affecting survival and carrying capacity of the population; and 7) estimates of kitten, subadult, and adult survival were similar to those in New Mexico (Logan and Sweanor 2001).

RESULTS

I obtained 768 locations from 10 adult (7 male [M], 5 female [F]) and 2 kitten cougars (1 M, 1 F). Estimated ages of adult cougars ranged 1.5–8 years. Duration of monitoring for individual animals ranged 1.5–34 months. Two cougars died from natural causes; M7 died as a result of injuries sustained in a fight with M2, and F8 died during a fire (Chapter 7). I lost contact with the 2 kittens, F11 and M5, after monitoring for 4 and 6 months, respectively; their fates were unknown. Cougar M3 was killed from an illegal shooting.

Mean annual home range for 3 established adult male cougars (each monitored approximately 3 years) was 809.2 ± 336.1 km^2 (SD) and that of adult females (monitoring periods ranged 8–23 months), was 237.3 ± 131.5 km^2 (Table 11). Home ranges of adult males were significantly larger than for adult females (Signed Rank = 33.0, P = 0.001). Percent home range overlap for 3 established cougars averaged 33% (range 18.0–52.0%) (Table 12).

Land area of the Black Hills was estimated at 8,400 km^2 (8,387.1 ± 515.8 km^2) (Figure 8). The cougar habitat-relation model ranked habitat in the Black Hills National Forest from 5 (lowest habitat quality) to 18 (highest habitat quality) (Table 13, Figure 9). Cougar locations (n = 494) occurring in the Black Hills National Forest were used to test the habitat-relation model. Cougars selected habitat at ranks 13–18 and avoided habitat at ranks $\leq$12 (Table 14). Based on this result, habitat in the Black Hills National Forest was reclassified into 2 habitat categories: high-ranked (Ranks 13–18, 6,702.9 km^2) and low ranked habitat (Ranks $\leq$12, 1,697.1 km^2) (Figure 10).

Five independent family groups were documented in the home range of M2, whereas 3 groups were documented in the home range of M1. Only 2 females were documented in the home range of M4. However, much of the animal's home range was in remote, inaccessible habitat. Therefore, family groups were likely underrepresented. I considered habitat comprising the home range of M2 to be of higher quality than that of M1. First, the cumulative home range of M2 (the younger of the 2 adult males) (739.2 km^2) was smaller than that of M1 (1,281.8 km^2). Also, 42% (311.1 km^2) of M2's cumulative home range was contained in Custer State Park and Wind Cave National Park which provide high-quality habitat, ample prey, and have limited (Custer State Park) or no (Wind Cave National Park) extractive uses. Moreover, 88% (1,124.4 km^2) of M1's home range was contained in the Black Hills National Forest, where 69% of the forest was considered suitable for timber harvest, either for wood production or management for big game (USDA Forest Service 1996). When habitat quality in the area of M2's home range that was contained in the Black Hills National Forest (320.7 km^2) was compared to that of M1, M2's home range had a lower percentage (10.5% for M2 versus 17.3% for M1) of low-quality habitat (ranks $\leq$12), and higher percentage (45.1% for M2 versus 33.7% for M1) of highest-quality habitat (ranks 15–18). Therefore, I estimated that 5 females could occur in an 809.2 km^2 home range of a male in high-quality habitat, whereas in lower-quality habitat, I estimated 2–3 females could occur in a male range. My observations were similar to those documented by Logan and Sweanor (2001), who found that adult males shared home ranges with an average of 3.3–4.9 females.

Based on 14 sightings of family groups (adult females traveling with 1–4 kittens) throughout the Black Hills, and an examination during necropsy of the reproductive tract of F8 (containing 2 feti), average number of kittens per female was estimated at 2.3. However, this estimate was based almost entirely on observations of kittens that survived long enough to travel with their mother, and better approximated weaned litter size. Therefore, I used the average nursling litter size (*n* = 3 kittens) of cougars determined by Logan and Sweanor (2001) for population modeling scenarios.

Because percent home-range overlap of adult males may have been underestimated due to failure to capture all adjacent adult males in the study area, I used spatial overlap of territorial males exhibited in my study as well as that determined by Logan and Sweanor (2001) for estimating the population. Logan and Sweanor (2001) reported the percent of each male's home range that was shared by other males averaged 50–68%. Under the assumption that 50% overlap among male territories existed in the Black Hills, I estimated the average size of a defended territory for adult male cougars in the Black Hills was 404.6 km^2. At this territory size, approximately 21 adult males could occur in the mountain range. At 3 females per male home range, 31 adult females could occur in the area, whereas 52 adult females could occur in the region at 5 females/male range. Means and upper and lower 95% confidence intervals were calculated for 5 population scenarios (Table 16). Based on 50 population simulations of the 5 scenarios, the population size of cougars in the Black Hills was estimated at 127–149 cougars; 46–49 adult females, 12–29 adult males, 21–24 yearling females and males, and 45–48 female and male kittens.

Using the highest estimate of the 5 population scenarios, I estimated carrying capacity in the Black Hills at 152 cougars and used that value for the initial population size for population modeling. Of 2,370 population simulations run for a 100-year period, regardless of number of male (0–9) and female (0–5) immigrants added to the Black Hills cougar population per decade, the population increased to a mean of 166 cougars (range 164–171 cougars) (Table 17). Based on 620 simulations where the amount of high-quality habitat was successively decreased by 100 km^2, a minimum of 5,277 km^2 of high-quality habitat was necessary to maintain a population of 153 cougars in the Black Hills for 100 years.

DISCUSSION

High-quality cougar habitat occurred throughout the Black Hills, and based on reported sightings by SDGF&P and locations of radiocollared animals, the distribution of cougars encompassed the entire Black Hills. However, the distribution of the highest ranked habitats was not uniformly distributed, suggesting densities of cougars could vary locally within the Black Hills National Forest. When compared to other protected populations, predicted density of resident adult cougars in the Black Hills (0.73–0.95 cougars/100 km^2) was similar to that reported for cougars in Florida (0.74 cougars/100 km^2) (Maehr 1997), but lower than reported for cougars in California (0.96 cougars/100 km^2) and New Mexico (0.94–2.0 cougars/100 km^2) (Logan and Sweanor 2001). Lower densities resulted from relatively large home ranges of adult male cougars in the Black

Hills compared to other populations. For example, when annual home ranges of male cougars (Minimum Convex Polygon [MCP] Method 100%) (D. M. Fecske unpublished data) were compared to facilitate comparisons with other populations (where n > 1 study animal), mean annual home range of cougars in the Black Hills (680 km^2 [*n* = 9] was greater than mean ranges of adult males in other cougar populations, (e.g., Alberta, 334 km^2 [*n* = 6], Ross and Jalkotzy 1992; Arizona, 196 km^2 [*n* = 5], Cunningham et al. 1995; Colorado, 256 km^2 [*n* = 12], Anderson et al. 1992; Florida, 432 km^2, [*n* = 12] Maehr 1997; Montana, 462 km^2, [*n* = 2], Murphy 1983; New Mexico, 188 [*n* = 72], Logan and Sweanor 2001; and Wyoming 320 [*n* = 2] Logan 1983).

Lower cougar densities and larger annual ranges of adult male cougars could indicate the population in the Black Hills has not reached biological carrying capacity and/or that habitat quality is poorer than that of other populations. The Black Hills National Forest is intensively managed. Cumulative impacts of land use practices (fire suppression, silvicultural treatments, livestock grazing, intensive beaver trapping) since European colonization have altered the composition and structure of the vegetation, and the water regime (Larson and Johnson 1999). I attributed reduced daytime habitat use by cougars near improved-surface, light-duty gravel roads to the large expanses of regularly distributed, thinned ponderosa pine stands, which support little understory vegetation (Chapter 8). Moreover, the relatively large home ranges of male cougars exhibited in this study could be indicative of the distribution of high-quality habitat patches within the land cover/topography matrix. However, to what extent the current landscape is affecting cougar population density is unknown.

Continued population expansion may be reflected in greater percent overlap of male home ranges and/or smaller male territory sizes that indicate more regularly-spaced females (Sandell 1989). Logan and Sweanor (2001) observed greater female aggregation as cougar density increased, although results were not statistically significant. My method for determining cougar population size can be repeated with data from additional radiocollared cougars to aid in documenting population trends and to estimate biological carrying capacity. However, because many factors influence spatial relationships of cougars (e.g., fluctuations in prey densities, natural disturbances such as fires, and mortalities), population status should not be assessed using home-range size (including shifts), and overlap alone. Rather, data on home ranges should be used in conjunction with other information (e.g., documentation of regular dispersal by typically philopatric subadult female cougars (Logan and Sweanor 2001), increased verified sightings, and greater numbers of mortalities due to collisions with vehicles) to verify population expansion and carrying capacity.

The habitat-relation model and population modeling was based, in part, on the distribution of deer. However, other prey items may be important to cougars in the Black Hills. For example, elk (*Cervus elaphus*) are distributed throughout the Black Hills and are considered primary prey of cougars (Anderson 1983).

Also, bighorn sheep (*Ovis canadensis*) occur in the Black Hills, and may be important prey to cougars locally (Wehausen 1996), or to individual cougars (Ross et al. 1997). In theory, incorporating models for other primary prey could increase the area identified as high-quality habitat and increase the population estimate for cougars in the Black Hills. However, cougars in my study selected habitat ranks 13–18, and those were the ranks recoded to represent high-quality habitat for estimating population size. Indeed, high-ranked cougar habitat likely incorporated vegetation and topographic characteristics associated with other prey species consumed by cougars. For example, I did not document seasonal migration of cougars in the Black Hills in response to migrations of deer. Therefore, smaller prey items known to be consumed by these animals (i.e., porcupines, *Erethizon dorsatum*, Chapter 6) may help sustain the animals when other prey species are limited seasonally. Small prey also sustain cougars between kills of larger animals (Beier 1991), and are important to subadult cougars while they develop efficient hunting skills (Sunquist and Sunquist 2002). Nevertheless, additional digital layers (e.g., habitat-relation models for other large prey species) could be incorporated into the GIS as they become available, and information updated as part of an adaptive management process (Morrison et al. 1998).

The cougar population estimate and population simulations included the Wyoming portion of the Black Hills (Figure 8). Murphy et al. (1999) advocated boundaries for research studies be based on topographic features associated with natural declines in rates of successful dispersal of cougars. The Black Hills are isolated from other mountain ranges by the Northern Great Plains (Froiland 1990). Moreover, cougar densities are known to vary with abundance of topographic variability, forested cover, and prey (Riley and Malecki 2001). Consequently, successful dispersal should decline in areas adjacent to the Black Hills that contain reduced topographic variability and cover. Thus, anecdotal statements as to reduced preference of cougars for prairie habitat (Roosevelt 1893) outside of the drainages would be supported by this hypothesis. Implications are that the population dynamics of cougars in the Black Hills mountain range should be modeled as a single subpopulation and density estimates in the surrounding lands should not be extrapolated from data obtained in the Black Hills study area.

Cougars are hunted in portions of the Black Hills occurring in Wyoming. During the winters of 1998–99, 1999–00, and 2000–01, 1, 3, and 5 cougars, respectively were harvested from Unit 1 of the Wyoming Black Hills Unit, which includes portions of the Black Hills; of those, 5 cougars were killed in the Black Hills study area (Wyoming Game and Fish Department Cougar Harvest Summaries [1998–2001], unpublished data). Effects of these losses and animals killed for livestock depredation or nuisance behavior in both Wyoming and South Dakota during the same time period were not incorporated into the projected population modeling.

Program PUMA had limitations and, therefore, my modeling could benefit from additional information on the population. First, to model the population, an assumption of population equilibrium at biological carrying capacity (K) at the start of modeling is required by Program PUMA. I did not have evidence that cougars in the Black Hills were at K. I estimated K to be 152 cougars, the highest estimate derived from the data. Because all scenarios used to estimate the cougar population were based on limited data, caution should be taken when interpreting simulations until additional information (e.g., population trends, survival parameters) is obtained on the population. Also, projected population simulations were based on parameters not currently known for the Black Hills population (e.g., survival estimates were obtained from an unhunted cougar population in New Mexico, Logan and Sweanor 2001). It is possible that population parameters of Black Hills cougars differ from those in New Mexico. As additional information becomes available for the Black Hills cougar population, parameters in the model could be updated accordingly. However, based on documented mortalities, human-caused cougar mortality in the Black Hills showed similar patterns (i.e., deaths by vehicle collisions, legal and illegal killings) to those of other unhunted populations (Chapter 6). Furthermore, when modeling effects of immigration to project population size, Program PUMA allowed a maximum of 9 cougars/decade to be added to the population. Immigration rates were not available for the Black Hills population. Anderson (2003) determined that the genetic structure (based on microsattelite DNA analyses at 10 loci) of cougars from the central Rocky Mountains was similar to that of the Black Hills population, indicating gene flow occurred among 5 mountain ranges in the 2 states. He estimated the number of migrants/generation to the Black Hills from the mountain ranges in north-central and south-eastern Wyoming could be as many as 22 cougars, with 10% of those being female.

In my population modeling, the number of immigrant cougars added to the population per decade seemed insignificant to the stability or augmentation of the Black Hills population (Table 17). However, the importance of immigrants to the Black Hills should not be understated. First, it is likely that immigrant animals were responsible for re-establishing the Black Hills population and, thus, likely would aid in offsetting future population declines due to natural disturbances (e.g., prey crashes, large-scale fires) or non-natural mortality (legal or illegal killing, mortalities due to collisions with vehicles). In New Mexico, recruitment of an increasing population was equally divided between immigrant cougars and progeny of residents (Logan and Sweanor 2001). Second, in a metapopulation, immigrants maintain genetic diversity within subpopulations. Anderson (2003) reported that cougars from the Black Hills had a slightly lower heterozygosity than 4 other geographically distinct cougar populations. This finding is suggestive of reduced genetic variability and more limited gene flow to the Black Hills (although additional data are needed because the lower heterozygosity could have been an artifact of the small sample size [n = 8] obtained from the

Black Hills population). Thus, it is important to manage cougar populations regionally, maintaining adequate numbers to enable immigration among subpopulations.

Under the conditions set by the model, the population increased to 165 cougars without immigration. In theory, as cougar density increased above biological carrying capacity, density dependent influences should limit population growth. As the Black Hills population increased, higher levels of density dependence were not incorporated into the simulations, but remained at moderate juvenile and mild adult density dependence. Additionally, although demographic stochastic variation was incorporated into the model, I did not account for large catastrophes accompanied by temporarily reduced carrying capacity. Small-scale fires are a regular occurrence in the Black Hills and large-scale fires are within the realm of possibility (Turner 1974) and both could impact the cougar population temporarily. For example, in September 2000, a 337.9 km^2 fire killed an adult, female radiocollared cougar, and displaced 2 adult male radiocollared cougars (Chapter 7). Moreover, dramatic fluctuations in prey densities that could increase or decrease carrying capacity for cougars were not incorporated into the model. Although the projected population increased slightly past current estimated carrying capacity, my population modeling, not accounting for additional sources of mortality, did not refute the logistic population growth model (White 2000). In Idaho and Utah, where cougars were protected or had little hunting pressure, the number of resident adults remained relatively stable

(Seidensticker et al. 1973, Hemker et al. 1984). Moreover, in New Mexico, Logan and Sweanor (2001) documented reduced population growth as the cougar population approached carrying capacity.

A major threat to small populations of carnivores is habitat loss (Sunquist and Sunquist 2001). In the Black Hills, housing developments continue to encroach into cougar habitat. Logan and Sweanor (2001) advocated identifying, mapping, and conserving current cougar habitat and landscape linkages to maintain self-sustaining, interconnected populations. I modeled effects of habitat loss on the cougar population to identify the area of high-quality habitat needed to maintain the Black Hills population long-term. Based on the analysis, a minimum of 5,277 km^2 of high-quality habitat was necessary to sustain the population at the estimated carrying capacity (153 cougars) (Figure 11). With this information, managers could begin to develop plans for long-term conservation of this species (Logan and Sweanor 2001). Lands totaling 5,277 km^2 should be identified and systematically protected, managed, or enhanced for the species. Based on my modeling, about 35% of the Black Hills National Forest (including Norbeck Wildlife Preserve and 2 Wilderness areas, Black Elk and Beaver Creek) contained the highest-ranked cougar habitat (Ranks 15–18, 1,646.3 km^2). This habitat could be given priority in management to cougars and deer. Additionally, high-quality cougar habitat in Custer State Park should be identified and maintained. Habitat with ranks 13–14 surrounding highest-ranked cougar habitat could be given priority to cougars and deer when planning timber sales and other extractive uses, but managed with the intent of allowing the land to regenerate to its historic state. Habitat with lower ranks could be enhanced for cougars, until a network of cougar conservation lands exists throughout the Black Hills.

Table 9. Macro-habitat characteristics ranked by suitability to white-tailed deer in the Black Hills National Forest; greater values indicate greater suitability. Individual grid databases for 5 habitat characteristics were overlaid and summed to create a habitat-relation model. Structural stages (SS) of stands were based on tree size (diameter at breast height, dbh; 2 = <2.5 cm dbh, 3 = 12.7–22.9 cm dbh, 4 = >22.9 cm dbh) and % canopy cover (CC) (A = 0–40% CC, B = 41–70% CC, C = 71–100% CC).

Habitat Characteristics	Summer	Rank	Winter	Rank
Dominant overstory	Ponderosa pine/ deciduous(PD) Aspen (A) Aspen/conifer (AC) Spruce (S) Spruce/deciduous (SD)	3	PD BP*	3
	Burned Pine* (BP)	2	P A AC	2
	Ponderosa pine (P) Meadow (M) Other (O)	1	S O SD M	1
SS %CC	P3C A3C A3A S3B A3B S3C	3	P3C BP3A* BP4A*	3
	P3A A2 BP3B* P3B A4A BP3C* P4A A4B BP4A* S4A A4C BP4B* S4B S3A BP4C* S4C BP3A*	2	S3A P3A A3B BP3C* S3B P3B A3C BP4B* S3C P4A A4A BP4B* S4A M A4B BP4C* S4B A2 A4C S4C A3A BP3B*	2
	P4B M P4C	1	P4B P4C	1
Elevation (m)	1881–2079	3	1554–1728	3
	2080–2178, 1782–1880	2	1467–1553, 1722–1815	2
	>2178, <1782	1	<1467, >1518	1
Slope (degrees)	0–13	3	0–11	3
	14–20	2	12–19	2
	>20	1	>19	1
Aspect	1–29, 30–119	3	245–345	3
	344–360, 1–28, 120–164	2	200–244, 336–360, 1–20	2
	165–343	1	21–199	1

* Burned pine was not delineated in the USDA Forest Service GIS, and was considered the same rank as pine.

Table 10. Macro-habitat characteristics ranked by suitability to mule deer in the Black Hills National Forest; greater values indicate greater suitability. Individual grid databases for 5 habitat characteristics were overlaid and summed to create a habitat-relation model. Structural stages of stands were based on tree size (diameter at breast height, dbh; 2 = <2.5 cm dbh, 3 = 12.7–22.9 cm dbh, 4 = >22.9 cm dbh) and % canopy cover (CC) (A = 0–40% CC, B = 41–70% CC, C = 71–100% CC).

Habitat characteristics	Summer	Rank	Winter	Rank
	Ponderosa pine (P)	3	PMR	3
Dominant	Aspen (A)	2	P	2
overstory	Spruce (S)		A	
	Ponderosa Pine/Mt. Mahogany/		BP*	
	Rocky Mt.Juniper (PMR)		PA	
	Pine/spruce (PS)			
	Burned Pine* (BP)	1	M	1
	Pine/aspen (PA)		O	
	Meadow (M)			
	Other (O)			
	P3B PMR3C	3	P3C	3
	P3C		BP3A*	
	S3C		BP4A*	
SS %CC	P3A	2	A3A PMR3A PA3C	2
	PS3C		MD PMR3B BP3A*	
	P4A		PA3A PS3A	
	S3A		PA3B PS3B	
	P4B M	1	P4B	1
	P4C		P4C	
Elevation	1496–1605	3	1616–1729	3
(m)	1485–1495, 1606–1609	2	1606–1615, 1730–1747	2
	<1485, >1609	1	<1606, >1747	1
Slope	8–15	3	13–23	3
(degrees)	6–7,16	2	12–13, 23–24	2
	<6, >16	1	<12, >24	1
Aspect	340–360, 1–23	3	222–360, 1–140	3
	124–153, 229–339	2	141–221	2
	154–290	1	——	1

* Burned pine was not delineated in the USDA Forest Service GIS, and was considered the same rank as pine.

Table 11. Annual home-range estimates (Adaptive Kernel [90%]) of radiocollared cougars (*Puma concolor*) monitored ≥8 months (M = male, F = female) in the Black Hills, South Dakota and Wyoming (1998–2001). N = Number of locations used to generate home range estimates.

COUGAR ID	AGE*	N	HOME RANGE (km^2)
M1 1999	4	52	854.1
M1 2000		37	1219.7
M1 2001		41	1329.7
M2 1999	3	46	462.1
M2 2000		48	900.5
M2 2001		34	847.5
M3 1999	2.5	25	297.3
M4 1999	2.5–3.0	34	251.4
M4 2000		42	689.1
M4 2001		39	729.3
M12 2000	2	36	2314.7
F6 2000	1.5	48	395.0
F6 2001		48	127.1
F8 2000	3–4	27	206.7
F9 2000	6–7	44	187.2
F9 2001		47	74.8
F10 2000	2	40	429.3
F10 2000		45	241.0

* Age determined tooth wear and fur-color characteristics (Anderson and Lindzey 2000)

Table 12. Percent home-range overlap among 3 adult male cougars (*Puma concolor*) (M1, M2, and M4) in the Black Hills, South Dakota and Wyoming (1998–2001). The overlap zone was identified using 90% and 60% Adaptive Kernel (AK) home-range estimates.

Year	M1 M2	M1 M2	M1 M4	M1 M4	Total overlap for M1	
	90%	60%	90%	60%	90%	60%
1999	5.11	0.0	12.8	0.0	17.9	0.0
2000	15.3	2.3	36.7	20.2	52.0	22.0
2001	16.0	12.0	15.0	0.0	28.0	12.0

Table 13. Macro-habitat characteristics ranked by expected suitability to cougars in the Black Hills National Forest, South Dakota and Wyoming (1998–2001); greater ranks indicate higher quality habitat. Individual grid databases for prey habitat quality, slopes, and buffered streams were overlaid and summed and then multiplied by the human population density and road grids to create the final habitat-relation model for cougars.

Data bases of Habitat characteristics	Category	Rank
Prey quality	Overlay of the white-tailed deer and mule deer habitat-relation models maintaining the highest rank of habitat quality for each cell in the final prey database.	15 (highest habitat quality) 14 13 12 11 10 9 8 7 6 5 (lowest habitat quality)
Slopes	>50%	2
	20–50%	1
	<20%	0
Buffered Stream	Within 581 m from stream	2
	Outside buffered area	1
Population Density	Moderate	——
	High	0
	Low	——
Roads	Class 1	0
	Class 2	——
	Class 3	——
	Class 4	——

Table 14. Selection of ranked habitat (18 = highest habitat quality, 5 = lowest habitat quality) by cougars (*n* = 10) in the Black Hills, using Manly's (1972) Alpha Preference Index. Percent habitat use and availability were determined by overlaying buffered (0.5 km) cougar and random locations (*n* = 494) onto the cougar habitat-relation model. Alpha values measure the probability of selecting an individual rank of habitat when all habitat ranks were equally available (Krebs 1989). Habitat ranks with values greater than Manly's Alpha (0.08333) were selected (denoted by *) and ranks with values lower, were avoided.

Habitat Rank	% Used	% Availability	Alpha
6	0.001	0.012	0.0077
7	0.001	0.003	0.0306
8	0.006	0.007	0.0787
9	0.107	0.134	0.0734
10	0.693	1.721	0.0370
11	3.129	5.745	0.0500
12	10.26	13.623	0.0692
13	19.196	20.954	0.0841*
14	26.234	24.320	0.0991*
15	24.375	20.471	0.1094*
16	11.419	9.450	0.1110*
17	3.775	3.010	0.1152*
18	0.804	0.549	0.1345*

Table 15. Parameters incorporated into Program PUMA (Beier 1993) to model the population under various scenarios of immigration and habitat quality for cougars in the Black Hills, South Dakota and Wyoming (1998–2001).

Parameter	Value
Female kitten survival rate	0.66[1]
Female yearling survival rate	0.88[1]
Female adult survival rate	0.86[1]
Male kitten survival rate	0.66[1]
Male yearling survival rate	0.56[1]
Male adult survival rate	0.91[1]
Mean litter size	3.0
Area of high-quality (HQ) habitat	variable[2]
Density of females in HQ habitat	0.62
Density of males in HQ habitat	0.18
Area of low-quality (LQ) habitat	variable[2]
Density of females in LQ habitat	0.25
Density of males in LQ habitat	0.18
Percent overlap in male ranges	33
Density dependence	Juvenile: moderate; Adult: mild
No. male immigrants / decade	variable[2]
No. female immigrants / decade	variable[2]
Catastrophes?; #years; % K reduced; duration	No; 0; 0; 0

[1] Survival rates were obtained from a 10-year study on an unhunted cougar population (Logan and Sweanor 2001).

[2] Parameters varied in simulations to test their effects on the population.

Table 16. Population estimate (Program PUMA; Beier 1993) of cougars in the Black Hills, South Dakota and Wyoming (1998–2001) under varying conditions of female density in low-quality (LQ) habitat and percent overlap of male home ranges. Female density in high-quality (HQ) habitat remained constant.

	Population Simulation				
Parameter	1–10	11–20	21–30	31–40	41–50
Mean Total Population Size	129	135	135	141	152
Mean No. adult females	46	46	48	48	48
Mean No. adult males	15	21	15	21	32
Mean No. yearling females	11	11	12	12	12
Mean No. yearling males	11	11	12	12	12
Mean No. female kittens	23	23	24	24	24
Mean No. male kittens	23	23	24	24	24
Area of HQ habitat	6702	6702	6702	6702	6702
Density of females in HQ habitat	0.62	0.62	0.62	0.62	0.62
Density of males in HQ habitat	0.18	0.25	0.18	0.25	0.38
Area of LQ habitat	1697	1697	1697	1697	1697
Density of females in LQ habitat	0.25	0.25	0.37	0.37	0.37
Density of males in LQ habitat	0.18	0.25	0.18	0.25	0.38
Percent overlap in male ranges	33	50	33	50	68

Simulation 1–10: 2 females per male territory in LQH, 33% overlap of adult male territories;
Simulation 11–20: 2 females per male territory in LQH, 50% overlap of adult male territories;
Simulation 21–30: 3 females per male territory in LQH, 33% overlap of adult male territories;
Simulation 31–40: 3 females per male territory in LQH, 50% overlap of adult male territories;
Simulation 41–50: 3 females per male in LQH and 68% overlap of adult male territories.

Table 17. Population simulations using Program PUMA (Beier 1993) projecting effects of immigration on the cougar population in the Black Hills, South Dakota and Wyoming (1998–2001) after 100 years, holding other parameters constant.

No. Immigrating males/decade	No. Immigrating females/decade	No. Runs	Mean	Lower, Upper 95% confidence interval
0	0	200	165.3	164.9, 165.7
1	0	260	165.2	164.6, 165.8
1	1	110	165.3	164.3, 166.2
2	0	40	165.3	162.4, 168.1
2	1	100	165.8	165.1, 166.5
3	1	70	165.6	164.8, 166.3
3	2	30	167.2	165.8, 168.6
4	0	90	165.6	165.1, 166.0
4	1	170	165.8	165.1, 166.5
4	2	10	165.5	——
5	0	90	165.9	164.7, 167.1
5	1	250	166.2	165.8, 166.3
5	2	60	166.3	165.0, 167.7
5	3	40	167.2	165.2, 169.1
6	0	10	166.3	——

Table 17. (Cont.)

No. Immigrating males/decade	No. Immigrating females/decade	No. Runs	Mean	Lower, Upper 95% confidence interval
6	1	50	165.8	165.3, 166.3
6	2	10	165.4	——
7	0	10	166.1	——
7	1	60	167.0	165.2, 168.8
7	2	60	163.3	165.5, 167.2
7	3	40	167.2	165.7, 168.7
8	0	10	167.5	——
8	1	50	167.5	166.4, 166.8
8	2	10	171.4	——
8	4	10	167.3	——
9	0	20	167.6	165.0, 170.1
9	1	150	167.0	166.4, 167.5
9	2	70	167.0	165.9, 168.2
9	4	30	167.3	164.3, 170.8
9	5	110	167.0	165.8, 168.2

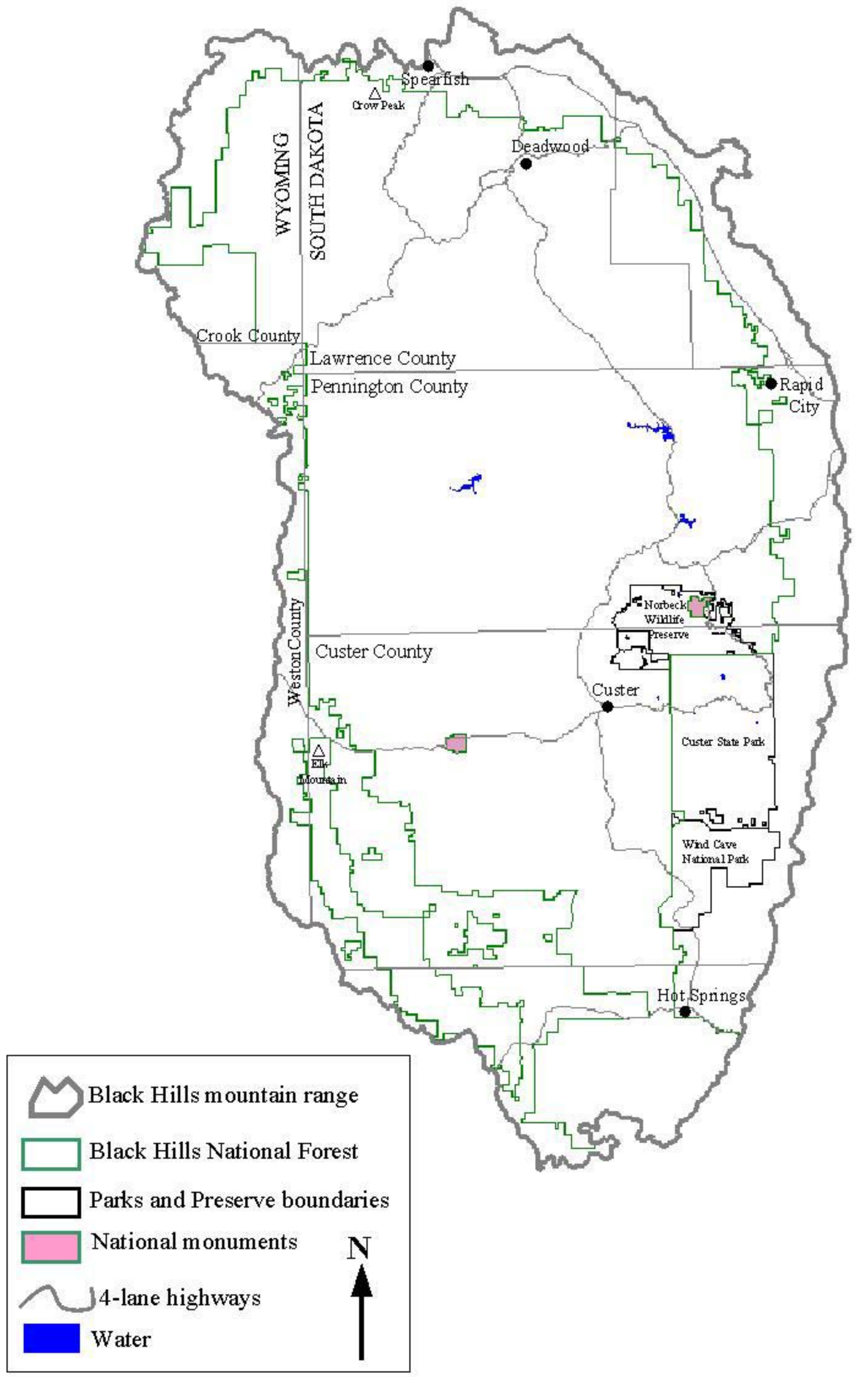


Figure 8. Black Hills of South Dakota and Wyoming study area.

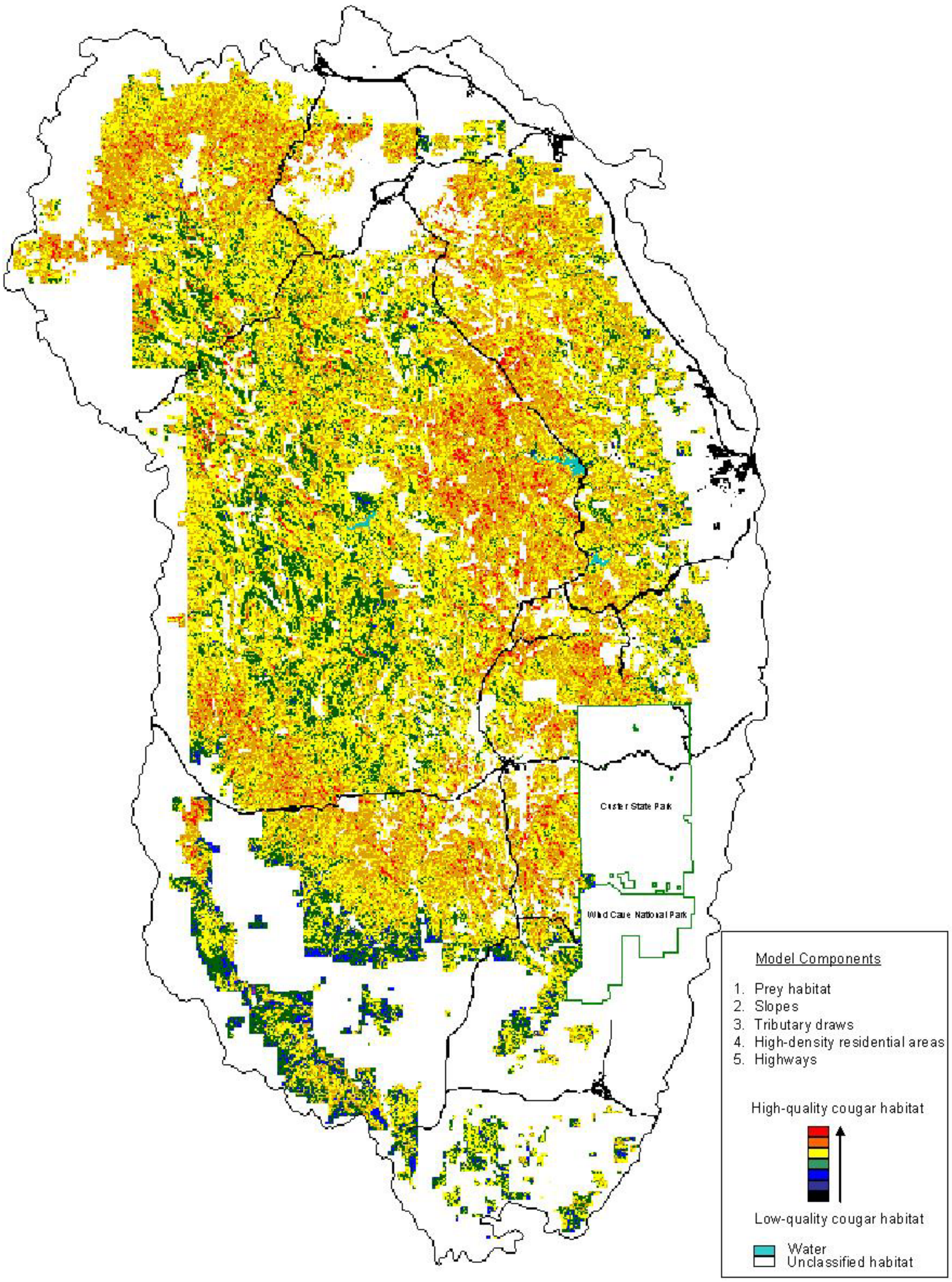


Figure 9. Cougar ranked habitat-relation model for the Black Hills National Forest, South Dakota and Wyoming (1998–2001).

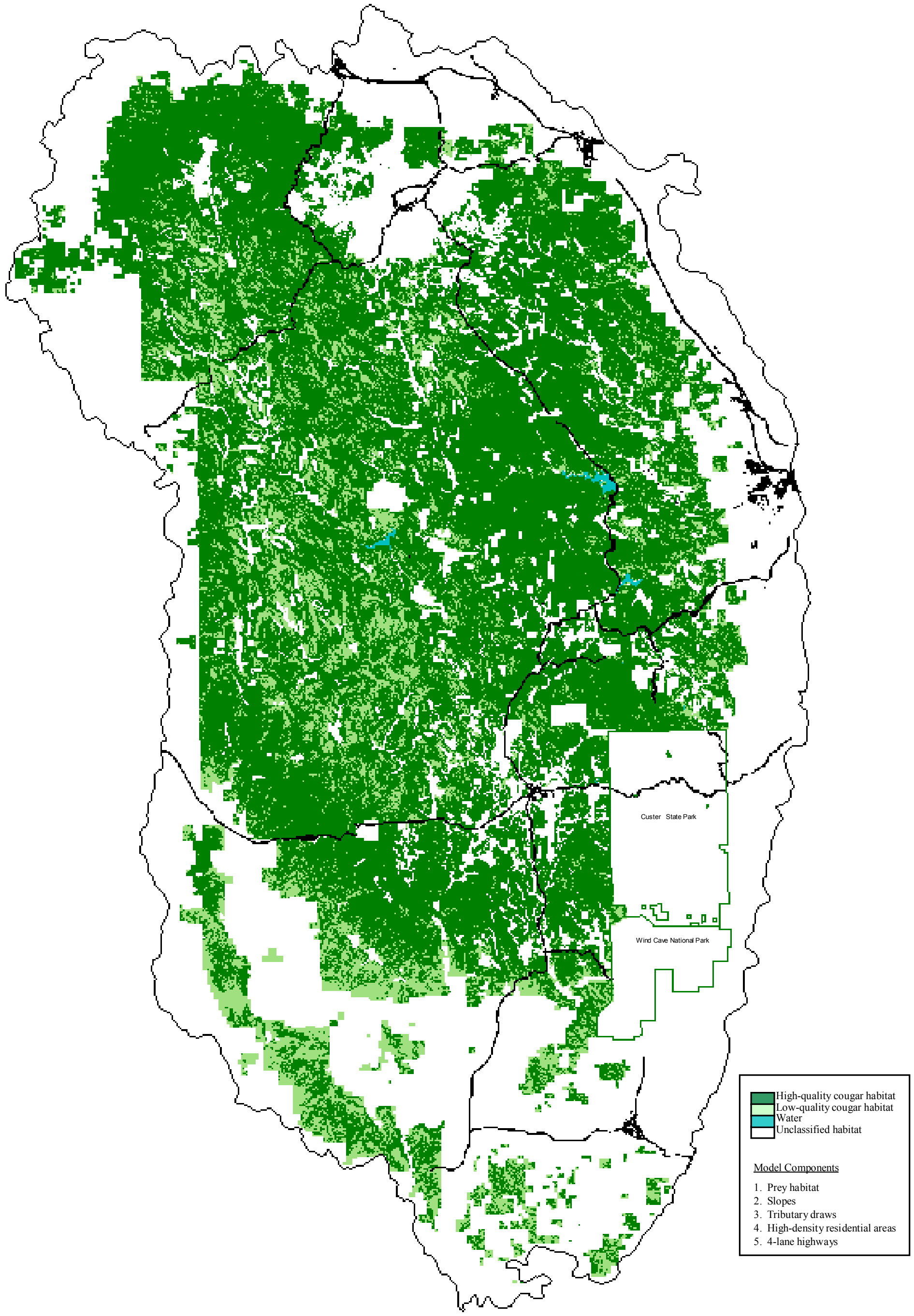
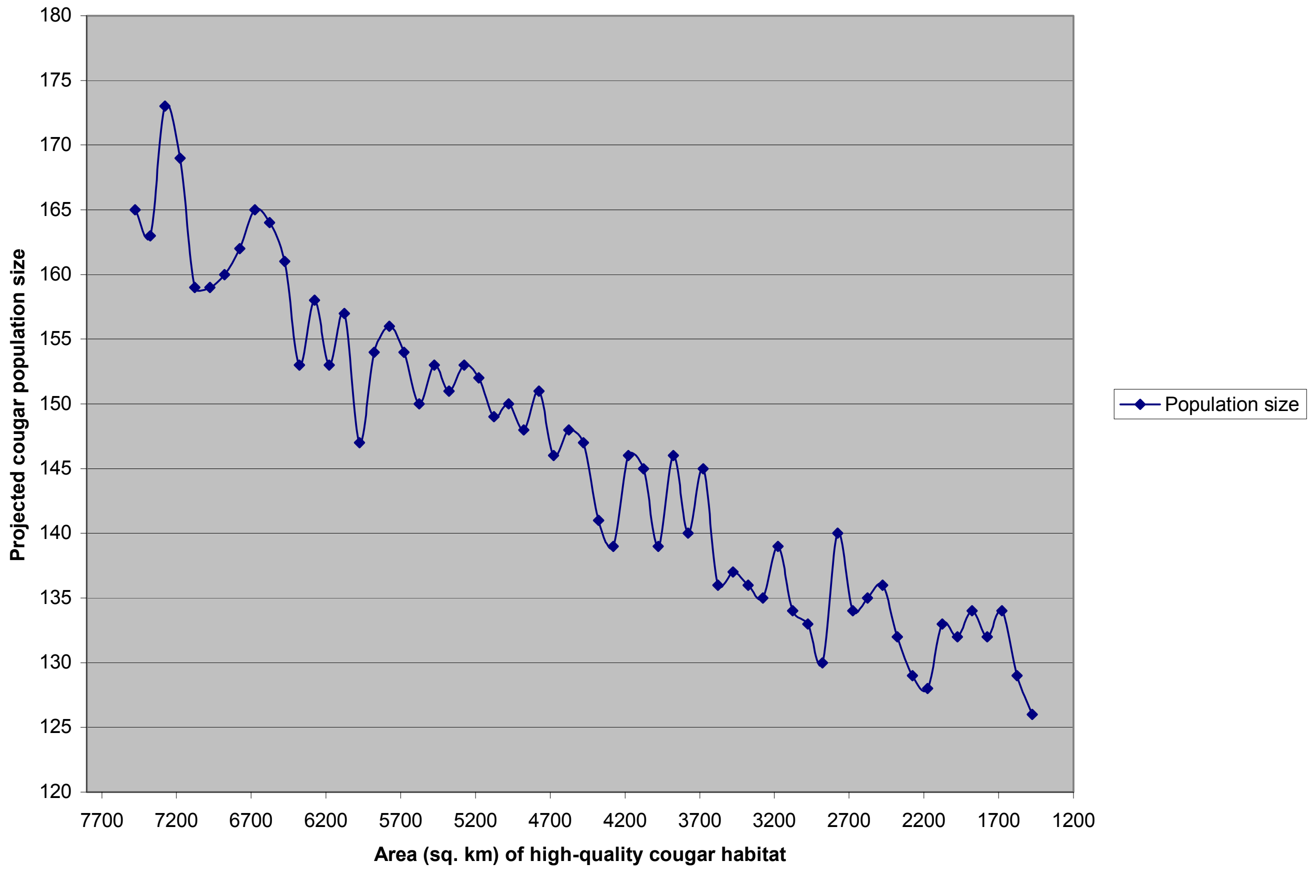


Figure 10. Cougar habitat-relation model for the Black Hills, South Dakota and Wyoming (1998–2001) recoded into habitat classes (high-quality and low-quality) for incorporation into Program PUMA.

Figure 11. Projected cougar population size (*n* = 100 years) in the Black Hills, South Dakota and Wyoming in response to successive decreases of 100 km^2 high-quality cougar habitat for each successive population simulation.



CHAPTER 6: CHARACTERISTICS OF COUGAR MORTALITIES IN THE BLACK HILLS, SOUTH DAKOTA

ABSTRACT

I documented deaths of 25 cougars (*Puma concolor*) in the Black Hills, South Dakota from 1996 to 2002. Cougar carcasses were obtained from the South Dakota Department of Game, Fish and Parks, transported to South Dakota State University, necropsied, and cause of death determined. Age (based on tooth wear and fur coloration characteristics) and sex of carcasses were determined. Nutritional condition was assessed based on kidney fat (ranked as high, medium, or low). Cougars were killed by collisions with vehicles (n = 9), shootings (n = 9), from capture-related or trap injuries (n = 4), or natural causes (n = 2). Sex ratio of the dead lions was 52:48 and age ranged from 4–5 months to 9 years. Of 21 cougars examined, 17 had high or moderate levels of kidney fat suggesting they were in relatively good nutritional condition. Sixteen cougars showed cursory evidence of porcupine (*Erethizon dorsatum*) consumption.

INTRODUTION

Historically, Cougars occurred throughout South Dakota (Paquet and Hackman 1995), and in the late 1800's were relatively common (Turner 1974). Cougars were found in the plains and Badlands region of the state and were numerous in the Black Hills (Young and Goldman 1946). In the early 1900s, the population dramatically declined from bounties placed on the animal in 1899

(SDGF&P 1998). The species remained unprotected until 1978, when its status was changed to state threatened. Since receiving protection, cougar sightings have increased, especially the last few years (19, in 1995; 40, in 1996; and 56, in 1997). However, many were unverified and no information existed on population characteristics of this species in South Dakota. As part of a study to determine distribution and estimate population size of cougars in the Black Hills (Chapter 5), I documented mortalities of cougars from 1996 to 2002.

METHODS

Carcasses of cougars killed in the Black Hills were transported to South Dakota State University for necropsy. I determined place of death through interviews with South Dakota Department of Game, Fish and Parks (SDGF&P) employees. Locations where deaths occurred were recorded by county (Table 18). During the initial examination of the carcass, I determined sex and estimated age of animals. Age was estimated based on presence of a subcanine ridge, wear on incisors and canines, coloration (white or yellowed) of the teeth, and fur coloration (i.e., presence of spots on the body or barring on the limbs) (Anderson and Lindzey 2000). Carcasses were then necropsied and, if unknown, cause of death was established. Nutritional condition of animals was evaluated by ranking kidney fat as high, moderate, or low. Evidence of porcupine (*Erethizon dorsatum*) consumption was documented from a cursory examination of the carcass.

RESULTS

Twenty-five cougar mortalities were documented over the 6-year period, 1996–2002. Sex ratio of mortalities was 52:48. Age of mortalities ranged from 4–5 months to 8–9 years. Causes of mortality were categorized as: shooting, vehicle collision, intraspecific interaction, fire, accidental (unintentional trapping in a bobcat snare, and capture-related), and unknown (Table 18). Of mortalities, 9 (36%) were due to shooting, 9 (36.0%) resulted from vehicle collisions, 2 (8%) were trap-related, 2 (8%) were capture-related mortalities, 2 (8%) were due to natural causes, 1 (4%) from an intraspecific interaction, and 1 (4%) from a fire (Chapter 7). Ten (40%) of the mortalities occurred in the southern counties of the Black Hills (Custer and Fall River), 8 (32%) mortalities occurred in the central Black Hills (Pennington), and 7 (28%), in the northern counties (Lawrence, Meade, and Butte counties). Of the 21 specimens assessed, 17 (80.9%) had high or moderate kidney-fat levels, indicating these animals were in good nutritional health at the time of their death. Based on cursory examination of carcasses, 16 (76.2%) cougars showed evidence of porcupine consumption (presence of quills in intestines or on extremities).

DISCUSSION

I documented both human-caused and natural mortality of cougars in the Black Hills. Although cougars are protected, 88% of the deaths I encountered were human-caused. My findings were similar to those of protected cougar populations in Colorado, Arizona, and British Columbia, where humans also were the primary cause of cougar deaths (Logan and Sweanor 2000). South Dakota law provides that citizens can obtain a permit (issued by the Secretary of SDGF&P) to kill individual, problem cougars that persistently kill livestock, pose a threat to the public's health, safety or welfare, or damage property. In addition, any person can legally kill a cougar in an emergency situation involving an immediate threat to human life (SDGF&P 1998).

Six male and 3 female cougars were killed from collisions with vehicles. All collisions either occurred on primary or secondary highways (Chapter 8). Seven of 9 the animals were $\leq$2 years old; of those, 3 were kittens (<1 year old). Two young male cougars were killed on Interstate 90, a high-speed highway (104–120 km/h) that occurs on the northern and eastern periphery of the Black Hills. These animals could have been in the process of dispersing, which can occur anywhere from 10–33 months (Sweanor et al. 1999), or were forced to use suboptimal habitat to avoid aggressive encounters with older males (Logan et al. 1996). Moreover, an adult male cougar and a male kitten were killed on U.S. Route 16, where at least 3 adult cats (2 radio-collared adult males and 1 uncollared female with two kittens) were documented to cross on more than one occasion, all within a 0.8 km segment of road (D. M. Fecske, unpublished data). In 1997, on the same segment, an adult cougar was hit by a car but not killed. Specific locations on high-speed highways could act as population sinks for cats with home ranges fragmented by such roads. In populations in California and Florida, where animals exist in severely fragmented habitat, vehicle collisions were the predominant cause of death to cougars (Logan and Sweanor 2000). This information has important long-term management implications for cougars. Managers could identify locations where lions are known to cross high-speed highways and construct wildlife underpasses. Wildlife culverts were constructed in Florida in 1994 to decrease cougar/vehicle collisions. The culverts were used by cougars and other species as well (i.e., black bears (*Ursus americanus*), bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), deer (*Odocoileus virginianus*), etc.) (Foster and Humphrey 1995).

In unhunted cougar populations, intraspecific killing may be the major natural cause of death of these territorial carnivores. In New Mexico, 44.0% of kitten deaths resulted from infanticide and cannibalism, and intraspecific aggressive encounters resulted in 100% of deaths of subadults and 52.0% of adults, respectively; all killing was done by adult male cougars (Logan et al. 1996). Intraspecific aggression also was the predominant cause of death to cougars in Florida (Maehr 1997) and California (Beier et al. 1993). I documented an intraspecific aggressive encounter between 2 radio-collared male cougars in the Black Hills (66 kg, 4 to 5-year-old and 54 kg, 2.5-year-old), which resulted in the death of the younger cat. Other reported natural causes of death include deaths from other carnivores (Boyd and Neale 1992), injuries sustained during pursuit of prey (Ross et al. 1995), starvation, accidents (Lindzey 1987), and from parasites and disease (Dixon 1982). There have been no published reports of cougars killed during natural disturbances such as fire. I documented the death of a radio-collared, adult female cougar from a recent fire in the Black Hills (Chapter 7). The death probably occurred because most of the animal's 129.5 km^2 home range was contained within a region of the 337.9 km^2 fire. The lion's death likely occurred on the second day of the fire when 196.5 km^2 burned, trapping her in the draw where she died.

Results of the cougars evaluated for body fat reserves indicated that overall, the population of cougars in the Black Hills is in good nutritional health. My data indicated that females traveling with yearlings, older animals with past wounds, and relatively young animals that may not have not established a home range may be more likely to possess relatively low fat reserves. Gross examination of carcasses revealed evidence of consumption of porcupines in all age classes represented, indicating this species may be an important food item, annually, to cougars in the Black Hills.

CHAPTER 7: MORTALITY OF AN ADULT COUGAR DUE TO A FOREST FIRE

ABSTRACT

I documented the death of an adult, radio-collared female cougar (F8) from a forest fire in the Black Hills, South Dakota. Over a 6-day period beginning 24 August 2000, a fire burned 337.9 km^2 in the southwestern Black Hills. On 2 September, I located the carcass of F8 in a draw, 3.4 km south of the northern perimeter of the burn. A necropsy conducted on the cougar indicated it died from asphyxiation. The assumption that large terrestrial carnivores have the ability to escape fire should be reexamined by wildlife biologists, especially in isolated, fire-prone areas like the Black Hills. Cougar population suppression due to high-intensity, large-scale fires could be incorporated into population models by allowing for stochastic processes and temporarily decreasing habitat quality in burned areas.

INTRODUCTION

Cougar (*Puma concolor*) mortality from natural causes has been documented throughout the species range (i.e., California [Beier and Barrett 1993], Canada [Ross et al. 1995], Florida [Taylor et al. 2002], Idaho [Hornocker 1970], Nevada [Ashman et al. 1983], New Mexico [Logan et al. 2000], and Utah [Gashwiler and Robinette 1957, Lindzey et al. 1988]). Detailed studies on natural mortality in unhunted cougar populations have reported that intraspecific killing by adult male cougars is the most common cause of death; adult males have killed kittens, subadults, and adults of both sexes (Beier and Barrett 1993, Maehr 1997, Logan and Sweanor 2001, Taylor et al. 2002). Other known causes of mortality include deaths from other carnivores like gray wolves (*Canis lupus*) (Boyd and Neale 1992) and coyotes (*Canis latrans*) (Logan and Sweanor 2001), injuries sustained during attempts at capturing prey (e.g., porcupines (*Erethizon dorsatum*) (Robinette et al. 1959), deer (*Odocoileus spp.*), (Lindzey et al. 1988) elk (*Cervus elaphus*), and bighorn sheep (*Ovis canadensis*) (Ross et al. 1995)), starvation, accidents (Lindzey 1987), parasites, disease (e.g., rabies) (Dixon 1982, Logan and Sweanor 2001), old age (Hornocker 1970), and snakebites (Logan and Sweanor 2001). However, there have been no published reports of cougars killed during natural disturbances such as fire. I documented the death of an adult, female cougar from a forest fire in the Black Hills, South Dakota.

The Jasper fire was the largest fire that occurred in the Black Hills since the settlers colonized the region in the 1800s. The fire, a result of arson, was started on 24 August 2000 at approximately 1430 hrs, south of U.S. Highway 16 between Newcastle, Wyoming, and Custer, South Dakota. Over a 6-day period the Jasper fire burned 337.9 km^2 in the southwestern Black Hills. The greatest area (196.5 km^2) burned on 26 August, between 0600 hrs and 1800 hrs. Overall, the intensity of the burn was ranked as high in 39%, moderate in 32%, low in 24%, and unknown in 5% of the burned area. The fire was contained on 8 September 2000 at 1800 hrs (USDA Forest Service 2001).

METHODS

As part of a study to document distribution and abundance of cougars in the Black Hills (Chapter 5), I captured, immobilized, affixed transmitters to (Telonics Inc., Mesa, Arizona), and released a total of 12 cougars (7 males and 5 females) during the winters of 1998–2001. Cougar #8 (F8) was a 41 kg adult female, approximately 3–4 years old (Anderson and Lindzey 2000) at the time of her capture on 31 January 2000. I located radio-collared cougars weekly using aerial telemetry techniques.

RESULTS AND DISCUSSION

On 2 September 2000, during the first relocation flight after the Jasper fire, I located F8; the radio collar was emitting a mortality signal. I found the carcass of F8 in a draw 3.4 km south of the northern perimeter of the burn. The cougar's death likely occurred 26 August when strong winds from the south directed the fire northward at an average rate of 24.3 km^2 per hour, trapping F8 in the draw where she died; seventy five percent of F8's 205.9 km^2 annual home range (90% Adaptive Kernal estimate, n = 26 locations) was encompassed within the perimeter of the Jasper Fire.

I necropsied the cougar on 1 November 2000. I observed that F8's front and rear toe and plantar pads and hair were burned as well as facial vibrissae, but that little of her pelage was singed. The fact that F8's mouth, trachea, and lungs were coated with black soot indicated that death was due to asphyxiation. I saw no indication that the cougar was incapacitated, limiting its ability to escape the fire. Although F8 had no stomach or intestinal tract contents, I classified her in good nutritional condition based on high amount of fat reserves surrounding the internal organs. I also observed two feti in the reproductive tract of the cougar, approximately 3–4 weeks from parturition (Sharon Seneczko, DVM, Custer, South Dakota, personal communication).

The assumption that large terrestrial carnivores have the ability to escape fire should be reexamined by wildlife biologists, especially in isolated, fire-prone areas like the Black Hills. Large fires could temporarily suppress cougar population growth through direct mortality of individual females and their offspring, subsequent infanticide by displaced territorial males, and by reducing female carrying capacity from a reduction of prey habitat quality. Cougar population suppression due to high-intensity, large-scale fires could be incorporated into population models by allowing for stochastic processes and temporarily decreasing habitat quality in burned areas.

In the Black Hills, direct losses of primary cougar prey (e.g., deer (*Odocoileus virginianus*, *O. hemionus*) and elk (*Cervus elaphus*) from fires may be negligible relative to respective population sizes. However, to what extent populations of smaller prey (e.g., porcupines (*Erethizon dorsatum*)) are impacted is unknown. Regardless, the loss of individual cougars and temporary reduction in habitat quality for large and small-sized prey could impact the spatial and population dynamics of this relatively small cougar population. After the Jasper fire, I documented home range shifts of 2 radio-collared males (M1 and M4), whose home ranges overlapped that of F8; both males shifted home ranges north of the area formally occupied by F8. Based on previous locations of F8 occurring in close proximity to M1 and M4, it is likely that she interacted with both males. Shifts by the 2 cougars could have been due to absence of F8, temporary abandonment of the burned area by deer (Dubreuil 2002), or interactions with other uncollared, displaced territorial males.

Table 18. Characteristics of cougar mortalities in the Black Hills, South Dakota (1996-2002).

Date	Sex	Age	Fat	Presence of Quills	Mortality	County
1996	M	8.5-9.5	L	Yes	Shooting	Custer
Spring 1998	M	2	L		Vehicle	Lawrence
12/29/98	F	2.5	H	Yes	Accidental	Pennington
3/9/99	F	4-5	H	Yes	Accidental	Custer
Winter 1999	F	3	NE	NE	Shooting	Custer
10/10/99	M	4-5 mo.	M	Yes	Vehicle	Custer
11/4/99	M	1.5-2.5	H	Yes	Vehicle	Meade
11/99	M	3	NE	NE	Shooting	Fall River
11/28/99	F	1.5-2.5	H	Yes	Shooting	Pennington
3/26/00	M	2.5-3.5	H	Yes	Interaction	Custer
8/26/00	F	3.5-4.5	H		Fire	Custer
9/22/00	F	1.5-2.5	NE	NE	Shooting	Fall River
Spring 2001	F	10 mo.	H		Unknown	Pennington
5/10/02	M	3-4	L	Yes	Vehicle	Pennington
11/1/01	F	<12 mo.	M		Vehicle	Lawrence
2/03/02	M	1.5	H	Yes	Accidental	Fall River
3/03/02	M	1-1.5	M	Yes	Shooting	Meade

Table 18. (Cont.)

Date	Sex	Age	Fat	Presence Of Quills	Mortality	County
10/7/01	M	U	M	Yes	Shooting	Butte
4/26/02	M	1.5-2.0	H	Yes	Vehicle	Lawrence
8/10/02	F	3	M		Vehicle	Lawrence
9/6/02	F	<12 mo.	M	Yes	Vehicle	Pennington
9/5/02	M	<12 mo.	M	Yes	Vehicle	Pennington
10/5/02	M	5-6	M	Yes	Shooting	Custer
11/14/02	F	2	NE		Shooting	Pennington
12/17/02	F	5	L	Yes	Accidental	Pennington

[1] Fat reserves were ranked as high (H), medium (M), or low (L) based on kidney fat

CHAPTER 8: EFFECT OF ROADS ON HABITAT USE BY COUGARS

ABSTRACT

I examined effect of roads on habitat use by cougars (*Puma concolor*) in the Black Hills, South Dakota. Day-time (n = 768) locations of 12 radio-collared cougars were obtained during weekly flights (1999–2001) via aerial telemetry techniques. Locations were incorporated into a geographic information system (GIS) of roads (Class 1 (primary highways), 2 (secondary highways), 3 (improved surface, light-duty roads), and 4 (unimproved roads). I tested the null hypotheses that cougars select habitat at random distances to roads and at random road densities and cougar use of habitat near roads did not differ with respect to road class, sex, age class (young adults [1–2 years old] versus adults [$\geq$3 years old]), and habitat quality (based on a cougar habitat-relation model that ranked the Black Hills National Forest according to its suitability to the species (Rank 5 [lowest quality]–Rank 18 [highest quality]). I examined use of habitat near roads for an adult female cougar fitted with a Global Position System collar during crepuscular, diurnal, and nocturnal periods. I also identified road classes where cougar tracks in snow were located and cougar/vehicle collisions occurred. During daylight hours, cougars avoided ($P \leq 0.001$) habitat near Class 3 roads. However, on occasions cougars were located in close proximity to these roads (n = 400 locations), high-ranked (Ranks $\geq$14) habitat was selected. Young female cougars were located closer to Class 1 (P = 0.007) and Class 2

roads (P = 0.013) than older females. Cougars in the Black Hills have adapted to a heavily-roaded landscape, although lack of concealment cover may be affecting their use of habitat near roads. My data indicated cougars selected habitat in a way that minimized their visibility, by avoiding roads and shifting activity patterns when adjacent habitat offered little concealment cover. I suggest use of habitat near Class 3 roads by cougars would increase if roads were closed or had limited access, and if thinned ponderosa pine stands adjacent to Class 3 and 4 roads were managed for understory vegetation.

INTRODUCTION

Cougars (*Puma concolor*) use large expanses of land to obtain food, find mates, and care for young. Like other large carnivores, cougars are considered an umbrella species (Logan and Sweanor 2001), in that maintaining or enhancing habitat to sustain their numbers automatically conserves viable populations of other species (Minta et al. 1999). Roads are landscape characteristics that may affect population dynamics of large carnivores (Paquet and Hackman 1995). Direct effects from roads on cougars include death from collisions with vehicles, habitat fragmentation, and barriers to movement (Clevenger et al. 2001, Fecske et al. 2002). Roads indirectly affect carnivores by reducing overall habitat effectiveness due to lowered security benefits, increased human access to remote areas, and development associated with presence of roads (e.g., mining, logging, housing developments; Murphy et al. 1999).

Since removal of a bounty and subsequent protection as a state-threatened species in 1978, cougar numbers in South Dakota have increased and a breeding population exists in the Black Hills of South Dakota and Wyoming (See Chapter 5). About 90% of the Black Hills is surrounded by 4-lane highways and overall road density for the Black Hills National Forest/Custer State Park study area is estimated at 2.1 km road/km^2 (Fecske unpublished data). Also, the Black Hills National Forest contains higher road densities than National Forests in Wyoming and Colorado (Baker and Knight 2000). Among other objectives, the USDA Forest Service manages the Black Hills National Forest for its scenic attractiveness. Along a $\geq$0.8 km buffer of primary and secondary highways, much of the area is retained in a primarily natural state to provide scenic beauty to motorists. Habitat adjacent to improved and unimproved gravel roads follows other management guidelines, ranging from partial retention of natural vegetation to maximum modification of the forest for timber production.

The goal of this research was to examine cougar use of habitat near roads to understand potential effects of roads on this cougar population. I tested the null hypotheses that: 1) cougars in the Black Hills were located at random distances to roads and at random road densities and 2) cougar use of habitat near roads did not differ with respect to road class, age class (young adult [1–2 years old] versus adult [$\geq$3 years old]), and sex. I examined habitat quality (based on a cougar habitat-relation model that ranked habitat in the Black Hills National Forest according to its presumed suitability to the species [See Chapter

5]) at locations on occasions the animals were located near roads. For an adult female cougar fitted with a global positioning system (GPS) collar I analyzed habitat use near roads during crepuscular, diurnal, and nocturnal periods. Additionally, I documented road classes where tracks of cougars in snow were found and where cougars were killed by collisions with vehicles.

METHODS

During the winters (January–April) 1998–99, 1999–00, and 2000–01, I captured, affixed transmitters to, and released a sample of cougars to monitor movements. Capture methods followed guidelines established by the American Society of Mammalogists for care and use of research animals (Animal Care and Use Committee 1998) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (IACUC No. 99-A002). Capture protocol was similar to that used by Anderson (2003). In mornings, after a fresh snowfall, field crews in 2–4 vehicles searched for cougar tracks in snow on roads in the Central Black Hills (Custer and Pennington counties) from sunrise until about 1200 hrs. If fresh tracks were located, hounds were unleashed at the site in the direction the cougar(s) traveled with the intent of chasing and treeing the animal(s). Treed cougars were immobilized with a combination of Telazol® (2.2 mg/0.45kg) and xylazine hydrochloride (0.45mg/0.45 kg), delivered in a dart propelled from a CO_2 pistil ; effects of the xylazine hydrochloride were reversed using Antagonil® (0.57mg/0.45 kg). Immobilized cougars were weighed and their age was determined based on tooth wear and fur color characteristics

(Anderson and Lindzey 2000). Adults (≥2 years of age for males, and ≥1.5 years for females; Young and Goldman 1946, Logan and Sweanor 2000) were fitted with radio-collars (Mod-500 transmitters with activity and mortality sensors, Telonics Inc., Mesa, AZ). Kittens (<1 year) were fitted with ear-tag transmitters (M6300 with a 12-hour duty cycle, Advanced Telemetry Systems, Inc., Isanti, MN). All study animals were monitored weekly from fixed-wing aircraft via aerial telemetry techniques (Quigley and Crawshaw 1989). Radio-telemetry location error using this methodology averaged 0.152 km (n = 8; range 0.040–0.500 km; See Chapter 4).

On 4 November 2001, I captured and fitted F6 (3-year-old female) with a store-on-board GPS collar (Telonics, Inc. Mesa, AZ); I recovered the collar 12 June 2002. I obtained locations (Universe Transverse Mercator projection) weekly during daylight hours using aerial telemetry techniques (Quigley and Crawshaw 1989).

I incorporated locations of cougars into a geographic information system (GIS) (Arc/Info and Arc/View, ESRI, Inc., Redlands, CA) to enable statistical analysis of data. Location coverages for each cougar were generated to determine distributions of distances to roads available to cougars using 2 digital road databases (USGS Digital line graph files, USDA Black Hills National Forest Service database, Figure 12). Four classes of roads were analyzed: 1) Class 1 roads were all-weather, hard surface, primary highways; 2) Class 2 roads were all-weather, hard surface, secondary highways; 3) Class 3 roads, were all-weather, improved surface, light-duty roads; and 4) Class 4 roads were unimproved roads. Class 4 roads were not completely represented outside of the National Forest. Therefore, cougar locations beyond the Black Hills National Forest Service road database were excluded from analyses of locations in relation to Class 4 roads.

Over a 4-year period (1998–2002), I documented road classes in which cougars were struck by vehicles (n = 10), and where tracks of cougars in snow were observed; snow tracks of cougars that led to the capture of study animals were classified by age and sex.

I analyzed cougar habitat selection in relation to roads within annual home ranges to represent third-order habitat selection as described by Johnson (1980). I created home range (90% Adaptive Kernel) and core-use area (50% Adaptive Kernel) coverages based on telemetry locations of adult cougars monitored $\geq$8 months. I generated equal numbers of random locations for annual ranges, and conducted proximity analyses to determine distances of cougar and random locations to roads (by road class). Annual use of areas near roads by cougars during day-light hours was assessed by comparing the distributions of distances of cougar and random locations obtained from the proximity analyses. Kruskal-Wallis tests (Systat 9.0 SPSS Inc. Chicago, Illinois) were conducted by sex. Additionally, I compared distances of cougar locations to roads by age class (young adult [1–2 years old] versus older adult [$\geq$3 years old]) and sex by conducting an Analysis of Variance (ANOVA) on the ranked median distances (Conover and Iman 1981) of study animals by road class.

I overlaid annual home ranges, core-use areas, and a polygon of the Black Hills Study area (Black Hills National Forest and Custer State Park) onto digital road files to obtain and compare road densities. Road densities (km/km^2) (by road class) in annual ranges of cougars were compared to road densities that occurred in core-use areas and in the Black Hills study area using the signed-rank test (Conover 1999). I set $P < 0.10$ as the criterion for statistical significance because sample sizes were small, which reduced statistical power and increased the probability of Type 2 errors. Bonferonni corrections for alpha were used when multiple tests were conducted on data to adjust for experiment wise error rate.

Habitat characteristics at cougar locations near roads were analyzed using a ranked cougar habitat-relation model (See Chapter 5). Landscapes that sustain cougar populations have been characterized as having vegetative communities and topographic characteristics that not only attract prey but also confer hunting advantages to cougars (via concealment and stalking cover) (Seidensticker et al. 1973, Logan and Irwin 1985, Koehler and Hornocker 1991). Conversely, anthropogenic features of the landscape (e.g., 4-lane highways, human-dominated landscapes) are known to negatively affect use of habitat by cougars and decrease survival (Beier and Barrett 1993, Foster and Humphrey 1995, Dickson and Beier 2002). Using GIS technology (Arc/Info, Arc/View, ESRI, Inc., Redlands, CA; and IMAGINE, Leica Geosystems, Atlanta, GA software), high-quality prey (white-tailed [*Odocoileus virginianus*] and mule deer [*Odocoileus hemionus*]) habitat in the Black Hills National Forest was modeled. Grids of macrohabitat characteristics (dominant overstory vegetation, percentage overstory canopy cover, structural stage of forest stands [USDA Forest Service GIS], elevations, slopes, and aspects [USGS 30-m digital elevation model]) were recoded and ranked according to their predicted suitability to deer (DePerno 1998, Dubreuil 2002). The grid layers were summed and then combined to create a ranked habitat-relation model of cougar prey, where greater values equaled greater quality prey habitat. Then, landscape elements that provided concealment and stalking cover to cougars (dense (riparian) vegetation [Dickson and Beier 2002] and slopes (>50%, Logan and Irwin 1985) were ranked and incorporated into the model, as well as elements considered unsuitable to the species (high-density residential/urban areas and area comprising 4-lane highways (55-m buffer surrounding 4-lane highways). The final cougar habitat-relation model ranked habitat in the Black Hills from 5 (least suitable) to 18 (most suitable).

Roads were buffered using first quartile distances of cougars to Class 1, Class 2, Class 3, and Class 4 roads, plus radio-telemetry error (500 m; Chapter 4) to account for locations that occurred at the farthest buffered edge. Cougar locations located within the first quartile distance to roads were buffered by 500 m and circular points were overlaid on the cougar ranked habitat-relation model.

Distribution of ranked habitats contained in buffered cougar locations near roads were compared to the distributions of characteristics within the buffered Class 1, Class 2, Class 3, and Class 4 roads using Manly's Alpha (Manly 1972). Similarly, I analyzed use of habitat near roads for F6 fitted with a GPS collar from 4 November 2001 to 12 June 2002. I compared use of habitat near roads by this cougar during 3 time periods (Crepuscular hours; 1 hour before and after dawn and dusk, diurnal hours; >2 hours after dawn to <2 hours before dusk, and nocturnal hours; >2 hours after dusk to <2 hours before dawn) using Kruskal-Wallis tests.

RESULTS

I obtained 768 locations from 10 adult (7 male, 5 female) and 2 kitten (1 male, 1 female) cougars. Estimated ages of 10 adult cougars ranged 1.5–8 years. Use of habitat near roads by male cougars was based on data from 5 adult male cougars monitored 35, 33, 32, 9 and 12 months, totaling 11 annual samples of cougar locations. Use of habitat near roads by female cougars was based on data from 4 adult cougars monitored 23, 22, 22, and 8 months, totaling 7 annual samples of cougar locations. Class 1 and Class 2 roads were not uniformly distributed throughout the Black Hills (Figure 12) or equally represented between radiocollared male and female cougar home ranges. Therefore, analyses of habitat use near Class 1 and Class 2 roads were limited to female cougars. Cougar locations averaged 5.0 ± 3.0 km from the nearest Class 1 roads (*n* = 293 female locations), 3.9 ± 2.6 km from the nearest Class 2 roads (*n*

= 293 female locations), 0.406 ± 0.032 km from the nearest Class 3 roads (*n* = 768), and 0.637 ± 0.039 km from the nearest Class 4 roads (*n* = 704). Distribution of distances to roads for males and females were j-shaped for combined road classes, Class 3, and Class 4 roads, and skewed to the left for Class 1 and Class 2 roads. Therefore, medians of data sets best represented the centers of distributions. Mean median distances of cougar locations to Class 1, Class 2, Class 3, and Class 4 roads were 4.5, 3.6, 0.335, and 0.541 km, respectively (Table 19).

During daylight hours, female and male cougars in the Black Hills avoided Class 3 roads (Mann-Whitney U = 276, n = 18, $P < 0.001$, Table 19; Mann-Whitney U = 328,119, n = 768, $P < 0.001$, Table 20). Individually, on 4 occasions (F6 and F10 in 2001, M3 in 1999 and M4 in 2001) cougars avoided Class 3 roads (Table 21 and 22). There was a significant interaction between road class and age class ($F_{3,47}$ = 225.335, $P < 0.001$) for female cougars; young females (1–2 years old) selected habitat closer to Class 1 ($F_{1,47}$ = 7.989, P = 0.007) and Class 2 ($F_{1,47}$ = 6.603, P = 0.013) roads than older ($\geq$3 years old) females. Based on first quartile distances of cougar locations to roads (n = 768, 0.132 km), when cougars were located in close proximity to Class 3 roads (n = 400 locations), they selected habitat with ranks 14–18 and avoided habitats with ranks $\leq$13 (Table 23).

Median road densities in annual home ranges (n = 18) of Class 1, Class 2, Class 3, and Class 4 roads were 0.028, 0.049, 1.5, and 0.389 km/km^2

respectively (Table 24). Overall road densities in annual home ranges of male and female cougars did not differ from core use areas (*P* = 0.071) or road densities in the Black Hills study area (*P* = 0.119). However, by sex, annual, and core use areas of female cougars had higher (*P* = 0.008) road densities than did those of the Black Hills study area (Table 24).

Nine cougars (6 males, 3 females) were killed in collisions with vehicles from 1998 to 2002 and documented by the South Dakota Department of Game, Fish and Parks (SDGF&P) (Table 25). Another cougar was struck by a vehicle and reported, but not killed. Ages of the animals that were killed ranged from <1 year to 3–4 years old. Eight collisions occurred on Class 1 roads and the remaining 2 on Class 2 roads.

Of 45 sets of cougar snow tracks observed on roads during a 3-year period, 3 (7%) occurred on Class 1 roads, 2 (4%) on Class 2 roads, 28 (62%) on Class 3 roads, and 12 (28%) occurred on Class 4 roads. Of 11 tracks of cougars in snow that led to the capture of study animals, 1 (9%) was found on a Class 1 road, 1 (9%), on a Class 2 road, 8 (73%) on Class 3 roads, and 1 (9%) occurred on a Class 4 road.

During the 7-month monitoring period, F6 gave birth to a litter and was observed traveling with 1 kitten. Female F6 selected habitat near roads (all road classes combined) during diurnal (*P* = 0.005) and nocturnal hours (*P* < 0.0001) (Table 26). By road class, F6 selected habitat near Class 2 roads during all time periods, and selected habitat near Class 3 roads during crepuscular and nocturnal hours.

DISCUSSION

Throughout their geographic range, cougars have adapted to a variety of habitats and environmental conditions. However, an essential component of cougar habitat is concealment cover (Sunquist and Sunquist 2002). Dense thickets, overhanging foliage, and other landscape elements (e.g., roots and logs of downed trees, rock outcrops, boulder piles, and undercut cliffs) provide cougars cover (Hornocker 1970, Sunquist and Sunquist 2002, Akenson et al. 2003). Concealment cover is important for hunting and stalking prey, security while feeding and resting, and for providing den sites for females with kittens (Seidensticker et al. 1973, Laing and Lindzey 1991, Logan and Sweanor 2000). Seidensticker et al. (1973) noted that cougars in Idaho were "constantly moving through the country in a way that optimized encounters with prey and provided them with the best possible positions in terms of cover from which to launch attacks." Moreover, cougars dragged their prey into brush or dense thickets before feeding and generally remained near their kills until they were consumed (Seidensticker et al. 1973). In the forests of Oregon, cougar day beds were located among rock outcrops and downed logs (Akenson et al. 2003). Jalkotzy et al. (1999) frequently located day beds under spruce trees where cougars were concealed by overhanging boughs. Cougar nurseries have been documented in concealed places including shallow caves and rock piles, thickets, underneath overhanging vegetation, and among tree roots of uprooted trees (Sunquist and Sunquist 2002). Based on these findings, cougars in the Black Hills should select habitat within their home ranges that maximizes their concealment. With respect to habitat use near roads, concealment cover also may provide cougars "psychological security" (Naugle et al. 1997) from perceived and real threats by human presence and activity. The data suggested cougars selected habitat in a way that minimized their visibility by avoiding roads and shifting activity patterns when adjacent habitat offered little concealment cover.

During daylight hours, male and female cougars avoided areas near Class 3 roads, the predominant road class in the Black Hills (Figure 12). Although less-traveled and in more remote country relative to Class 1 and 2 roads, Class 3 roads in the Black Hills National Forest often were associated with past logging activity, manifested by adjacent stands of thinned ponderosa pine with little understory cover. Furthermore, the forests of the Black Hills are interspersed with grasslands and meadows, and Class 3 roads that traveled through open habitat offer little adjacent concealment cover to cougars. Under these conditions, cougars could remain out of sight by selecting habitat at a greater distance from Class 3 roads during the day. Conversely, darkness provides security concealment to cougars and the animals could travel and/or hunt near this road class during crepuscular and nocturnal hours. Vandyke et al. (1986) found that cougars in Arizona and Utah shifted their activities to after sunset when they were located in close proximity to humans. Based on the high percentage of fresh tracks of cougars observed in snow on Class 3 roads on mornings after fresh snowfall, the animals used habitat near Class 3 roads during crepuscular and/or nighttime hours. The fact that 8 of 11 study animals were detected from snow tracks located on Class 3 roads provided further evidence that both sexes and at least cougars in age classes of study animals crossed and used areas near Class 3 roads. Additionally, F6 was located closer to Class 3 roads during nocturnal and crepuscular hours, but not during diurnal hours.

Class 3 roads were avoided, and Class 4 roads (the least traveled and most remote class) were neither selected for, nor avoided by cougars. My data did not allow a comparison of the frequency that road classes were crossed by cougars, because I did not document search effort by road class. However, Vandyke et al. (1986) reported cougars crossed unimproved roads more frequently than hard surfaced and improved gravel roads. Nevertheless, when cougars were located near Class 3 and Class 4 roads, high-quality habitat was selected. High-quality habitat for cougars consisted of a landscape that could support white-tailed deer and mule deer, and conferred hunting advantages to cougars via riparian (relatively dense) vegetation and topographic characteristics (steep slopes associated with rugged topography). In Arizona and Utah, where the animals were using unimproved roads more than expected (Vandyke et al. 1986), aspen(*Populus tremuloides*)/spruce (*Picea spp.*)-fir (*Abies spp.*) and spruce-fir stands with dense understories and large boulders were selected by females with kittens (Laing and Lindzey 1991). I also observed radio-collared cougars and an uncollared cougar in dense white spruce (*Picea glauca*) stands near unimproved roads. I speculated the animals were using the cool, moist stands for concealment cover to enhance thermoregulation during hot weather (Jalkotzy et al. 1999), and possibly stalking cover, as white-tailed deer are known to select mixed white spruce stands during summer (DePerno et al. 2002).

Because of the unequal distribution of Class 1 and Class 2 roads in the Black Hills (Figure 12), I were unable to make inferences on habitat selection near Class 1 and Class 2 roads by male cougars. However, Class 1 and Class 2 roads were neither selected nor avoided by female cougars, even though these roads had the highest traffic volume. The fact that much of the habitat adjacent to Class 1 and 2 roads existed in a primarily natural state due to the high scenic integrity objective, likely increased its value to cougars by providing cover. Dickson and Beier (2002) reported cougars in California did not avoid high-speed paved roads due to adjacent riparian vegetation, which was selected by cougars. However, the data indicated young adult females (1–2 years old) were located closer to Class 1 and Class 2 roads than older (≥3 years old) adult females, suggesting that social status may play a role in determining habitat selection by cougars near roads. Adult males are known to kill other males that invade territories as well as immigrant females with which they are unfamiliar (Logan and Sweanor 2001). Consequently, young adults of both sexes may be forced into less-suitable habitat as they avoid territorial males. Van Dyke et al. (1986)

indicated that juvenile cougars encountered human disturbances more frequently than older adults.

Although habitat near Class 1 and 2 roads was neither selected, nor avoided by female cougars, these road classes clearly affect survival of this population as all 10 cougar collisions with vehicles occurred on Class 1 and Class 2 roads. Based on GPS data, F6 used habitat near Class 2 roads during all time periods, and her male kitten was killed in a collision with a vehicle on a Class 2 road. Establishment and use of habitat near highly traveled roads could be an indication of range expansion in the Black Hills. However, based on my data, high-quality habitat in areas with relatively high densities of Class 1 and Class 2 roads in the Black Hills may act as population sinks (Hellgren and Maehr 1993). Collisions with vehicles on high-speed highways were a major source for mortality for cougars in California (Beier and Barrett 1993) and Florida (Foster and Humphrey 1995).

Road densities within cougar home ranges in the Black Hills were not lower than the study area average. In fact, for females, densities were higher than the study area. My results differ from those of Van Dyke et al. (1986) who reported that cougars in Arizona and Utah selected habitat with relatively low road densities compared to density within the study area, and Beldon and Hagedorn (1993) noted that cougar home ranges in Florida contained approximately half the density of roads in comparison to overall densities in the study area. High road densities throughout the Black Hills result in few opportunities for cougars to select habitats exclusive of roads.

MANAGEMENT IMPLICATIONS

Ruediger (1996) identified a cycle of road development in which roads begin as gravel, and are subsequently improved by paving, widening, upgrading from 2 lane to 4 lane, and eventually becoming multilane interstate highways. He hypothesized that the impacts roads have on mid- and large-sized carnivores were correlated with road development. Cougars in the Black Hills are using a heavily-roaded landscape currently dominated by Class 3 roads. Additionally, the more highly-traveled roads (Class 1 and Class 2) impact the population by contributing to unnatural mortality as a result of cougar/vehicle collisions. To ensure continued presence of a viable cougar population, serious consideration should be taken before additional Class 3 roads are upgraded in the Black Hills. Residential development in the Black Hills is increasing and, thus, long-term management for cougars should be considered in future development. Ruediger (1996) recommended agencies consider constructing wildlife passage structures to enable successful travel under roads by large carnivores for roads in which traffic volume exceeds 2000 vehicles per day. Ng et al. (2004) determined that the presence of suitable habitat on both sides of highways was important in predicting use of underpasses and drainage culverts by mammals, including carnivores. In the Black Hills, such structures could be placed at known cougar crossings and where high-quality cougar habitat has been identified. Clevenger et al. (2003) reported that road-killed animals tended to occur near vegetative cover and away from wildlife passages or culverts. In Florida, 24 wildlife underpasses with associated fencing were installed over a 64-km stretch of an Interstate Highway to provide cougars and other large mammals safe passage (Foster and Humphrey 1995).

My data indicated that use of habitat near roads may be more related to concealment habitat. However, for females, differential habitat selection occurred near roads based on age class. Because individual cougars with a lower social status may not be able to regularly exploit high-quality habitat, certain landscape modifications related to roads could enhance habitat for the species. Closing or limiting access to Class 3 roads (to create more remote Class 4 roads) and managing for increased understory vegetation near Class 3 and Class 4 roads may increase use of habitat by cougars. Class 3 roads that travel through high-quality cougar habitat (based on prey abundance and stalking topography) could be targeted for closure. Forests within roadless areas could be managed for human use (e.g., timber harvesting) if the landscape was managed within the framework in which it evolved. In the Black Hills, this management would include logging pine, but maintaining or increasing appropriate species of understory vegetation within logged stands, and in tributary draws and along riparian zones (Froiland 1990). Increased understory vegetation would provide cougars concealment cover and benefit other species, including deer. In the Black Hills, white-tailed deer also used habitat near roads when dense understory vegetation was present (DePerno et al. 2002, Klaver 2001).

In February 2003, the status of the cougar in South Dakota was changed to a game animal with a closed hunting season (SDGF&P 2003). If hunted for recreation, road closures could especially be important for the long-term sustainability of the population because Black Hills cougars may be more sensitive to a population crash than other larger and less isolated populations. Currently, cougars are hunted in the Wyoming Black Hills and quotas have increased in the last 3 years. During the winters of 1998 to 2002, 1,1,3, and 7 cougars, respectively, were harvested from the Wyoming Black Hills Unit (Wyoming Game and Fish Department Cougar Harvest Summaries 1998–2002). Where cougars are hunted, the extensive road system results in a decreased ability of individual cougars to remain undetected by hunters (or poachers) searching for tracks (Logan and Sweanor 2001, Jalkotzy et al. 1999). Due to high road densities, cougars in the Black Hills probably cross roads more often than those of other populations, making their presence more visible after snowfall. Thus, hunter success rate would potentially be high and should be taken into consideration when designing a harvest strategy. Road density standards have been suggested to maintain viable, local carnivore populations (grizzly bears [*Ursus arctos*] in Montana [0.31 km/km^2], Paquet and Hackman 1995; black bears [*Ursus americanus*] in Maryland [1.14 km/km^2], Fecske et al. 2002; black bears in North Carolina [<0.5 km/km^2], Brody 1984). Hunted populations of carnivores likely require lower road densities than unhunted populations due to increased fear of human activity (Hellgren and Maehr 1993). Therefore, regional variation in road density standards for a given species might occur (Fecske et al. 2002). Cougars in the Black Hills are using habitat with road densities at 2.2 km/km^2. Road density standards should be established to maintain viable cougar populations and adjusted accordingly if the population becomes hunted because hunting could further decrease use of habitat by cougars near roads.

Regardless of hunting, road closure would benefit cougars by limiting human access to remote country and thus, minimizing human/cougar encounters. Human encroachment associated with roads (i.e., residential or summer homes) threatens survival of individual cougars due to a lack of human tolerance for their presence (Logan and Sweanor 2001). Thus, land planners could build future roads and housing projects away from habitat considered high-quality for cougars. Additionally, population trends could be monitored using road kills as an index of abundance in conjunction with other population surveys. Frequency of road mortalities has been proposed as an index of relative abundance to monitor population trends in carnivores (i.e., polecats, *Mustela putorius*, [Birks and Kitchener 1999], raccoons, *Procyon lotor* [Clark and Andrews 1982], and skunks, *Mephitis mephitis* [Bartlett and Martin 1982]); a similar approach also may be applicable to cougars in the Black Hills. If the population remains stable, in areas where cougars are more likely to cross Class

1 and 2 roads, wildlife crossing signs could be placed to increase public awareness of potential cougar crossings to decrease mortality.

Table 19. Mean median distances (km) of adult male (M, 11 annual data sets from 5 adult male cougars) and female (F, 7 annual data sets from 4 female cougars) cougar locations (*N*) to roads by road class (Class 1, 2, 3, and 4 roads) in the Black Hills, South Dakota and Wyoming (1998–2001). Significant differences between median distances of cougar and random locations to roads were determined using Kruskal-Wallis tests. Alpha = 0.10, Bonferroni correction Alpha = 0.033.

Sex	Road Class	*N*	Mean median distance: cougar locations	Mean median distance: random locations	Mann-Whitney U	*P*-value
MF	Class 3	18	0.335	0.205	276	< 0.001 -[1]
MF	Class 4	18	0.541	0.484	180	0.569
F	Class 1	7	4.5	4.6	23.5	0.898
F	Class 2	7	3.6	4.1	20	0.564
F	Class 3	7	0.295	0.193	46	0.006 -
F	Class 4	7	0.509	0.446	26	0.848
M	Class 3	11	0.361	0.212	97.5	0.015 -
M	Class 4	11	0.562	0.508	66	0.718

[1] - Selection for habitat away from roads.

Table 20. Median distances (km) of male (M) and female (F) cougar locations (*N*) to roads by road class (Class 1, 2, 3, and 4 roads) in the Black Hills, South Dakota and Wyoming (1998–2001). Significant differences between median distances of cougar and random locations to roads were determined using Kruskal-Wallis tests. Alpha = 0.10, Bonferroni correction Alpha = 0.025.

Road Class	Sex	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
1	F	322	4.8	4.9	47256	0.970
2	F	322	3.4	3.7	46313	0.696
3	MF	768	0.286	0.205	328199	< 0.001 -[1]
3	F	322	0.284	0.199	57307	< 0.001 -
3	M	446	0.287	0.216	111467.5	< 0.001 -
4	MF	704	0.488	0.478	238970	0.414
4	F	297	0.439	0.407	41895	0.279
4	M	407	0.505	0.519	80731	0.866

[1] - Selection for habitat away from roads.

Table 21. Median distances (km) of female (F) cougar locations (*N*; 7 annual data sets from 4 cougars) to roads by road class (Class 1, 2, 3, and 4 roads) in the Black Hills, South Dakota and Wyoming (1998–2001). Significant differences between median cougar and random locations were determined using Kruskal-Wallis tests. Alpha = 0.10, Bonferroni correction Alpha = 0.014.

Cougar ID	Road Class	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
F6-2000	Class 1	42	2.0	2.7	727	0.166
F6-2000	Class 2	42	1.5	1.5	8490	0.768
F6-2000	Class 3	42	0.357	0.244	1039	0.160
F6-2000	Class 4	39	0.359	0.312	789	0.776
F6-2001	Class 1	48	2.0	1.8	1335	0.180
F6-2001	Class 2	48	2.0	2.8	833	0.019
F6-2001	Class 3	48	0.404	0.182	1619	0.001 -[1]
F6-2001	Class 4	33	0.393	0.337	587	0.586
F8-2000	Class 1	27	4.4	2.2	424	0.303
F8-2000	Class 2	27	6.0	6.6	319	0.431
F8-2000	Class 3	27	0.205	0.169	403	0.505
F8-2000	Class 4	27	0.272	0.467	245	0.039
F9-2000	Class 1	44	6.7	8.3	803	0.169
F9-2000	Class 2	44	4.5	4.2	1081	0.346
F9-2000	Class 3	44	0.295	0.221	1155	0.119

Table 21. (Cont.)

Cougar ID	Road Class	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
F9-2000	Class 4	37	0.296	0.317	666	0.841
F9-2001	Class 1	47	5.9	6.7	866	0.071
F9-2001	Class 2	47	4.6	5.3	1047	0.664
F9-2001	Class 3	47	0.278	0.203	1281	0.182
F9-2001	Class 4	47	0.323	0.286	1097	0.955
F10-2000	Class 1	40	5.0	5.8	843	0.679
F10-2000	Class 2	40	4.1	4.8	653	0.157
F10-2000	Class 3	40	0.299	0.175	1026	0.030
F10-2000	Class 4	40	1.080	0.633	1037	0.023
F10-2001	Class 1	45	5.2	4.6	1065	0.672
F10-2001	Class 2	45	2.8	3.7	800	0.086
F10-2001	Class 3	45	0.230	0.160	1348	0.007 -
F10-2001	Class 4	45	0.839	0.772	1109	0.436

[1] - Selection for habitat away from roads.

Table 22. Median distances (km) of locations of male (M) cougar locations (11 annual data sets from 5 cougars) to roads by road class (Class 1, 2, 3, and 4) in the Black Hills, South Dakota and Wyoming (1998–2001). Significant differences between median cougar and random locations were determined using Kruskal-Wallis tests. Alpha = 0.10, Bonferroni correction Alpha = 0.009.

Cougar ID	Road Class	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
M1-1999	Class 3	52	0.215	0.165	1499	0.339
M1-1999	Class 4	52	0.591	0.604	1456	0.499
M1-2000	Class 3	37	0.174	0.106	844	0.085
M1-2000	Class 4	37	0.759	0.676	779	0.307
M1-2001	Class 3	40	0.263	0.133	977	0.089
M1-2001	Class 4	40	0.870	0.591	908	0.299
M2-1999	Class 3	46	0.239	0.263	1068	0.938
M2-1999	Class 4	46	0.324	0.329	1070	0.925
M2-2000	Class 3	48	0.255	0.226	1259	0.433
M2-2000	Class 4	46	0.238	0.311	953	0.412
M2-2001	Class 3	34	0.343	0.230	693	0.158
M2-2001	Class 4	27	0.415	0.247	419	0.346
M3-1999	Class 3	25	0.745	0.195	454	0.006 -[1]
M3-1999	Class 4	7	0.547	0.134	35	0.180
M4-1999	Class 3	34	0.257	0.198	652	0.364

Table 22. (Cont.)

Cougar ID	Road Class	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
M4-1999	Class 4	34	0.589	0.841	376	0.013
M4-2000	Class 3	42	0.308	0.241	983	0.336
M4-2000	Class 4	42	0.680	0.670	913	0.782
M4-2001	Class 3	39	0.459	0.211	1045	0.004 -
M4-2001	Class 4	31	0.644	0.666	456	0.730
M12-2001	Class 3	36	0.712	0.363	785	0.123
M12-2001	Class 4	32	0.522	0.522	525	0.861

[1] - Selection for habitat away from roads.

Table 23. Selection of habitat near Class 3 roads by 10 adult cougars using Manly's Alpha Preference Index (Manly 1972). The first quartile distance (0.132 km, n = 768 locations) represented the maximum distance considered to be close to a road. Roads were buffered by 0.132 km plus maximum telemetry error (0.5 km). Percent habitat use was determined by overlaying cougar locations that fell within the first quartile distances to roads onto a ranked cougar habitat-relation model (Chapter 5); ranks ranged 5–18, where rank 18 represented highest-quality habitat for cougars. Percent habitat availability was determined by overlaying buffered roads onto the habitat-relation model. Alpha values measure the probability of selecting a rank of habitat when all habitat ranks are equally available (Krebs 1989). Habitat ranks with values greater than Manly's Alpha were selected and ranks with values lower, were avoided.

Habitat Rank	Class 3 Roads (*n* = 400) Manly's Alpha = 0.11			Class 4 Roads (*n* =) Manly's Alpha 0.11		
	%U	%A	Alpha	%U	%A	Alpha
5–10	0.60	1.77	0.04	0.93	2.17	0.05
11	3.14	5.11	0.07	2.80	5.40	0.06
12	10.42	13.16	0.09	10.26	13.17	0.09
13	19.20	21.26	0.10	18.90	21.14	0.10
14	26.10	24.52	0.12 *	26.01	24.43	0.12 *
15	24.32	20.82	0.13 *	24.92	20.47	0.14 *
16	11.67	9.72	0.14 *	11.67	9.61	0.14 *
17	3.69	3.02	0.14 *	3.66	2.99	0.14 *
18	0.85	0.61	0.16 *	0.85	0.61	0.16 *

Table 24. Comparison of median road densities (RD; m/km²) by road class between cougar annual home ranges [90% Adaptive Kernel (AK)], in core-use areas (50% AK), and road density in the Black Hills study area, South Dakota and Wyoming (1998–2001). Significant differences between road densities in annual and core-use area were determined using the Kruskal-Wallis tests with Bonferroni corrections for alpha. Significant differences between road densities in 90% AK and 50% AK ranges and the Black Hills study area were determined using the signed rank test. Alpha = 0.10, Bonferroni correction Alpha = 0.02.

Road Class	Sex	*N*	RD (m/km²) (90 AK)	RD (m/km²) (50 AK)	Mann-Whitney U	*P*-value	RD (m/km2) Black Hills Study Area	y[1] (90 AK)	*P*-value[2] (90 AK)	y[1] (50 AK)	*P*-value[2] (50 AK)
All	MF	18	2,170	2,500	219	0.071	2,140	11	0.881	11	0.881
All	F	7	2,292	2,957	42	0.025	2,140	6	0.992 +	6	0.992 +
All	M	11	2,117	2,015	72	0.570	2,140	5	0.500	5	0.500
1	F	7	28	0	8	0.033	60	3	0.500	3	0.500
2	F	7	49	2	19	0.477	34	5	0.937	3	0.500
3	MF	18	1,539	1,722	213	0.107	1,542	9	0.593	10	0.760

Table 24. (Cont.)

Road Class	Sex	*N*	RD (m/km^2) (90 AK)	RD (m/km^2) (50 AK)	Mann-Whitney U	*P*-value	Road Density (m/km2) Black Hills Study Area	y[1] (90 AK)	*P*-value[2] (90 AK)	y[1] (50 AK)	*P*-value[2] (50 AK)
3	F	7	1,592	1,976	40	0.048	1,542	4	0.773	5	0.937
3	M	11	1,524	1,472	69	0.577	1,542	5	0.500	5	0.500
4	MF	18	389	508	195	0.296	504	6	0.119	9	0.593
4	F	7	592	885	34	0.225	504	4	0.773	5	0.937
4	M	11	370	450	72	0.450	504	2	0.033	4	0.274

[1] y = in a binomial experiment, the number of successes or the number of positive values resulting from subtracting road density of the Black Hills study area from 90% and 50% AK ranges of cougars.

[2] $P = P(x \leq y, p = 0.5)$ for a given N, where N = number of cougar years.

'+' indicated densities of roads were greater than those in the Black Hills study area.

Table 25. Documented cougar-vehicle collisions (*n* = 10) in the Black Hills, South Dakota (1998–2002).

Date	Sex	Age Class	Road Name	Road Class
Spring 1998	M	1-2	Interstate Highway 90	Class 1
10/10/99	M	<1	U.S. Highway 16	Class 1
11/4/99	M	1-2	Interstate Highway 90	Class 1
11/1/99	F	<1	U.S. Highway 14a	Class 1
12/14/01	U[1]	U	U.S. Highway 85	Class 1
5/10/02	M	3-4	U.S. Highway 16	Class 1
4/26/02	M	1-2	National Forest Road 17	Class 2
8/10/02	F	3	U.S. Highway 14a	Class 1
9/6/02	F	<1	U.S. Highway 385	Class 1
9/5/02	M	<1	County Highway 228	Class 2

[1] U = unknown

Table 26. Crepuscular (Crep.), diurnal, and nocturnal distances (km) of locations (*N*) of female cougar No.6 to roads by road class (All road classes combined, Class 1, 2, 3, and 4 roads) in the Black Hills, South Dakota (November 2001–June 2002). Significant differences between cougar and random locations were determined using the Kruskal-Wallis tests. Alpha = 0.05, Bonferroni correction Alpha = 0.01.

Road Class	Time of Day	*N*	Median distance: (cougar)	Median distance: (random)	Mann-Whitney U	*P*-value
All	Crep.	484	0.813	1.1	106727	0.017
All	Diurnal	808	0.810	1.0	300303	0.005 +[1]
All	Nocturnal	956	0.831	1.1	408596	0.000 +
1	Crep.	121	2.6	3.0	7623	0.579
1	Diurnal	202	2.5	2.5	21901	0.201
1	Nocturnal	239	2.3	2.8	27622	0.534
2	Crep.	121	1.5	2.1	5522	0.001 +
2	Diurnal	202	1.4	1.9	13679	0.000 +
2	Nocturnal	239	1.4	2.3	17785	0.000 +
3	Crep.	121	0.237	0.319	5708	0.003 +
3	Diurnal	202	0.242	0.275	17950	0.037
3	Nocturnal	239	0.283	0.364	23921	0.002 +
4	Crep.	121	0.469	0.526	6827	0.365
4	Diurnal	202	0.403	0.529	18118	0.052
4	Nocturnal	239	0.512	0.550	26957	0.288

[1] + Selection for habitat near roads.

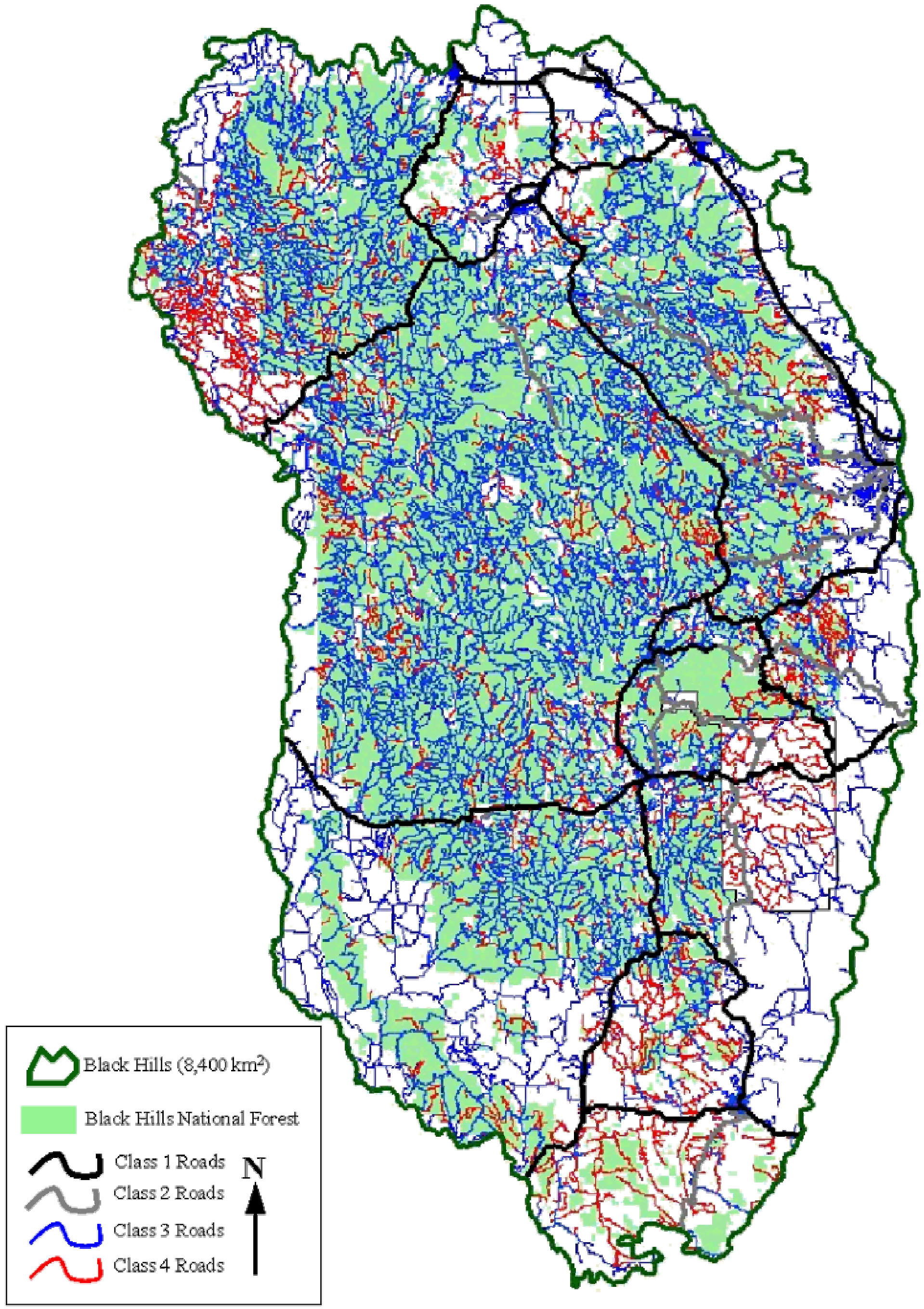


Figure 12. Classification of roads in the Black Hills study area, South Dakota and Wyoming (1998-2001).

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