Annotated Bibliography for the Black Hills Experimental Forest

Updated November 28, 2011

Adams, M. B., L. Loughry, et al. (2004). Experimental Forests and Ranges of the USDA Forest Service. GTR-NE-321 (revised 2008). Newtown Square, PA, USDA Forest Service, Northeastern Research Station: 110.

> The USDA Forest Service has an outstanding scientific resource in the 79 Experimental Forests and Ranges that exist across the United States and its territories. These valuable scientific resources incorporate a broad range of climates, forest types, research emphases, and history. This publication, revised in March 2008, describes each of the research sites within the Experimental Forests and Ranges network, providing information about history, climate, vegetation, soils, long-term data bases, research history and research products, as well as identifying collaborative opportunities, and providing contact information. A section of the publication covers the history of the Black Hills Experimental Forest and describes the general type of research conducted there.

Boldt, C. E. and J. L. Van Deusen (1974). Silviculture of ponderosa pine in the Black Hills: The status of our knowledge. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

> This publication is intended as a guide for professional foresters. It describes major silvicultural conditions likely to be encountered in the Black Hills, reasonable treatment options, and probable results and implications of these treatments. It also describes silvical characteristics and behavior of Black Hills ponderosa pine, and a variety of proven silvicultural tools. The publication draws on research about growing stock levels conducted on the Black Hills Experimental Forest since the early 1960s.

Brown, P. M. (2003). Fire, climate, and forest structure in ponderosa pine forests of the Black Hills. Department of Forest, Rangeland, and Watershed Stewardship. Fort Collins, CO, Colorado State University. PhD: 103.

> The fire history of ponderosa pine forests in the Black Hills was examined using fire-scar and tree-age data spanning the past four to six centuries. Fire chronologies were determined for over 1000 trees collected from over 50 locations, including the Black Hills Experimental Forest. Tree-ring evidence supports the prevailing historical model of frequent surface fires promoting and maintaining mostly open forest stands. However, compared to other ponderosa pine forests in the southwest US or southern Rocky Mountains, forests in the Black Hills burned less frequently and had a greater range of variability in fire behavior. Surface fire frequency varied from an average of every 10 to 13 years at lower elevation sites on the ponderosa pine-northern Great Plains prairie ecotone to as much as 30 to 33 years at higher elevations. Fires largely ceased in all areas shortly after Euro-American settlement began in the 1870s. Pre-settlement age structure documents very pulsed patterns of tree establishment, with the most abundant cohort occurring from 1770 to 1805. Extended wet conditions likely promoted abundant tree regeneration, fast growth, and longer periods between surface fires that would have permitted more trees to reach canopy status, therefore becoming more "fireproof" during later surface fires. The absence of fire was likely more critical to structuring the current forest than any potential variation in fire behavior.

Brown, P. M. (2006). "Climate effects on fire regimes and tree recruitment in Black Hills ponderosa pine forests." Ecology 87(10): 2500-2510.

Climate influences forest structure through effects on both species demography (recruitment and mortality) and disturbance regimes. Here, I compare multi-century chronologies of regional fire years and tree recruitment from ponderosa pine forests in the Black Hills of southwestern South Dakota and northeastern Wyoming to reconstructions of precipitation and global circulation indices. Trees were samples from over 50 locations, including the Black Hills Experimental Forest. Regional fire years were affected by droughts and variations in both Pacific and Atlantic sea surface temperatures. Drought conditions and fires were synchronous with La Ninas, cool phases of the Pacific Decadal Oscillation (PDO), and warm phases of the Atlantic Multidecadal Oscillation (AMO). The opposite pattern (El Nino, warm PDO, cool AMO) was associated with fewer fires than expected. Regional tree recruitment largely occurred during wet periods in precipitation reconstructions, with the most abundant recruitment coeval with an extended pluvial from the late 1700s to early 1800s. Widespread even-aged cohorts likely were not the result of large crown fires causing overstory mortality, but rather were caused by optimal climate conditions that contributed to synchronous regional recruitment and longer intervals between surface fires.

Chen, X., L. Vierling, et al. (2004). "Using lidar and effective LAI data to evaluate IKONOS and Landsat 7 ETM+ vegetation cover estimates in a ponderosa pine forest." Remote Sensing of Environment 91(1): 14-26.

Structural and functional analyses of ecosystems benefit when high-accuracy vegetation coverages can be derived over large areas. This study utilizes IKONOS, Landsat 7 ETM+, and airborne scanning light detection and ranging (lidar) to quantify coniferous forest and understory grass coverages in a ponderosa pine (*Pinus ponderosa*) dominated ecosystem in the Black Hills of South Dakota. Linear spectral mixture analyses of IKONOS and ETM+ data were used to isolate spectral endmembers (bare soil, understory grass, and tree/shade) and calculate their subpixel fractional coverages. We then compared these endmember cover estimates to similar cover estimates derived from lidar data and field measures collected in the Black Hills Experimental Forest. Results demonstrate the power of using high-resolution lidar data to measure effective LAI of confierous forests over large regions and to validate spectral unmixing results of satellite imagery. In addition, IKONOS data and Landsat 7 ETM+ data are useful for making the important distinction between tree/shade coverage and exposed understory grass coverage during peak summertime greenness. Results also suggest that the enhanced vegetation index (EVI) is a more sensitive measure than the normalized difference of vegetation index (NDVI) when using IKONOS multispectral imagery to assess forest cover.

Clawges, R., K. Vierling, et al. (2008). "The use of airborne lidar to assess avian species diversity, density, and occurrence in a pine/aspen forest." Remote Sensing of Environment 112(5): 2064-2073.

This study assesses the utility of light detection and ranging (lidar) data for quantifying vegetation structural characteristics that relate to avian diversity, density, and occurrence. Airborne lidar data was acquired for the Black Hills Experimental Forest in South Dakota,

and vegetation and bird data were collected in the field. Indices of foliage height diversity calculated from lidar data were positively and significantly correlated with indices of bird species diversity, with the highest correlations observed when foliage height diversity categories contained proportionally more foliage layers near the forest floor (< 0.5 m). In addition, lidar-derived indices of vegetation volume were significantly correlated with bird density. The researchers combined lidar-derived vegetation height data with multispectral IKONOS data to delineate habitat types according to the presence of prominent vegetation layers at lower levels of the forest and predominant tree type (deciduous or conifer). Habitat type delineations were tested by examining the occurrence and relative density of two bird species common to the study area that prefer lower level vegetation for foraging and nesting. Dark-eyed Juncos were significantly associated with the 0.5–2.0 m high vegetation layer in pine-dominated stands, and Warbling Vireos were significantly associated with this same layer in aspen-dominated stands. These results demonstrate that discrete-return lidar can be an effective tool to remotely quantify vegetation structural attributes important to birds, and may be enhanced when used in combination with spectral data.

Dix, M. E., A. D. Tagestad, et al. (1984). Detecting tip mining Olethreutinae (Tortricidae) moths in the northern and central Great Plains with synthetic attractants. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

This study explored the use of synthetic attractants to trap male Olethreutinae moths in the northern and central Great Plains. Fifteen sites, including one in the Black Hills Experimental Forest, were surveyed during late spring and early summer 1984. Twenty-one tortricid species, four noctuid species, one pyralid species, and one gelechid species were caught in the traps, with no species being caught at every site. Species varied in the time of the month they were caught and the synthetic compounds they were attracted to. Overall, results demonstrate that several compounds can be used to document the presence and determine the distribution and flight period of a specific moth.

Dykstra, D. (2002). Short-term studies of ecosystem-atmosphere CO2 exchange at the Black Hills Experimental Forest flux tower site. Rapid City, SD, South Dakota School of Mines and Technology. M.S.: 78.

Fettig, C. J., K. K. Allen, et al. (2006). "Effectiveness of bifenthrin (*Onyx*) and carbaryl (Sevin SL) for protecting individual, high-value conifers from bark beetle attack (Coleoptera: Curculionidae: Scolytinae) in the Western United States." Journal of Economic Entomology 99(5): 1691-1698.

This study explores the effectiveness of two different insecticides for protecting individual trees from various species of bark beetles (western pine beetle [*Dendroctonus brevicomis*], mountain pine beetle [*D. ponderosae*], *Ips* spp, pinyon ips [*I. confusus*], and spruce beetle [*D. rufipennis*]). Research was conducted on *Pinus ponderosa* trees in Arizona, California, and the Black Hills Experimental Forest in South Dakota; *P. contorta* in Montana; *P. edulis* in Colorado; *P. monophylla* in Nevada; and *Picea engelmannii* in Utah. Few trees were attacked by *Ips* spp. in Arizona, so that study was discontinued. Sevin SL (2.0%) was effective for protecting *P. ponderosa*, *P. contorta*, and *P. monophylla* for two field seasons. Estimates of efficacy could not be made during the second field season in *P. edulis* and *P. engelmannii* due to insufficient mortality in untreated, baited control trees. Two field

seasons of efficacy was demonstrated in *P. ponderosa* against *D. brevicomis* and *P. monophylla* against *I. confusus* for 0.06% Onyx. We conclude that Onyx is an effective individual tree protection tool, but repeated annual applications may be required in some systems if multiyear control is desired.

Hansen, C. P. (2009). Occupancy modeling of ruffed grouse in the Black Hills National Forest. Columbia, MO, University of Missouri. M.Sc.: 134.

Ruffed grouse (*Bonasa umbellus*) is an important game bird and the management indicator species for quaking aspen (*Populus tremuloides*) in the Black Hills National Forest (BHNF). The BHNF seeks the development a robust monitoring protocol to evaluate the status, trends, and habitat associations of ruffed grouse. This study combined roadside drumming counts with occupancy modeling to determine ruffed grouse occupancy estimates, detection probabilities, and micro-habitat preferences. Drumming surveys were conducted at about 400 locations, including several in the Black Hills Experimental Forest. Estimates of ruffed grouse occupancy were constant between spring 2007 and 2008 (psi = 0.12, SE = 0.03) and positively influenced by the amount of aspen. Estimates of detection probability were also constant between spring 2007 and 2008 (p = 0.27, SE = 0.06). Detection probability was influenced by survey date in a quadratic form and negatively influenced by wind speed at the time of the survey. Ruffed grouse selection of micro-sites was largely driven by vegetative cover above 1 meter in height, likely due to increased protection from predators. The most appropriate sampling design for monitoring of ruffed grouse on the BHNF is a standard multi-season design with 3 repeat surveys at each site. The number of sites necessary to achieve occupancy estimates with adequate precision is high due to low ruffed grouse occupancy and detection rates. Evaluating both broad-scale occupancy and small-scale activity center selection will make monitoring protocol for ruffed grouse more robust, and it will lead to findings that can help forest managers improve conditions for ruffed grouse at both the population and individual level in the BHNF.

Hansen, C. P., J. J. Millspaugh, et al. (2011). "Occupancy modeling of ruffed grouse in the Black Hills National Forest." Journal of Wildlife Management 75(1): 71-77.

Ruffed grouse (*Bonasa umbellus*) is an important game bird and the management indicator species for quaking aspen (*Populus tremuloides*) in the Black Hills National Forest (BHNF). The BHNF seeks the development a robust monitoring protocol to evaluate the status, trends, and habitat associations of ruffed grouse. This study combined roadside drumming counts with occupancy modeling to determine ruffed grouse occupancy estimates, detection probabilities, and micro-habitat preferences. Drumming surveys were conducted at about 400 locations, including several in the Black Hills Experimental Forest. Estimates of ruffed grouse occupancy were constant between spring 2007 and 2008 (psi = 0.12, SE = 0.03) and positively influenced by the amount of aspen. Estimates of detection probability were also constant between spring 2007 and 2008 (p = 0.27, SE = 0.06). Detection probability was influenced by survey date in a quadratic form and negatively influenced by wind speed at the time of the survey. Overall, ruffed grouse occupancy and detection probabilities in the BHNF were low, but results suggest that occupancy could be enhanced by increasing the extent of aspen. To improve monitoring efficiency and maximize probability of detecting ruffed grouse, drumming surveys should be conducted

during the peak of drumming (mid-May), during favorable weather conditions such as low wind speeds, and during early morning.

Hansen, C. P., M. A. Rumble, et al. (2010). Monitoring ruffed grouse in the Black Hills: Protocol and user's manual for the occupancy spreadsheet program. Fort Collins, CO.

Monitoring ruffed grouse (*Bonasa umbellus*) in the Black Hills National Forest is a priority for forest managers due to the bird's status as the management indicator species for quaking aspen (*Populus tremuloides*) and its value to hunters and other recreational groups. We conducted drumming surveys at about 400 locations, including several in the Black Hills Experimental Forest, to estimate occupancy and assess the influence of sampling and site variables on estimates of detection probability. Using these estimates and simulations, we developed a monitoring protocol for ruffed grouse in the Black Hills. We then created a user-friendly program in Microsoft Excel that calculates ruffed grouse occupancy and detection probability estimates. (The program is available at http://www.fs.fed.us/rm/forest-grassland-lab/products/ruffed-grouse-occupancy.) The user's manual herein briefly describes the theory behind occupancy modeling and explains how to enter and analyze data and interpret results from drumming surveys. Additionally, we provide recommendations on which type of occupancy and detection probability estimates should be calculated, depending on the needs of the investigator. The program does not provide precision estimates for heterogeneous occupancy or detection probabilities.

Hoffman, G. R. (1986). An ecological study of the vegetation of the Black Hills National Forest of South Dakota and Wyoming: A habitat type classification. Vermilion, SD, University of South Dakota, Department of Biology.

A vegetation classification based on concepts and methods developed by Daubenmire was used to identify 12 forest habitat types and one shrub habitat type in the Black Hills. Study plots were located across the Black Hills, including the Black Hills Experimental Forest. Two of the habitat types identified fall in the *Quercus macrocarpa* series, seven in the *Pinus ponderosa* series, one in the *Populus tremuloides* series, two in the *Picea glauca* series, and one in the *Cercocarpus montanus* series.

Hoffman, G. R. and R. R. Alexander (1987). Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: A habitat type classification. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

A vegetation classification based on concepts and methods developed by Daubenmire was used to identify 12 forest habitat types and one shrub habitat type in the Black Hills. Study plots were located across the Black Hills, including the Black Hills Experimental Forest. Two of the habitat types identified fall in the *Quercus macrocarpa* series, seven in the *Pinus ponderosa* series, one in the *Populus tremuloides* series, two in the *Picea glauca* series, and one in the *Cercocarpus montanus* series. This publication includes a key for identifying habitat types and a discussion of management implications associated with each type.

Huntsman, B. O., R. W. Baumann, et al. (1999). "Stoneflies (Plecoptera) of the Black Hills of South Dakota and Wyoming, USA: Distribution and zoogeographic affinities." Great Basin

Naturalist 59(1): 1-17.

This study surveyed stonefly (Plecoptera) fauna of the Black Hills and examined zoogeographic affinities. Twenty-seven species representing 22 genera and 6 families were found, including 15 new state records for South Dakota and 2 for Wyoming. Authors also examined specimens from various institutions, with several of these specimens collected from streams in the Black Hills Experimental Forest. An analysis of the North American distribution of each species showed a strong relationship between the Black Hills and the Rocky Mountains, with much weaker relationships between the Black Hills and eastern and northern regions. Evidence suggests that the Black Hills fauna is a result of expansion and subsequent vicariance of stonefly populations during Pleistocene climatic oscillations.

Markstrom, D. C., H. E. Troxell, et al. (1983). "Wood properties of immature ponderosa pine after thinning." Forest Products Journal 33(4): 33-36.

This study was conducted to determine whether there are significant differences in wood properties of stemwood from trees grown under different silvicultural regimes. Trees from three growing stock levels in sapling and pole stands at the Black Hills Experimental Forest (20, 60, and 100 square feet per acre) were sampled at three vertical positions along the stem for their wood properties. Wood grown during the 10-year period after initial thinning was compared for growth and wood properties. Wide differences in radial growth, induced by thinning treatments, were not accompanied by significant differences in specific gravity, latewood percentage, tracheid length, nor microfibril angle. In contrast, all properties except microfibril angle were significantly affected by vertical position on the stem.

Mills, T. R. (1994). The effects of forest management on birds in the Black Hills, South Dakota. Wildlife and Fisheries Sciences Department. Brookings, SD, South Dakota State University. M.Sc.: 134.

The purpose of this study was to assess bird species and populations in relation to 13 different forest structures and compositions as affected by management practices and to assess the habitat capability model (HABCAP) used by the Forest Service. Non-game birds were counted in seven structural stages of ponderosa pine (*Pinus ponderosa*), four structural stages of quaking aspen (*Populus tremuloides*), and meadow habitats in the Black Hills National Forest (BNHF) and Black Hills Experimental Forest during 1992 and 1993. Sixty-nine species were observed in total, with species richness and diversity being higher ($p<0.1$) in aspen than in ponderosa pine or meadows. Sapling-pole structural stages of aspen with moderate overstory canopy cover (40-70%) had the highest species richness and diversity. Hierarchical log-linear analysis was used to model variation in abundance of 21 bird species among structural stages, years, sample sessions, and interactive sources of variation. Variation due to structural stages was evident for all species except Warbling Vireos, and annual and sample session variation was specific to individual species. Assessment of the HABCAP model showed that several species needed to be added and coefficients had to be revision to customize the model to the BHNF.

Mills, T. R., M. A. Rumble, et al. (1996). Evaluation of a habitat capability model for nongame birds in the Black Hills, South Dakota, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

The Black Hills National Forest uses a habitat capability model (HABCAP) to predict consequences of land management decisions on wildlife, but its accuracy is largely unknown. We tested this model's predictive accuracy for nongame birds in 13 vegetative structural stages of ponderosa pine (*Pinus ponderosa*), aspen (*Populus tremuloides*)/birch (*Betula papyrifera*), and meadow habitats in the Black Hills National Forest and Experimental Forest from 1992 through 1994. We used data collected during the first two years to test HABCAP model coefficients for 11 species, and develop coefficients for 9 species not included in the existing model. We then made a different-time-and-location test of the revised model coefficients for all 20 species. The final model provides managers with more accurate assessments of effects of alternative forest management practices on nongame birds.

Oliver, W. W. and C. B. Edminster (1986). Growth of ponderosa pine thinned to different stocking levels in the western United States. Future Forests of the Mountain West: A Stand Culture Symposium, Missoula, MT, USDA Forest Service, Intermountain Research Station.

Growth of ponderosa pine was studied by the western Forest and Range Experiment Stations of the USDA Forest Service in response to increasing demands for better and more precise estimates of yields possible through intensive management. We summarized results of 15 to 20 years of growth after thinning each of five stands to a wide range of stocking levels. The stands--two in the Black Hills of South Dakota (the Brownsville plots and plots on the Black Hills Experimental Forest), and one each in northern Arizona, central Oregon, and northern California--ranged in size from small saplings to large poles and in age from about 20 to 90 years. Within the fundamental constraints of site quality, thinning influenced growth markedly and, on the better sites, stands were more responsive to manipulation than they were on poorer sites. Results at every installation demonstrated the marked decline in volume production and, conversely, the rapid attainment of merchantable-sized material at low residual stand densities.

Orr, H. K. (1973). The Black Hills (South Dakota) flood of June 1972: Impacts and implications. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Rains of 12 inches or more in 6 hours fells on the east slopes of the Black Hills the night of June 9, 1972. Resulting flash floods exacted a disastrous toll in human life and property. Rainfall and discharge so greatly exceeded previous records that recurrence intervals have been presented in terms of multiples of estimated 50- or 100- year events. Quick runoff was produced in the heaviest rainfall areas regardless of hydrologic condition. Flood sources included all major geologic and soil types and practically all land uses in the Black Hills. The highest measured peak runoff per unit area came from a 7-mile drainage, all on sedimentary formations, the upper portion of which burned over in 1936, but which is now well vegetated, apparently stable, and in good hydrologic condition. Greatest damage occurred where man-origin debris piled up against bridges, highways, homes, and other improvements.

Orr, H. K. (1975). Watershed management in the Black Hills: The status of our knowledge. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

This paper describes the climate, geology, soils, vegetation, and water yields of the Black Hills National Forest, including the Black Hills Experimental Forest. It also provides a

review and discussion of watershed management research and problems unique to the Black Hills. Research needs with respect to water quality, data collection, and model development are highlighted.

Rowell, E., C. Seielstad, et al. (2006). "Using laser altimetry-based segmentation to refine automated tree identification in managed forests of the Black Hills, South Dakota." Photogrammetric Engineering and Remote Sensing 72(12): 1379-1388.

The success of a local maximum (LM) tree detection algorithm for detecting individual trees from lidar data depends on stand conditions that are often highly variable. A laser height variance and percent canopy cover (PCC) classification was used to segment a 2600-ha portion of the Black Hills Experimental Forest based on stand condition prior to stem detection. The area is dominated by *Pinus ponderosa*, with lesser concentrated populations of *Picea glauca*, *Populus tremuloides*, and *Betula papyrifera*. The performance of the LM algorithm was tested using canopy height model (CHM) smoothing decisions and crown width estimation for each stand condition ranging from open savannah to multi-strata stands. Results showed that CHM smoothing improves stem predictions for low density stands and no CHM smoothing better detects stems in dense even-aged stands, specifically dominant and co-dominant trees. At a threshold of approximately 2200 stems ha-1, stem detection accuracy is no longer obtainable in any stand condition.

Schmid, J. M., S. A. Mata, et al. (1991). "Bark temperature patterns in ponderosa pine stands and their possible effects on mountain pine beetle behavior." Canadian Journal of Forest Research 21(10): 1439-1446.

This study explored the impact of growing stock level on bark temperatures of ponderosa pine (*Pinus ponderosa* Laws.) due to the potential of higher temperatures to deter mountain pine beetles (*Dendroctonus ponderosae* Hopk.). Bark temperatures on the north and south sides of five ponderosa pines in each of four growing stock levels in the Black Hills Experimental Forest and Brownsville plots in the Black Hills National Forest, were monitored periodically from May through August 1989. Bark temperatures were generally higher on trees in plots with lower growing stock levels, especially around noon, and north-side temperatures were cooler and less variable than south-side temperatures. Diurnal differences in temperature were greatly influenced by the amount of cloud cover. Authors suggest that un-thinned stands may be preferred by mountain pine beetles because temperatures seldom exceed 80 degrees Fahrenheit, even during midday.

Schmid, J. M., S. A. Mata, et al. (1991). "Water potential in ponderosa pine stands of different growing-stock levels." Canadian Journal of Forest Research 21(6): 750-755.

Water potential was measured in ponderosa pine stands to quantify water stress under different stocking levels and to examine the role of water stress in the susceptibility of trees to infestation by mountain pine beetles (*Dendroctonus ponderosae*). Measurements were taken on five ponderosa pine (*Pinus ponderosa* Laws.) in each of four stands of different growing-stock levels at the Black Hills Experimental Forest and Brownsville plots in the Black Hills National Forest. Mean water potentials at dawn and midday varied significantly among growing-stock levels at one location, but differences were not consistent. Mean dawn and midday water potentials within growing-stock levels

significantly decreased during the summer but showed minor increases during the overall decline. Stress levels were considered high enough to influence physiological functioning and, therefore, influence susceptibility to attack by mountain pine beetles. However, mountain pine beetle infestations did not develop within the stressed stands, suggesting that resistance may be only one factor in the outbreak scenario.

Severson, K. E. and C. E. Boldt (1977). "Options for Black Hills forest owners: Timber, forage, or both." Rangeman's Journal 4(1): 13-15.

Experiments were started in the early 1960s on the Black Hills Experimental Forest to determine the effects of thinning on the production and quality of wood and forage. Six different growing stock levels (GLS) were established in ponderosa pine forests to explore a wide range of management options (20, 40, 60, 80, 100, and 120 square feet per acre). A decade following the original thinning, forage production was measured in the 20, 60, and 100 GLS treatments as well as in unthinned stands. Clearcuts were also established to monitor forage production. Responses in wood production to treatments were irregular, but noticeable decreases in wood production per unit of growing stock at the upper GSLs suggests that stands at 60 square feet per acre and above are fully stocked with trees. Wood properties did not show marked differences between GSLs. Forage production was highest at GSL 20; surprisingly, there was significantly less forage on clearcut stands, potentially due to higher levels of evapotranspiration. No significant differences were found in nutritive components between GSLs for the sampled shrub, forb, and grass species. If managing for both timber and forage, GSLs between 60 and 100 in both the sapling and pole classes maximize site potential. Thus, good timber management can also produce suitable range and wildlife habitat in the Black Hills.

Severson, K. E. and G. E. Chester (1974). Growth characteristics of bearberry in the Black Hills. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

It can be difficult to identify current annual growth on bearberry (*Arctostaphylos uva-ursi*), an evergreen shrub, because its growth varies widely between plants and between sites. A study was initiated in the Black Hills Experimental Forest in 1971 to assess growth patterns of bearberry and to determine which morphological characteristics are useful for identifying current annual growth. Most annual growth (66 percent) occurrs during June when moisture and temperature conditions are apparently optimum. Annual growth can be readily recognized by the presence of nodes and by color changes, with new growth on stems tending to be lighter in color.

Severson, K. E. and D. W. Uresk (1988). "Influence of ponderosa pine overstory on forage quality in the Black Hills, South Dakota." Great Basin Naturalist 48(1): 78-82.

This study compared nutritive attributes in understory plant species from sapling and pole ponderosa pine (*Pinus ponderosa*) stands growing at five stocking levels ranging from clear-cuts (0 m2/ha basal area) to unthinned (40 m2/ha basal area). Forage quality was assessed in pole and sapling ponderosa pine stands growing at five stocking levels - 0, 5. 14, 23, and unthinned (which approximated 40 m2/ha basal area)-in the Black Hills Experimental Forest. Crude protein, acid detergent fiber, acid detergent lignin, ash, calcium, and phosphorus were evaluated for cream peavine (*Lathyrus ochroleucus*), bearberry (*Arctostaphylos uva-ursi*), and timber oatgrass (*Danthonia intermedia*). Acid

detergent fiber, acid detergent lignin, and ash showed some significant differences among growing stock levels for cream peavine growing in sapling stands. Crude protein content of timber oatgrass was different among growing stock levels in pole stands. In all cases, however, no trends or patterns relative to stocking levels were evident. In general, modifying the overstory of ponderosa pine in the Black Hills by clearcutting or thinning did not result in predictable changes in nutritional values of selected understory species.

Shepperd, W. D. and M. A. Battaglia (2002). Ecology, silviculture, and management of Black Hills ponderosa pine. Fort Collins, CO, USDA Forest Service, Rocky Mountain Research Station.

This broad-based synthesis discusses the general ecology and silviculture of the ponderosa pine (*Pinus ponderosa*) ecosystem in the Black Hills. This paper draws on information and results of research on ponderosa pine from numerous sources within the Black Hills ecosystem, including research conducted on the Black Hills Experimental Forest. Both even- and uneven-aged silviculture systems are described, and management alternatives are presented that can be used to produce and maintain desired growth and stocking conditions for a variety of natural resource objectives. Unlike previous synthesizes of ponderosa pine in the Black Hills, this paper broadens the discussion to include natural disturbances that govern ecosystem processes in this ecosystem, wildlife habitat and management, and watershed management of the Black Hills.

Shepperd, W. D. and S. E. McElderry (1986). "Ten-year results of a ponderosa pine progeny test in the Black Hills." Western Journal of Applied Forestry 1(3): 79-83.

A study was initiated in 1967 to determine the extent of genetic variation in silviculturally important traits of ponderosa pine (*Pinus ponderosa*) and to identify superior genotypes for use in local tree improvement programs. Seeds were collected from parent trees throughout the Black Hills and planted as 2-0 stock on the Black Hills Experimental Forest. This paper reports and compares ten-year survival and growth of open-pollinated progenies of 77 parent trees using a cluster-analysis technique. Five clusters were identified that account for most of the variability in survival and growth of the open-pollinated families. One cluster, containing 6 families, exhibited exceptional survival and growth. Another, containing 12 families, exhibited poor survival and growth. The performance of families in these two groups appears to be related to location and elevation of parent trees.

Smith, R. C., W. B. Kurtz, et al. (1988). "Cost efficiency of pruning Black Hills ponderosa pine." Western Journal of Applied Forestry 3(1): 10-14.

Trees pruned in stands of ponderosa pine (*Pinus ponderosa*) managed at several growing stock levels were used to determine the number of years for pruning wounds to heal. The 46 pine trees included in this study were located on the Black Hills Experimental Forest and pruned in 1962. The mean time for pruning wounds to heal was 11 years, and comparison of different stock densities showed that this was quicker where the density was lower. Costs and returns from pruning the butt log of trees to be retained to final harvest were also analyzed. Trees pruned to 17.5 ft (for 16-ft lumber) would earn real internal rates of return (IRR) of 7.8-14.0%, those pruned to 8.5 ft (for 8-ft lumber) earned somewhat higher IRRs at 8.6-16.1%. Overall, financial outcomes are best on productive sites if pruning costs are kept low and high-valued products are anticipated.

Toomey, M. and L. A. Vierling (2005). "Multispectral remote sensing of landscape level foliar moisture: Techniques and applications for forest ecosystem monitoring." Canadian Journal of Forest Research 35(5): 1087-1097.

Broad-scale monitoring of varying moisture levels of leaves has ramifications for understanding fire potential, biogeochemistry, and ecosystem dynamics. Five different shortwave infrared (SWIR)-derived spectral indices, principal components analysis (PCA), and the tasseled cap transformation (TCT), derived from Landsat Thematic Mapper (TM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data, were used to quantify landscape-level foliar moisture in ponderosa pine (*Pinus ponderosa*) stands within and proximal to the Black Hills Experimental Forest. Landsat TM data demonstrated stronger correlations with field-based estimates of foliar moisture than did ASTER data. The authors suggest that spectral indices and TCT are more practical for ecosystem moisture monitoring than PCA because of the empirical nature of PCA. They also recommend modifications to existing methods of satellite-based fire susceptibility monitoring to account for primary effects of vegetation curing and temporal variation in ground fuels.

Uresk, D. W., D. R. Dietz, et al. (1975). "Constituents of in vitro solution contribute differently to dry matter digestibility of deer food species." Journal of Range Management 28(5): 419-421.

This study assessed the response of plants to the chemical constituents used in a common in vitro technique used to measure the digestibility of deer food. Plant material was collected from the Black Hills Experimental Forest and consisted of dormant or dead leaves and stems of five species commonly eaten by deer during the fall. Apparent digestibility was lowest, 28-29%, for water alone, buffer alone, and buffer plus pepsin. Dry matter loss increased to 32-33% with either buffer + alcohol + HCl or buffer + alcohol + HCI + pepsin. Highest apparent digestibility, 44%, was reached with the addition of rumen fluid from white-tailed deer (*Odocoileus virginianus dacotensis*). HCl contributed significantly to digestion, but pepsin did not. This was the most surprising and significant discovery of this experiment, one which the authors propose might be explained by the low protein value of dead and dormant plants.

Uresk, D. W., C. B. Edminster, et al. (2000). "Wood and understory production under a range of ponderosa pine stocking levels, Black Hills, South Dakota." Western North American Naturalist 60(1): 93-97.

The purpose of this study was to compare relative quantities of wood and forage produced under a range of tree stocking levels. Stemwood and understory production were estimated during three nonconsecutive years under five different growing stock levels in ponderosa pine (*Pinus ponderosa*) stands on the Black Hills Experimental Forest. Stemwood production was consistently greater at mid- and higher-stocking levels, and understory production was greater in stands with less pine; however, there were no differences in total (stemwood + understory) production. Results discredit arguments that small clearcuts and unthinned stands should not be included in site plans due to productivity loss. Authors suggest that these types of stands are actually important for their contributions to community structure, particularly to plant and animal species richness.

Uresk, D. W. and K. E. Severson (1989). "Understory-overstory relationships in ponderosa pine

forests, Black Hills, South Dakota." Journal of Range Management 42(3): 203-208.

This study examined understory-overstory relationships among 7 different growing stock levels (GSLs) of 2 size classes (saplings and poles) of ponderosa pine (*Pinus ponderosa*) in the Black Hills Experimental Forest. Production of graminoids, forbs, and shrubs was generally similar between sapling and pole stands. Trends among GSLs were also similar between these tree size classes. Graminoids and forbs were most abundant in clearcuts and stands with 5 m^2/ha basal area, intermediate in stands with 14-23 m^2/ha basal area, and lowest in unthinned stands. Total understory production followed the same trends. Production of shrubs was highly variable, but appeared greatest at intermediate stocking levels. Models were developed to predict graminoid and forb production and total production, but variability of shrub production precluded selection of a single model. Standard errors of the estimate indicate that reasonably good predictive models can be developed for pole and sapling stands considered separately or combined. When years were combined, however, SEs increased markedly, indicating less reliable models.

Uresk, D. W. and K. E. Severson (1998). "Response of understory species to changes in ponderosa pine stocking levels in the Black Hills." Great Basin Naturalist 58(4): 312-327.

This study explored how individual plant species respond to changes in forest basal area and how these responses affect plant species richness in forest understories. Understory production was estimated on three replicates each of eight growing stock levels, ranging from clearcuts to unthinned stands, in both sapling- and pole-sized pine stands in the Black Hills Experimental Forest. Measurements were made over 3 non-consecutive years (1974, 1976 and 1981). Production of many herbaceous species, especially *Agropyron* spp. (wheatgrasses) [including *Elymus* spp.] and *Carex* spp. (sedges), declined as growing stock of ponderosa pine increased. While trends in total understory production were similar, there were specific differences between sapling and pole stands. Sedges and *Oryzopsis asperfolia* (roughleaf ricegrass) were more abundant in sapling stands, whereas *Danthonia intermedia* (timber oatgrass) was more abundant in pole stands. Shrub production, dominated by *Arctostaphylos uva-ursi* (bearberry), was relatively consistent across all stocking levels, except in unthinned stands. Several species, including *Linnaea borealis* (twinflower) and *Shepherdia canadensis* (buffaloberry), were found only under relatively dense pine canopies. Floristic species richness was greater at lower stocking levels of ponderosa pine, but the total number of species would be greater if all stocking levels were represented on the landscape of the Black Hills.

Van Deusen, J. L. (1974). Five-year results of a ponderosa pine provenance study in the Black Hills. Fort Collins, CO, USDA Forest Service, Rocky Mountain Forest and Range Experimental Station.

A study was initiated to determine the extent of genetic variation in silviculturally important traits of ponderosa pine (*Pinus ponderosa*) and to identify superior genotypes for use in local tree improvement programs. Seeds were collected from parent trees representing 75 provenances of natural stands in the Great Plains and Northern Rockies and planted as 2-0 stock on the Black Hills Experimental Forest. Survival and height growth data were collected after five growing seasons. Results showed that trees from no other provenance survived significantly better or grow significantly taller than trees from the Black Hills. Trees from southern Colorado, New Mexico, and western Montana

showed significantly poorer survival and height growth. High mortality evidently resulted from a combination of intense grass competition and root rot.