Bienn. Symp. North. Wild Sheep and Goat Counc. 10:118-125.

APPLICATION OF A GIS-BASED BIGHORN SHEEP HABITAT MODEL IN ROCKY MOUNTAIN REGION NATIONAL PARKS

PATRICIA Y. SWEANOR, National Biological Service, 4512 McMurray, Fort Collins, CO 80526
MICHELLE GUDORF, National Park Service, 12795 W. Alameda Parkway, Lakewood, CO 80228
FRANCIS J. SINGER, National Biological Service, NREL, Colo. State Univ., Fort Collins, CO 80523

Abstract: We evaluated bighorn sheep habitat in and around nine Rocky Mountain National Parks, in seven study areas, to determine if enough suitable habitat was available to support translocations of bighorn sheep. We used a bighorn sheep model developed by Smith et al. (1991) and modified by Johnson and Swift (1995) and ourselves. We used standardized digital data bases as well as digitized map and field data in a Geographic Information System (GIS) application of the model (Johnson and Swift 1995). Mapped habitat projections were produced using the Geographic and Resource Analysis and Support System (GRASS). The factors most significantly affecting the distribution of suitable bighorn sheep habitat were presence of escape terrain, openness of vegetation cover, and presence of domestic sheep. All seven study areas had some presently suitable bighorn sheep habitat.

INTRODUCTION

Bighorn sheep have been extirpated from many areas of their historical range in the western United States (Buechner 1960). The National Park Service has sought to perpetuate sustainable populations of native bighorn sheep via reintroductions into historical ranges in National Park areas. Reintroductions of bighorn sheep from remnant herds into vacant habitat have helped increase the species abundance and distribution (Rowland and Schmidt 1981). However, many herds remain small, isolated, and exhibit low dispersal tendencies (Smith et al. 1988). Long-term sustainability of bighorn sheep requires both wide spread distributions, that can withstand localized stochastic events, and corridors of habitat that allow for genetic interchange between small herds (Risenhoover et al. 1988). In 1991, the NPS initiated a project to help restore widespread, interconnected distributions of bighorn sheep herds extending across jurisdictional boundaries of individual resource agencies (Gudorf et al. 1997). Under this initiative, the National Park Service, the U.S. Forest Service (USFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), and state wildlife agencies worked together to evaluate interagency lands for suitable bighorn sheep habitat and possible bighorn sheep translocations.

To help evaluate translocation possibilities in the seven study areas, we endeavored to systematically quantify bighorn sheep habitat abundance and distribution. We used a geographic information system (GIS) application (Johnson and Swift 1995) of a bighorn sheep habitat model (Smith et al. 1991).

STUDY AREAS

The seven study areas were centered around nine National Parks (Fig. 1) and included surrounding BLM, USFS, BIA and state lands. One study area in Utah (CANY) included both Canyonlands and Arches National Park. Three study areas in Colorado included Colorado National Monument (COMO), Curecanti National Recreation Area and Black Canyon on the Gunnison National Monument (BLCA), and Dinosaur National Monument (DINO). One study area in North Dakota encompassed the north and south units of Theodore Roosevelt National Park (THRO). The study area in South Dakota included Badlands National Park. The study area along the Montana, Wyoming border consisted of Bighorn Canyon National Recreation Area and surrounding areas (BICA). Study area size ranged from 2249 km^2 (BLCA) to 7250 km^2 (CANY).

Habitat parameters considered important for bighorn sheep were identified in a habitat model developed by Smith et al. (1991). The model was used and refined by Johnson and Swift (1995). The model incorporated a linear process of elimination, where land area was removed from consideration if it did not meet specific habitat constraints. Land area was considered either suitable or unsuitable, and was not ranked by quality factors. Habitat variables evaluated by the model were escape terrain, escape terrain buffer, vegetation openness (i.e., horizontal visibility), water sources, natural barriers, human-use area, man-made barriers, and domestic livestock (Table 1). Summer, winter and lambing ranges as well as migration corridors were also delineated (Table 2).

Figure. 1. Nine National Park areas in six states were included in the GIS-based, bighorn sheep habitat analyses. Final analyses from 52 additional study areas, Capital Reef and Mesa Verde National Parks, were not available for this report.

Values for bighorn sheep habitat parameters were obtained from field observations, historical records, U.S. Geological Survey (USGS) digital elevation models (DEMs), USGS park maps, USGS digital line-graph data (DLG), USGS topographical maps, USFS aerial photos, BIA digital data, and BLM surface management maps (Table 3). Habitat data were entered into a computer-based mapping program, GRASS, that analyzes and displays digitized data in spatial formats of grid or pixel cells. Groups of these pixel cells delineated the areas that met specific habitat criteria. These thematic maps were then overlaid to determine what areas met composite habitat requirements. Areas of winter lambing and summer ranges were also delineated.

Some considerations pertaining to habitat suitability were not evaluated in the GIS-procedure, e.g., forage type and biomass, predation, interagency plans for adjacent areas, wild ungulate concentrations, and nearby bighorn sheep populations. These concerns were addressed by a panel of resource managers and researchers, convened to evaluate the GIS model results from each study area (Gudorf et al. 1995, 1996; Sweanor et al. 1994a, 1994b, 1995a, 1995b, 1995c).

RESULTS

All study areas contained some suitable bighorn sheep habitat (Table 4). In addition, all study areas had suitable summer, winter, and lambing areas (Figs. 2 and 3). However, lambing habitat was limited and constituted only 10% of the total bighorn sheep habitat in the 7 study areas.

Escape terrain was the dominant variable affecting the extent of bighorn sheep habitat. Although buffered escape terrain included areas up to 500 m from escape terrain (Table 1), most land area in the study areas (56%) did not meet that criteria. However, some study areas had significantly more buffered escape terrain than other areas. Buffered escape terrain comprised 68% of DINO but only 11% of THRO (Table 4).

Table 1. Criteria in the GIS-model application for evaluating bighorn sheep habitat. Additional criteria were used to determine suitability of seasonal ranges (Table 2).

Habitat Requirement	Definition
Escape terrain	Areas with slope > 27°, < 85°
Escape terrain buffer	Areas within 300m of escape terrain and areas ≤ 1000m wide that are bounded on ≥ 2 sides by escape terrain
Vegetation density	Areas must have visibility >55%, as defined by the mean percent of squares visible on a 1 m^2 target, divided into 36 equal squares, 14 m from an observer viewing N,E,W,S from a height of 90 cm along a 10 pt, 280 m transect
Water sources	Areas must be within 3.2 km of water sources
Natural barriers	Areas that bighorn sheep can not access are excluded, e.g., rivers > 2000 cfs, areas with visibility < 30% that are 100 m wide, cliffs with > 85° slope
Human use areas	Areas covered by human development are excluded.
Man-made barriers	Areas that can not be accessed due to man-made barriers are excluded, e.g., major highways, wildlife-proof fencing, aqueducts, major canals are excluded.
Domestic livestock	Areas within 16 km of domestic sheep are excluded

Table 2. Habitat criteria used for evaluation of summer, winter and lambing ranges, as well as migration corridors for bighorn sheep (Smith *et al.* 1991).

Seasonal Range	Requirements
Summer range	Areas meeting all requirements listed in Table 2
Winter range	Areas meeting requirements in Table 2, that are also south facing slopes (135° - 235° aspect), with snowpack < 25 cm
Lambing range	Areas that meet the requirement listed in Table 2 that are not north facing slopes (315° - 45° aspect), are < 1 km from water, and are > 2 ha in size
Migration corridors	Areas that meet the requirements in Table 2 plus areas with horizontal visibility of 30 to 55% if the area is < 4.5 km wide, and areas with horizontal visibility < 30% if the area is < 100m wide.

Dense vegetation significantly restricted potential bighorn sheep habit in some areas but had no effect in other areas. In the slick-rock canyon regions of CANY and in the river badlands of BADL, vegetation structure did not limit any areas of bighorn sheep habitat. However, in the forested, canyon regions of BLCA, COMO, and DINO, thick vegetation restricted 2617 km^2 of otherwise suitable bighorn sheep habitat (Table 4).

The presence of domestic sheep affected bighorn sheep habitat in all study areas except THRO and BADL. Domestic sheep restricted 5401 km² of buffered escape terrain in the other five study areas. Areas of bighorn sheep habitat in COMO, BLCA, and DINO were significantly affected by the presence of domestic sheep (Table 4).

We modified model parameters either based on habitat data availability or local climatic conditions. Some habitat variables in the model, such as water availability in areas with unmapped seeps and ephemeral streams (CANY, THRO), were difficult to measure. In those areas water was not considered limiting. Additionally, the effect of some model variables varied among the study area. For example, the effect of slope aspect for lambing range was omitted in the relatively snow-free desert and river badlands areas (CANY, BADL, THRO) but was retained for the snow-rich areas of BICA, BLCA, COMO, and DINO.

DISCUSSION

Bighorn sheep habitat was primarily defined by the amount of buffered escape terrain in an area. Bighorn sheep require escape terrain to evade predators and disturbance (Geist 1971). Escape terrain is a primary component of bighorn sheep habitat, because it is a geo-physical land feature that can not be altered by management. All areas within flight distance of escape terrain (up to 500 m) were considered suitable habitat if they met other habitat criteria. Buffered escape terrain, therefore, represented a baseline of the maximum possible bighorn sheep habitat in an area.

In our study, significant portions of potential bighorn sheep habitat were limited by dense vegetation. Due to fire suppression, the density of forested vegetation in many areas of historical bighorn sheep habitat has increased dramatically (Wakelyn 1987). Bighorn sheep generally avoid thick vegetation because it restricts their ability to detect predator approach. Yet, vegetation is a manageable component of bighorn sheep habitat, and documenting areas limited by dense vegetation identifies opportunities to increase suitable bighorn sheep range through management, for example, via prescribed burns.

Large areas of potential bighorn sheep habitat were also limited by the presence of domestic sheep. Contact with domestic sheep is deleterious to bighorn sheep populations because non-fatal infectious diseases of domestic sheep can cause significant mortality when transmitted to bighorn sheep (Jessup 1981). Bighorn rams are attracted to domestic ewes, and the two species must be separated by a significant distance, or barriers, to deter contact. There are some opportunities to improve bighorn sheep ranges by documenting the sheep grazing allotments that affect bighorn habitat and then, for example, retiring those allotments or perhaps converting them to cattle.

Model parameters such as man-made barriers and human development had little effect on bighorn sheep habitat projections in this study. This was probably because the study areas were centered around National Parks. However, THRO was affected by oil and gas exploration, and planned future development could significantly diminish the already limited lambing habitat (Sweanor et al. 1994b). In addition, movements of bighorn sheep in THRO were restricted by fences constructed to control bison movements.

Some model variables were poorly documented or understood in some study areas. For example, water availability in dry regions such as CANY, BADL and THRO may be affected by ephemeral streams and undocumented seeps and springs (Sweanor et al 1994 b, 1995a, 1995b). Snow depth measurements were unavailable for lambing habitat in all areas. Additionally, the effect of slope aspect on suitability of lambing habitat was questionable for study areas without significant springtime snow accumulations (Sweanor et al. 1995a,b). The juxtaposition of escape terrain, e.g., whether it is above or below feeding areas, may affect how far into feeding areas bighorn sheep will venture (Sweanor et al.1995b), and shade may be an important consideration in some sparsely vegetated zones of, e.g., BADL. Such lapses of information in the model application help emphasize what habitat requirements need further clarification and field studies.

A GIS-model application does not produce a management plan, rather it presents scenarios of present conditions, and resultant effects of management actions. For example, maps of buffered escape terrain overlaid by maps of manageable factors allows a visual evaluation of current management concerns and options. The GIS-model results from each of the study areas in this study were presented to panels of bighorn sheep managers and researchers to evaluate the output and to discuss the need for translocations and /or other management actions (Gudorf et al. 1995, 1996; Sweanor et al. 1994a, 1994b, 1995a, 1995b, 1995c).

To accurately evaluate any GIS-model output, sources of error must be identified and monitored. Computer-based model analyses can not compensate for deficiencies in knowledge about habitat requirements or lack of habitat data. Model applications are only as good as the habitat studies they are based on. Field studies that quantify habitat requirements remain the cornerstone of effective management. Additional

Table 3. Sources of the bighorn sheep habitat parameter values used in the GIS habitat model analyses.

Parameter Value	Source	Scale
Escape terrain (slope) and buffer	USGS Digital Elevation Models (DEMs)	1: 24,000
Vegetation density	Park, BLM, USFS vegetation maps USGS land use /land cover maps Field surveys	1: 24,000 1:250,000
Water sources	USGS digital line graphs data, park maps Field data delineated on topographical maps BLM digital data bases	1:100,000 1: 50,000 1: 24,000
Snow pack	Not available	
Natural barriers	USGS Digital Line Graphs (DLG) USGS topographical maps Field surveys	1: 24,000
Aspect	USGS DEMs	1: 24,000
Human-use areas	BLM land use and development maps USGS topographical maps USGS land use/land cover maps	1:100,000 1: 24,000 1:250,000
Manmade barriers	USGS topographical maps USGS park maps Field surveys	1: 24,000
Livestock grazing	BLM, USFS allotment data Field surveys	1: 24,000

Table 4. Bighorn sheep habitat estimates in the seven study areas.

Habitat Component	Study Areas (km^2)							
	CANY	BADL	BICA	COMO	BLCA	DINO	THRO	Total
Study area size	7250	5322	3418	2249	2891	4293	3494	28,917
Buffered escape terrain with visibility > 55%	4087	807	2090	340	958	1238	340	9,860
Buffered escape terrain > 16 km from domestic sheep	3158	807	1922	145	468	361	368	7,229
Suitable habitat (all parameters in Table 1 evaluated)	3112	802	1506	116	110	100	203'	5,949
Summer range	3102'^	790	1264*	534*	544*	888*	328'	7,450
Winter range	1410'^	247	627*	175*	332*	227*	207'	3,225
Lambing range	503'^	21	209*	45*	99*	86*	6'	969

' Areas within 16 km of domestic sheep were included in these seasonal range estimates.
^ Only documented water sources were considered in the evaluation.
* Water availability was not considered limiting.

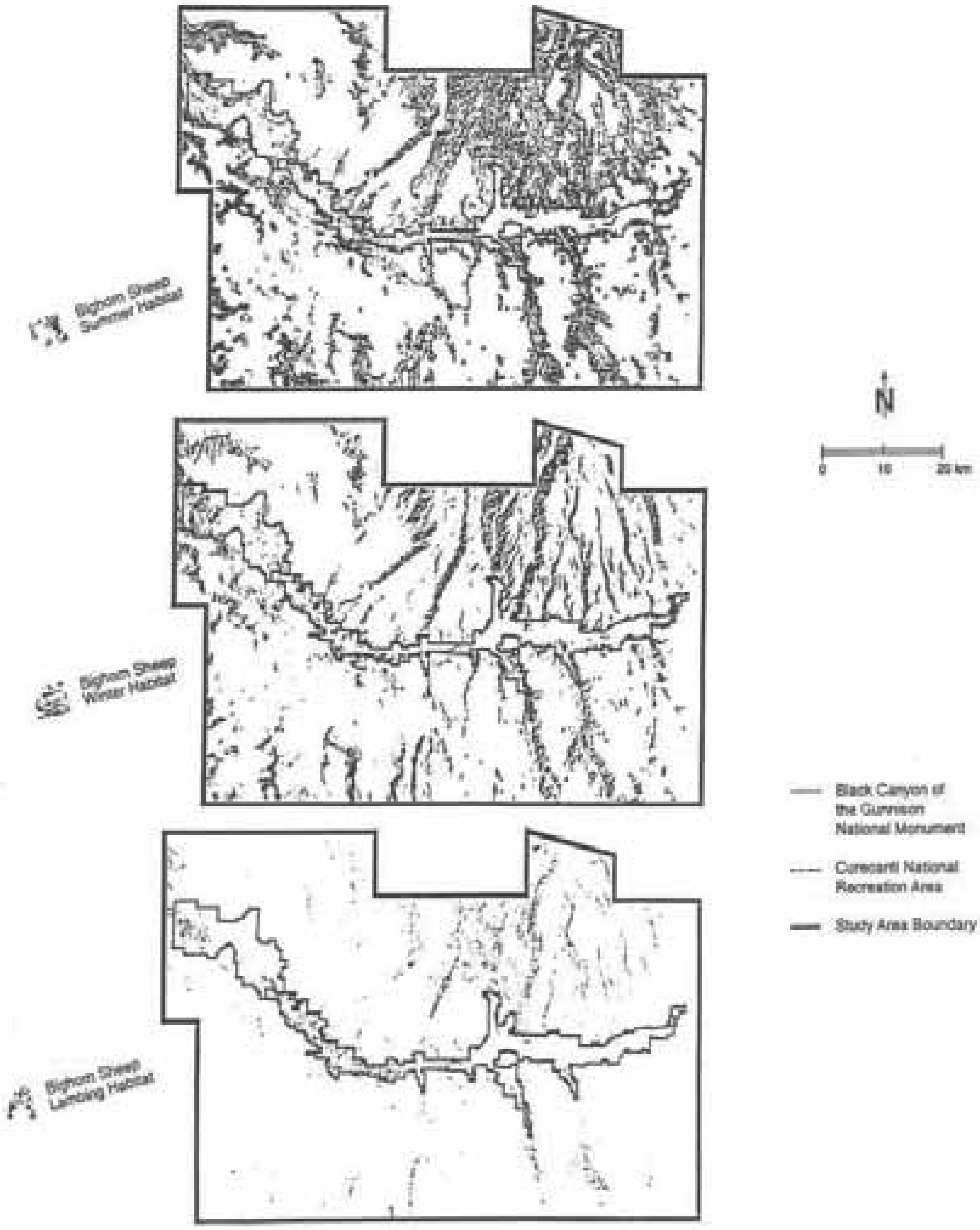

Figure 2. Bighorn sheep habitat projections generated by the GIS-based habitat model application in BLCA. The BLCA study area included Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument in Colorado.

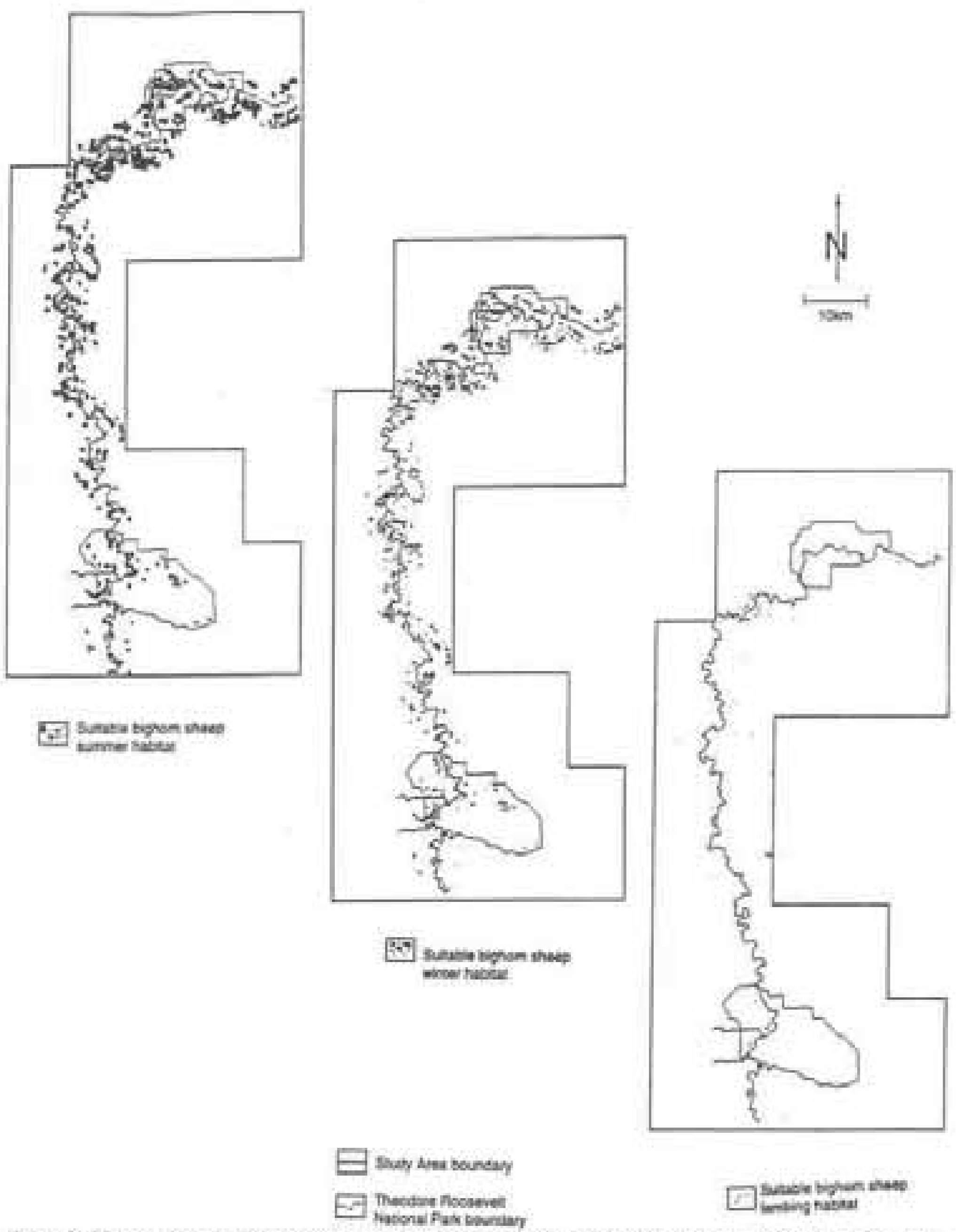

Figure 3. Bighorn sheep habitat projections generated by the GIS-based habitat model application in THRO. The THRO study area included the north and south units of Theodore Roosevelt National Park in North Dakota.

errors in a GIS applications of models may be caused by inaccuracies in standardized spatial data sets, use of data at inappropriate scales, and mistakes in digitizing (Collins and Smith 1994)

GIS model applications enable us to study, organize, evaluate, and map habitat in a systematic, quantifiable, and repeatable way. Habitat modeling provides us with a synopsis of our present state of knowledge, allows us to form predictions based on this knowledge, helps us realize what aspects of bighorn sheep biology are poorly understood, and directs needed field work. Together GIS applications and habitat modeling, based on sound field data, can aid in producing effective regional management programs for bighorn sheep.

LITERATURE CITED

Buechner, H. K. 1960. The bighorn sheep in the United States, its past, present and future. Wildl. Monogr. 4:174.

Collins, F. C., and J. L. Smith. 1994. Taxonomy for error in GIS. International Symp. On Spatial Accuracy of Natural Resource Data Bases: Unlocking the Puzzle. 1-7.

Geist, V. 1971. Mountain sheep, a study in behavior and evolution. Univ. Chicago Press. Chicago. 383pp.

Gudorf, M., P. Y. Sweanor, J. Singer, V. Bleich, J. Cordova, C. Hauke, L. Lee, T. Lyttle, P. Paired., S. Petersburg, B. Sloan. 1995. Bighorn sheep habitat assessment of the greater Colorado National Monument area. National Park Service and National Biological Service cooperative report. Colorado national Monument, Fruita, CO. 52pp.

Gudorf, M., P.Y. Sweanor, F. J. Singer, A. Blankenship, V. Bleich, T. Easterly, J. Emmerich, C. Eustace. L. Irby, D. Jaynes, B. Jellison, R. Kissell, J. Lindsay, J. Parks, T. Peters, K. Reid, S. Stewart, T. Voss. 1996. Bighorn sheep habitat assessment of the greater Bighorn Canyon National Recreation Area. National Park Service and National Biological Service cooperative report. Bighorn Canyon National Recreation Area, Lowell, WY. 43pp.

Gudorf, M., P.Y. Sweanor, F. J. Singer. 1997. Bighorn sheep restoration: modeling habitat suitability within GIS. George Wright Soc. Proc.

Jessup, D. M. 1981. Pneumonia in bighorn sheep: effects on populations. Cal-Neva Wildl. Soc. Trans. 72-78.

Johnson, T., and M. Swift. 1995. A test of a Rocky Mountain bighorn sheep habitat evaluation procedure. Rocky Mountain National Park report. Rocky Mountain National Park, Estes, CO.

Risenhoover, K. L., J. A. Bailey, and L. A. Wakelyn. 1988. Assessing the Rocky Mountain bighorn sheep management problem. Wildl. Soc. Bull. 16:346-352.

Rowland, M. M., and J. L. Schmidt. 1981. Transplanting desert bighorn sheep - a review. Desert Bighorn Counc. Trans. 25-28.

Smith, T. S., J. T. Flinders, and D. W. Olsen. 1988. Status and distribution of Rocky Mountain bighorn sheep in Utah. Bienn. Symp. North American Sheep and Goat Counc. 6:5-12.

Smith, T. S., J. T. Flinders, and D. S. Winn. 1991. A habitat evaluation procedure for Rocky Mountain bighorn sheep in the inter-mountain west. Great Basin Naturalist 51:205-225.

Sweanor, P.Y., M. Gudorf, S. Chambers, F. J. Singer, J. Bissonette, J. Ellenberger,, T. Johnson, S. Petersburg, R. Schiller, and K. Symonds. 1994a. Bighorn sheep habitat assessment of the greater Dinosaur National Monument area. National Park Service and National Biological Service cooperative report. Dinosaur National Monument, Dinosaur, CO. 65pp.

Sweanor, P.Y., M. Gudorf, F. J. Singer, R. Andrascik, W. F. Jensen, C. W. McCarty, M. Miller, D. Reed, and R. Schiller. 1994b. Bighorn sheep habitat assessment of the greater Theodore Roosevelt National Park area. National Park Service and National Biological Service cooperative report. Theodore Roosevelt National Park, Medora, ND. 55pp.

Sweanor, P. Y., M. Gudorf, F. J. Singer, S. Bellow, S. Buskirk, J. Cresto, B. Dunn, J. Gross, J. Guymon, C. Hauke, K. McCoy, N. McKee, K. McKinlay-Jones, M. Moses, R. Nolan, S. Petersburg, R. Ramey, B. Rodgers, B. Sloan, B. Woyewodziz. 1995a. Bighorn sheep habitat assessment of the greater Canyonlands/ Arches National Park area. National Park Service and National Biological Service cooperative report. Canyonlands National Park, Moab, UT. 57pp.

Sweanor, P. Y., M. Gudorf, F. J. Singer, T. Benzon, J. Berger, B. Bessken, S. Cordts, C. Douglas, M. Moses, G. Plumb, R. Sherman, E. Williams. 1995b. Bighorn sheep habitat assessment of the greater Badlands National Park area. National Park Service and National Biological Service cooperative report. Badlands National Park, Interior, S.D. 66pp.

Sweanor, P.Y., M. Reynolds, M. Gudorf, F. J. Singer, B. Dunn, R. Harris, C. Jenkins, D. Masden, C. McCarty, M. Miller, D. Reed. 1995c. Bighorn sheep habitat assessment of the greater Curecanti National Recreation Area and Black Canyon of the Gunnison National Monument. National Park Service and National Biological Service coop. report. Curecanti National Recreation Area, Gunnison, CO. 49 pp.

Wakelyn, L. A. 1984. Analysis and comparison of existing and historic bighorn sheep ranges in Colorado. Master of Science thesis. Colorado State Univ. CO. 111pp.