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A HABITAT EVALUATION PROCEDURE FOR ROCKY MOUNTAIN BIGHORN SHEEP IN THE INTERMOUNTAIN WEST  

Tom S. Smith¹, Jerran T. Flinders¹, and David S. Winn² 

ABSTRACT.—Several habitat evaluation procedures have been developed for bighorn sheep. However, none of these procedures specifically addresses the Rocky Mountain subspecies nor analyzes both the quantity and quality of potential bighorn habitat with regard to minimum viable population (MVP) criteria. This bighorn habitat evaluation procedure combines (1) a quantitative assessment of bighorn range to determine if there are adequate quantities of resources to support an MVP of bighorn sheep, and (2) a qualitative assessment of a range to predict the probable density of bighorns the range can support. Extensive literature review, intensive bighorn research, and a modeling tool, pattern recognition (PATREC), facilitate critical analysis of proposed bighorn reintroduction sites. The resultant stepwise approach to bighorn habitat evaluation enhances the ability of wildlife biologists to make timely and accurate bighorn habitat assessments. 

Key words: Habitat evaluation procedure, geographic information system, pattern recognition, minimum viable population, bighorn sheep, Ovis canadensis canadensis. 

The precipitous decline of Rocky Mountain bighorn sheep (Ovis canadensis canadensis) after arrival of American settlers has been well documented (Buechner 1960). As early as 1880, some bighorn herds had been extirpated, while others suffered sharp reductions. Even recently, Jahn and Trefethen (1978) warned that without more effective management, an additional loss of 8% of bighorn sheep could be expected over the next 25 years.

The inability to successfully restore bighorn to former ranges in the western United States results in part from habitat deficiencies that hamper herd growth and persistence. For example, Utah's reintroduction program has not succeeded in restoring Rocky Mountain bighorn to former ranges (Smith et al. 1988). Transplanted sheep have failed to increase, and the current statewide total is approximately equal to the number of transplant animals released (Smith et al. 1988). Reasons for this include: (1) inadequate quantities of available range, (2) severe competition with other ungulates, (3) contact with domestic livestock, (4) improper juxtaposition of key habitat components, (5) inadequate quantities of one or more critical seasonal ranges, and (6) excessive human harassment. More rigorous assessments of proposed reintroduction areas would enhance program success. This habitat evaluation procedure (HEP) is an effort to provide wildlife professionals with a better tool for assessing bighorn habitat quality.

Although several bighorn habitat evaluation procedures have been developed (Ferrier and Bradley 1970, Merritt 1974, Golden and Tsukamoto 1980, Grunigen 1980, Hansen 1981, et al. 1983a, 1983b, 1983c), several of these procedures have limitations that complicate their applicability to the Rocky Mountain bighorn. For example, Ferrier and Bradley's (1970) method requires data on bighorn utilization of vegetation, total range vegetation, and degree of human influence. In the western United States, vegetation data have often been difficult to gather due to the complexity of local vegetation and the limited number of research programs that have been able to collect data such as Ferrier and Bradley's. The current study addresses these and other limitations of past methods by developing a systematic approach that is feasible in the intermountain West. 

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1980, Wilson et al. 1980, Holl 1982, and Armentrout and Brigham 1988), this HEP has been developed because (1) a Rocky Mountain bighorn sheep HEP is nonexistent and (2) none of the above procedures critically examines actual, or proposed, bighorn ranges for the minimum area necessary to support at least a minimum viable population (MVP) of bighorn sheep. An MVP has been defined by Shaffer (1983) as the smallest isolated population having at least a 95% probability of surviving at least 100 years. Though precise MVP estimates for bighorn sheep are not available, Berger (1990) studied 122 bighorn sheep populations in southwestern United States and found that 100% of the bighorn populations with fewer than 50 individuals went extinct within 50 years. Berger also reported that bighorn populations with more than 100 sheep had persisted for 70 or more years. Consequently, he concluded that 50 bighorn sheep did not constitute a minimum viable population and that managers should strive for herds numbering more than 100 (J. Berger, University of Nevada, personal communications). Additionally, Geist (1975) and others (Sands 1976, Van Dyke et al. 1983) have suggested that wildlife managers should maintain herds of at least 125 individuals if the herds are to survive and persist. Based on this information, it is suggested that 125 individuals represent a current "best estimate" MVP (termed MVPE hereafter) for bighorn sheep populations. Because restoration efforts should strive to establish populations with long-term persistence, this bighorn habitat evaluation procedure assesses the ability of a proposed site to support at least 125 bighorn sheep. This requirement can be relaxed if a reintroduction site is situated so that exchange with nearby herds is expected. In the Mojave Desert of southern California and Nevada, Schwartz et al. (1986) report a stable metapopulation of desert bighorns consisting of 23 subpopulations, many of which fall far short of the 125 MVP estimate. However, due to the close proximity of individual herds and the presence of migration corridors, rams regularly travel between them and maintain gene flow, thereby alleviating the genetics problems which insular, nonmigratory populations face. Therefore, if other populations are close and have access to the reintroduced population, the problem of meeting MVPE criteria may be alleviated. Regarding interherd migrations, Schwartz et al. (1986) cite distances that bighorn have been observed traveling between herds in southern California. Extrapolation of these data to more forested regions should be done with discretion.

The importance of thorough site evaluation prior to bighorn reintroduction is illustrated by research from Bear Mountain of the Flaming Gorge National Recreation Area in northeastern Utah. Cursorial evaluation of the Bear Mountain transplant area suggests that about 6900 ha of habitat area is available to bighorn sheep. However, when one uses this HEP to identify how much suitable habitat actually exists, only 3800 ha (a 55% reduction) meets the criteria for suitable bighorn habitat (Smith and Flinders 1991). Subsequent research conducted at Bear Mountain verifies the fact that less than half the area is acceptable and usable by bighorn (Smith and Flinders 1991). Hence, even though considered an excellent site by many, Bear Mountain barely meets the minimum space requirements for an MVPE of 125 bighorn sheep.

**BIGHORN HEP CAPABILITIES**

This bighorn HEP (1) estimates the quantity and quality of occupied, or proposed, bighorn ranges, (2) predicts a site's ability to support at least an MVPE of bighorn sheep, (3) identifies population limiting factors, (4) enables estimation of the effects of management activities on bighorn habitat, (5) assists identification of cost-effective habitat management strategies, and (6) allows use of geographic information systems (GIS) technology for habitat evaluations (Fig. 1). This HEP may be used to evaluate proposed transplant sites or currently occupied ranges.

**BIGHORN HEP OVERVIEW**

This HEP performs two analyses: estimation of habitat quantity (Part 1) and quality (Part 2). The combination of these two habitat characteristics determines range carrying capacity. Part 1 uses questions regarding bighorn habitat requirements to define probable range area and boundaries. Part 2 employs pattern recognition (PATREC) to assess range quality.
ROCKY MOUNTAIN BIGHORN SHEEP HABITAT EVALUATION PROCEDURE: AN OVERVIEW

START

Part 1: Quantitative Assessment of Available Bighorn Habitat
* Comprised of questions which address the various limiting factors which define and delimit probable bighorn ranges.
* The final output for quantitative assessment is the amount of habitat available and whether or not that amount will support a minimum viable population (MVPE) of bighorns on those ranges.

Adequate Quantity of Range Exists to Support MVPE of Bighorns? NO Refer to MANAGEMENT DECISION FLOW CHART (See Figure 3).
YES Proceed with the Qualitative Assessment of bighorn habitat as outlined in Part 2 of this habitat evaluation procedure.

Part 2: Qualitative Assessment of Delineated Bighorn Ranges
* Comprised of PATREC Models (PATTERN RECOGNITION) which assess the delineated habitat and evaluate its relative value for bighorns.
* The final output for qualitative assessment is a measure of the area’s ability to support at least a minimum viable population (MVPE) of bighorn sheep.

Adequate Quality of Range Exists to Support MVPE of Bighorns? NO Refer to MANAGEMENT DECISION FLOW CHART (See Figure 3).
YES Proceed with bighorn transplant or utilize PATREC outputs to remedy identified habitat deficiencies.

STOP

Fig. 1. An overview of the Bighorn Habitat Evaluation Procedure.
Bighorn sheep movements are restricted by both intrinsic (behavioral and physical) and extrinsic factors (fences, geographic barriers, etc.). Because bighorn response to habitat variables is reasonably predictable, it is possible to estimate bighorn range size. Although bighorn will occasionally ignore normal barriers to movement, managers should not expect disjunct portions of range, separated by barriers, to contribute significantly to bighorn ranges. A proposed bighorn reintroduction site comprising scattered range segments, crisscrossed with barriers, with key habitat components ineffectively juxtaposed or absent, would ultimately fail to sustain a herd for long. Part 1 presents the normally restrictive barriers and assists in identifying the probable range boundaries, maximum range area, and juxtaposition of key habitat components. Part 1 focuses on critical aspects of bighorn habitat and helps managers determine a site's ability to provide suitable bighorn habitat in the amount needed to support an MVPE of sheep.

Bighorn range quality results from the interaction of many abiotic and biotic characteristics. These interactions create patterns of habitat suitability. The PATREC approach captures in simple mathematical form the process by which most biologists intuitively assess habitat suitability patterns (Grubb 1988). To date, PATREC models have been applied to a variety of wildlife, including Bald Eagles (Grubb 1988), deer (Kling 1980), Sage Grouse (Evans 1983), and bighorn sheep (Holl 1982). For a thorough description of PATREC, see Kling (1980) and Williams et al. (1977). Before proceeding with Part 2 of this HEP, review of PATREC is essential. Particularly helpful is the User's Guide to PATREC for Habitat Evaluation (Kling 1980).

Although most rigorous evaluation of habitat occurs when Parts 1 and 2 are applied, it is not essential that both be used. Part 1 is the key component and cannot be omitted for it defines the ranges that Part 2 analyzes. When insufficient range quantity or irreparable habitat problems have been identified through application of Part 1, site analysis need not proceed. Application of Part 2 requires a more detailed database. It may be used to identify specific weaknesses of a reintroduction site and to determine which remedial approach will yield greatest benefits. We believe that prior to reintroduction of bighorns, rigorous site analysis based on Part 1 alone would greatly enhance the success of many reintroduction efforts.

METHODS

Stepwise discussion of the HEP follows and corresponds to numbered steps in Figure 2.

Part 1

Quantitative Assessment of Available Bighorn Habitat

Sequential questions enable the user to (1) determine the probable range boundaries for an actual, or proposed, bighorn herd, (2) analyze the total area of that range in terms of MVPE criteria, (3) determine if adequate quantities of winter, lambing, and summer ranges exist, and (4) decide if the juxtaposition of habitat components is adequate.

STEP 1.—Any portion of range that might allow contact between bighorns and their exotic relatives, including domestic sheep and goats, should be excluded from consideration.

Recent research has verified the incompatibility of domestic sheep, goats, and bighorn sheep on the same ranges (Foreyt 1990). Exotic relatives of bighorn sheep, including mouflon sheep (Ovis ammon musimon), barbary sheep (Ammotragus lervia), and ibex (Capra ibex), are sources of disease, competition, and genetic pollution for bighorn sheep (Geist 1988). Domestic sheep (and goats in one instance) have been implicated as the disease source responsible for several recent bighorn sheep catastrophic die-offs (Jessup 1981, Goodson 1982, Capurro 1988, Coggins 1988). Bighorn sheep and mouflon sheep readily cross and produce viable offspring. Impure, genetically polluted bighorns have no historic, conservation, or scenic value. Although minimum distances for separation of bighorn and exotics, including domestic sheep, have been suggested (Holl and Bleich 1983, Armentrout and Brigham 1988, Coggins 1988), bighorn sheep and mouflon sheep readily cross and produce viable offspring. Impure, genetically polluted bighorns have no historic, conservation, or scenic value. Although minimum distances for separation of bighorn and exotics, including domestic sheep, have been suggested (Holl and Bleich 1983, Armentrout and Brigham 1988, Coggins 1988), the potentially catastrophic consequences of exotic-bighorn interactions justify a policy of absolute separation. If separation is not possible, the area should not be considered potential bighorn range until exotics are
removed. Ranges recently vacated of exotics require no resting period before bighorn transplanting because the pneumophillic diseases that precipitate die-offs are transmitted by direct contact only.

Steps 2 and 3.—Estimate the probable range boundaries of available bighorn habitat.

Steps 2 and 3 determine whether bighorns are already present on the site and, if so, their range boundaries. When the bighorn herd is established and approximate range boundaries known, steps 4–8 can be disregarded, since their role is to estimate the probable extent of bighorn ranges.

Step 4.—Delineate and buffer core bighorn habitat areas.

All bighorn habitat is dependent upon the presence and extent of escape terrain areas. Escape terrain comprises slopes greater than 60% (about 27°) that have occasional rock outcroppings whereon bighorn can outmaneuver predators and find secure bedding areas. For a more thorough discussion of escape terrain, see Van Dyke et al. (1983). Because escape terrain provides antipredator protection, bedding and lambing areas, and areas of lesser snowpack, it has been identified as the most critical habitat component for bighorns (Buechner 1960, Ferrier and Bradley 1970, Geist 1971, Wilson et al. 1980, Van Dyke et al. 1983). Specialized for leaping and climbing rather than for running on flat terrain (Geist 1971), bighorns are tied to escape terrain and seldom venture far from it (McCann 1956, Oldemeyer et al. 1971, Brown 1974, Van Dyke et al. 1983, Hansen 1984, Gionfriddo and Krausman 1986). On Bear Mountain, 95% of all bighorn activity occurred within 300 m of escape terrain (Smith and Flinders 1991). Therefore, areas not within 300 m of escape terrain should be excluded when evaluating bighorn ranges.

Occasionally, a segment of range is bounded on two or more sides by escape terrain. If the range between escape terrain areas is 1000 m wide or less, the entire area should be included as potential bighorn habitat. In such situations, bighorn are apparently willing to roam farther from safety (up to 500 m) because of the increase in escape route options (Van Dyke et al. 1983).

Step 5.—Identify additional restrictions for range boundary determinations including natural and man-made barriers to bighorn movement.

A. Natural barriers

1. Water: swift and/or wide rivers and lakes. Although Cowan (1940) occasionally observed bighorn swimming, water has been noted elsewhere to effectively delimit bighorn ranges (Graham 1980, Wilson et al. 1980, Smith and Flinders 1991). Rivers and lakes break range continuity and are commonly barriers to bighorn movements. Consequently, because bighorn herds rarely inhabit both sides of a canyon when a major river is present, managers should consider one side, but not both sides, of a continuous water body as bighorn range.

2. Dense vegetation. Smith and Flinders (1991), Brundige and McCabe (1986), Risenhoover and Bailey (1980), Wilson et al. (1980), McCann (1956), Cowan (1940) and others have stated that bighorn sheep hesitate crossing even narrow tracts of dense vegetation, particularly timber. Aversion to low visibility, likely a predator-avoidance strategy, restricts bighorn movements. Dense timber, thick shrubs, and lush herbaceous tracts often form impassable barriers to bighorns. For this reason, low-visibility areas at least 100 m wide should be considered movement barriers to bighorn sheep. Because these areas can restrain bighorn from utilizing more suitable terrain beyond, they need to be identified. Smith and Flinders (1991) present methodology for determining the horizontal visibility of an area. They found that areas with less than 80% horizontal visibility were little used by bighorns, regardless of their other qualities (e.g., distance to cliffs, herbaceous plant production, etc.).

3. Cliffs: continuous, nontraversable cliff complexes. Although bighorn rely heavily on cliffs, some cliff complexes do not qualify as escape terrain, but rather function as barriers to movement. Sheer, vertical cliffs, lacking negotiable terrain, can limit bighorn movements and range size. Of particular concern are continuous bands of sheer cliffs because they may isolate other
PART 1: QUANTITATIVE HABITAT ASSESSMENT FLOW DIAGRAM

START

1. Do exotic species occupy the area? 
   - YES: Stop Evaluation. See Text.
   - NO:

2. Bighorn sheep currently occupy the area? 
   - YES:
   - NO: Delineate and buffer core bighorn habitat areas

3. Boundaries of bighorn ranges are known? 
   - YES:
   - NO:

4. Identify additional restrictions for range boundary determinations including natural and man-made barriers to bighorn movement

5. Probable Bighorn Range Boundaries Well Defined? 
   - YES:
   - NO: Refer to text for assistance.

6. Within the potential ranges identified above, deduct unusable portion of habitat as identified in text

7. Adequate Quantity of Range Exists to Support MVPE of Bighorns? 
   - YES:
   - NO: Refer to MANAGEMENT DECISION FLOW CHART (See Figure 3)

8. Determine if adequate winter ranges exist to support a MVPE herd by delineating the potential winter range size

Continued on next page

Fig. 2. Part 1: Quantitative Habitat Assessment flow diagram.
wise useful areas from the rest of the range. As a rule of thumb, although bighorn are adept climbers, if a human cannot negotiate a particular cliff area, bighorn should not be expected to do so either.

4. Valleys or plateaus. If valleys separating areas of escape terrain are wider than 1000 m, they may act as barriers to bighorn movements. Similarly, plateaus separating escape terrain areas by more than 1000 m should be considered range boundary delimiters. When confronted with these barriers, bighorn will attempt to circumvent them if possible. However,
if long and continuous, these barriers may totally isolate ranges that otherwise would have value to the herd. In such cases these areas must not be included as bighorn range.

B. Man-made barriers
1. Water: canals, reservoirs, aqueducts. Linear waterways generally tend to impede bighorn movements. Concrete-lined canal systems, reservoir impoundments, and aqueduct structures can create impassable barriers and bighorn death traps (Grallam 1980). As a general rule, these structures should be considered range delimiters, and bighorn sheep should not be expected to routinely cross them to access other portions of potential range (Sleznik 1963).

2. Impassable fencing. Fencing can restrict bighorn movements and result in mortality, particularly for rams whose horns may become entangled. Helvie (1971) presents a useful discussion of the types of fencing that limit bighorn movements. If barrier fencing exists on proposed bighorn ranges, boundaries should be drawn along them.

3. Major highways and high-use roadways. Besides the fencing often associated with major highways and high-use roadways (interstate, federal, or state highways), associated human activity often deters bighorn from regularly crossing these areas (Ferrier 1974, McQuivey 1978, Risenhoover 1981, Van Dyke et al. 1983). The impact of highways must be carefully evaluated, and those restricting bighorn movements should be considered boundaries of contiguous bighorn ranges.

4. Centers of human activity. Airports, dwellings, campgrounds, and ski resorts are examples of centers of human activity that frequently invade bighorn ranges. As such, they represent potential range delimiters to bighorn sheep, particularly when aligned in linear fashion. Each occurrence must be evaluated individually and range boundaries drawn accordingly.

Steps 6 and 7.—Determine whether probable bighorn range boundaries are well defined.

After identifying the above range-delimiting characteristics, managers should roughly define the boundaries of a proposed bighorn sheep release site. If this is not yet possible, given the data to this point, the following additional range constraints should further define range boundaries.

Step 8.—Deduct unusable portions of habitat from within identified potential bighorn ranges, as follows:
A. Areas beyond 3.2 km from water sources. McQuivey (1978) noted that 85% of bighorn activity occurred within 3.2 km of water. Brundige and McCabe (1986) reported that all bighorn in Custer State Park, South Dakota, remained within 1 km of watering sources. Van Dyke et al. (1983) concluded that water sources farther than 0.5 km from escape terrain received only limited use. Sands (1976) suggested that optimal spacing between water sources was 1.6 km. We believe that critical bighorn ranges will occur within 3.2 km of usable water sources; hence, areas beyond 3.2 km should be excluded from consideration as core-use ranges. It is important to note that seeps, springs, perennial snow patches, streams, rivers, ponds, lakes, and reservoirs all qualify as bighorn watering sources. However, excessive human activity around water sources (Jorgensen 1974), water heavily used by livestock and ungulate wildlife (Welles and Welles 1961, Van Dyke et al. 1983), alkaline waters (Jones et al. 1957), and water sources surrounded by dense vegetation should not be considered usable by bighorn. Schmidt (Colorado Division of Wildlife, personal communications) noted that guzzlers are generally avoided by Rocky Mountain bighorn sheep on Colorado ranges. Having observed the same phenomenon in northeastern Utah, Smith and Flinders (1991) recommended that guzzlers be fitted with remote watering troughs for bighorns to use. In the cooler, temperate regions where the Rocky Mountain subspecies normally occur, water is rarely a limiting factor, unlike areas of desert bighorn habitat to the south. However, where water resources are limited, they must be considered as effective range delimiters.

B. A 100-m-wide buffer should be placed around areas of low to moderate human use. Areas typically receiving low to moderate human activity include some trails, roads, dwellings, and campgrounds. Many have noted the negative effect of human activities on bighorn sheep (Dunaway 1971, Light
1991, Hicks and Elder 1979, Cionfriddo and Krausman 1986). Light (1971) defined "light use" on back-country trails as 0–100 visitors a year, "moderate use" as 100–500 visitors, and "high use" as over 500 visitors a year. He reported that low- to moderate-intensity activity displaced bighorn activity up to 100 m from the source. For this reason these areas should be buffered accordingly.

C. A 150-m-wide buffer around areas of high-intensity human use. Areas typical of high-intensity human activity include some airports, mines, tramways, campgrounds, ski resorts, and heliports. A 150-m-wide buffer beyond the periphery of such areas should be excluded from consideration as bighorn range.

D. All plant communities typified by horizontal visibility of less than 80%. Research by Smith and Flinders (1991), Brundige and McCabe (1986), Risenhoover (1981), and Risenhoover and Bailey (1980) indicates that bighorn avoid areas of poor visibility. Smith and Flinders (1991), using a gridded, meter-square target, measured percentage of target visible in various habitat types and found that bighorn avoid most areas in which horizontal visibility is less than 80%. Conifers with dense understory, brushy meadows, and many riparian areas are of such poor visibility as to preclude bighorn activity. As a rule of thumb, shrub communities with a mean height greater than 0.5 m, riparian areas with a dense understory, heavily forested areas, and more open timber stands with an understory greater than 0.5 m in height will be avoided by bighorn sheep. All such areas should be excluded from the potential bighorn range.

E. Portions of range seasonally occupied by concentrations of elk or cattle. If portions of potential bighorn range will have elk or cattle present concurrently with bighorn, such areas should be excluded from potential bighorn range. Aside from direct competition for forage (McCann 1956, Demarchi 1965, Oldemeyer et al. 1971, Morgan 1973, McQuivey 1978, Estes 1979, Van Dyke et al. 1983), disease transmission (Wishart 1978, Lawson and Johnson 1980, Van Dyke et al. 1983, De Forge 1988, Jessup 1981) and social intolerance (Wilson 1975, McQuivey 1978, Lawson and Johnson 1980, King and Workman 1984) are adequate reasons for excluding elk or cattle ranges from consideration as critical bighorn use areas. That these large ungulates often totally displace bighorn has been well documented; therefore, individual conflicts must be carefully evaluated. Whenever a proposed site will considerably overlap the range of elk, cattle, or perhaps even bison, careful consideration should be given the potential for competition and displacement.

After the areas identified in 8A to 8E have been deducted from potential range defined in steps 4–5, the remaining area represents range suitable for bighorn sheep if introduced into the area. Because transplanted bighorns often establish their home ranges around the release site (Geist 1971, Brundige and McCabe 1986), they can be expected to remain within a 15-mile radius of it once they have adjusted to the area, usually within a year of the release. This may help to further delimit probable ranges in case boundaries are yet ill defined.

STEP 9.—Ascertain whether adequate range exists to support an MVPE of bighorns.

Van Dyke et al. (1983) suggested that 1.9 bighorns per km$^2$ (5 per mi$^2$), averaged over an entire range, would represent a maximum density for ranges in the Great Basin portion of southeastern Oregon. If this represents a reasonable estimate for other sites in the Intermountain West, a minimum of 65 km$^2$ (25 mi$^2$) of habitat would be required to support 125 bighorn sheep. However, densities ranging from less than 0.4 bighorn per km$^2$ (1 per mi$^2$) (McQuivey 1978) to over 27 per km$^2$ (70 per mi$^2$) (Demarchi 1965) have been reported. Unfortunately, all reported bighorn densities appear to have been calculated for areas that included both usable and unusable portions of range. This underestimates true bighorn densities within occupied areas. For example, McQuivey (1978) calculated bighorn densities of several Nevada herds using polygons that circled all observed bighorn sightings. As a result, he included portions of unsuitable ranges with the suitable, thereby overestimating true range size. Demarchi (1965) reported that although the mean density of bighorn for the Chilocotin River area was 4.7 per km$^2$ (12.1 per mi$^2$), key grassland areas supported as many as 27 bighorn per
km² (70.4 per mi²). In light of these and other research reports, we suggest the following guidelines:

(1) The ranges defined through step 5 (unsuitable portions not yet withdrawn) should not be expected to support more than an average of 3.9 bighorns per km² (10 per mi²). This means that there must be at least 32 km² (12.5 mi²) of habitat identified to the level in step 5 to support at least an MVPE of bighorn sheep.

(2) The ranges remaining after step 8 has been applied (unsuitable portions of range deducted) should not be expected to support more than 7.7 bighorns per km² (20 per mi²). Hence, there must be at least 17 km² (6.5 mi²) of core habitat remaining in order to support at least an MVPE of bighorn sheep.

(3) Proposed ranges with an abundance of grassland can be expected to support more sheep than the above estimates, whereas those with less grassland should be expected to support fewer sheep. However, if range area estimates are not within reasonable boundaries of those recommended above, the site may not warrant a bighorn transplant.

Step 9 instructs wildlife biologists to compare the evaluation area against the minimum range area criteria necessary to support at least 125 sheep. Although these minimum area values are rough estimates, they do represent reasonable minimums and therefore should be seriously considered when potential bighorn reintroduction sites are evaluated. If a proposed release site is so restricted in size that these suggested area minimums cannot be met, the site should not be considered a good candidate for a future release of bighorn sheep. However, as mentioned earlier, another option exists: creating a metapopulation comprising subpopulations of less than 125 bighorn as long as bighorn movements can occur between them.

**Step 10.**—Refer to the management decision flow chart.

When a proposed range appears inadequate to support the suggested MVPE of bighorn sheep, the user is referred to the Management Decision Flow Diagram (see Fig. 3, adapted from Holl and Bleich 1982). Figure 3 suggests alternative actions to resolve the problem.

**Step 11.**—Determine if adequate winter range exists to support an MVPE herd by delineating the potential winter range size.

Even if a site is satisfactory in all other respects, when winter ranges are inadequate or lacking, a transplant will fail. Indeed, some transplant failures in Utah have been due, in part, to inadequate winter ranges (Smith et al. 1988). Winter ranges are delineated as follows:

A. Select all areas within 300 m of escape terrain. Areas of up to 1000 m from escape terrain may also be included if multiple escape routes exist, as described in step 4.


C. Of those areas selected in step 11B, exclude all escape terrain without southern exposures (SW-S-SE). Studies addressing winter range requirements have consistently noted that key winter ranges are typified by southern exposures (Shannon et al. 1975, Hudson et al. 1976, Stelfox 1976, Johnson 1983, Smith and Flinders 1991). Identify those areas.

D. Determine the total area of potential winter range from those areas that fit the criteria in steps 11A–C. Add the areas and calculate the total area of probable winter range available.

**Step 12.**—Verify whether adequate winter range exists to support an MVPE of bighorns.

Step 12, like step 9, alerts site evaluators to critical winter range deficiencies. How much winter range is adequate? Coggins (1980) reported winter range densities of 31 bighorns per km² (80 per mi²) for the Lostine River herd of northeast Oregon. Woodgerd (1964) and Blood (1963) reported winter range densities of 19–23 bighorns per km² (50 to 60 per mi²). Wehausen (1983) reported winter densities averaging 20 bighorns per km² (52 per mi²) for the Mt. Baxter herd. High-quality portions of the same winter ranges supported nearly double the average value, or 37 big-
BIGHORN SHEEP MANAGEMENT DECISION FLOW DIAGRAM

Fig. 3. Bighorn Sheep Management Decision flow diagram.

In light of these and other reports, we believe that winter ranges should not be expected to support more than 20 bighorns per km² (about 50 per mi²). Therefore, to sustain an MVPE of 125 bighorns, a particular range must have at least 6.5 km² (2.5 mi²) of available winter range. If an analysis of this step reveals inadequate winter range, then refer to the Management Decision Flow Diagram (Fig. 3),
which recommends alternative actions to resolve the problem.

**STEP 13.**—Determine if adequate lambing terrain exists to support an MVPE herd by delineating potential lambing terrain size.

In some instances, inadequate quantities of lambing terrain have been cited as the ultimate factor controlling bighorn herd size (Hansen 1982). The importance of adequate amounts of suitable lambing terrain cannot be overemphasized, as lamb survival and recruitment can have a greater effect upon transplant success than any other factor of herd population dynamics (Smith and Flinders 1991). Lambing terrain has been defined as the most precipitous, rugged, and remote areas of the bighorn ranges; in addition, these areas are near forage and have dry, southern exposures (Geist 1971, Van Dyke et al. 1983). Identify and select those areas meeting the following criteria:

A. Select all areas identified as potential escape terrain. These areas have already been identified in step 4.

B. Of areas identified in step 13A, select all southerly aspects. Lambing areas most commonly have southern exposures (Geist 1971, Van Dyke et al. 1983, Smith and Flinders 1991). Smith and Flinders (1991) indicated that most lambing areas fall within aspects from 90° to 270°. Select escape terrain areas that fit these aspect criteria.

C. Of areas identified in step 13B, select those typified by horizontal visibility of greater than 80%. Refer to step 8D for a discussion and description of the concept of horizontal visibility. Visibility is measured along predator-approach pathways, not into, or over, cliffs. Because bighorns consistently select against areas having poor visibility, only areas of good visibility are considered suitable for lambing.

D. Of areas identified in step 13C, select only portions within 1000 m of usable water sources. Because of the water demands of lactating ewes, and the inability of young lambs to travel far, water sources need to be within, or adjacent to, lambing areas (Van Dyke et al. 1983). Smith and Flinders (1991) suggest a maximum distance from water of 675 m. Beyond that distance use of lambing terrain declines rapidly. For purposes of this evaluation, areas beyond 1000 m from water should not be considered usable for lambing.

E. Deduct from areas identified in step 12D habitats that are smaller than 2 ha (5 acres). Van Dyke et al. (1983) suggest that ewes select rugged cliffs that are greater than 2 ha for lambing. They did say, however, that if an area is remote, extremely rugged, and free of harassment, parcels as small as 1 ha (2.5 acres) receive occasional use. For purposes of this assessment, areas less than 2 ha should not be considered potential lambing terrain unless extremely rugged and isolated.

F. Determine the total hectares of potential lambing terrain from areas meeting the criteria of steps 13A–E. Sum the areas of probable lambing terrain identified in steps 13A–E.

**STEP 14.**—Decide if adequate lambing terrain exists to support an MVPE of bighorns.

As in steps 9 and 12, step 14 warns biologists of proposed release sites that are deficient in critical lambing terrain. Although reported bighorn age/sex ratios vary widely, an MVPE population of 125 should have approximately 50–60 breeding ewes (inferred from data from Buechner 1960, Oldemeyer et al. 1971, Holl 1982, McQuivey 1978, Smith et al. 1988). Holl (1982) showed that 60 ha of escape terrain is needed to support 10 lambing ewes. If this assumption is true for bighorn in the Intermountain West, a minimum of 300–360 ha (1.2–1.4 mi²) of suitable escape terrain would be required to support the 50–60 ewes during lambing. It is recommended that at least 360 ha (1.4 mi²) of escape terrain, as classified in steps 13A–F, be available for lambing. If the available lambing terrain is less than the recommended baseline value of 360 acres, refer to the Management Decision Flow Diagram for suggested alternative actions.

**STEP 15.**—Determine if adequate summer range exists to support an MVPE herd by delineating potential summer range areas.

In some instances, inadequate quantities of summer range have been cited as the key factor limiting bighorn herd size (Arnett et al. 1990). Summer ranges, as defined here, refer to those areas utilized by all bighorns not involved in lambing activities from May...
through August. This nonlambing group includes the mature ram cohort (four-year-olds and older), yearlings, two-year-old ewes, young rams up to three years of age, and barren ewes. While these sheep are occupying summer ranges, ewes inhabit lambing ranges. Identify and select those areas meeting the following criteria:

A. Delimit all buffer areas (300 m) adjacent to, but not including, escape terrain. These areas were identified in step 4. They include areas having slopes less than 60%.

B. Of areas identified in step 15A, select those having horizontal visibility greater than 80%. Refer to step 8D for a discussion of the concept of horizontal visibility. Bighorns avoid areas of poor visibility; thus, areas of high visibility should be selected as suitable for summer range.

C. Of areas identified in step 15B, select only portions within 3.2 km of water. As discussed in step 8A, it is assumed that ranges farther than 3.2 km from water do not constitute key areas for sheep and are thus withdrawn from consideration as summer range.

D. Determine the total hectares of potential summer range from areas meeting the criteria in steps 15A–C. Calculate the total area of probable summer ranges as identified in steps 15A–C.

STEP 16.—Insure that adequate summer range exists to support an MVPE of bighorns.

As with steps 9, 12, and 14, step 16 alerts biologists to sites deficient in summer range. As discussed above, an MVPE population of 125 would have approximately 50–60 breeding ewes at most. This leaves approximately 65–75 nonbreeding bighorn to occupy summer ranges. In step 9 it was suggested that ranges would probably not support more than 7.7 bighorns per km² (20 per mi²). Therefore to support 65–75 bighorns on summer range, at least 8.4–9.7 km² (3.2–3.6 mi²) of summer range should be available. If available summer rangelands are significantly less than these recommended areas, consult the Management Decision Flow Diagram for alternatives.

STEP 17.—Determine whether all portions of range are properly arranged and connected.

The quantity, quality, and juxtaposition of forage, water, and escape terrain interact to determine bighorn population size and health (Hansen 1982, Van Dyke et al. 1983). In optimum bighorn habitats, water sources and escape terrain are interspersed throughout forage areas. This interspersion promotes herd dispersal and protects the range against overuse of plant communities. If escape terrain, water, and forage are not intermixed throughout the bighorn range, the situation is not ideal. If other critical elements of bighorn ranges are deficient (total area available, area of winter range, lambing terrain, or summer range), the area being evaluated may not be suitable for bighorn reintroduction unless management actions can correct the problems.

STEP 18.—This concludes Part 1 of the Rocky Mountain Bighorn Sheep Habitat Evaluation Procedure. If insurmountable habitat problems were encountered in Part 1, further evaluation (application of Part 2) of the proposed bighorn sheep ranges is unnecessary. If, however, the ranges appear to satisfy the foregoing minimum criteria, habitat quality estimation may be desirable. For range quality analysis proceed to Part 2 of this HEP.

**Part 2**

**Qualitative Assessment of Available Bighorn Habitat—PATREC**

Once bighorn range boundaries have been determined, an estimate of range quality may follow. A range that is capable of supporting an MVPE of bighorns must fulfill the continuously changing needs of herd members (Holl and Bleich 1982). Because varying seasonal demands accompany each bighorn cohort (ram and ewe superclass), three separate PATREC models have been constructed: (1) a ram spring-summer model, (2) a ewe spring-summer (lambing period) model, and (3) an all bighorn fall-winter model (Tables 1–3). These three models permit analysis of the habitat from the unique perspective of each group. Because Bear Mountain ram and ewe cohorts did not sufficiently segregate after the fall rut season, a single model was used to analyze habitat.

A map that estimates bighorn density for the site can be constructed from PATREC models. This density map presents changing
TABLE 1. Habitat evaluation model (PATREC) for spring-summer bighorn ram ranges of northeastern Utah [prior probabilities P(H) = High = .30, P(L) = Low = .70].

<table>
<thead>
<tr>
<th>Habitat attributes</th>
<th>Conditional probabilities</th>
<th>Habitat attributes</th>
<th>Conditional probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TERRAIN</strong></td>
<td></td>
<td><strong>VEGETATION</strong></td>
<td></td>
</tr>
<tr>
<td>1. The area is greater than, or equal to, 7250' elevation.</td>
<td>0.78 0.30</td>
<td>4a. The area has horizontal visibility greater than, or equal to, 90%.</td>
<td>0.67 0.10</td>
</tr>
<tr>
<td>2. The average slope of the area is:</td>
<td></td>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>a. less than 6°.</td>
<td>0.67 0.20</td>
<td>5a. Tree canopy cover is less than, or equal to, 6%.</td>
<td>0.55 0.33</td>
</tr>
<tr>
<td>b. 6° to 15°.</td>
<td>0.22 0.20</td>
<td>5b. The area has horizontal visibility greater than, or equal to, 80%.</td>
<td>0.77 0.01</td>
</tr>
<tr>
<td>c. greater than 15°.</td>
<td>0.11 0.60</td>
<td>6. The area has shrub cover greater than, or equal to, 15%.</td>
<td>0.67 0.10</td>
</tr>
<tr>
<td>3. The area is not within escape terrain.</td>
<td>0.89 0.40</td>
<td>6. The area has shrub cover greater than, or equal to, 15%.</td>
<td>0.99 0.43</td>
</tr>
<tr>
<td>4c. Average shrub height is less than, or equal to, 0.5 meters.</td>
<td>0.67 0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Grass, forb, and shrub cover is greater than, or equal to, 15%.</td>
<td>0.67 0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. The area supports greater than, or equal to, 250 kg per hectare (dry weight) of grasses and forbs.</td>
<td>0.78 0.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

for these variables before conducting a PATREC analysis. Replacement of PATREC values reported here with more appropriate ones from local situations is not that difficult. For example, in Table 1, habitat attribute 1 indicates that 7250' elevation is a break-point for observed bighorn densities. The assigned probabilities indicate that 78% of the time high densities of rams were observed above 7250', whereas low densities of rams occurred at or above that elevation only 30% of the time. The 7250' elevation contour corresponds to the canyon rim at Bear Mountain, a steep-sided plateau. Above 7250', bighorn rams utilize the relatively level rim areas, typified by slopes of less than 6° and abundant forage. With little reason to use the steep, less productive cliff areas, rams occur in higher numbers on the rim. Concurrently, driven by behavior to protect their newborn lambs, ewes are found mostly at lower elevations (in cliffs) typified by very steep slopes (35°-40°) (Table 2). Because many transplant sites have similar elevational break-points between precipitous escape terrain and the more level, high-productivity forage areas, managers can
TABLE 3. Habitat evaluation model (PATREC) for fall-winter bighorn ranges of northeastern Utah [prior probabilities P(H) = High = .30; P(L) = Low = .70].

<table>
<thead>
<tr>
<th>Habitat attributes</th>
<th>Conditional probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td><strong>TERRAIN</strong></td>
<td></td>
</tr>
<tr>
<td>1. The area is greater than, or equal to, 7000’ elevation.</td>
<td>0.90</td>
</tr>
<tr>
<td>2. The average slope of the area is:</td>
<td></td>
</tr>
<tr>
<td>a. less than 6°.</td>
<td>0.60</td>
</tr>
<tr>
<td>b. 6° to 15°.</td>
<td>0.30</td>
</tr>
<tr>
<td>c. greater than 15°.</td>
<td>0.10</td>
</tr>
<tr>
<td>3. The area is within 275 meters of, but not in, escape terrain.</td>
<td>0.80</td>
</tr>
<tr>
<td><strong>VEGETATION</strong></td>
<td></td>
</tr>
<tr>
<td>4a. Tree canopy cover is less than, or equal to, 5%.</td>
<td>0.90</td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>4b. The area has horizontal visibility greater than, or equal to, 90%.</td>
<td>0.90</td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>4c. Average shrub height is less than, or equal to, 0.4 meters.</td>
<td>0.90</td>
</tr>
<tr>
<td>5. Grass and forb cover is greater than, or equal to, 14%.</td>
<td>0.70</td>
</tr>
<tr>
<td>6. The area supports greater than, or equal to, 300 kg per hectare (dry weight) of grasses and forbs.</td>
<td>0.80</td>
</tr>
</tbody>
</table>

reasonably substitute those values. Also, note that each of the three PATREC submodels has several habitat attributes separated by the word "or." Because an underlying assumption of Bayes Theorem is that all habitat attributes are independent, those found to be independent are separated by "or," giving the user the option of selecting one of the listed alternatives, allowing for flexibility in the database.

PATREC analysis requires detailed, site-specific information and is tedious to conduct by hand. Manual application (i.e., noncomputer assisted) of PATREC models for wildlife has been successfully conducted for very large areas with satisfying results (Evans 1983, Wilson 1983). However, current GIS computer technology can be successfully employed to perform these same analyses in significantly less time and with much less effort. We fully recommend the GIS approach to PATREC analysis; however, an overview of both approaches is presented here for the benefit of those with, and without, GIS computer technology.

It is beyond the scope of this paper to discuss the intricacies of PATREC modeling. Therefore, a thorough review of Kling (1980), Evans (1983), or Wilson (1983) is essential, as each of these references contains detailed information regarding the theory, methodology, application, and utility of PATREC models for wildlife. The primary purpose of this section is to present an existing bighorn PATREC model, its application, and utility.

Because the manual and GIS computer approaches to PATREC model application differ widely, each is addressed separately. The following discussion is based on the step-wise procedure outlined in Figure 4. The numbers to the left of each step uniquely identify it and will be referred to below.

The Manual PATREC Model Approach

STEP 1.—Because PATREC models cannot be applied to an entire bighorn range simultaneously, available bighorn habitat (defined in Part 1) must be subdivided into PATREC model evaluation units (MEU) for the analysis of habitat quality. Once subdivided, each of the analysis subunits is individually evaluated. A subunit of 16.2 ha (40 acres) is suggested, although biologists can adjust the MEU’s area as needs dictate. However, as MEU size increases, model resolution will become coarser; and important, high-quality portions of range may go unidentified or be downgraded as they are averaged with adjacent areas of lesser quality. Mylar overlays on topographic maps can provide the necessary analysis grid of MEUs. A data sheet should be constructed that contains a unique label for referencing each MEU and its associated PATREC posterior probabilities.

STEPS 2 AND 3.—Each MEU should be evaluated using each of the three submodels (Tables 1–3). If a user suspects that lambing terrain may be inadequate, he may choose to apply only that PATREC submodel while omitting the other two.

Subunit evaluations compare each subunit’s habitat attributes with those listed in the PATREC models. If the subunit meets the criteria of each habitat attribute, then the high- and low-conditional probabilities
PART 2: QUALITATIVE HABITAT ASSESSMENT
FLOW DIAGRAM

Divide the available bighorn habitat (Part 1, Step 7) into PATREC model evaluation units (MEU) for quality analyses:
A. Divide each 1 m² section of range (2.59 km²) into sixteen 40 acre (16.2 ha) MEU's (or other appropriate size).
B. Record township, range, section # and subsection # (1-16) on a PATREC analysis data sheet.

Evaluate each MEU with regard to bighorn habitat parameters identified in the Ram & Ewe PATREC submodels (Tables 1 - 3)

Slope
Escape Terrain
Shrub Height
Site Production

Determine PATREC posterior probabilities for each MEU

Calculate potential population density estimates for each MEU

Area will support a MVP of bighorn rams
NO

Area will support a MVP of bighorn ewes
NO

Refer to MANAGEMENT DECISION FLOW CHART (See Figure 3)

YES
YES

Proceed with transplant or utilize PATREC model outputs to remedy indicated habitat deficiencies

STEP 4.—PATREC model outputs are expressed as probabilities. These probabilities express the likelihood that the evaluated parcel of range (MEU) will support a high-density population and the probability it will support a low-density population. Computations to provide these outputs are quite simple and
can be done by hand, though not recommended, or with a hand-held calculator or a computer. Once the required inventory data are gathered from an MEU and compared with habitat attribute criteria, the resulting conditional probabilities \( P(\text{ID}/H) \) and \( P(\text{ID}/L) \) are used in Bayes Theorem as follows:

\[
P(\text{H}/\text{ID}) = \frac{P(\text{H}) \times P(\text{ID}/H)}{P(\text{H}) \times P(\text{ID}/H) + P(\text{L}) \times P(\text{ID}/L)}
\]

where \( P(\text{H}/\text{ID}) \) is the probability that the area will support a high-density population based on inventory data. \( P(\text{H}) \) and \( P(\text{L}) \) are the probabilities of a high- or low-density area (prior probabilities) naturally occurring. Every sub-unit has an associated probability of supporting a high density and a low density of bighorn sheep. Since these two probabilities must sum to 1, 1 minus the high-density probability yields the low-density probability. For all three PATREC models the prior probabilities for high and low have been assigned the values of 0.30 and 0.70, respectively. This assignment of values is a reflection of the relative abundance of habitats in northeastern Utah capable of supporting high- and low-density bighorn sheep populations. This implies that a random sample of habitat would select high-density types 3 times out of 10 and low-density types 7 out of 10. These probabilities do not address land beyond the delineated bighorn range boundaries. These values can, and should, be changed to local situations when the proportion of high to low habitat is clearly different. In situations where the proportion is unknown, assigning probabilities of 0.50 to each cancels out the effects of this variable’s input on the model (see Kling 1980 for further discussion). \( P(\text{ID}/H) \) and \( P(\text{ID}/L) \) represent the probabilities that the inventory data have a high- or low-density potential, respectively (conditional probabilities). An example here will illustrate how Bayes Theorem is used.

Suppose a particular MEU was evaluated and only habitat attributes 2A, 6, and 7 of the spring-summer bighorn ram model (Table 1) were satisfied. The probability of the site providing high-density habitat for bighorn rams, given those inventory data, is then calculated. It should be noted that when habitat criteria are not satisfied by the site (numbers 1, 3, 4C, and 5), both high- and low-conditional probabilities are subtracted from 1. To illustrate, the necessary calculations are performed:

\[
P(\text{ID}/H) = (\text{product of all seven attributes' high probabilities multiplied})
\]

\[
P(\text{ID}/H) = (1-.78)(.67)(1-.89)(1-.67)(1-.67)(.67)(.78)
\]

\[
= 0.00092757
\]

\[
P(\text{ID}/L) = (\text{product of all seven attributes' low probabilities multiplied})
\]

\[
P(\text{ID}/L) = (1-.30)(.20)(1-.30)(1-.40)(1-.10)(.01)(.33)
\]

\[
= 0.000174636
\]

These conditional probabilities are then substituted into the Bayes Theorem as follows:

\[
P(\text{H}/\text{ID}) = \frac{(0.3)(0.00092757)}{(0.3)(0.00092757)+(0.7)(0.000174636)}
\]

\[
= 0.69
\]

\[
P(\text{L}/\text{ID}) = 1.0 - 0.69 = 0.31
\]

From these inventory data, we can conclude that the probability of the area supporting a high density of bighorn sheep is 0.69, or 69%. Conversely, the probability that the same area would support a low-density population is 0.31 or 31%.

**STEP 5.**—As discussed in step 8 of Part 1, bighorn population densities ranging from less than 0.4 bighorn per km\(^2\) (1 per mi\(^2\)) (McQuivey 1978) to over 27 per km\(^2\) (70 per mi\(^2\)) (Demarchi 1965) have been reported. For the sake of this model it is assumed that low-density habitat will support 1.0 bighorn per km\(^2\) and high-density habitat will support 25 bighorns per km\(^2\). Based on those density estimates, PATREC predicts that the MEU will support (0.69)(25 bighorn/km\(^2\)), or 17 bighorns per km\(^2\), when the population is at, or near, its carrying capacity.

**STEPS 6 AND 7.**—Because PATREC outputs can be translated into the long-term population densities that a range can be expected to support (discussed in step 5), the number of rams and ewes that an area may be expected to support can be calculated. Although the percent composition of rams, ewes, yearlings, and lambs varies from herd to herd, it is recommended that ram habitat be able to support at least 25 adult rams (four years old and older), and the ewe habitat at least 100 members of the ewe super-class (all ewes, yearlings, and lambs).
STEP 8.—If the PATREC model reveals deficiencies, management may choose to focus on each deficiency individually. The Management Decision Flow Diagram guides decision making in those instances.

STEP 9.—PATREC models also provide some insight as to what management could do to improve the area for bighorn sheep. In the above example, there is little that can be done about habitat attributes 1 (elevation) or 3 (amount of escape terrain), but 4C and 5 (shrub height and herbaceous vegetation cover) could be managed so that the probability of the area supporting a larger population could be increased. By trying various “What if?” scenarios, managers can also identify alternative habitat modifications most likely to have high cost/benefit returns. For instance, if managers were to alter shrub height by burning and thereby satisfy attribute 4C, the resultant P(H/ID) is 0.87, for a net increase in habitat suitability of 18%. However, if managers had chosen to alter attribute 5 instead by increasing the total herbaceous plant cover, the resulting probability that the site will be capable of supporting a high-density population would have increased to 0.98, giving a net increase of 29%. Once the differential in cost is calculated for each scenario, the plan of action that will return the most per unit effort invested will be apparent.

The GIS Computer PATREC Model Approach

No flow diagram has been provided for the GIS computer PATREC model approach. However, the following discussion should assist the reader in understanding an overview of the process.

As with the manual method, the entire bighorn range must be analyzed with each of the PATREC submodels for accurate habitat assessment. The GIS approach circumvents the need for subdividing the evaluation site into analysis units and thereby avoids the tedium associated with it. Instead, the habitat requirements specified by each submodel are used to identify qualifying portions of the GIS data base. For example, the ram spring-summer PATREC submodel (Table 1) indicates in habitat attribute 1 that elevations above and below 7250’ are important in determining habitat suitability. For this elevational attribute, the user would access the digital elevation map and reclassify it into only two categories: those above 7250’ and those below 7250’ elevation. Secondly, all areas (polygons) within each category would be encoded with the appropriate conditional probabilities, as presented in Table 1. Because areas below 7250’ elevation do not meet the given habitat criteria, they are labeled with 1 minus the given probabilities. In a like manner, the user proceeds to subdivide the GIS data base according to each of the habitat criteria listed, labeling each newly created category of polygons with the appropriate conditional probability values. Finally, all polygons are merged to create a composite map comprised of the intersection of all habitat attributes and associated probabilities. The GIS creates a new table for each polygon containing an entire listing of the conditional probabilities associated with its particular habitat attributes, as specified by the PATREC submodels. A composite map of these merged polygons is created independently for each submodel.

The information stored in the relational data base for each range polygon is used to calculate resultant probabilities using Bayes Theorem, as demonstrated above. Fortunately, many GIS applications have the ability to access the stored values, perform these time-consuming calculations for each subunit, and return the results, i.e., probabilities, for each polygon. The GIS can then use these resultant probabilities to calculate estimates of bighorn densities for each polygon. As in the manual method, the total number of sheep the site is capable of supporting is determined by summing the estimated density values for all polygons. These individual values (i.e., number of rams in spring-summer, number of ewes during lambing, etc.) must exceed those presented above in step 6 of the Manual PATREC approach. In this manner, seasonal/cohort weaknesses of a site are identified, and management can focus on the real problem areas. GIS utility and power streamline the PATREC process immensely and put within reach of many this powerful tool for habitat quality evaluation.

This concludes application of Part 2 of the bighorn HEP. Upon completion of bighorn habitat evaluation, the investigator should know whether or not an evaluated site could support reintroduced bighorn sheep and what
could be done in the event limiting factors need attention.

CONCLUSIONS

Although efforts have been underway for several decades to reestablish Rocky Mountain bighorn sheep to formerly occupied ranges, many transplant efforts have failed. In order for Utah, and other western states, to have a more successful reintroduction program, a rigorous, biologically based habitat assessment procedure has been devised. It is hoped that this procedure will help managers avoid "doomed-from-the-start" reintroductions and greatly enhance transplant success.

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LITERATURE CITED


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