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HABITAT EVALUATION PROCEDURE FOR ROCKY MOUNTAIN BIGHORN SHEEP IN THE WESTERN ROCKY MOUNTAINS AND GREAT BASIN REGIONS

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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 ranges to determine if adequate quantities exist to support a MVP of bighorn sheep, and 2) a qualitative assessment of the defined ranges to predict probable densities of bighorns those ranges can be expected to support. This paper presents a step-wise approach to bighorn habitat evaluation, thereby enhancing the ability of wildlife biologists to make prompt and accurate bighorn habitat assessments.

The precipitous decline of Rocky Mountain bighorn sheep (Ovis canadensis canadensis) following arrival of American settlers in the mid-1800's has been well documented (Buechner 1960). As early as 1880, some bighorn herds had been entirely extirpated, while others suffered sharp reductions in number. Even recently, Jahn and Trefethen (1978) warned that unless more effective management was initiated, an additional loss of 8 percent of all 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 serious habitat deficiencies which have hampered herd growth and persistence. For example, Utah's reintroduction program has not succeeded in restoring Rocky Mountain bighorn to former ranges in spite of more than 2 decades of effort (Smith et al. 1988). Currently, fewer bighorns exist than the total number transplanted, suggesting that a serious problem exists in the reintroduction program. Probable reasons for transplant failure include: 1) inadequate quantities of total available range, 2) severe competition with other ungulates, 3) contact with domestic livestock, 4) improper juxtaposition of key habitat components, 5) inadequate quantities of 1 or more critical seasonal ranges, and 7) excessive human harassment. Clearly, a more rigorous assessment of proposed reintroduction areas should result in a more successful reintroduction program. This habitat evaluation procedure (HEP) represents an effort to provide bighorn managers with a better tool for assessing bighorn habitat quality.

Although several bighorn habitat evaluation procedures exist (Armentrout and Brigham 1988, Holl 1982, Golden and Tsukamoto 1980, Grunigen 1980), this HEP has been developed because: 1) an exclusive Rocky Mountain bighorn sheep HEP is nonexistent and, 2) none of these other procedures critically examines actual, or proposed, bighorn ranges with regard to the minimum area necessary to support at least a minimum viable population (MVP) of bighorn sheep. A 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 (MVPE) for bighorn sheep are not available, Berger (1990) and Geist (1975) have suggested that bighorn managers should maintain herds of at least 100 to 125 individuals if the herd is to survive and persist over time. Because restoration efforts should strive to establish populations with long-term persistence, this bighorn habitat evaluation procedure rigorously assesses the ability of a proposed site to support at least 125 bighorn sheep. This requirement can be relaxed somewhat, however, if a particular site is situated such that exchange with nearby herds can be expected to occur. Nonetheless, for most transplant populations this will not be the case and each transplant site must be evaluated individually. Schwartz et al. (1986) provide several examples of distances which bighorn have been observed moving between distant herds of southern California, although extrapolation to more forested regions should be done cautiously.

A longer, more detailed version of this HEP is available upon request from the authors. Abbreviating it here has enabled inclusion in the 1990 proceedings which we felt would be of benefit to other sheep biologists.

OVERVIEW OF THE BIGHORN HABITAT EVALUATION PROCEDURE

A diagrammatic overview of this bighorn habitat evaluation procedure is presented in Figure 1. Two essential components comprise this habitat assessment tool: estimation of habitat quantity (Part 1) and estimation of habitat quality (Part 2). It is the combination of these 2 habitat characteristics which determines range carrying capacity. Part 1 is comprised of bighorn habitat requirement-based questions which define probable range area and boundaries. Part 2 utilizes the process of pattern recognition (PATREC) to assess range quality.

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 fairly predictable, it is possible to estimate probable range size based on a knowledge of bighorn movement delimiters. Although bighorn will occasionally ignore what are typically barriers to movement, managers should not expect portions of range, segregated by known barriers to movement, to contribute significantly to probable bighorn ranges. A proposed bighorn reintroduction site comprised of scattered range segments, crisscrossed with barriers to movement and with key habitat components ineffectively juxtapositioned or absent, would ultimately fail to support a herd capable of long-term persistence. Part 1 presents these normally restrictive barriers and assists in identifying the probable range boundaries, maximum area, and juxtaposition of key habitat components. Part 1 focuses attention on critical aspects of bighorn habitat and helps managers determine a site's ability to provide quality bighorn habitat of the magnitude needed to support a MVPE of sheep.

Bighorn range quality is the expression of complex interactions of many physiographic and biological characteristics. The PATREC approach, often referred to as "PATREC modeling", captures in simple mathematical form the process by which most biologists intuitively assess relative habitat conditions (Grubb 1988). PATREC's output is similar to saying "Based on my experience and knowledge, and given the habitat components and conditions just observed, the probability that the area is capable of supporting high densities of bighorn sheep is______." (Holl 1982). To date, PATREC models have been applied to a variety of wildlife, including bald eagles (Grubb 1988), deer (Kling 1980), sage grouse (Evans 1982), and bighorn sheep (Holl 1982) to name a few. For a thorough description of PATREC, see Kling (1980) and Williams et al. (1977). It is highly recommended that before proceeding with Part 2, background material on PATREC be obtained and reviewed. Particularly helpful is the "User's Guide to PATREC for Habitat Evaluation" (Kling 1980).

Although the most rigorous evaluation of habitat will occur when both Part 1 and Part 2 are applied to an area, it is not required that you do so. Part 1 is the key component of the HEP and cannot be omitted. Application of Part 1, rigorous site analysis, in of itself would greatly assist many bighorn reintroduction programs. Part 2 is more time intensive and requires a more detailed database, but provides some very useful information. Individual users must review their own time and budget restraints to determine how rigorously they can afford to analyze a potential reintroduction site. In many instances, sites being analyzed may never receive Part 2 analysis, having failed to provide either the minimum range quantity necessary to support a MVPE or due to irreparable habitat problems.

METHODS

A step-wise discussion of the bighorn habitat evaluation procedure follows. To shorten this paper, discussion has been minimized and only key literature citations given.

Part 1: Quantitative Assessment Of Available Bighorn Habitat

In Part 1, sequential questions direct 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 as needed by bighorn. The following numbered steps match those of Figure 1.

Step 1--Escape terrain is defined as slopes greater than 60% (about 27°), with occasional rock outcroppings whereon bighorn can out-maneuver predators and find secure bedding areas. Rugged escape terrain has been identified as the most critical bighorn habitat component (Van Dyke et al. 1983, Ferrier and Bradley 1980, Wilson et al. 1980), without which bighorn will not flourish (Hansen 1980). Research in northeastern Utah has indicated that 95% of all bighorn activity occurs within 300 meters of cliff escape terrain (Smith and Flinders 1991). Consequently, little is gained by including areas beyond 300 meters from cliff escape terrain in range size determinations. Identifying and delineating all escape terrain and adjacent 300 meter buffer zones satisfies Step 1. Occasionally a segment of range is bounded on 2, or more, sides by escape terrain. In such instances, if the distance between the escape terrain areas is less than, or equal to, 1000 meters, the entire area between should be included as potential bighorn habitat. This is done because bighorn have more escape routes when escape terrain borders more than 1 side of forage areas (Van Dyke et al. 1983).

Step 2--Bighorn movements are restricted by barriers which fall into 1 of 2 categories: natural and man-made. Identify them on the range being evaluated as follows:

A. **Natural Barriers**

1) Water - Swift and/or Wide Rivers and Lakes: Though Cowan (1940) noted bighorn occasionally swimming, water has been noted elsewhere to effectively halt bighorn movements (Smith and Flinders 1991, Graham 1980, Wilson et al. 1980). Rivers and lakes break continuity of range and should be considered barriers to bighorn range extensions in most cases but must be evaluated individually.

2) Dense Vegetation: Smith and Flinders (1991) and Risenhoover and Bailey (1980) have stated that bighorn sheep will not cross even narrow tracts of dense vegetation, particularly timber. For purposes of this habitat assessment, low visibility areas (of less than 50% horizontal visibility - see Smith and Flinders 1991 for methods used to determine), 100 meters wide, or more, will be considered effective movement barriers to bighorn sheep and should be identified as such.

3) Cliffs - Continuous, Non-Traversable Cliff Complexes: Sheer, vertical cliffs lacking negotiable terrain should be identified as barriers to movement.

4) Valleys or Plateaus: If valleys between areas of escape terrain are wider than 1000 meters, identify them as barriers to bighorn movements. Similarly, plateaus which separate escape terrain areas by more than 1000 meters should be considered range boundaries.

B. **Man-Made Barriers**

1) Water - Canals, Reservoirs, Aqueducts: Waterways are generally a barrier to bighorn movements. Concrete-lined canal systems, reservoir impoundments and aqueduct structures can create impassable barriers and bighorn death traps (Graham 1980).

2) Impassable Fencing: Fencing can restrict bighorn movements and cause mortality, particularly if rams get their horns entangled. Helvie (1971) reviews the types of fencing which limit bighorn movements. Fence lines must be evaluated individually for impact.

3) Major Highways and High-Use Roadways: Aside from the fencing often associated with major highways and high-use roadways, auto traffic often deters bighorn from traversing these areas (Van Dyke et al. 1983, Risenhoover 1981, McQuivey 1978). Highways must be individually evaluated and those clearly restricting bighorn movements must 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 which

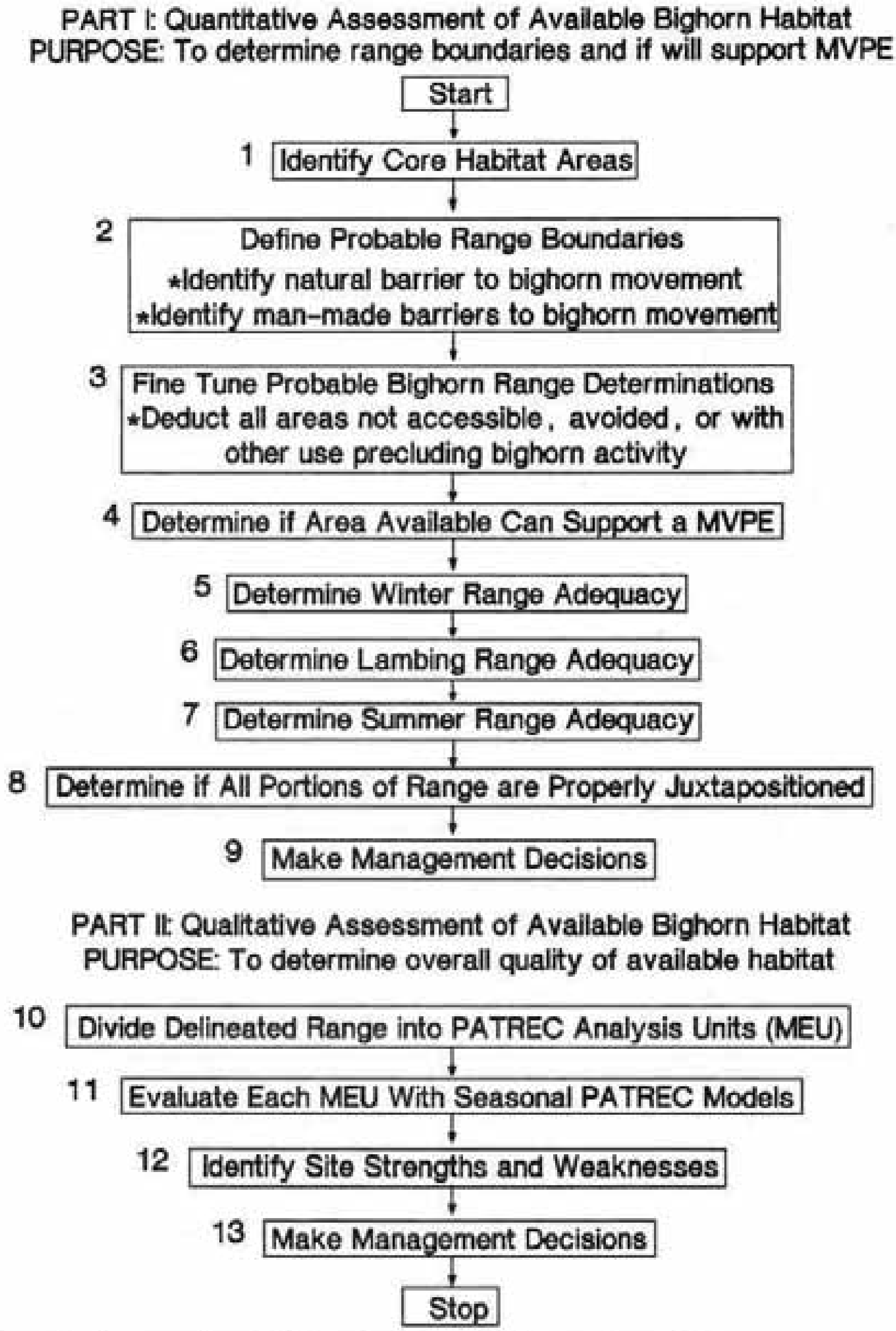

Figure 1. An overview of the Rocky Mountain bighorn sheep HEP.

frequently impact bighorn ranges and preclude bighorn use. Linear arrays of human activity can form barriers to movement. These have to be evaluated individually and range boundaries drawn accordingly.

Step 3--Within the limits of the probable bighorn range boundaries determined thus far, the following areas should be identified and deducted:

A. Areas Beyond 3.2 km Of Bighorn Watering Sources

1) McQuivey (1978) noted that 85 percent 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. Though not normally limiting to Rocky Mountain bighorn sheep, sparse water resources can impose a delimiter upon range size.

B. A 100 m Wide Buffer Around Areas Of Low To Moderate Human Use

1) Areas typical of low-to-moderate human activity include trails, roads, dwellings, and some campgrounds. Many have noted the negative effect of human activities upon bighorn sheep (Gionfriddo and Krausman 1986, Hicks and Elder 1979). Light (1971) defined "light use" as 0 to 100 visitors a year, "moderate use" as 100 to 500 visitors, and "high use" as over 500 visitors a year on backcountry trails. He reported that bighorn stayed 100 meters or more away from moderate use areas.

C. A 150 m Wide Buffer Around Areas Of High Intensity Human Use

1) Areas typical of high intensity human activity include airports, mines, tramways, campgrounds, ski resorts, and heliports. Identify and buffer these areas with a 150 m zone, excluding it from potential bighorn ranges. These should be evaluated individually in every occurrence.

D. All Plant Communities Typified By Horizontal Visual Obstruction Of Greater Than 50 Percent

1) Work by Smith and Flinders (1991) and Risenhoover and Bailey (1980) has indicated that bighorn avoid areas of poor visibility. Identify these vegetation types and exclude them from bighorn range considerations. Refer to Smith and Flinders (1991) for methods used in determining horizontal visibility within specific vegetation types.

E. All Portions Of Range Allowing Potential Contact With Domestic Sheep Or Goats At Any Time

1) Any portion of range which might allow bighorns and domestic sheep, or goats, to make contact should be excluded from consideration. Contact has been linked to catastrophic die-offs and should be avoided at all costs (Capurro 1988, Foreyt 1988).

F. All Portions Of Range Which Are Occupied By Concentrations Of Elk, Cattle or Bison

1) If portions of potential bighorn range will concurrently have concentrations of elk, cattle or bison present, managers should consider excluding them as potential bighorn ranges. Besides competing directly for the same forage resources (Van Dyke et al. 1983), disease transmission (Jessup 1981), and social intolerance (King and Workman 1984) are additional reasons for excluding potentially sympatric elk, cattle, bison and bighorn 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.

After deducting the above areas identified in 3A-3F from the range boundaries defined in steps 1 and 2, the remaining area represents the maximum range available to bighorn sheep if introduced to the area.

Step 4--Is there enough range, regardless of quality at this point in the evaluation, to support a MVPE of at least 125 bighorn sheep? Van Dyke et al. (1983) suggested a maximum density of bighorn sheep of 1.9 per km^2 (5 per mi^2) for the Great Basin in southeastern Oregon. If this held true for other sites of the western Rocky Mountains and Great Basin regions, then a minimum area 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 in the literature. Unfortunately, all reported densities appear to have been calculated for areas which included both usable and unusable portions of range. For example, McQuivey (1978) calculated bighorn densities using polygons which encircled all observed bighorn sightings for each herd. As a result, he included unusable habitat with the usable portions. 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 km^2 (70.4 per mi^2). From an extensive literature review and research in northeastern Utah, the following guidelines are suggested:

(1) The area defined in Step 2 (no deductions yet made of unusable portions) should not be expected to support more than an average of 3.9 bighorn per km^2 (10 per mi^2). This means that there must be at least 32 km^2 (12.5 mi^2) of habitat identified to the level in Step 2 to support at least an MVPE of bighorn sheep.

(2) The area defined in Step 3 (all deductions of unusable portions of range) should not be expected to support more than 7.7 bighorns per km^2 (20 per mi^2). This means that there must be at least 17 km^2 (6.5 mi^2) of critical habitat identified to the Step 7 level to support at least a MVPE of bighorn sheep.

(3) Proposed ranges with an abundance of grassland can be expected to support somewhat more than the above estimates, whereas those with less grasslands will probably support less. Minor adjustments in carrying capacity estimates which reflect the abundance of grasslands is justified.

This exercise of estimating a range's approximate carrying capacity serves to alert wildlife biologists of areas which are too small to support at least 125 bighorn sheep. Although these minimum area values are crude estimates at best, they do represent reasonable minimums, and as such, should be seriously considered when evaluating potential bighorn release sites. If a proposed release site is so limited in size that these suggested area minimums cannot be closely matched, or exceeded, bighorn transplant efforts should perhaps be directed on ranges elsewhere.

Step 5--This step directs the user to determine the probable extent of winter ranges present as follows:

A. **Select All Areas Within 300 m Of Escape Terrain**

1) Areas of up to 1000 m from escape terrain may also be included when bounded on 2 or more sides by escape terrain (see step 1 above).

B. **Within Areas Selected in Step 5A, Identify All Areas Receiving Less Than 25 CM Of Accumulated Snow**

1) Heavy snow accumulations can render potential winter range areas unusable (Smith and Flinders 1991, Johnson 1983). Research in northeastern Utah indicated that when snow depths exceeded 25 cm bighorns abandoned those portions of winter range, rendering them useless.

C. **Of Those Areas Selected In Step 5B, Identify All With Southern Exposures (SW-S-SE)**

1) Studies which have addressed winter range requirements have consistently noted that key winter ranges are typified by southern exposures (Smith and Flinders 1991, Johnson 1983). Identify these areas.

D. **Determine The Total Area Of Potential Winter Range From Those Areas Which Fit The Criteria In Steps 5A-C Above**

1) Add the areas and calculate the total area of available winter range.

Step 5 serves to warn biologists when a proposed release site is deficient in critical winter range area. How much winter range is enough? Coggins (1980) reported winter range densities of 31 bighorns per km^2 (80 per mi^2) for the Lostine River herd of Northeast Oregon. Woodgerd (1964) and Blood (1963) both reported winter range densities of 19 to 23 bighorns per km^2 (50 to 60 per mi^2). In light of these, and other reports, winter ranges should be able to conservatively support 20 bighorns per km^2 (about 50 per mi^2). Therefore, to sustain a MVPE of 125 bighorns a transplant site should have at least 6.5 km^2 (2.5 mi^2) of available winter range.

Step 6--Step 6 directs the user to determine the probable extent of lambing ranges present on the site under evaluation. In some instances, inadequate quantities of lambing terrain have been cited as the ultimate factor controlling bighorn herd size (Hansen 1982). To proceed with Step 6, identify and select those areas meeting the following criteria:

A. **All Areas Identified As Potential Escape Terrain**

1) These areas were already identified in Step 1 above.

B. **Of Areas Identified In Step 6A, Select All Southerly Aspects**

1) Lambing areas are most commonly found with southern exposures (Smith and Flinders 1991, Van Dyke et al. 1983, Geist 1971). Research in northeastern Utah indicated that all lambing areas fell between aspects from 100° (ESE) to 225° (WSW). Select those escape terrain areas which fit these aspect criteria.

C. **Of Areas Identified In Step 6B, Select Those Which Are Horizontal Visibility Exceeding 80 Percent**

1) Visibility was measured along predator approach pathways, not into, or over, cliffs (Smith and Flinders 1991). Bighorns actively select against poor visibility areas.

D. Of Areas Identified In Step 6C, Select All Portions Within 1000 m Of Water Sources

1) Because of the demands of lactation and the inability of young lambs to travel far, water sources need be within, or adjacent to lambing areas (Van Dyke et al. 1983). Research from northeastern Utah (Smith and Flinders 1991) suggested a maximum distance from water of 675 meters, beyond which, the quality of lambing terrain declined rapidly. For this evaluation, areas beyond 1000 meters of water do not contribute significantly to lambing terrain.

E. From Areas Identified in Step 6D, Deduct Those That Are Less Than 2 Hectares (5 Acres) In Size

1) Van Dyke et al. (1983) suggest that ewes select rugged cliff areas for lambing only those which are greater than 2 hectares in size. However, if the area is remote, extremely rugged and harassment is low, parcels of 1 hectare (2.5 acres) may be used (Van Dyke et al 1983). For this bighorn habitat assessment, unless the country is extremely rugged and isolated, areas less than 2 hectares should not be included as potential lambing terrain.

F. Of Areas Which Satisfied Steps 6A-E, Determine The Total Hectares Of Potential Lambing Terrain

1) Sum the total area of probable lambing terrain as identified in steps 6A-E above.

Step 6 assists identification of sites deficient in critical lambing terrain. Though reported bighorn age/sex ratios vary widely, a MVPE population of 125 would have approximately 50 to 60 breeding ewes at best (inferred from data from Smith et al. 1988a, McQuivey 1983). Holl (1982) conducted research which showed that 60 hectares of escape terrain were needed to support 10 ewes in the San Gabriel Mountains of southern California. If this relationship held true for the western Rocky Mountain and Great Basin Regions, at least 300 to 360 hectares (1.2 to 1.4 mi^2) of quality escape terrain would be required to support ewes during lambing. At present, data are unavailable from this region to allow calculation of the ewe-to-hectares of escape terrain relationship. Therefore, it is recommended that at least 360 hectares (1.4 mi^2)of escape terrain, as classified in steps 12A-F, be available for use as lambing terrain.

<u>Step 7</u>--Step 7 instructs the user to estimate the amount and location of summer ranges present on the site being evaluated. 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 (May through August). This non-lambing group includes the mature ram cohort (4-year olds and older), yearlings, 2-year old ewes, young rams up to about 3 years of age and barren ewes. While these non-lambing sheep occupy summer ranges, ewes are on lambing ranges. To proceed with Step 7, identify areas meeting the following criteria:

A. Identify Escape Terrain Buffer Areas (up to 300 m from the cliffs)

1) These areas were already identified in Step 1 above, and will be typified by slopes of less than 60 percent.

B. Of Areas Identified In Step 7A, Select Those Which Are Typified By Horizontal Visibility Exceeding 80 Percent
1) Bighorns avoid areas of poor visibility so only those areas of high visibility should be selected as candidates for quality summer ranges.
C. Of Areas Identified In Step 7B, Select All Portions Within 3.2 km Of Usable Water Sources
1) As discussed in 3A above, ranges farther than 3.2 km from water sources do not contribute significantly to bighorn habitat and should be excluded from consideration as summer ranges.
D. Determine The Total Hectares of Potential Summer Range From Those Areas Which Satisfied the Criteria of Steps 7A-C
1) Calculate the total area of ram summer ranges as identified in steps 7A-C above.

Step 7 helps identify areas deficient in summer range quantity. As discussed in Step 6, a MVPE population of 125 bighorns would have approximately 50 to 60 breeding ewes at best (inferred from data from Smith et al. 1988a, McQuivey 1983, Holl 1982), leaving approximately 65 to 75 non-breeding bighorn to occupy the summer range areas. Step 4 indicated that ranges could not be expected to support more than 7.7 bighorns per km^2 (20 per mi^2). Therefore, to support 65 to 75 bighorns on summer range there should be at least 8.4 to 9.7 hectares (3.3 to 3.8 mi^2) of qualifying range.

Step 8--The quantity, quality and juxtaposition of forage, water and escape terrain (the 3 crucial bighorn habitat components) have a strong influence upon bighorn population size and health (Van Dyke et al. 1983, Hansen 1982). In optimum bighorn habitats, water sources and escape terrain are dispersed throughout forage areas thereby promoting herd dispersal and less impact upon plant communities by overuse. If escape terrain, water, or forage is not intermixed throughout a bighorn range, this represents a suboptimal situation. If additionally, other critical elements of bighorn ranges are weakly met or absent (total area, winter ranges, or lambing terrain), the area being evaluated is probably unsuitable for a bighorn reintroduction until management alleviates the problem(s).

Step 9--Part I has provided many opportunities for identification of range weaknesses and strengths. If insurmountable habitat problems were encountered, then further evaluation (application of Part 2) of the proposed bighorn sheep ranges is moot. If, however, the ranges appear to satisfy the minimum criteria discussed, then proceed with Part 2 of this habitat evaluation procedure.

Part 2: Qualitative Assessment Of Available Bighorn Habitat - PATREC

Now that an estimation of the maximum area available for a transplant herd has been determined, an estimate of range quality may be desired. A high quality bighorn range, capable of supporting at least an MVPE of bighorn year-round, must meet the varying needs of herd members seasonally (Holl and Bleich 1982). Because of the varying, seasonal demands experienced by different bighorn cohorts, 3 separate PATREC models have been constructed (Tables 1-3). Three models enable analysis of habitat from each unique perspective.

Part 2 of this procedure has been specifically designed with data obtained from the Bear Mountain bighorn herd of northeastern Utah. Wildlife managers will need to recognize that some habitat-related questions may not be applicable to places other than the Bear Mountain area. However, because each specific PATREC question addresses an important habitat variable, managers should attempt to attain the correct values for that variable for the area in question.

The following discussion is based on the step-wise procedure outlined in Figure 1. The numbers to the left of each step in Figure 1 correspond to the following numbered steps.

<u>Step 10</u>--Divide the identified bighorn habitat polygon(s) into PATREC model evaluation units (MEU) for analysis of habitat quality. PATREC models cannot be "blanket applied" to an entire bighorn range simultaneously. The range must be sub-divided into meaningful analysis units which are then subsequently evaluated. A suggested MEU size is 16.2 hectares (40 acres), although biologists can adjust the MEU's area as needs dictate. However, as MEU size increases, model resolution will become coarser and high quality portions of the range may pass unnoticed or their quality down-graded when averaged with adjacent areas of lesser quality. Nevertheless, each application must be individually evaluated. Mylar overlays on topographic maps can provide the necessary analysis grid of MEU's. A data sheet should be constructed which contains a unique label for referencing each MEU and its associated PATREC posterior probability.

<u>Step 11</u>--Each MEU should be evaluated using the 3 sub-models (Tables 1-3). If a user suspects that adequate lambing terrain is the probably inadequate for a particular site in question, then he may choose to apply only that PATREC sub-model, forgoing the other 2, feeling summer and winter ranges are adequate. Similarly, any other seasonal range suspected of being deficient can alone be analyzed.

Site evaluations compare each site's habitat qualities with the habitat attributes listed in each of the PATREC models. Note that sometimes "OR" separates some attributes. This means that the user may choose any one of the attributes linked by "OR" but none of the others for analyzing the chosen MEU. This is because an underlying premise of PATREC is that individual habitat attributes are independent of one another and in these cases "OR" separates those clearly interdependent. This gives the user freedom to choose the attribute for which the most data are available. If the site meets the criteria of each habitat attribute, then the high and low conditional probabilities associated with each (as listed in the 2 right-hand columns) are used in calculation of the site's overall high and low density probabilities. When habitat attribute criteria are not met by the site, each high and low conditional probability is subtracted from 1.0 and the result recorded for use in subsequent calculations. Referring to Table 1, suppose the MEU being analyzed is not over 7250' in elevation. The probabilities recorded are 1.0 - 0.78 (0.22) for high and 1.0 - 0.30 (0.70) for low.

PATREC model outputs are expressed as a probabilities. These probabilities indicate the likelihood that the tract of land being evaluated will support a high density population and the probability it will support a low density population. The sum of these 2 probabilities (high and low) is 100%, so if a MEU has a 90% probability of supporting high densities of sheep, the likelihood of it supporting a low density population of sheep is 10%. Computations to provide the final outputs are quite simple and can be done by hand, although not recommended. A hand-held calculator or a computer is much faster than by hand. Once the required inventory data (appropriate site characteristics) are gathered from a MEU and compared against the habitat attribute criteria, the resulting conditional probabilities P(ID/H) and P(ID/L)) calculated. P(ID/H) is calculated by multiplying all probabilities listed in the Conditional Probability - High column together. Remember that in some cases 1.0 minus the listed probability is used when the habitat attribute is not met by the site. P(ID/L) is calculated the same way, only using those probabilities listed, or 1.0 minus them when not met, in the right hand column of the tables. Together, these 2 conditional probabilities are utilized in Bayes Theorem as follows:

$$P(H/ID) = \frac{P(H) \times P(ID/H)}{P(H) \times P(ID/H) + P(L) \times P(ID/L)}$$

Where P(H/ID) is the probability that the MEU will support a high density population based on the inventory data. P(H) and P(L) are the probabilities of a high or low density area (prior probabilities) naturally occurring. For all 3 PATREC models the prior probabilities for High and Low have been assigned the values of 0.30 and 0.70 respectively because field experience in northeastern Utah suggests that only 30 percent of the time would one encounter a parcel of land with those qualities which make it of high value for bighorn sheep, the rest is low. These ratios of high to low quality land refer only to land within 300 meters of escape terrain, not beyond it. As discussed, all land beyond 300 meters has a probability near zero of being bighorn habitat at all. These values can, and should, be changed to local situations when the proportion of high to low habitat is clearly different. P(ID/H) and P(ID/L) represent the probabilities 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 it was found that only habitat attributes 2A, 6, and 7 of the spring-summer bighorn ram model (Table 1) were satisfied. To calculate the probability that this site is one which would support high densities of bighorns, the value for P(ID/H) and P(ID/L) must be calculated. Since attributes 2A, 6 and 7 were met by site criteria, use the probabilities recorded in each column. However, when attributes are not met by the site, (numbers 1, 3, 4C, and 5), both high and low conditional probabilities must be subtracted from 1. As a result the following calculations are performed:

$$P(ID/H) = (1-.78)(.67)(1-.89)(1-.67)(1-.67)(.67)(.78) = .000922757$$

$$P(ID/L) = (1-.30)(.20)(1-.30)(1-.40)(1-.10)(.01)(.33) = .000174636$$

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

$$P(H/ID) = \frac{(0.3)(0.000922757)}{(0.3)(0.000922757 + (0.7)(0.000174636)} = 0.69$$

$$P(L/ID) = 1.0 - 0.69 = 0.31$$

From these inventory data it is concluded that the probability of the MEU being capable of supporting a high density population is 0.69, or 69%. Conversely, the probability of that same area supporting a low density population would be 0.31 or 31%. Simply stated, given the pattern of habitat features present on the site, this site has a greater chance of supporting high densities of sheep than low (69% versus 31%).

Step 12--If through PATREC model analysis habitat deficiencies are identified (the models indicate which attributes are related to high quality habitats), management may choose to focus first on these. Some deficiencies, such as insufficient cliff escape terrain, obviously cannot be corrected.

Step 13--PATREC models provide some insight as to what management could do to improve the area for bighorn sheep. By trying various "What if?" scenarios managers can also get a feel for which project will return the most for their effort. For example, if horizontal visibility if low due to shrub cover, the impact of converting that shrubland to grass by burning or some other method, can be projected by recalculating the resulting probability using the now met attribute's associated probabilities for high and low. In this way, management can get a feel for which habitat project will return the greatest improvement in habitat quality. Cost can also come into consideration. Although a particular habitat treatment may yield the greatest improvement in overall suitability for bighorn sheep, cost associated with that treatment may be prohibitive. However, once the differential in cost is calculated for each management scenario, the plan of action which will return the most for the effort invested will become much easier to determine.

For an entire range, one must sum up the calculated P(H/ID)s for all MEU's and determine the mean value. This value represents the overall range quality and should indicate to managers whether a high or low quality range has been inventoried, what its deficiencies are and give some insight as to how they should be remedied.

This concludes application of Part 2 of the Bighorn HEP. Upon completion of bighorn habitat evaluation, the investigating biologist should know whether or not a site in question could support reintroduced bighorn sheep and what can 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 particular, the state of Utah's Rocky Mountain bighorn sheep reintroduction program, as well as those in other locations, has failed to significantly place bighorn onto former ranges. In order for Utah, and perhaps other western states, to have a more successful reintroduction program a more rigorous, biologically-based, habitat assessment procedure is presented here. In this way doomed-from-the-start reintroductions will be avoided and transplant success greatly enhanced. It is believed that application of this procedure will insure greater transplant success as well as direct management to the most effective habitat treatments.

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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)

Habitat Attributes	Conditional Probabilities High	Low
Terrain		
1) The area is over 7250′ elevation.	0.78	0.30
2) The area's average slope is:		
a) less than 6 °.	0.67	0.20
b) 6 ° to 15 °.	0.22	0.20
c) greater than 15 °.	0.11	0.60
3) Less than 50% of the area is comprised of escape terrain.	0.89	0.30
Vegetation		
4a) The area has horizontal visibility greater than 90%.	0.67	0.10
OR		
4b) Tree canopy cover is less than 10%.	0.89	0.60
OR		
4c) Average shrub height is less than 0.5 meters.	0.67	0.40
5) Grass, forb and shrub cover is greater than 15%.	0.67	0.10
6) The area has sage-bitterbrush associations present (must be a combined cover ≥ 10% and > 1 acre in size)	0.67	0.01
7) The area supports greater than 250 kg per hectare (dry weight) of grasses and forbs.	0.78	0.33

Table 2. Habitat evaluation model (PATREC) for fall-winter bighorn ranges of northeastern Utah (Prior probabilities P(H) = High = .30; P(L) = Low = .70)

Habitat Attributes	Conditional Probabilities High	Low
Terrain		
1) The area is over 7000' elevation.	0.90	0.20
2) The area's average slope is:		
a) less than 6 °.	0.60	0.20
b) 6 ° to 15 °.	0.30	0.01
c) greater than 15 °.	0.10	0.79
3) Less than 20% of the area is comprised of escape terrain.	0.90	0.30
Vegetation		
4a) Tree canopy cover is less than 5%.	0.90	0.40
OR		
4b) The area has horizontal visibility greater than 90%.	0.90	0.40
OR		
4c) Average shrub height is less than 0.4 meters.	0.90	0.40
5) Grass and forb cover is greater than 14%.	0.70	0.20
6) The area supports greater than 300 kg per hectare (dry weight) of grasses and forbs.	0.80	0.10

Table 3. Habitat evaluation model (PATREC) for spring-summer bighorn lambing ranges of northeastern Utah (Prior probabilities P(H) = High = .30; P(L) = Low = .70)

Habitat Attributes	Conditional Probabilities High	Low
Terrain		
1) The area is below 6400' elevation.	0.67	0.44
2) The area's average slope is:		
a) less than 35 °.	0.11	0.33
b) 35 ° to 40 °.	0.77	0.01
c) greater than 40 °.	0.12	0.66
3) More than 75% of the area has aspects between 180-270° from north.	0.67	0.11
4) Water is present on the site.	0.89	0.44
Vegetation		
5a) Tree canopy cover is less than 6%.	0.55	0.33
OR		
5b) The area has horizontal visibility greater than 80%.	0.77	0.99
6) The area has shrub cover less than 6%.	0.99	0.43