Habitat patch dynamics of desert bighorn sheep Ovis canadensis nelsoni in the Eastern Mojave Desert

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HABITAT PATCH DYNAMICS OF DESERT BIGHORN SHEEP

OVIS CANADENSIS NELSONI IN THE

EASTERN MOJAVE DESERT

by

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Bachelor of Science
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1990

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of the requirements for the degree of

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in

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CHAPTER 1

INTRODUCTION

Conservation biology began to emerge into the forefront of ecological research in the late 1970's and early 1980's. The rapid rise of the environmental movement, the widening gulf between population biologists and naturalists, and growing concerns over the human-induced extinction crisis all contributed to the formulation and rise of this new field (Soule 1986). For the first time, biologists, ecologists, zoo keepers, wildlife managers, geneticists, and various other professionals all joined together in an attempt to preserve biodiversity. The chapters of this dissertation incorporate several broad topics: bighorn sheep ecology, landscape ecology, remote sensing, and Geographic Information Systems (GIS). Although any and all of these topics could be used to describe the contents of this work, the concepts of habitat configuration and fragmentation are the cohesive ideas running throughout the different papers.

In order to preserve wild species, adequate habitat must first be preserved. From a conservation standpoint, habitat fragmentation is extremely important because of its potential to increase the probability of wildlife populations declining into extinction. The process of habitat fragmentation occurs when a given area of habitat is transformed into any number of smaller patches, together comprising a smaller amount of area than the...
former, contiguous area. These patches, by definition, are surrounded by dissimilar areas that are often viewed as inhospitable by the organisms utilizing the patches. The hypothesized effects of fragmentation are often based around the theory of island biogeography set forth by MacArthur and Wilson (1967). The basic tenant of island biogeography is that the number of species on an island is determined by a dynamic equilibrium between the processes of immigration and extinction. When considering terrestrial habitat fragmentation, habitat patches surrounded by a relatively inhospitable matrix area are often viewed as habitat islands. The theory of island biogeography is used in terrestrial systems not only to predict population interactions between multiple species over time, and to predict biodiversity levels within habitat patches, but also to predict the fate of individual species over time, due to the movement of individuals between habitat patches.

Landscape ecology and patch dynamics are two areas of ecological research that have become increasingly popular over the past several decades. As landscapes become fragmented, they may transform into series of smaller, discrete habitat areas, or habitat patches. Implicit to patch definition is the idea that habitat discontinuities responsible for patch formation have a biological significance to patch users, and this significance must impart some form of benefit to the user (Wiens 1976). Thus patchiness must be defined based on the organism's perceptions. Burkey (1989) made a connection between habitat fragmentation and density dependence, noting that without density dependence, fragmentation has no impact on population viability.

Movement corridors are often investigated during landscape and habitat fragmentation research. The dynamic equilibrium aspect of island biogeography states
that the number of species on any given island is determined by immigration and extinction rates. It has been proposed that maintaining corridors between habitat patches enhances gene flow by increasing immigration rate (Wilson and Willis 1975, Brown and Kodric-Brown 1977). Harris (1984) has also pointed out that corridors allow wide-ranging species access to large areas, regardless of individual patch sizes, and alleviate inbreeding depression that can build up in small populations. Fahrig and Merriam (1985) found that isolated populations of white-footed mice receiving no immigrants were more likely to go to extinction than more connected populations receiving more immigrants.

Without movement corridors, many isolated populations would slowly dwindle in number, and many might dwindle into extinction. Metapopulation theory states that some animal populations exist as a “population of populations” (Levins 1969, Hanski and Gilpin 1991). The populations making up the overall metapopulation “wink” in and out of existence over time, and in a healthy system are in dynamic equilibrium, much as in island biogeography. Lande (1987) developed a metapopulation model establishing a minimum percentage of suitable habitat necessary for population survival. He found that species with high fecundity, survivorship, and dispersal ability could persist in extensively fragmented habitat, while in contrast, species with a lower demographic potential could not persist even under higher percentages of suitable habitat.

The individual papers making up this dissertation are designed, in one aspect or another, to examine desert bighorn habitat, and the disjunct nature of that habitat. The first paper, Chapter Two, addresses scale issues by examining four Eastern Mojave Desert mountain ranges at both 30 m and 100 m data resolution (Eldorado Mountains in Nevada; Black Mountains in California; and two sections of Eagle Mountain in
California). This chapter is designed to illustrate that before habitat fragmentation and consequential population-level responses can be addressed, it is imperative to match the processes in question with the appropriate scale of investigation. The first hypothesis of this paper states that higher resolution data, 30 m data, will produce a significantly different landscape than lower resolution data, 100 m data, with respect to the critical desert bighorn habitat component Land Surface Ruggedness. The second hypothesis states that once the two landscapes have been defined, applying a desert bighorn habitat model to the Eldorado Mountains will result in the percentages of ewe locations classified in each habitat category using 30 m data being statistically different from ewe locations classified using 100 m data.

The second paper, Chapter Three, takes another look at the definitions of preferred desert bighorn habitat in the Eastern Mojave Desert, and attempts to ascertain if current habitat models are adequate, and to determine if habitat patch size plays any role in patch occupancy. One objective of this chapter is to derive a traditional habitat model from desert bighorn literature and then apply that model to the four mountain ranges to determine the number of ewe locations and the percentage of landscape accounted for in each individual range. A second objective is to use ewe relocation data, ruggedness values, and distances from permanent water to build a habitat model for each of the four ewe populations, as well as an average and maximum habitat model constructed from the four individual range models, to determine if a new model can be produced that is more appropriate for Eastern Mojave Desert mountain ranges. The last objective of this paper is to apply the best habitat model to each range, and determine if occupied habitat patches are larger than unoccupied patches.
The third paper. Chapter Four expands the findings of Chapter Three by using the habitat model that incorporated the largest percentage of ewe locations in all four mountains ranges, and determining if desert bighorn habitat exists in a divided or undivided state, and attempting to ascertain, giving the current data, if the effects of additional habitat fragmentation can be predicted for these mountain ranges. Habitat patches as defined in island biogeography and metapopulation theories exist as aggregations of suitable habitat separated by an inhospitable matrix. But if matrix areas are not inhospitable, and can be inhabited to some degree, then the landscape may exist in a heterogeneously undivided state. Home range data from ewes in all four mountain ranges are calculated and compared to the areas covered by habitat patches in each of the ranges. If ewes can widely disperse, if habitat patches are smaller than individual home ranges, and individual habitat patches do not contain entire ewe populations, then the landscape exists in a heterogeneously undivided state.

As stated above, the themes of habitat configuration and fragmentation are the cohesive ideas running throughout the following papers. In this work, the term fragmentation is used to reference the natural distribution of habitat features, and is not used to reference anthropogenic habitat fragmentation. The evaluations of habitat configuration are designed to discern the disjunct nature of critical habitat features. This disjunct nature must be understood and explained before anthropogenic impacts can be measured and understood. This is crucial in conservation efforts of desert bighorn because the human population of the world currently stand at nearly six billion, and by most accounts will not stop growing until at least ten billion. Human and desert bighorn habitats will move closer together, and each will be affected by the other. The overall goal
of this dissertation is to increase the level of knowledge about how scalar issues influence desert bighorn ecology, thus increasing our ability to fully predict and measure the affects of increasing human disturbance on desert bighorn populations and metapopulations.
Literature Cited


CHAPTER 2

AN EXAMINATION OF DESERT BIGHORN HABITAT USING
30 m and 100 m ELEVATION DATA

Abstract

The incorporation of Geographic Information Systems (GIS) into wildlife ecology is thought to enhance the ability of researchers to address ecological questions by allowing the use of multiple resolutions of data. Four Eastern Mojave Desert mountain ranges were examined using 30 m and 100 m resolution elevation data to determine if 30 m or 100 m resolution data categorizes the landscape more accurately when considering desert bighorn *Ovis canadensis nelsoni* ewe habitat. For each mountain range, ewe locations had a significantly lower Land Surface Ruggedness Index (LSRI) value at 100 m than at 30 m resolution. Ewe locations analyzed at 100 m resolution had a significantly lower value with respect to habitat classification than when analyzed at 30 m resolution. Further consideration of these results demonstrated that 30 m data, although more accurate, are not automatically more appropriate for all ecological questions. Seventy-six percent of ewe classifications remained unchanged with respect to habitat category from one data resolution to the other. In addition, although there was a significant difference in habitat
quality between resolutions using all four habitat classification categories, there was very little differentiation in the proportion of landscape designated as good or excellent habitat between the two resolutions (30 m = 27.5%, 100 m = 26.6%). Although 30 m resolution data may be more desirable to many researchers because of a finer grain of resolution, 100 m data derived from 3-arc-second data yields similar results and thus should provide adequate accuracy for grossly categorizing desert bighorn habitat.

### Introduction

Geographic Information Systems (GIS), satellite imagery, and other remote sensing tools have greatly aided research efforts in wildlife ecology. GIS technology has revolutionized wildlife ecology by providing a means of rapidly viewing expansive geographic areas, simultaneously manipulating multiple data layers, and allowing investigation of an area using data derived at multiple resolutions. But this new technology has also contributed to the propagation of mistakes and misconceptions. These advances in computing and data manipulation have made it relatively easy to overlook many assumptions associated with data resolution such as resolution equity, both within and between data sets. Overlooking such assumptions can dramatically increase the possibility of drawing erroneous conclusions.

GIS programs are useful for identifying and viewing spatial patterns of critical resources and other habitat parameters at scales ranging from a daily home range encompassing a few square meters, to a system’s landscape perspective encompassing hundreds of square kilometers. However, certain inherent limitations exist when employing GIS technology to examine data at multiple resolutions. One example of such
a limitation is using GIS to extrapolate conclusions rendered at one scale to address questions asked at another scale, because researchers have known for several decades that the concepts of scale and pattern are inexorably linked (Hutchinson 1953). Wiens (1992) noted that researchers have realized patterns observed in ecological studies are dependent upon the scale at which they are viewed. Levin (1992) stated that no environmental predictions can be made, or ecological parameters evaluated, without first referencing the scale relevant to the organism or process under investigation. Because of knowledge of these scalar issues, most researchers are cautious to match the scale of their measurements to the scale of the questions under investigation. For example, a researcher studying rodents with home ranges of a few square meters will not examine the rodents' foraging habits by measuring vegetation in square hectare quadrats. It is obvious that a square hectare may contain considerable vegetative variation and diversity, and thus a home range of a few square meters encapsulated within that hectare may not be representative of the vegetation found throughout the hectare. In this instance, researchers usually scrutinize the resolutions of both the items or processes under investigation, as well as investigative techniques.

Unfortunately, researchers often do not give the same scrutiny to the resolution of their underlying data, i.e. elevation data, nor consider how a change in data resolution can potentially alter their conclusions. GIS technology has made it relatively easy to display a database and derive a wide array of statistics, extrapolations, and detailed maps from the data. To compound the problem, GIS users often employ multiple data layers in a project, and use each data layer as if the resolutions are equitable, even if such equity is questionable or is even known to be false. Different data sets representing different
resolutions are employed out of necessity due to a lack of fine-grained data in a given region. Such fine-grained data may be lacking because the information illustrated on the map may be measured and referenced on a larger scale than the ecological questions being explored. For example, it is quite possible to collect field data at a very fine resolution, e.g. 3-5 m resolution, but then overlay an existing road map that was constructed using 30 m or 100 m resolution data, because it is the only transportation data available. The domain of scale (Wiens 1989, Pickett et al. 1994) for these two parameters is very different. The floral heterogeneity of an ecosystem may change significantly over a relatively small area, thus the influence of individual plants on local species diversity may be very large, but their effect on regional species diversity is very small. In essence the domain of an individual plant may be very small, but the domain of an overall plant community is very large. The domain of the road network is much larger than the domain of the localized species diversity, and may or may not be larger than the domain of the overall plant community. But in order to incorporate the road map layer, the larger domain must be used, even though the questions under investigation involve a very localized domain. Although the output may look meaningful, the investigator may be drawing falsely detailed inferences, due to different processes occurring at different domains. It is also possible to reference conclusions drawn from an existing study utilizing one resolution of data, and then erroneously apply those conclusions to other studies utilizing different data resolutions (Wiens et al. 1993), causing the same domain of scale problem.

The purpose of this research is to demonstrate how altering the resolution of elevation data can alter conclusions derived from a habitat evaluation model for desert
bighorn (*Ovis canadensis nelsoni*). Specifically, this study is designed to determine if composition and juxtaposition of one aspect of desert bighorn habitat, Land Surface Ruggedness (LSRI), is dependent upon the resolution of elevation data used to derive LSRI values. In addition, a habitat analysis model is applied to a single mountain range using 30 m and 100 m elevation data to determine if the model is affected by a change in data resolution. The specific hypothesis is that three-arc-second elevation data will yield a significantly different habitat analysis map for an Eastern Mojave Desert mountain range than will 30 m elevation data. This is expected because three-arc-second elevation data have larger cell sizes (90 m x 70 m) relative to 30 m elevation data (30 m x 30 m), and will tend to smooth the landscape, as long as the landscape has a high degree of topographic heterogeneity, thus deriving lower average LSRI values than those derived from 30 m data. It is consequently expected that LSRI values derived from three-arc-second data will lead to a significantly different bighorn habitat classification map than those using 30 m data.

**Study Area**

The study areas were three Eastern Mojave Desert mountain ranges. The Eldorado Mountains located in Clark County, Nevada, the Black Mountains located in the Death Valley National Park, Inyo County, California, and two separate segments of Eagle Mountain, located in Riverside County, California (Figure 1).

The Eldorado Mountains are located in the Lake Mead National Recreation Area, Clark County, Nevada, and encompass nearly 36,000 ha. The Eldorados are comprised of two relatively separate sections, north and south, that are somewhat separated by a canyon.
Figure 1. Study Area map illustrating the relative locations of the Eldorado Mountains. Clark County, NV. Eagle Mountain, Riverside County, CA. and the Black Mountains. Inyo County, CA.
running east-west (locally known as Burro Wash). The ewe locations used for the
Eldorados only come from the northern section, which encompasses nearly 9,000 ha. The
northern Eldorados are divided by a series of north-south oriented bluffs. Topography to
the west of the bluffs consists of wide rolling hills and gentle washes. Topography to the
east of the bluffs consists of a series of maze-like ridges with narrow steep-sided washes
that continue until the terrain drops off steeply to the banks of the Colorado River.
Elevations range from 197 m to 973 m (Ebert 1993).

The Black Mountains form the southern half of the Amargosa Range in the
southeastern section of Death Valley National Park, Inyo County, California, and
encompass approximately 72,000 ha. The Black Mountains tend northwest-southeast, and
form a wedge-shaped fault block which has been raised between the two fault zones.
Topography is characterized as very steep and rugged. Elevations range from -81 m to
1946 m (Longshore and Douglas 1995).

Eagle Mountain is located in, and adjacent to, the southeastern corner of Joshua
Tree National Park, Riverside County, California. The range is divided into two main
segments by a large wash running east-west (Big Wash). Because each segment contains
a separate non-interactive group of desert bighorn ewes, each segment was treated
independently.

The northern segment contains both an east-west and a north-south section, and
encompasses approximately 23,000 ha. The east-west section surrounds an abandoned
iron ore mine, and is composed of steep ridges on the north, and a flatter section to the
south where ridges intersect the mine site. The north-south section is comprised of rolling
hills bounded by the mine townsite on the east, and Pinto Basin on the west. Elevations in
the north range from 300 m to 1077 m (Divine and Douglas 1996).

The southern segment is situated within Joshua Tree National Park, and encompasses approximately 16,000 ha. This segment tends east-west, and is comprised mainly of steep, rocky escarpments. Elevations range from 400 m to 1631 m (Divine and Douglas 1996).

Methods

Land Surface Ruggedness Composition

To determine if topography is categorized differently at the two data resolutions, the Land Surface Ruggedness Index (LSRI) that Ebert (1993) adapted from Beasom et al. (1983) was calculated from 30 m and three-arc-second resolution elevation data. The basic tenant behind LSRI is that the total length of topographic contour lines traversing an area is a function of the “ruggedness” of that area. Beasom et al. (1983) measured Land Surface Ruggedness by laying a regularly spaced grid over the map area under investigation, and counting the number of intersections between contour lines and grid lines. This number was used to index the ruggedness of each area, with a higher number of intersections equating to a “rougher” landscape. Although this method is straightforward and replicable, it does not transfer easily into GIS applications. Thus, Ebert (1993) adapted the Beasom et al. (1983) technique for use in a GIS program by developing an LSRI generated by overlaying a 100 m x 100 m grid onto an elevation map and measuring the slope from each cell to each of its surrounding 8 cells. (Slope is calculated by measuring the difference in elevation from the center of one cell to the center of another cell) It was found that both total slope, the summation of all slope values
within the 300 m x 300 m window, and average slope, the average of all slope values within the 300 m x 300 m window, gave equally good approximations of total contour line length. This study was designed to compare two different resolutions of elevation data, and because the number of cells in a 300 m radius circle differs between the two resolutions, average slope was chosen for comparison. Based on data in Ebert (1993), the use of average slope is not a significant departure from the original method utilizing total slope.

Two resolutions of elevation data, 30 m data and three-arc-second data, were obtained from United States Geological Service (USGS) digital files for each mountain range, and downloaded into Geographic Resources Analysis Support System (GRASS) GIS software (USACERL 1993). Cell size of 30 m data is 30 m x 30 m, and cell size of three-arc-second data, in this region of the country, is approximately 90 m x 70 m. To calculate an LSRI for 30 m data, a slope map was generated from elevation data using percent slope as the output. Slope values were averaged within a 11 x 11 cell window (330 m x 330 m) centered over each cell (Figure 2).

To calculate an LSRI for three-arc-second data, elevation data were first resampled using ARC/INFO (Kreis 1995) to produce a regular 100 m x 100 m grid. Percent slope values were calculated within GRASS and averaged within a 3 x 3 cell window (300 m x 300 m) centered over each cell (Figure 3). The cell windows can not be the exact same size for both resolutions because the necessity of a center cell dictates an odd number of rows and columns. Thus cell window size for 30 m data can be 270 m x 270 m, or 330 m x 330 m, but not 300 m x 300 m.
Histograms were produced for each mountain range to graphically illustrate the distribution of landscape cells relative to LSRI values for both 30 m and 100 m elevation data. A paired t-test (Zar 1984) was conducted using Minitab (Minitab 1996) for each mountain range to determine if the mean landscape LSRI value differed between 30 m and 100 m elevation data.

Figure 2. 11 x 11 cell window used to calculate an LSRI value for each cell at 30 m resolution. (Each cell measures 30 m x 30 m)
Figure 3. 3 x 3 cell window used to calculate an LSRI value for each cell at 3-arc-second resolution. (Each cell measures 100 m x 100 m)

Sheep Locations

Location data from radio-collared bighorn ewes were collected at Eagle Mountain specifically for this project, while bighorn ewe location data were collected at the Eldorado and Black Mountains by other Cooperative Unit Investigators for previous studies, and generously donated for this project. Ewe locations were used because ewes are more gregarious and more habitat limited than rams. Weekly radio-telemetry flights were flown over the Eldorado Mountains between December 1989 and November 1991. During these flights, and concurrent ground surveys, 19 ewes yielded 1840 locations (Ebert 1993). Bi-monthly radio-telemetry flights were flown over the Black Mountains between September 1992 and August 1994. During these flights, 8 ewes yielded 364 locations (Longshore and Douglas 1995). Bi-monthly radio-telemetry flights were flown over Eagle Mountain between August 1993 and August 1995. During these flights, 15
ewes in the northern region yielded 713 locations, while 7 ewes in the southern region yielded 277 locations (Divine and Douglas 1996).

Sheep location was conducted via Cessna 206 fixed-wing aircraft (Lake Mead National Recreation Area’s plane, and Lake Mead Air, Boulder City, Nevada). The aircraft were equipped with a removable, belly-type antenna as described by Lecount and Carrel (1980). Locations were obtained by flying over the range in a rough search pattern listening for signals on a Telonics TR-2 programmable scanner/receiver (Telonics Inc., Mesa, Arizona). Once a signal was heard the observer determined which frequency was being detected while the pilot flew in the direction of strongest signal reception until the signal began to fade. Once the signal faded, the pilot returned to the area of strongest reception and began to spiral inward to determine the signal’s focal point. The focal point, the point of strongest reception, was plotted as the location for that frequency (Mech 1983, Kenward 1987). Locations were plotted by hand on United States Geological Survey (USGS) 7.5 minute maps (1:24,000 scale) or 15 minute (1:62,500 scale) topographic maps, and later recorded as Universal Trans-Mercator coordinates. Aerial locational errors were assumed to average 4 ha, as reported by Krausman et al. (1984).

Due to multiple factors, including topographic features, cryptic coloration, and aircraft / personnel safety considerations, most bighorn sheep coordinates were based solely on signal strength, and do not have visual verification. Because most of these locations do not have visual confirmation, they must be treated as area locations and not simple point locations. Thus, some measure of error must be considered when assigning LSRI values to each sheep location. In order to assign an area LSRI value to a point
location, a 200 m radius circle was centered on each location. ARC INFO (Kreis 1995) was used to calculate the average LSRI value within the 400 m diameter circle. Because the error is based on a circle, and the landscape is based on a square grid system, the circle used to delineate the sheep location often bisected individual cells (Figure 4). In order to accurately find an average LSRI value within the circle, the bisected cells were weighted according to their relative contribution to the area of the circle.

Histograms were produced for each mountain range to illustrate the distribution of ewe locations relative to LSRI values. Paired t-tests (Zar 1984) were then conducted using the statistical software Minitab (Minitab, 1996) for each ewe population to determine if the mean LSRI value of sheep locations were statistically different between 30 m and 100 m elevation data.

Figure 4. Sample 11 x 11 cell window with an error circle imposed on top. Shaded cells are used to illustrate landscape cells that must be weighted to produce accurate average LSRI value for all cells within the circle.
Habitat Analysis

To determine and classify appropriate desert bighorn habitat, a habitat evaluation model that Ebert (1993) adapted from Cunningham (1989) was further modified and used. This model incorporates five bighorn habitat components: natural topography, vegetation type, precipitation, water type and use, and human utilization. Each component is subdivided into various categories, and scores are assigned to each category based on its potential value to desert bighorn. Natural topography, vegetation type, and human utilization scores range from 0-20 points, while precipitation scores range from 0-5, and water type and use scores range from -8 to 20. Based on its cumulative score, each area is then classed on the following basis:

<table>
<thead>
<tr>
<th>Score</th>
<th>Habitat Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 45</td>
<td>Poor</td>
</tr>
<tr>
<td>46-60</td>
<td>Fair</td>
</tr>
<tr>
<td>61-73</td>
<td>Good</td>
</tr>
<tr>
<td>74-85</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

The additional model modifications made for this project consisted of using average LSRI values instead of total LSRI values, and modifying the topographic categories. For this analysis, the “rugged” topographic category was subdivided into “rugged” and “very rugged” with only the “very rugged” category receiving the maximum 20 points. For more information on the original model, see Cunningham (1989), and for more details concerning the GIS adaptations of the Cunningham model, see Ebert (1993). Because the detailed information needed to run the model was only available for the Eldorado Mountains, the Black Mountains and both of the Eagle Mountain segments were left out of the habitat analysis. The model was run on the entire Eldorado Mountains, 32,000 ha, both at 30 m and 100 m cell resolution.
Results

Land Surface Ruggedness Composition

LSRI maps produced from 30 m elevation data look very similar to those produced from 100 m elevation data (Figures 5-12). But for each mountain range, the distribution of LSRI values in the landscape changed slightly between resolutions. For each range, 100 m data are clustered around lower LSRI values, whereas 30 m data have a greater range, and are not as clustered (Figures 13-16, Table 1). In all cases, the average LSRI value was higher with 30 m data than with 100 m data (Table 1). At the 95% significance level, the mean values of each data set are not equal to zero (two-tailed test) (Table 2). Thus the mean LSRI value for 30 m data is significantly larger than the mean LSRI value for 100 m data.

Sheep Locations

For each mountain range, the distribution of LSRI values assigned to sheep locations changed from one data resolution to the other. In general, sheep locations characterized at 30 m resolution tended to have a higher average LSRI value than when characterized at 100 m resolution (Figures 17-20, Table 3). The Eldorado Mountains (Figure 17) and both the northern (Figure 19) and southern (Figure 20) regions of Eagle Mountain have the most pronounced shift towards smoother values at 100 m resolution, while 100 m data in the Black Mountains (Figure 18) does not show as clear a shift.
Figure 5. Land Surface Ruggedness Index map for the Eldorado Mountains, Nevada. Derived from 30 m elevation data.
Figure 6. Land Surface Ruggedness Index map for the Eldorado Mountains, Clark County, Nevada. Derived from 100 m elevation data.

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Figure 7. Land Surface Ruggedness Index map for the Black Mountains, Inyo County, California. Derived from 30 m elevation data.
Figure 8. Land Surface Ruggedness Index map for the Black Mountains, Inyo County, California. Derived from 100 m elevation data.
Figure 9. Land Surface Ruggedness Index map for northern Eagle Mountain, Riverside County, California. Derived from 30 m elevation data.
Figure 10. Land Surface Ruggedness Index map for northern Eagle Mountain, Riverside County, California. Derived from 100 m elevation data.
Figure 11. Land Surface Ruggedness Index map for southern Eagle Mountain, Riverside County, California. Derived from 30 m elevation data.
Figure 12. Land Surface Ruggedness Index map for southern Eagle Mountain, Riverside County, California. Derived from 100 m elevation data.
Eldorado Mountains

Figure 13. Histogram showing distribution of landscape cells relative to LSRI values for 30 m and 100 m data in the Eldorado Mountains, Clark County, NV.

Black Mountains

Figure 14. Histogram showing distribution of landscape cells relative to LSRI values for 30 m and 100 m data in the Black Mountains, Inyo County, CA.
Eagle Mountain - North

Figure 15. Histogram showing distribution of landscape cells relative to LSRI values for 30 m and 100 m data for the northern segment of Eagle Mountain, Riverside County, CA.

Eagle Mountain - South

Figure 16. Histogram showing distribution of landscape cells relative to LSRI values for 30 m and 100 m data for the southern segment of Eagle Mountain, Riverside County, CA.
Table 1. Mean, standard deviation, minimum, and maximum LSRI values (average percent slope) for each of the four mountain ranges under investigation, at 30 m and 100 m cell resolution.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Res.</td>
<td>30</td>
<td>100</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>mean</td>
<td>31.9</td>
<td>19.4</td>
<td>38.6</td>
<td>31.5</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>13.8</td>
<td>10.1</td>
<td>20.8</td>
<td>18.0</td>
</tr>
<tr>
<td>min.</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>max.</td>
<td>134</td>
<td>91</td>
<td>118</td>
<td>108</td>
</tr>
</tbody>
</table>

Table 2. Results of paired t-tests for each mountain range under investigation, to determine if mean LSRI values at 30 m are equivalent to the mean LSRI values at 100 m.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of LSRI Categories*</td>
<td>131</td>
<td>118</td>
<td>74</td>
<td>80</td>
</tr>
<tr>
<td>mean LSRI (30 m) - mean LSRI (100 m) **</td>
<td>91663</td>
<td>240724</td>
<td>112291</td>
<td>81150</td>
</tr>
<tr>
<td>S.D.</td>
<td>120247</td>
<td>186175</td>
<td>109808</td>
<td>74935</td>
</tr>
<tr>
<td>SE mean</td>
<td>10506</td>
<td>17139</td>
<td>12765</td>
<td>8378</td>
</tr>
<tr>
<td>t</td>
<td>8.72</td>
<td>14.05</td>
<td>8.80</td>
<td>9.69</td>
</tr>
<tr>
<td>p</td>
<td>0.0000***</td>
<td>0.0000***</td>
<td>0.0000***</td>
<td>0.0000***</td>
</tr>
</tbody>
</table>

*Categories formed by dividing LSRI values into groups of 5 (1-5, 6-10, 11-15 etc.)

**Values denote the product of LSRI values and the number of cells at each LSRI value, not simply number of cells.

***denotes significance at the 95% level.
Figure 17. Distribution of ewe locations relative to LSRI values for 30 m and 100 m resolution data for the Eldorado Mountains, Clark County, Nevada, between December 1989 and November 1991.

Figure 18. Distribution of ewe locations relative to LSRI values for 30 m and 100 m resolution data for the Black Mountains, Inyo County, California, between September 1992 and August 1994.
Figure 19. Distribution of ewe locations relative to LSRI values for 30 m and 100 m resolution data for the northern Eagle Mountain region, Riverside County, California between August 1993 and August 1995.

Figure 20. Distribution of ewe locations relative to LSRI values for 30 m and 100 m resolution data for the southern Eagle Mountain region, Riverside County, California between August 1993 and August 1995.
Table 3. Mean, minimum, and maximum LSRI values (average percent slope) of desert bighorn ewe locations in each of the four mountain ranges under investigation at 30 m and 100 m cell resolution

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Res.</td>
<td>30  100</td>
<td>30  100</td>
<td>30  100</td>
<td>30  100</td>
</tr>
<tr>
<td>Mean</td>
<td>39.3 22.5</td>
<td>58.7 46.7</td>
<td>39.9 22.2</td>
<td>43.6 26.3</td>
</tr>
<tr>
<td>St. Dev</td>
<td>14.2 10.5</td>
<td>17.4 16.1</td>
<td>9.3 7.9</td>
<td>8.3 8.1</td>
</tr>
<tr>
<td>min.</td>
<td>2  2</td>
<td>7  3</td>
<td>11  1</td>
<td>21  4</td>
</tr>
<tr>
<td>max.</td>
<td>106  85</td>
<td>81  73</td>
<td>63  51</td>
<td>64  52</td>
</tr>
</tbody>
</table>

The mean LSRI value associated with sheep locations at 30 m resolution differs significantly (95% level) from the mean LSRI value associated with sheep locations at 100 m data resolution (two-tailed test) (Table 4). The mean LSRI value for 30 m data is significantly larger than the mean LSRI value for 100 m data.
Table 4. Results of paired t-tests comparing average slope (LSRI) values assigned to desert bighorn ewe locations, to determine if the mean LSRI value derived from 30 m elevation data is significantly different than the mean LSRI value derived from 100 m elevation data, for all four ewe populations.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>1840</td>
<td>364</td>
<td>713</td>
<td>277</td>
</tr>
<tr>
<td>mean lsri (30 m) - mean lsri (100 m)</td>
<td>16.87</td>
<td>12.05</td>
<td>17.70</td>
<td>17.27</td>
</tr>
<tr>
<td>S.D.</td>
<td>9.3</td>
<td>6.77</td>
<td>7.371</td>
<td>5.74</td>
</tr>
<tr>
<td>S.E. mean</td>
<td>0.217</td>
<td>0.35</td>
<td>0.27</td>
<td>0.34</td>
</tr>
<tr>
<td>t</td>
<td>77.84</td>
<td>33.92</td>
<td>64.15</td>
<td>50.08</td>
</tr>
<tr>
<td>p</td>
<td>0.0000*</td>
<td>0.0000*</td>
<td>0.0000*</td>
<td>0.0000*</td>
</tr>
</tbody>
</table>

* denotes significance at the 95% level

**Habitat Analysis**

Employing the habitat model for both 30 m and 100 m data demonstrates the amount of the landscape in the Eldorado Mountains classified as good or excellent habitat is similar for both resolutions (Figures 21 and 22, Table 5). As cell resolution is decreased from 30 m down to 100 m, the percentage of landscape classified as poor habitat decreased, while the percentage classified as fair habitat increased (Table 5). Cell resolution made very little difference with respect to amount of landscape classified as either good or excellent sheep habitat.
Habitat Class
- Poor
- Fair
- Good
- Excellent
- No Data

Figure 21. Desert bighorn habitat classification map derived from 30 m elevation data for the Eldorado Mountains, Clark County, Nevada.
Figure 22. Desert bighorn habitat classification map derived from 100 m elevation data for the Eldorado Mountains, Clark County, Nevada.
Table 5. Amount and percentage of the landscape found in each category of desert bighorn habitat in the Eldorado Mountains at 30 m and 100 m data resolutions.

<table>
<thead>
<tr>
<th>Habitat Category</th>
<th>Hectares (30 m)</th>
<th>Hectares (100 m)</th>
<th>Percent of Landscape (30 m)</th>
<th>Percent of Landscape (100 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>47.005</td>
<td>38.788</td>
<td>35.0</td>
<td>28.9</td>
</tr>
<tr>
<td>Fair</td>
<td>50.347</td>
<td>59.664</td>
<td>37.5</td>
<td>44.5</td>
</tr>
<tr>
<td>Good</td>
<td>33.818</td>
<td>32.766</td>
<td>25.2</td>
<td>24.4</td>
</tr>
<tr>
<td>Excellent</td>
<td>3132</td>
<td>2.990</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>134.302</td>
<td>134.208</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Taking the habitat analysis a step further and examining LSRI values associated with each ewe location yields similar results (Table 6). The percentage of ewes found in excellent habitat is similar between 30 m and 100 m data, but there is a higher percentage of ewes found in fair habitat with 100 m data than with 30 m data (Table 6). There is also a lower percentage of ewes classified into good habitat with 100 m data than with 30 m data (Table 6).
Table 6. Number and percentage of desert bighorn ewe relocations found in each category of bighorn sheep habitat in the Eldorado Mountains, at 30 m and 100 m data resolutions.

<table>
<thead>
<tr>
<th>Habitat Category</th>
<th>Number Ewes (30 m)</th>
<th>Number Ewes (100 m)</th>
<th>% Ewes (30 m)</th>
<th>% Ewes (100 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>2</td>
<td>3</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td>Fair</td>
<td>115</td>
<td>265</td>
<td>6.25</td>
<td>14.40</td>
</tr>
<tr>
<td>Good</td>
<td>1144</td>
<td>1025</td>
<td>62.17</td>
<td>55.71</td>
</tr>
<tr>
<td>Excellent</td>
<td>569</td>
<td>535</td>
<td>30.92</td>
<td>29.08</td>
</tr>
<tr>
<td>Insuff. Data *</td>
<td>10</td>
<td>12</td>
<td>0.54</td>
<td>0.65</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1840</td>
<td>1840</td>
<td>99.99</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Necessary data missing, thus habitat analysis could not be completed for these areas.

Assigning ewes in poor habitat a value of 1, ewes in fair habitat a value of 2, ewes in good habitat a value of 3, and ewes in excellent habitat a value of 4, the difference in mean habitat classification of ewe locations between 30 m and 100 m resolution is significant (p=0.0000) at a 95% confidence level (n=1828, mean = .0985, S.D. = 0.4953).

Data in Table 7 show the percentage of ewe locations that changed habitat classification due to the change in data resolution. Twenty-four percent of all classifications were put into a different habitat category (Table 7). Of these changes, most were a one-category decrease in quality from either excellent to good, or from good to fair.
Table 7. Breakdown of number and percent of ewe locations in the Eldorado Mountains that remained unchanged, and that were switched into a different habitat category, when analyzed at both 30 m and 100 m data resolutions.

<table>
<thead>
<tr>
<th>Categories (No Change)</th>
<th>Number Ewes</th>
<th>Categories (Increase)</th>
<th>Number Ewes</th>
<th>Categories (Decrease)</th>
<th>Number Ewes</th>
</tr>
</thead>
<tbody>
<tr>
<td>E - E</td>
<td>431</td>
<td>G - E</td>
<td>103</td>
<td>E - G</td>
<td>133</td>
</tr>
<tr>
<td>G - G</td>
<td>864</td>
<td>F - G</td>
<td>28</td>
<td>E - F</td>
<td>2</td>
</tr>
<tr>
<td>F - F</td>
<td>86</td>
<td></td>
<td></td>
<td>G - F</td>
<td>177</td>
</tr>
<tr>
<td>P-P</td>
<td>2</td>
<td></td>
<td></td>
<td>F - P</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1383</td>
<td>TOTAL</td>
<td>131</td>
<td>TOTAL</td>
<td>313</td>
</tr>
<tr>
<td>% Unchanged</td>
<td>75.7%</td>
<td>% Increased</td>
<td>7.2%</td>
<td>% Decreased</td>
<td>17.1%</td>
</tr>
</tbody>
</table>

Habitat Categories: Excellent = (E) Good = (G) Fair = (F) Poor = (P)

Discussion

The advent and rapid incorporation of GIS technology has led some wildlife ecologists to design and conduct research efforts using a variety of data resolutions. Before the advent of GIS, recording, displaying, and statistically manipulating daily movement data of species with very small home ranges such as Tenebrionid beetles (Johnson et al. 1992) would have been tedious at best, while the study of species interacting in metapopulations such as Checkerspot butterflies (Harrison 1991) would have been a lifetime commitment. One result of GIS technology and the associated ease of data manipulation has been an insatiable desire for fine-grained data. With the accuracy now possible via hand-held Global Positioning Systems (GPS), researchers design projects requiring data at 30 m resolution, 5 m resolution, and at least in theory at less than 1 m resolution. But a large portion of data available during the past several decades does not have a relatively fine grain size. For instance, three-arc-second data are readily available...
for most of the United States, but 30 m resolution data have been much more difficult to obtain. Because cities and other human developments drive the production of more detailed geographic information, remote locations may not have maps showing basic attributes such as elevation data, road coverages, and vegetative stands at fine resolutions.

This study was designed in part to address the concerns of some bighorn sheep biologists that three-arc-second data does not have a fine enough "grain" (Kotliar and Wiens 1990, Forman 1995) to be used for accurate habitat calculation, and will not give as accurate a habitat analysis as will data derived from 30 m data. The usual argument is that data collected at 30 m resolution will break an area into smaller, more numerous segments than will 100 m data, and thus 100 m data will tend to be "smoother" because it will average extreme values, whereas 30 m data will not. Thus 30 m data should yield better, more accurate, results. It is true that analyzing a heterogenous area using smaller segments yields a more accurate depiction of the area when compared to the same area separated into fewer segments. Because averaging eliminates extremes, a larger number of smaller segments have a much better chance of representing a wide range of variation than a small number of larger segments.

The term accuracy may be misleading when applied to some habitat and conservation issues. In this case, accuracy gained by using 30 m data is only useful if bighorn sheep view their habitat at 30 m resolution, and thus make decisions about foraging, dispersal, and predator avoidance, etc. based on 30 m blocks of habitat. It is relatively impossible to assume 30 m data is more "accurate" than 100 m data without defining what accuracy is in reference to. If accuracy refers to an absolute categorization of slope, then 30 m data is more accurate, and more appropriate, than 100 m data. But if
accuracy refers to a categorization of slope as viewed by bighorn, then 30 m data are not necessarily more accurate, nor more appropriate, than 100 m data because sheep may perceive and interact with the landscape at different levels, and make different behavioral decisions based on a hierarchical structure of spatial habitat requirements.

Unfortunately, other studies investigating the role of spatial scale in bighorn habitat selection have yet to be undertaken. Thus, while there is very little or no data to directly support or refute the claim that sheep perceive and interact with the landscape at different levels, there is circumstantial evidence. McQuivey (1978), Reisenhoover et al. (1988), and Dunn (1996) all point out that open terrain is vital to bighorn because of their reliance on vision for predator detection. McCarty and Bailey (1994) reported that studies conducted on bighorn habitat requirements found most sheep remained within 5 and 1300 m of escape terrain, and between 400 and 3200 m of permanent water. This necessity for open spaces coupled with these widely varying habitat component values support the concept that desert bighorn are opportunistic generalists that view the habitat at many different spatial scales. Sheep may view the landscape on the scale of tens of meters in terms of water availability, but view the landscape on the scale of hundreds of meters in terms of predator avoidance. With respect to vegetation, Reisenhoover and Bailey (1985) suggested desert bighorn forage should be continually distributed because a wide distribution allows for adequate spacing for predator avoidance and avoidance of density-mediated alterations in feeding behavior. Finally, Berger (1978), Wehausen (1980), Miller and Smith (1985), and Dunn (1996) all reported bighorn reaction to human disturbance is reliant upon many factors such as distance to disturbance and the proximity of sheep to escape terrain. Thus as the mixture of factors changes, so probably does the scale at which...
bighorn are sensitive to the surrounding landscape.

The results of the LSRI classification demonstrate that ewe locations had a significantly lower LSRI value when calculated with 100 m data versus 30 m data. The results of the habitat analysis also show that the average habitat classification of desert bighorn ewes using 100 m data was significantly lower than the average habitat classification using 30 m data. But these findings speak mainly to statistical significance, and speak very little to biological significance. The results of the habitat analysis demonstrate that 76% of ewe classifications remained unchanged from one resolution to another. Although the remaining 24% of ewe classifications cannot be summarily dismissed, and warrant further investigation, the fact that 76% did not change is intriguing. Furthermore, looking at the amount of land classified in each category for each resolution, most of the changes occurred in the fair and poor habitat categories, with very little change occurring in the good and excellent habitat categories. Consequently, ninety-three percent of ewe locations using 30 m data, and eighty-five percent of ewes using 100 m data were located in either good or excellent habitat. This suggests that many of the factors being measured by habitat evaluation methodology have the same domain of scale, and thus their effects are much the same at either 30 m or 100 m cell size. But it must be noted that sub-dividing habitat into categories, as was done in this study, by necessity involves arbitrary designations that may or may not have biological reality. It is possible that sheep in some mountain ranges or even in these mountain ranges under some environmental conditions, view fair habitat (as designated here) as good habitat, or vice-versa, thus the percentage of ewe classifications that would change between resolutions would be larger than reported here.
From a biological standpoint, it appears that applying Cunningham's habitat analysis to the Eldorado Mountains using LSRI data derived from 30 m or 100 m elevation data yields no clear biological difference with respect to classifying desert bighorn ewe habitat. Although 30 m data may be more desirable because it has a finer grain of resolution, 100 m data derived from three-arc-second data yield similar results. The bottom line of this research is that although there is a statistical difference between the two resolutions, there is no clear biological difference in regards to this particular question. thus wildlife researchers and managers should not automatically dismiss the utility of three-arc-second elevation data. Coarser resolution data should yield adequate results when used for general habitat categorization, due to the fact that bighorn are generalists, and have large home ranges, and the key habitat factors examined in this model appear to operate under similar constraints at both at 30 and 100 m resolution. In addition, the fact that desert bighorn have such large home ranges, and have such good dispersal ability, gives us some insight that, at least for some behavioral and ecological decisions, bighorn do not view the landscape or make decisions based on 30 meter plots of land.
Literature Cited


CHAPTER 3

DESERT BIGHORN SHEEP HABITAT: REVISITING THE ISSUE IN THE EASTERN MOJAVE DESERT

Abstract

For decades researchers have attempted to develop a universal, or at least a regional, habitat model that adequately predicts the specific areas of a landscape desert bighorn (Ovis canadensis nelsoni) will occupy. These efforts have met with mixed results. Desert bighorn literature was searched to formulate an average habitat model from recent research efforts. This model was then applied to four mountain ranges in the Eastern Mojave Desert to determine its capabilities of predicting habitat used by ewes. A habitat model was then developed for each individual range based on ewe locations, ruggedness values, and distances from permanent water, gathered in each range. In addition, average and a maximum habitat models were developed using values taken from the four individual range models. All six newly developed models were then applied to each of the four mountain ranges to determine how well each model predicted sheep utilization. Results from the six models were then compared to results obtained from applying the traditional model to each of the four ranges. The maximum habitat model had the best performance of the six new models, accounting for 78% of ewe locations.
while covering 33% of the landscape in the four ranges. The traditional habitat model only accounted for 51% of ewes while covering 15% of the landscape in the four ranges. In addition, the traditional and maximum habitat models were sub-divided into habitat patches in order to determine if habitat patches occupied by ewes were significantly larger than those unoccupied by ewes. Although from the raw data this appears to be true for all four mountain ranges, due to small sample sizes, there is no statistical support for this claim.

Introduction

Determining what critical components comprise suitable habitat for desert bighorn, *Ovis canadensis nelsoni*, has been an elusive goal of researchers for several decades. During this time, a multitude of habitat components have been examined in an attempt to determine the relative importance of each in defining desert bighorn habitat. These components include, slope, aspect, percent vegetative cover, escape terrain, topographic ruggedness, water availability, predation, human intrusion, forage availability, visibility, and competition with other species such as burros, cattle, and domestic sheep. While most bighorn researchers generally agree that three habitat parameters, distance from permanent water, distance from escape terrain, and vegetation, are most critical in defining desert bighorn sheep habitat, relative importance of these three parameters is more controversial.

A majority of bighorn researchers considers availability of free water to be a crucial habitat component (McCarty and Bailey 1994). Turner and Weaver (1980) contended that a paucity of water is the most important factor limiting desert bighorn
herds. However, it has also been suggested that at least some bighorn populations are not limited by the availability of free water because they do not utilize free water sources (Watts 1979, Krausman and Leopold 1986, Etchberger 1993). In addition to water considerations, most researchers report strong associations between bighorn locations and steep and/or rugged slopes (Leslie and Douglas 1979, Sandoval 1980, Hansen 1982, Bates and Workman 1983, Holl and Bleich 1983, Elenowitz 1983, Gionfriddo and Krausman 1986, Wakeling and Miller 1989, Haas et al. 1990, Ebert 1993, McCarty 1993). Slope values have been commonly used to delineate escape terrain, and although virtually every piece of bighorn literature has attested to the integral role escape terrain plays in desert bighorn ecology, a single definition of escape terrain has yet to be agreed upon. (McCarty and Bailey 1994).

The role of vegetative components in defining desert bighorn habitat has similarly been investigated in numerous studies, but has yet to be determined in any definitive manner. Buechner (1960) stated that vegetation is the most important component of desert bighorn habitat, while Cunningham (1989) simply noted that bighorn are opportunistic and adaptable to vegetation, and Steel and Workman (1990) reported that forage did not influence micro-habitat use of sheep in Utah. The vegetative habitat requirements as defined by the Desert Bighorn Council Technical Staff (1980) are diverse cover with equal portions of shrubs, perennial grasses, and forbs, with a variety of species of each vegetation type recommended. Compounding the vegetation issue is the fact that it is additionally difficult to assign quantitative values to individual forage species because their relative value to bighorn may change between seasons and even between mountain ranges depending on a multitude of factors including abiotic conditions, disturbance.
regime, and floral and faunal species abundance.

The most common methodology used to define suitable desert bighorn habitat is straightforward and has remained essentially unaltered over the past few decades. Since most desert bighorn research has been driven by management concerns, most studies have focused on defining suitable habitat and subsequently determining the amount of suitable habitat available to each population. Most studies have been conducted by outfitting bighorn sheep with radio-collars, and tracking the animals for a period of 2-3 years while periodically recording their respective locations. These movement data are then used to determine home range size of individuals and of populations, and are used to determine the degree of utilization each mountain range receives. Home range data are also used as a template within which the relative abundance of each habitat component is determined. Mountain ranges are then compared with one another to highlight habitat differences between ranges, and to determine the relative quality of each range.

Few studies have broken from traditional methodology and attempted to view desert bighorn habitat in any explicit spatial context. Most researchers have been content with defining suitable or preferred habitat and reporting the percentage of sheep locations contained within that definition, and have not attempted to refine their definitions to include spatial considerations, although there have been a few exceptions. McCarty and Bailey (1994) reviewed multiple studies on desert bighorn home ranges, and concluded that all habitat components usually occur within 17-25 contiguous km$^2$, and thus maximum distance between components should be 30-35 km$^2$. Holl and Bleich (1983) found that the ewe population size in the San Gabriel Mountains (CA), was directly proportional to the amount of available escape terrain. Armentrout and Brigham (1988) set one of the most
well-defined spatial definitions when they imposed a minimum size limit of 2 hectares for defining suitable escape terrain. Although these exceptions are vague, they represent the best published attempts to include spatial context into desert bighorn habitat requirements.

The objective of this research was to first derive a traditional desert bighorn habitat model from the literature, and then apply it to four ewe populations recently investigated in the Eastern Mojave Desert. Second, to develop a habitat model for each range based on sheep locations, ruggedness values (in place of escape terrain) and distance from permanent water values gathered in each individual range. Third, to test the four range-derived models, including an average and maximum model derived from the four, and determine if a single habitat model can be formulated that accounts for more sheep locations than the traditional model, and is suitable for all four populations. Finally, to determine if sub-dividing preferred habitat into discrete habitat patches adds new insight into desert bighorn habitat selection with respect to patch size.

**Study Area**

The study areas were comprised of three eastern Mojave Desert mountain ranges. The Eldorado Mountains located in Clark County, Nevada, the Black Mountains located in the Death Valley National Park, Inyo County, California, and two separate segments of Eagle Mountain, located in Riverside County, California (Figure 1).

The Eldorado Mountains are located in the Lake Mead National Recreation Area, Clark County, Nevada, and encompass nearly 36,000 ha. The Eldorados are comprised of two relatively separate sections, north and south, that are somewhat separated by a canyon running east-west (locally known as Burro Wash). This study focuses solely on the
Figure 1. Study Area map illustrating the relative locations of the Eldorado Mountains, Clark County, NV, Eagle Mountain, Riverside County, CA, and the Black Mountains, Inyo County, CA.
northern section encompassing nearly 9,000 ha. The northern Eldorados are divided by a series of north-south oriented bluffs. Topography to the west of the bluffs consists of wide rolling hills and gentle washes. Topography to the east of the bluffs consists of a series of maze-like ridges with narrow steep-sided washes that continue until the terrain drops off steeply to the banks of the Colorado River. Elevations range from 197 m to 973 m (Ebert 1993). The range has abundant water sources due to the proximity of the Colorado River, and at least four natural springs.

The Black Mountains form the southern half of the Amargosa Range in the southeastern section of Death Valley National Park, Inyo County, California, and encompass approximately 72,000 ha. The Black Mountains tend northwest-southeast and form a wedge-shaped fault block which has been raised between two fault zones. Topography is characterized as very steep and rugged. Elevations range from -81 m to 1946 m (Longshore and Douglas 1995). There are seven permanent springs in the area.

Eagle Mountain is located in, and adjacent to, the southeastern corner of Joshua Tree National Park, Riverside County, California. The range is divided into two main segments by a large wash running east-west (Big Wash). Because each segment contains a separate non-interactive group of desert bighorn ewes, each segment was treated independently.

The northern segment contains both an east-west section and a north-south section, and encompasses approximately 23,000 ha. Topography consists of rolling hills with intermittent steep canyons and ridges, and elevation ranges from 300 m to 1077 m. There are two natural springs in the north, and although both were treated as permanent, one spring dries up during hot, dry periods, but the exact timing of its disappearance is
unknown and unpredictable.

The southern segment is situated within Joshua Tree National Park and encompasses approximately 16,000 ha. This segment tends east-west and is comprised mainly of steep, rocky escarpments. Elevations range from 400 m to 1631 m (Divine and Douglas 1996). There are two permanent springs that, because of their close proximity to one another, were considered as a single water source.

Methods

Land Surface Ruggedness

To obtain a measure of ruggedness, the Land Surface Ruggedness Index (LSRI) that Ebert (1993) adapted from Beasom et al. (1983) was calculated from 30 m elevation data. The basic tenet behind LSRI is that the total length of topographic contour lines traversing an area is a function of the "ruggedness" of that area. Beasom et al. (1983) measured Land Surface Ruggedness by overlaying a regularly spaced grid over the map area under investigation and counting the number of intersections between contour lines and grid lines. This number was used to index the ruggedness of each area, with a higher number of intersections equating to a "rougher" landscape. Although this method is straightforward and replicable, it does not transfer easily into Geographic Information Systems (GIS) applications. Thus, Ebert (1993) adapted the Beasom et al. (1983) technique for use in a GIS program by developing a Land Surface Ruggedness Index generated by laying a 100 m x 100 m grid onto an elevation map and measuring the slope from each cell to each of its surrounding 8 cells. (Slope is calculated by measuring the difference in elevation from the center of one cell to the center of another cell).
found that both total slope, the summation of all slope values within the 300 m x 300 m window, and average slope, the average of all slope values within the 300 m x 300 m window, gave equally good approximations of total contour line length. Average slope was chosen as the LSRI value for this study, instead of total slope as used by Ebert (1993). Based on the data in Ebert (1993) the use of average slope is not a significant departure from the original method.

Thirty meter data were obtained from United States Geological Service (USGS) digital elevation files for each mountain range, and downloaded into Geographic Resources Analysis Support System (GRASS) GIS software (USACERL 1993). Cell size of 30 m data is 30 m x 30 m. To calculate an LSRI, a slope map was generated from the elevation data using percent slope as the output. Slope values were then averaged within an 11 x 11 cell window (330 m x 330 m) centered over each cell.

**Sheep Locations**

Location data from radio-collared bighorn ewes were collected at Eagle Mountain specifically for this project, while bighorn ewe location data were collected at the Eldorado and Black Mountains by other Cooperative Unit Investigators for previous studies, and generously donated for this study. Ewe locations were used because ewes are more gregarious and more habitat limited than rams. Weekly radio-telemetry flights were flown over the Eldorado Mountains between December 1989 and November 1991. During these flights, and concurrent ground surveys, 19 ewes yielded 1840 locations (Ebert 1993). Bi-monthly radio-telemetry flights were flown over the Black Mountains between September 1992 and August 1994. During these flights, 8 ewes yielded 364 locations (Longshore and Douglas 1995). Bi-monthly radio-telemetry flights were flown.
over Eagle Mountain between August 1993 and August 1995. During these flights, 15 ewes in the northern region yielded 713 locations, while 7 ewes in the southern region yielded 277 locations (Divine and Douglas 1996).

Sheep location was conducted via Cessna 206 fixed-wing aircraft (Lake Mead National Recreation Area’s plane, and Lake Mead Air, Boulder City, Nevada). The aircraft were equipped with a removable, belly-type antenna as described by Lecount and Carrel (1980). Locations were obtained by flying over the range in a rough search pattern listening for signals on a Telonics TR-2 programmable-scanner/receiver (Telonics Inc., Mesa, Arizona). Once a signal was heard the observer determined which frequency was being detected while the pilot flew in the direction of strongest signal reception until the signal began to fade. Once the signal faded, the pilot returned to the area of strongest reception and began to spiral inward to determine the signal’s focal point. The focal point, the point of strongest reception, was plotted as the location for that frequency (Mech 1983, Kenward 1987). Locations were plotted by hand on United States Geological Survey (USGS) 7.5 minute maps (1:24,000 scale) or 15 minute (1:62,500 scale) topographic maps, and later recorded as Universal Trans-Mercator coordinates. Aerial location errors were assumed to average 4 ha², as reported by Krausman et al. (1984).

Due to multiple factors, including topographic features, cryptic coloration, and aircraft / personnel safety considerations, most bighorn sheep coordinates were based solely on signal strength, and do not have visual verification. Consequently, all locations must be treated as area locations and not simple point locations, thus some measure of error must be considered when assigning LSRI values to each sheep relocation. In order
to assign an area LSRI value to a point location, a 200 m radius circle was centered on each location. ARC/INFO (Kreis 1995) was used to calculate the average LSRI value within the 400 m diameter circle. Because the error is based on a circle, and the landscape is based on a square grid system, the circle used to delineate the sheep location often bisected individual grid cells (Figure 2). In order to accurately calculate an average LSRI value within the circle, bisected cells were weighted according to their relative contribution to the area of the circle.

Figure 2. Sample 11 x 11 cell window with an error circle placed on top to illustrate landscape cells that must be weighted to produce an accurate average LSRI value for all cells within the circle.

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Habitat Models

Literature Based Model

Primary bighorn sheep literature was searched to determine which habitat components have been most repeatedly examined in research studies. A definition of suitable habitat was formulated by determining the habitat components most commonly included in definitions of desert bighorn habitat, and incorporating the most common parameters for those values. Because identical definitions were rarely used between research studies, average values were derived for each habitat component. These values were not calculated as mathematical averages, but as approximations of the most commonly used values. For example, there were 16 separate distances from escape terrain: (5, 55, 105, 25, 25, 50, 75, 100, 200, 200, 100, 100, 100, 100, 600, 1300). Looking at the values, there are 7 values within ±25 m of 100 m, making this the most common value. It was determined that using a most common value would be more realistic and useful than attempting to use a mathematical average that itself might never have been used. This method may lower the power of the conclusions, but nonetheless was determined to be the most appropriate way of determining the most common value.

Population Based Models

Suitable habitat was defined for each mountain range using two basic desert bighorn habitat components, LSRI, and distance from permanent water. Each sheep location in each mountain range was associated with its corresponding LSRI value, and distance from permanent water value. The LSRI data were sub-divided into 5-unit increments (i.e. 16-20%, 21-25% slope, etc.), and distance from permanent water data
were sub-divided into half-kilometer increments. The number of sheep locations found in each sub-division was then recorded. Suitable habitat was defined as LSRI or distance from permanent water increments accounting for a minimum of 70% of sheep locations. To obtain the 70% level, the LSRI category accounting for the most sheep locations was first incorporated into the definition, and then the next adjacent category containing the highest number of sheep locations was added. This procedure was repeated for each ewe population until the range of LSRI values incorporated a minimum of 70% and a maximum of 79% of sheep locations. This same procedure was repeated for distance from permanent water values, for each mountain range. This yielded a habitat model for each mountain range comprised of LSRI values accounting for a minimum of 70% of sheep locations, and distance from permanent water values accounting for a minimum of 70% of sheep locations. It is understood that this methodology yields no predictive power for the range in which a definition was formulated, and that the utility of that definition is in applying it to the other three mountain ranges, and analyzing the results. It must be further noted that within the individual range models, although each individual habitat component, when examined separately, accounted for a minimum of 70% of ewe locations, the composite of both components does not necessarily account for a minimum of 70% of locations.

An average habitat model was formulated from the four individual range models by calculating the mathematical average of the LSRI values (rounded to the nearest 5 unit increment), and calculating the mathematical average of the distance from permanent water (rounded to the nearest half-kilometer). A maximum habitat model was formulated by using the lowest LSRI and distance from permanent water values of the four models to
set the lower model boundary, and then using the highest LSRI and distance from permanent water values to set the upper model boundary.

Spatial Context

To determine if analyzing desert bighorn habitat as a series of preferred habitat patches and intervening matrix areas adds additional insight into desert bighorn habitat selection, the traditional habitat model, and the one model of the six derived models that accounted for the largest percentage of ewe locations, were overlaid onto a topographic map in GRASS. The data were then clumped using a 2 x 2 grid overlaid on each cell (USACERL 1993). This process clumped all data contiguously located on a vertical or horizontal side (diagonal contiguity was ignored), and resulted in an output of the number of clumps. To incorporate cells attached diagonally, and to ensure clumps that were not connected but that were extremely close together were not considered different patches, the landscape was resampled, and all clumps within 120 m of one another (measured edge to edge) were re-classified and assigned the same clump number. A report was then run on the clumped data to determine the number of clumps, the size of each clump, and the number of ewe locations found in each clump.
Results

Habitat Models

Literature Based Model

McCarty and Bailey (1994) compiled an extensive review of desert bighorn research projects. They referenced more than 15 separate research projects offering definitions of escape terrain, and at least 8 different research projects offering definitions of a critical distance from permanent water. Escape terrain was most often defined as areas within 100 m of slopes greater than 60%; and Leslie and Douglas's (1979) notation of a maximum distance from permanent water of 3.2 km was the most commonly used value for distance from water. Other components such as vegetation composition, cover, and nutritional value, aspect, and proximity to human intrusion were too variable or ambiguous to obtain an average value, and thus were not included in the definition. It was also determined that because desert bighorn inhabit a wide geographical region, and because of a paucity of seasonal data, habitat models would be based on yearly averages, and not on seasonal averages. The final, traditional habitat model, was determined to be all areas within 100 m of slopes greater than 60%, and within 3.2 km of permanent water.

Applying the literature-based habitat model to the four ewe populations in the Eastern Mojave Desert yielded relatively poor predictive power. Table 1 shows that, for all four ewe populations combined, the traditional habitat model only accounted for approximately 49% of all ewe locations, and approximately 22% of the total landscape. Figures 3-6 illustrate the traditional model as applied to each of the four mountain ranges.
Figure 3. Map of the Eldorado Mountains, Clark County, Nevada, illustrating suitable desert bighorn habitat as defined by the traditional habitat model. Black indicates areas within 100 m of slopes greater than 60% and are within 3.2 km of permanent water.
Figure 4. Map of the Black Mountains, Inyo County, California, illustrating suitable desert bighorn habitat as defined by the traditional habitat model. Black indicates areas within 100 m of slopes greater than 60%, and are within 3.2 km of permanent water.
Figure 5. Map of northern Eagle Mountain, Riverside County, California, illustrating suitable desert bighorn habitat as defined by the traditional habitat model. Black indicates areas within 100 m of slopes greater than 60%, and are within 3.2 km of permanent water.
Figure 6. Map of southern Eagle Mountain, Riverside County, California, illustrating suitable desert bighorn habitat as defined by the traditional habitat model. Black indicates areas within 100 m of slopes greater than 60%, and are within 3.2 km of permanent water.
Table 1. Percentage of ewe locations, and percentage of area in each of the four mountain ranges under investigation that are explained by the traditional habitat model, (within 100 m of slopes greater than 60%, and within 3.2 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>1.021 / 1.840</td>
<td>55.5 %</td>
<td>4.341 / 8.771</td>
<td>49.5 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>201 / 364</td>
<td>55.2 %</td>
<td>9.954 / 71.565</td>
<td>13.9 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>285 / 713</td>
<td>40.0 %</td>
<td>2.946 / 23.231</td>
<td>12.7 %</td>
</tr>
<tr>
<td>Eagle Mtn (S)</td>
<td>123 / 277</td>
<td>44.4 %</td>
<td>392 / 16.426</td>
<td>11.5 %</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>48.8%</strong></td>
<td></td>
<td><strong>21.9%</strong></td>
</tr>
</tbody>
</table>

Population Based Models

**Eldorado Mountains Model**

Based on ewe locations recorded between December 1989 and November 1991 in the Eldorado Mountains. 73% of ewe locations were in areas with LSRI values between 26 and 55. and 70% of ewe locations were within 2.0 km of a permanent water source. Combining these two components yielded a habitat model comprised of areas with LSRI values between 26 and 55. and within 2.0 km of permanent water. This model accounted for approximately 48% of ewe locations in the Eldorado Mountains. and approximately 29% of all ewe locations in all four populations (Table 2). Additionally, this model covered approximately 43% of the Eldorado Mountains. and approximately 16% of the total landscape in all four mountain ranges (Table 2).
Table 2. Percentage of ewe locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the Eldorado Mountains habitat model. (LSRI values between 26 and 55, and within 2.0 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>882 / 1840</td>
<td>47.9 %</td>
<td>3.784 / 8.771</td>
<td>43.1 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>24 / 364</td>
<td>6.6 %</td>
<td>1.940 / 71.565</td>
<td>5.9 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>227 / 713</td>
<td>31.8 %</td>
<td>1.819 / 23.231</td>
<td>7.8 %</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>81 / 277</td>
<td>29.2 %</td>
<td>943 / 16.426</td>
<td>5.7 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>28.9%</td>
<td></td>
<td>15.6%</td>
</tr>
</tbody>
</table>

Black Mountains Model

Based on ewe locations recorded between September 1992 and August 1994 in the Black Mountains, 73% of ewe locations were in areas with LSRI values between 46 and 85. Relative to permanent water, 71% of ewes were found within 4.0 km of a permanent water source. Combining these two components yielded a habitat model comprised of areas with LSRI values between 46 and 85, and within 4.0 km of permanent water. This model accounted for approximately 55% of ewe locations in the Black Mountains and approximately 33% of all ewe locations in the four populations (Table 3). Additionally, this model covered approximately 14% of the Black Mountains, as well as approximately 14% of the total landscape in all four mountain ranges (Table 3).
Table 3. Percentage of sheep locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the Black Mountains habitat model. (LSRI values between 46 and 85, and within 4.0 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>531 / 1.840</td>
<td>28.9 %</td>
<td>2,400 / 8,771</td>
<td>27.4 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>200 / 364</td>
<td>55.0 %</td>
<td>10,159 / 71,565</td>
<td>14.2 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>154 / 713</td>
<td>21.6 %</td>
<td>1,905 / 23,231</td>
<td>8.2 %</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>71 / 277</td>
<td>25.6 %</td>
<td>1,205 / 16,426</td>
<td>7.3 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>32.8%</td>
<td></td>
<td>14.3%</td>
</tr>
</tbody>
</table>

**Northern Eagle Mountain Model**

Based on ewe locations recorded between August 1993 and August 1995 at Eagle Mountain. 76% of northern ewes were located in areas with LSRI values ranging between 31 and 50. Relative to permanent water, 73% of ewes were found within 4.5 km of a permanent water source. Combining these two components yielded a habitat model comprised of areas with LSRI values between 31 and 50, and within 4.5 km of permanent water. This model accounted for approximately 55% of ewe locations in the northern segment of Eagle Mountain, and approximately 40% of ewe locations in all four populations (Table 4). Additionally, this definition covered approximately 22% of northern Eagle Mountain, and approximately 24% of the total landscape in all four mountain ranges (Table 4).
Table 4. Percentage of ewe locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the northern Eagle Mountain habitat model. (LSRI values between 31 and 50, and within 4.5 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>892 / 1.840</td>
<td>48.5 %</td>
<td>3.813 / 8.771</td>
<td>43.5 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>28 / 364</td>
<td>7.7 %</td>
<td>9.443 / 71.565</td>
<td>13.2 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>395 / 713</td>
<td>55.4 %</td>
<td>5.117 / 23.231</td>
<td>22.0 %</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>138 / 277</td>
<td>49.8 %</td>
<td>2.697 / 16.426</td>
<td>16.4 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>40.3 %</td>
<td></td>
<td>23.8 %</td>
</tr>
</tbody>
</table>

**Southern Eagle Mountain Model**

Based on ewe locations recorded between August 1993 and August 1995 at Eagle Mountain, 78% of southern ewes were located in areas with LSRI values between 36 and 55. Relative to permanent water, 70% of ewes were found within 4.5 km of a permanent water source. Combining these two components yielded a habitat model comprised of areas with LSRI values between 36 and 55, and within 4.5 km of permanent water. The southern Eagle Mountain model accounted for approximately 57% of sheep locations in southern Eagle Mountain, and approximately 43% of ewe locations in all four populations (Table 5). Additionally, this definition covered approximately 6% of southern Eagle Mountain, and approximately 21% of the total landscape in all four mountain ranges (Table 5).
Table 5. Percentage of ewe locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the southern Eagle Mountain habitat model. (LSRI values between 36 and 55, and within 4.5 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>770 / 1.840</td>
<td>41.9%</td>
<td>3.401 / 8.771</td>
<td>38.8 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>78 / 364</td>
<td>21.4%</td>
<td>8.748 / 71.565</td>
<td>12.2 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>357 / 713</td>
<td>50.1%</td>
<td>4.265 / 23.231</td>
<td>18.4 %</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>158 / 277</td>
<td>57.0%</td>
<td>2.539 / 16.426</td>
<td>15.5 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>42.6%</td>
<td></td>
<td>21.2 %</td>
</tr>
</tbody>
</table>

Average Model

Based on ewe locations recorded between December 1989 and August 1995 in all four mountain ranges, 56% of ewes were located in areas with LSRI values ranging between 36 and 60. Relative to permanent water, 87% of ewes were found within 4.0 km of a permanent water source. Combining these two components yielded a habitat definition of areas with an LSRI value between 36 and 60, and within 4.0 km of permanent water. Additionally, this definition accounted for approximately 43% of all ewe locations and approximately 22% of the landscape in all four mountain ranges (Table 6).
Table 6. Percentage of ewe locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the average habitat model. (LSRI values between 36 and 60, and within 4.0 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>873 / 1840</td>
<td>47.5 %</td>
<td>3.810 / 8.771</td>
<td>43.4 %</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>89 / 364</td>
<td>24.5 %</td>
<td>9.359 / 71.565</td>
<td>13.1 %</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>340 / 713</td>
<td>47.7 %</td>
<td>3.915 / 23.231</td>
<td>16.9 %</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>150 / 277</td>
<td>54.2 %</td>
<td>2.276 / 16.426</td>
<td>13.9 %</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>43.5 %</td>
<td></td>
<td>21.8 %</td>
</tr>
</tbody>
</table>

Maximum Model.

Based on ewe locations recorded between December 1989 and August 1995 in all four mountain ranges. 90% of ewes were located in areas with LSRI values between 26 and 85. Relative to permanent water, 90% of ewes were found within 4.5 km of a permanent water source. Combining these two components yielded a habitat definition of areas that had LSRI values between 26 and 85, and within 4.5 km of permanent water. Additionally, this definition accounted for approximately 73% of all ewe locations and 38% of the landscape in all four mountain ranges (Table 7).
Table 7. Percentage of ewe locations and percentage of the landscape in each of the four mountain ranges under investigation that are explained by the maximum habitat model. (LSRI values between 26 and 85, and within 4.5 km of permanent water)

<table>
<thead>
<tr>
<th>Mountain Range</th>
<th>Proportion of Ewe Locations</th>
<th>Percentage of Ewe Locations</th>
<th>Proportion of Range (ha)</th>
<th>Percentage of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado Mtns.</td>
<td>1548 / 1840</td>
<td>84.1%</td>
<td>6.443 / 8.771</td>
<td>62.1%</td>
</tr>
<tr>
<td>Black Mtns.</td>
<td>265 / 364</td>
<td>72.8%</td>
<td>21.861 / 71.565</td>
<td>30.6%</td>
</tr>
<tr>
<td>Eagle Mtn. (N)</td>
<td>475 / 713</td>
<td>66.6%</td>
<td>7.515 / 23.231</td>
<td>32.4%</td>
</tr>
<tr>
<td>Eagle Mtn. (S)</td>
<td>190 / 277</td>
<td>68.6%</td>
<td>4.093 / 16.426</td>
<td>24.9%</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>73.0%</td>
<td></td>
<td>37.5%</td>
</tr>
</tbody>
</table>

**Spatial Components**

**Traditional Model**

Based on the traditional habitat model of areas within 100 m of slopes greater than 60%, and within 3.2 km of permanent water, the GRASS "Clump" function (USACERL 1993) identified 20 patches (clumps) in the Eldorado Mountains (Figure 7), 83 patches in the Black Mountains (Figure 8), 49 patches in northern Eagle Mountain (Figure 9), and 31 patches in southern Eagle Mountain (Figure 10). Because this definition has a distance component built-in, an additional inter-patch distance was not added. To further explore patches identified by the traditional habitat definition, and to determine if patch size plays a role in habitat selection, the number and average size of patches containing ewe locations was extracted, and contrasted with the number and average size of patches lacking ewe locations. Table 8 shows that not only are there fewer patches containing ewe locations than lacking ewe locations, but that the average size of patches containing ewe locations
Figure 7. Map of the Eldorado Mountains, Clark County, Nevada, illustrating 20 suitable desert bighorn habitat patches as defined by the traditional habitat definition (Within 100 m of slopes greater than 60%, and within 3.2 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.

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Figure 8. Map of the Black Mountains, Inyo County, California, illustrating 83 suitable desert bighorn habitat patches as defined by the traditional habitat definition (Within 100 m of slopes greater than 60%, and within 3.2 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Figure 9. Map of northern Eagle Mountain, Riverside County, California, illustrating 49 suitable desert bighorn habitat patches as defined by the traditional habitat definition (Within 100 m of slopes greater than 60%, and within 3.2 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Figure 10. Map of southern Eagle Mountain, Riverside County, California, illustrating 31 suitable desert bighorn habitat patches as defined by the traditional habitat definition (Within 100 m of slopes greater than 60%, and within 3.2 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
appears larger than those of patches lacking ewe locations. But applying a two-sample t-test with 95% significance demonstrates that none of the four mountain ranges has a statistically larger average patch size for patches containing ewes (Eldorados p=0.34, Blacks p=0.13, n Eagle p = 0.14, s Eagle p= 0.18) relative to patches lacking ewes.

Table 8. Number of traditional habitat patches, average, minimum and maximum patch sizes for patches containing ewe locations, and patches lacking ewe locations. (Values rounded to nearest hectare)

<table>
<thead>
<tr>
<th></th>
<th>Eldorado Mountains</th>
<th>Black Mountains</th>
<th>Eagle Mountain (N)</th>
<th>Eagle Mountain (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Patches</td>
<td>20</td>
<td>83</td>
<td>49</td>
<td>21</td>
</tr>
<tr>
<td>No. Patches (With sheep)</td>
<td>10</td>
<td>4</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>Avg. Patch Size (ha) (patches with sheep)</td>
<td>456</td>
<td>2184</td>
<td>160</td>
<td>437</td>
</tr>
<tr>
<td>Min. Patch Size (ha) (patches with sheep)</td>
<td>4</td>
<td>42</td>
<td>5</td>
<td>77</td>
</tr>
<tr>
<td>Max. Patch Size (ha) (Patches with sheep)</td>
<td>4146</td>
<td>5084</td>
<td>1469</td>
<td>1313</td>
</tr>
<tr>
<td>St. Dev. (ha) (patches with sheep)</td>
<td>1307</td>
<td>2246</td>
<td>385</td>
<td>586</td>
</tr>
<tr>
<td>No. Patches (lacking sheep)</td>
<td>10</td>
<td>79</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>Avg. Patch Size (ha) (lacking sheep)</td>
<td>7</td>
<td>15</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Min. Patch Size (ha) (lacking sheep)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Max. Patch Size (ha) (lacking sheep)</td>
<td>22</td>
<td>129</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>St. Dev. (Ha) (lacking sheep)</td>
<td>6</td>
<td>23</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

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Maximum Model

Based on the maximum habitat model derived from all four mountain ranges under investigation, areas with LSRI values between 26 and 85 and within 4.5 km of permanent water, the GRASS "Clump" function (USACERL 1993) identified 7 patches in the Eldorado Mountains, 46 patches in the Black Mountains, 15 patches in northern Eagle Mountain, and 3 patches in southern Eagle Mountain. Adding a 60 m distance component to the model and reclassifying all patches within 120 m of each other as a single patch, lowered the number of patches from 7 to 2 in the Eldorado Mountains (Figure 11), from 46 to 37 in the Black Mountains (Figure 12), from 15 to 9 in northern Eagle Mountain (Figure 13), and from 3 to 2 in southern Eagle Mountain (Figure 14). To further explore the patches identified with the maximum habitat definition, the number and average size of patches containing ewe locations was extracted, and contrasted with the number and average patch size of patches lacking ewe locations. Table 9 shows that not only are there fewer patches containing ewe locations than lacking ewe locations, but the average size of patches containing ewe locations appears to be larger than the average size of patches lacking ewe locations. But at a 95% significance level, none of the four mountain ranges exhibits a statistically larger patch size for patches containing ewes (Eldorados p = NA, Blacks p = 0.1, n Eagle p = 0.19, s Eagle p = NA) relative to patches lacking ewes.
Figure 11. Map of the Eldorado Mountains, Clark County, Nevada, illustrating 2 suitable desert bighorn habitat patches as defined by the maximum habitat model (LSRI values between 26 and 85, and are within 4.5 km of permanent water). Both patches are designated by a unique shade, but only one can be differentiated at this scale.
Figure 12. Map of the Black Mountains, Inyo County, California, illustrating 37 suitable desert bighorn habitat patches as defined by the maximum habitat model (LSRI values between 26 and 85, and within 4.5 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.

Black Mountains 30 m NAD83
Figure 13. Map of northern Eagle Mountain, Riverside County, California, illustrating 9 suitable desert bighorn habitat as defined by the maximum habitat definition (LSRI values between 26 and 85, and within 4.5 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Figure 14. Map of southern Eagle Mountain, Riverside County, California, illustrating 2 suitable desert bighorn habitat patches as defined by the maximum habitat model (LSRI values between 26 and 85, and within 4.5 km of permanent water). Both patches are designated by a unique shade, but only one can be differentiated at this scale.
Table 9. Number of maximum habitat patches, average, minimum and maximum patch sizes for patches containing ewe locations, and patches lacking ewe locations. (Values rounded to nearest hectare)

<table>
<thead>
<tr>
<th></th>
<th>Eldorado Mountains</th>
<th>Black Mountains</th>
<th>Eagle Mountain (N)</th>
<th>Eagle Mountain (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Patches</td>
<td>2</td>
<td>37</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>No. Patches (With sheep)</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Avg. Patch Size (ha) (patches with sheep)</td>
<td>NA</td>
<td>7201</td>
<td>2472</td>
<td>NA</td>
</tr>
<tr>
<td>Min. Patch Size (ha) (patches with sheep)</td>
<td>6439</td>
<td>3435</td>
<td>133</td>
<td>4084</td>
</tr>
<tr>
<td>Max. Patch Size (ha) (Patches with sheep)</td>
<td>6439</td>
<td>9999</td>
<td>4502</td>
<td>4084</td>
</tr>
<tr>
<td>St. Dev. (ha) (patches with sheep)</td>
<td>0</td>
<td>3387</td>
<td>2201</td>
<td>0</td>
</tr>
<tr>
<td>No Patches (lacking sheep)</td>
<td>1</td>
<td>34</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Avg. Patch Size (ha) (lacking sheep)</td>
<td>NA</td>
<td>8</td>
<td>16</td>
<td>NA</td>
</tr>
<tr>
<td>Min. Patch Size (ha) (lacking sheep)</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Max. Patch Size (ha) (lacking sheep)</td>
<td>5</td>
<td>40</td>
<td>43</td>
<td>9</td>
</tr>
<tr>
<td>St. Dev. (ha) (lacking sheep)</td>
<td>0</td>
<td>10</td>
<td>17</td>
<td>0</td>
</tr>
</tbody>
</table>

* NA = Not Applicable
Discussion

The task of defining suitable desert bighorn sheep habitat is arguably one of the most important challenges facing desert bighorn ecologists and managers, yet it is also one of the most difficult to accomplish. Because desert bighorn occupy large geographical regions, use widely diverse habitats, and are habitat generalists, the elucidation of a single habitat definition is perhaps unrealistic. McCarty and Bailey’s (1994) comprehensive review of desert bighorn sheep literature serves to highlight the scope of this problem. Almost every mountain range supporting a herd of desert bighorn sheep differs from other ranges supporting desert bighorn, and thus has a slightly different habitat definition.

This analysis was designed to test a traditional or paradigm model of desert bighorn habitat on four Eastern Mojave Desert mountain ranges, and to compare the suitability of this model to the suitability of models developed from sheep relocation data gathered in individual mountain ranges. On average, the traditional habitat model had poor predictive capabilities, but was better than all the habitat definitions derived from the individual ranges in terms of predicting habitat used by ewes during the respective time frames. The largest shortcoming of the traditional habitat model is the 3.2 km distance from permanent water value. This value was reported by Leslie and Douglas (1979) as a summer value, and was never intended to be applied as a year-around maximum distance from water. Unfortunately, many desert bighorn researchers have disregarded this inherent limitation, and have inappropriately used this seasonal value as a year-round value. Thus the major reason the traditional model has such poor predictive capabilities is because ewes tend to inhabit areas farther than 3.2 km from permanent water in the fall and winter months. Most ewe locations that were not accounted for by the traditional
habitat model are from fall and winter months.

The construction of a habitat definition (model) for each mountain range based on sheep data from that range met with varying degrees of success. When applied to all four ranges, each of the definitions had poorer predictive capabilities than the traditional model. Part of this failure might be explained by the method of defining appropriate habitat.

Combining the two habitat components together, each accounting for a minimum of 70% of sheep locations, does not mean that 70% of locations will meet conditions. Large amounts of potential habitat were dropped out because they only had the correct value for one or the other of the variables. These areas might be still important because the relative importance of the two variables might change on a temporal basis. Additionally, the four mountain ranges are quite different, and these differences are certainly hindering development of a unified habitat definition. The northern and southern sections of Eagle Mountain are very similar in all respects, and are similar in topographic relief to the Eldorado Mountains. But the Eldorado Mountains are different in terms of water availability than either of the Eagle Mountain sections, or the Black Mountains, because the Eldorado’s border the Colorado River, and have several natural springs. The Black Mountains are similar with respect to water availability to Eagle Mountain, but has a much larger range of topographic relief than Eagle Mountain, or the Eldorado Mountains.

The average habitat model does not have good predictive capabilities because it is simply a mixture of the four individual ranges, and neither has the largest distance from permanent water value, nor the widest range of LSRI values. Thus the average habitat model is no better than the individual models, and is not better at predicting ewe utilization than the traditional model. But the maximum habitat model encompasses a
higher percentage of ewe locations when averaged over all four ranges than does the traditional model. This increase is mainly due to the expanded distance from permanent water value, 3.2 km to 4.5 km, allowing more fall and winter ewe locations to be accounted for, as well as the incorporation of a very wide range of topographic relief (ruggedness). Thus, a single habitat definition can be developed for these four Eastern Mojave Desert mountain ranges that accounts for more ewe locations than the traditional habitat definition. But it should be understood that these are base habitat models using only two habitat components. It is possible that the predictive capabilities of each of these models might be enhanced by incorporating additional habitat components such as degree of human intrusion, or predation pressure, because restraints acting on these components probably operate on different scales of resolution, and thus would add more complexity to the model. It should also be noted that these models are based on an annual cycle, not a seasonal cycle. Although making seasonal-specific models might increase predictive capabilities in some instances, preliminary data analysis in these ranges yielded no clear seasonal effects on LSRI values or distance from permanent water values associated with sheep locations.

The most interesting result of this study may be the incorporation of a spatial component to the habitat models. Over the past several years, the emerging discipline of landscape ecology has gained increasing importance and prominence in wildlife ecology. The ideas of patches, patch configuration, patch dispersal, and average patch size have begun to become incorporated into ecological studies. To date, most of the applied landscape ecology work has been done either on insects or small mammals because of the limited home ranges and small geographical regions involved. But many of the questions
raised at these smaller scales need to be investigated for larger, more mobile animals that can disperse over large geographic areas.

In these mountain ranges, the average size of occupied habitat patches appeared to be larger than the average size of unoccupied habitat patches, although because of small sample sizes, there was no statistical support for this claim. But there are many possible reasons why larger areas would be preferred, and most of those reasons relate to resource availability. The preference for large contiguous areas might be explained by the need for a larger volume of food, the need for a diversity of food plants to meet nutritional requirements, the need to avoid contact with other individuals, or because of the need to incorporate several small, widely-spaced microhabitats such as arroyos or steep canyons that provide crucial habitat components such as lambing grounds, cool shaded areas for heat avoidance, or wide open spaces for predator avoidance.

Because of the sporadic timing of aerial relocation data, these locations represent a snapshot in time and not a daily or weekly window of time, and thus it may be premature to conclude that desert bighorn ewes occupy larger habitat patches more often than smaller habitat patches, even in these four mountain ranges. But it is not premature to conclude that habitat patch dynamics might play an important role in desert bighorn sheep ecology. Clearly, based on these findings, further exploration into desert bighorn habitat patches has the possibility of yielding new, insightful information concerning how bighorn interact with their surroundings. Desert bighorn ecologists need to begin to add the concepts of patches, average patch size, and patch juxtaposition to their habitat vocabulary.
Literature Cited


CHAPTER 4

EFFECT OF HABITAT FRAGMENTATION ON DESERT BIGHORN EWES IN THE EASTERN MOJAVE DESERT

Abstract

Habitat fragmentation, both natural and anthropogenic, is one of the most serious problems facing wildlife habitat today. As the human population continues to grow and expand its urban boundaries, suitable wildlife habitat will become an increasingly fragmented, and thus an increasingly valuable resource. In order to predict what effects habitat fragmentation may have on an individual species, something must be known about how individuals of that species interact with their environment. Desert bighorn (Ovis canadensis nelsoni) ewe home range values were examined in four Eastern Mojave Desert mountain ranges to determine if the landscape in these four areas can be labeled heterogeneously undivided habitat. In three of the four mountain ranges, ewe home ranges were larger than the average habitat patch. Also, single habitat patches did not contain entire populations of ewes, unless those patches were the largest in that landscape. Finally, for all four mountain ranges, the average nearest neighbor distance was smaller than the distance a bighorn ewe can travel in a day. Thus the landscape in each of the four mountain ranges appears to function as heterogeneously undivided habitat. Unfortunately
the data presented here can not be used to predict the effects of additional habitat
fragmentation of these areas. The utility of using spatially explicit models to examine
desert bighorn movements between mountain ranges may be a lucrative area for future
research, but its utility for intra-mountain movements is questionable.

Introduction

Desert Bighorn Sheep, *Ovis canadensis nelsoni*, currently inhabit seven western
states. Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah, as well as
portions of Mexico (McCarty and Bailey 1994). Prior to the early 1990's, the paradigm in
desert bighorn ecology and management had been that sheep exist in small to medium­
sized discrete populations inhabiting different mountain ranges. Thus proper management
dictated each population be treated as a discrete entity. Even though instances of long­
distance inter-mountain movements have been detected for many years (Schwartz et al.
1986), it was not until the mid-1980's that the importance of inter-mountain or large scale
movements of desert bighorn came to the forefront of research interests (Ough and deVos
what impacts habitat fragmentation may have on desert bighorn populations. They agreed
that the three major consequences of habitat fragmentation proposed by Wilcox and
Murphy (1985) are applicable to the conservation of desert bighorn. These consequences
are: 1. subdivision, size reduction, or destruction of demographic units; 2. loss of potential
immigrants; and 3. impedance of immigration caused by alteration of natural habitat.

Although the major emphasis of desert bighorn habitat conservation has recently
focused on protection of inter-mountain travel corridors and associated metapopulations.
the same concerns can and should be addressed on an intra-mountain scale. Just as disruption of travel corridors between mountain ranges can endanger sheep populations by diminishing or eliminating gene flow (Krausman 1997), severing corridors between habitat patches, and intra-mountain patch fragmentation might also endanger sheep populations. The driving concern behind habitat fragmentation is two-fold: fragmentation can cause a reduction in total habitat area, and can also cause remaining habitat patches to become disjunct and inviable (Wilcove et al. 1986).

It must be noted that although corridors can alleviate some detrimental effects of fragmentation, they also pose some of the same problems as habitat fragmentation. Scale becomes crucial when considering movement corridors because a landscape element acting as a corridor for one organism may act as a barrier to another (Noss 1991). In addition, contagious diseases, predators, fires, domestic animals, and human exposure can all be exacerbated because of corridors connecting two or more habitats, or fragmenting a habitat patch (Simberloff and Cox 1987). So although movement corridors can alleviate minimum size requirements and associated mobility limitations for many terrestrial vertebrates, including desert bighorn, they can also help spread disturbances. In the case of desert bighorn, proximity to human influences, especially domesticated livestock, is certainly one of the largest detriments of many movement corridors.

The hypothesized effects of fragmentation have often been based on the theory of island biogeography (MacArthur and Wilson 1967, Diamond and May 1981), which has the basic tenet that the number of species on an island is determined by a dynamic equilibrium between the processes of immigration and extinction. Population persistence is dependent upon population size, which, in turn, is dependent upon island size, and
colonization rates. Thus terrestrial habitat patches surrounded by inhospitable matrix areas have often been viewed as habitat islands. Harris (1984) and Berger (1990) both noted that species occurring in small populations are the most vulnerable to extirpation. These combined ideas have led researchers to conclude the dynamics of heterogeneous terrestrial habitat might be better understood if examined in the context of island biogeography.

In contrast, it must be noted that island biogeography theory has many associated problems when extrapolated to terrestrial habitats. Thus must be used with caution. One major problem is that terrestrial habitats are usually not true “islands” because they are rarely surrounded by an “inhospitable matrix”. Because terrestrial habitats are mosaics of different habitats, and species can often traverse most or all of the mosaic at some frequency, the isolation component of island biogeography is compromised (Knaapen et al. 1992, Forman 1995). Also, small habitat patches may often contain only a single, or a very few habitat types, whereas larger patches may be an aggregate of multiple habitat types (Forman 1995). Thus area effects may be convoluted with effects of habitat differentiation.

Metapopulation theory has also been used to research possible effects of fragmentation on population persistence. Metapopulation theory states that some populations exist as a “population of populations” (Levins 1969, Hanski and Gilpin 1991). The populations making up the overall metapopulation “wink” in and out of existence over time. Metapopulations most often exist because a species has a very low rate of dispersal, but even the low rate allows individuals from one population to colonize and repopulate areas left vacant by periodic extinctions of other populations. Metapopulations
can be differentiated from a source-sink scenario (Pulliam 1988, Lomnicki 1988, Pulliam and Danielson 1991, Ritchie 1997) if certain "source" habitats consistently sustain higher growth rates and emigration rates than certain "sink" habitats.

Metapopulations can either exist with or without well-defined movement corridors. In areas where the matrix is easily traversable, dispersing individuals may not be restricted to well-defined movement corridors, but in systems with inhospitable and largely untraversable matrix areas, well-defined movement corridors would be essential. Species with very low dispersal abilities may need artificial colonization events to maintain a functioning metapopulation, rather than exist as a series of small populations, all on a slow but inevitable decline to extinction (Hanski and Gilpin 1991). Lande (1987) developed a metapopulation model establishing a minimum percentage of suitable habitat necessary for population survival. He found that species with high fecundity, survivorship, and dispersal ability (demographic potential) could persist in extensively fragmented habitat, i.e. fragmentation up to 50%. In contrast he theorized that species with lower demographic potential could not persist in highly fragmented habitat, even if high proportions of suitable habitat (i.e. 50-80%) still exist.

Both island biogeography theory and metapopulation theory depend on a heterogeneously divided landscape (Addicott et al. 1987). In other words, the landscape is made up of multiple patch types, and patches are aggregated and separated by an unsuitable matrix area, an area where fitness of the organism under consideration is relatively low, or even zero (Southwood 1977). But terrestrial habitats cannot always be assumed to be composed of suitable island habitat patches surrounded by an inhospitable matrix. Conversely, heterogeneously undivided habitat can be defined as the presence of
two or more patch types, with or without matrix areas, with all the areas being relatively suitable in terms of fitness (Addicott et al. 1987). In addition, heterogeneously undivided landscape are organism-specific because resources can only be divided or undivided dependent upon an organism's ability to move between them.

Forman and Godron (1986) define landscapes as being heterogeneous areas differing in the flow of species, materials, and energy among landscape elements such as matrices, patches, and corridors. In a landscape there are multiple types of patches, including disturbance, remnant, regenerated, ephemeral, and environmental resource patches (Forman and Godron 1986). In a heterogeneous environment, patches are not resources, but are formations caused by the spatial orientation of resources (Wiens 1984). Environmental resource patches are formed when patch elements differ from the surrounding matrix due to a difference in resources or environmental conditions within the patch. Ephemeral patches are due to short-term environmental fluctuations such as annual production or vegetation green-up following a rainfall event (Forman and Godron 1986).

Proponents of Percolation Theory (Stauffer 1985) and Critical Threshold Theory (With and Crist 1995) theorize the effects of habitat fragmentation are in part dependent upon the relative degree of existing landscape fragmentation, and thus fragmentation levels above a certain threshold may have a much more profound effect on population viability than levels of fragmentation below the critical threshold. Andren and Delin (1994) concluded that in some landscapes, the effect of fragmentation may be dependent upon the relationship between animal movements and patch distribution. They noted that if habitat patch fragments are smaller than an organism's required area, and if each patch fragment does not contain an entire population, and if the distance between patch fragments is less
than the distance individuals can readily move in a day, then the landscape exists in a
ceterogenously undivided state (Addicott et al. 1987).

The goal of this project was to describe habitat of desert bighorn in four Eastern
Mojave Desert mountain ranges in a spatially-explicit manner, and to attempt to determine
if it is possible to predict the effects of habitat fragmentation on these populations.
utilizing data gathered via aerial telemetry. The specific prediction to be tested was that
desert bighorn exist in a heterogeneously undivided habitat. If true, data from relocations
of radio-collared ewes will show that average patch size is smaller than the average ewe
home range, and that individual patches do not contain entire populations of desert
bighorn. Finally, the average distance between nearest-neighbor habitat patches will be
less than the distance ewes can travel in a day.

**Study Area**

The study areas were comprised of three Eastern Mojave Desert mountain ranges.
The Eldorado Mountains located in Clark County, Nevada, the Black Mountains located
in the Death Valley National Park, Inyo County, California, and two separate segments of
Eagle Mountain, located in Riverside County, California (Figure 1).

The Eldorado Mountains are located in the Lake Mead National Recreation Area,
Clark County, Nevada, and encompass nearly 36,000 ha. The Eldorados are comprised of
two relatively separate sections, north and south, that are separated by a canyon running
east-west (locally known as Burro Wash). This study focuses solely on the northern
section, encompassing nearly 9,000 ha. The northern Eldorados are somewhat divided by
a series of north-south oriented bluffs. Topography to the west of the bluffs consists of
Figure 1. Study Area map illustrating the relative locations of the Eldorado Mountains, Clark County, NV, Eagle Mountain, Riverside County, CA, and the Black Mountains, Inyo County, CA.
wide rolling hills and gentle washes. Topography to the east of the bluffs consists of a series of maze-like ridges with narrow steep-sided washes that continue until the terrain drops off steeply to the banks of the Colorado River. Elevations range from 197 m to 973 m (Ebert 1993). This range has abundant free water due to the proximity of the Colorado River, and five permanent springs.

The Black Mountains form the southern half of the Amargosa Range in the southeastern section of Death Valley National Park, Inyo County, California, and encompass approximately 72,000 ha. The Black Mountains tend northwest-southeast, and form a wedge-shaped fault block which has been raised between two fault zones. Topography is characterized as very steep and rugged. Elevations range from -81 m to 1946 m (Longshore and Douglas 1995). There are seven permanent springs in the area.

Eagle Mountain is located in, and adjacent to, the southeastern corner of Joshua Tree National Park, Riverside County, California. The range is divided into two main segments by a large wash running east-west (Big Wash). Because each segment contains a separate non-interactive group of desert bighorn ewes, each segment was treated independently.

The northern segment contains both an east-west section and a north-south section, and encompasses approximately 23,000 ha. Topography consists of rolling hills with intermittent steep canyons and ridges, and elevations ranging from 300 m to 1077 m. There are two natural springs in the north, and although both were treated as permanent, one spring dries up during hot, dry periods, but the exact timing of its disappearance is unknown and unpredictable.
The southern segment is situated within Joshua Tree National Park, and encompasses approximately 16,000 ha. This segment tends east-west, and is comprised mainly of steep, rocky escarpments. Elevations range from 400 m to 1631 m (Divine and Douglas 1996); this area contains two permanent springs located very close to another and thus they were treated as a single water source.

Methods

Patch Definition

Desert bighorn habitat patches were defined using 30 m resolution (cell size = 30 m x 30 m) digital elevation data. For all four mountain ranges, elevation data were input into Geographic Resources Analysis Support System (GRASS) Geographic Information System (GIS) software (USACERL 1993). All areas in each mountain range with Land Surface Ruggedness Index (LSRI) values between 26 and 85, and within 4.5 km of a permanent water source were delineated and defined as preferred desert bighorn ewe habitat. (See Chapter Two for a complete description of LSRI calculation) The GRASS "clump" function was then used to clump cells in the habitat model into separate clumps or "patches". The clump function only connects cells that are attached horizontally or vertically. To incorporate cells attached diagonally, and to ensure clumps that are not connected but are extremely close together are not considered different patches, the landscape was re-sampled, and all clumps within 120 m of one another, measured edge to edge, were re-classified and assigned the same clump number. The 120 m distance was chosen because desert bighorn sheep literature commonly refers to bighorn ewes as being located within 100 m of escape terrain, and when utilizing 30 m data, 120 m is the closest
whole-cell measurement over 100 m. The size of each patch to the nearest hectare and the nearest neighbor distance, measured edge to edge to the nearest meter, were both computed within GRASS.

**Sheep Locations**

Location data from radio-collared bighorn ewes were collected at Eagle Mountain specifically for this project, while bighorn ewe location data were collected at the Eldorado and Black Mountains by other Cooperative Unit Investigators for previous studies, and generously donated for this study. Ewe locations were used because ewes are more gregarious and more habitat limited than rams. Weekly radio-telemetry flights were flown over the Eldorado Mountains between December 1989 and November 1991. During these flights, and concurrent ground surveys, 19 ewes yielded 1840 locations (Ebert 1993). Bi-monthly radio-telemetry flights were flown over the Black Mountains between September 1992 and August 1994. During these flights, 8 ewes yielded 364 locations (Longshore and Douglas 1995). Bi-monthly radio-telemetry flights were flown over Eagle Mountain between August 1993 and August 1995. During these flights, 15 ewes in the northern region yielded 713 locations, while 7 ewes in the southern region yielded 277 locations (Divine and Douglas 1996).

Sheep location was conducted via Cessna 206 fixed-wing aircraft (Lake Mead National Recreation Area’s plane, and Lake Mead Air, Boulder City, Nevada). The aircraft were equipped with a removable, belly-type antenna as described by LeCount and Carrel (1980). Locations were obtained by flying over the range in a rough search pattern listening for signals on a Telonics TR-2 programmable scanner/receiver (Telonics Inc.).
Mesa Arizona). Once a signal was heard the observer determined which frequency was being detected while the pilot flew in the direction of strongest signal reception until the signal began to fade. Once the signal faded, the pilot returned to the area of strongest reception and began to spiral inward to determine the signal's focal point. The focal point, the point of strongest reception, was plotted as the location for that frequency (Mech 1983, Kenward 1987). Locations were plotted by hand on United States Geological Survey (USGS) 7.5 minute maps (1:24,000 scale) or 15 minute (1:62,500 scale) topographic maps, and later recorded as Universal Trans-Mercator coordinates. Aerial locational errors were assumed to average 4 ha², as reported by Krausman et al. (1984).

Due to multiple factors, including topographic features, cryptic coloration, and aircraft / personnel safety considerations, most bighorn sheep location coordinates were based solely on signal strength, and do not have visual verification. Consequently, all locations must be treated as area locations and not simple point locations, and some measure of error must be considered when assigning LSRI values to each sheep relocation. In order to assign an area LSRI value to a point location, a 200 m radius circle was centered on each location. ARC-INFO (Kreis 1995) was used to calculate the average LSRI value within the 400 m diameter circle. Because the error is based on a circle, and the landscape is based on a square grid system, the circle used to delineate the sheep location often bisected individual grid cells (Figure 2). In order to accurately find an average LSRI value within the circle, the bisected cells were weighted according to their relative contribution to the area of the circle.
Ewe Home Ranges

Ewe home ranges were calculated from relocation data utilizing a Minimum Convex Polygon (MCP) analysis (Mohr 1947). Although this method has met with criticism because outlying locations tend to cause an overestimation of home range size, it was nevertheless employed because it is easily understood and is still widely used by wildlife managers and researchers alike. In order to counter-balance outlying ewe locations, home range polygons were constructed using only 90% of ewe locations. Calculations were done with the CALHOME home range program. Version 1, produced by the United States Forest Service Pacific Southwest Research Station and California Department of Fish and Game. Home ranges were calculated both on a one-year and a two-year basis. A paired t-test (Zar 1984) was conducted to determine if the mean home range size differed significantly between years, for each mountain range.
Results

Patches

The Eldorado Mountains contain 2 habitat patches. One patch encompasses approximately 4.5 ha. while the other encompasses 6,400 ha (Table 1. Figure 3). The nearest edge to edge distance between the two patches is 960 m.

Table 1. Patch size and nearest neighbor distance for 2 desert bighorn habitat patches in the Eldorado Mountains. Clark County, Nevada.

<table>
<thead>
<tr>
<th>Patch Number</th>
<th>Patch Size (ha)</th>
<th>Nearest Neighbor Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.6</td>
<td>960</td>
</tr>
<tr>
<td>2</td>
<td>6,400.0</td>
<td>960</td>
</tr>
</tbody>
</table>

The Black Mountains contain 37 habitat patches ranging in size from 0.1 to 9.999 ha. (Table 2. Figure 4). The average patch size is approximately 591 ha., with a standard deviation of 2.145 ha. The average edge to edge nearest neighbor distance is 321 m. with a standard deviation of 275 m (Table 2).

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Figure 3. Map of the Eldorado Mountains, Clark County, Nevada, illustrating 2 suitable desert bighorn habitat patches (LSRI values between 26 and 85, and within 4.5 km of permanent water).
Figure 4. Map of the Black Mountains, Inyo County, California, illustrating 37 suitable desert bighorn habitat patches (LSRI values between 26 and 85, and within 4.5 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Table 2. Patch size and nearest neighbor distance for 37 desert bighorn habitat patches in the Black Mountains, Inyo County, CA.

<table>
<thead>
<tr>
<th>Patch Number</th>
<th>Patch Size (ha)</th>
<th>Nearest Neighbor Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>499</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>93</td>
</tr>
<tr>
<td>3</td>
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<td>93</td>
</tr>
<tr>
<td>4</td>
<td>6.6</td>
<td>1270</td>
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<td>5</td>
<td>16.8</td>
<td>700</td>
</tr>
<tr>
<td>6</td>
<td>9.3</td>
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<td>3.2</td>
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<tr>
<td>9</td>
<td>2.1</td>
<td>107</td>
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<tr>
<td>10</td>
<td>2.8</td>
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<td>6.1</td>
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<td>15</td>
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<td>16</td>
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<td>241</td>
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<td>29</td>
<td>13.7</td>
<td>150</td>
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<td>30</td>
<td>39.8</td>
<td>284</td>
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</table>
Table 2. (Cont.) Patch size and nearest neighbor distance for 37 desert bighorn habitat patches in the Black Mountains, Inyo County, CA.

<table>
<thead>
<tr>
<th>Patch Number</th>
<th>Patch Size (ha)</th>
<th>Nearest Neighbor Distance</th>
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</thead>
<tbody>
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<td>31</td>
<td>37.7</td>
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<tr>
<td>32</td>
<td>2.6</td>
<td>165</td>
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<tr>
<td>33</td>
<td>0.1</td>
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<td>35</td>
<td>19.0</td>
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<td>36</td>
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<td>305</td>
</tr>
<tr>
<td>37</td>
<td>0.2</td>
<td>824</td>
</tr>
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</table>

Northern Eagle Mountain contains 9 habitat patches ranging in size from 0.1 ha to 4.501 ha (Table 3. Figure 5). The average patch size is 835 hectares, with a standard deviation of 1.649 hectares. The average edge to edge nearest neighbor distance is 284 m. with a standard deviation of 171 m.

Table 3. Patch size and nearest neighbor distance for 9 desert bighorn habitat patches in northern Eagle Mountain, Riverside County, CA.

<table>
<thead>
<tr>
<th>Patch Number</th>
<th>Patch Size (ha)</th>
<th>Nearest Neighbor Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
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<td>2</td>
<td>132.6</td>
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<td>9</td>
<td>4501.9</td>
<td>694</td>
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</table>
Figure 5. Map of northern Eagle Mountain, Riverside County, California, illustrating 9 desert bighorn habitat patches (LSRI values between 26 and 85, and within 4.5 km of permanent water). Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Southern Eagle Mountain contains 2 patches with sizes of 9 and 4.083 hectares (Table 4. Figure 6). The nearest edge to edge distance between the two patches measures 120 m (Table 4).

Table 4. Patch size and nearest neighbor distance for 2 desert bighorn habitat patches in southern Eagle Mountain. Riverside County. CA.

<table>
<thead>
<tr>
<th>Patch Number</th>
<th>Patch Size (ha)</th>
<th>Nearest Neighbor Distance (m)</th>
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</thead>
<tbody>
<tr>
<td>10</td>
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<td>11</td>
<td>4083.9</td>
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**Ewe Home Ranges**

A paired t-test (Zar 1984) was run for all four ewe populations to determine if the mean home range values differed between years. The Eldorado Mountains population was the only ewe population that did not have a significant difference in average home range values between years at the 95% significance level (n=17, t=.32, p=.075). The Black Mountains (n=8, t=2.43, p=.045), and both northern Eagle Mountain (n=14, t=4.41, p=.0007), and southern Eagle Mountain (n=5, t=5.26, p=.0062), all had significant differences between the mean home range values for each of the two years. Because this mean value measures the home range size, and not the number of patches visited per se, and because habitat needs of a population are measured on a scale of decades and not
Figure 6. Map of southern Eagle Mountain, Riverside County, California, illustrating 2 suitable desert bighorn habitat patches (LSRI values between 26 and 85, and within 4.5 km of permanent water). Both patches are designated by a unique shade, but only the larger patch is visible at this scale.
single years, home ranges were calculated for each individual year, and then were
combined and calculated as multiple-year home range values.

Nineteen ewes in the Eldorado Mountains yielded an average year one home range
of 926 ha with a standard deviation of 381 ha, and an average year two home range of 992
ha with a standard deviation of 456 ha. Combining locations from both years into one
data set yields a two-year average home range of 1,193 ha with a standard deviation of
435 ha (Table 5).

Table 5. Home range sizes (based on 90% Minimum Convex Polygons) for nineteen
desert bighorn ewes in the Eldorado Mountains, Clark County NV, for August 1993-July
Computed)

<table>
<thead>
<tr>
<th>Ewe ID</th>
<th>No. Relocations (89-90)</th>
<th>Home Range (ha)</th>
<th>No. Relocations (90-91)</th>
<th>Home Range (ha)</th>
<th>No. Relocations (89-91)</th>
<th>Home Range (ha)</th>
</tr>
</thead>
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<td>1137</td>
<td>62</td>
<td>737</td>
<td>123</td>
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<td>55</td>
<td>1010</td>
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Eight ewes in the Black Mountains yielded an average year one home range of 2.816 ha with a standard deviation of 1.433 ha, and an average year two home range of 4.405 ha with a standard deviation of 1.035 ha. Combining locations from both years into one data set yields a two-year average home range of 4.675 ha with a standard deviation of 1.819 ha (Table 6).


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Fourteen ewes in northern Eagle Mountain yielded an average year one home range of 4.048 ha with a standard deviation of 1.356 ha, and an average year two home range of 4.369 ha with a standard deviation of 1.143 ha. Combining locations from both years into one data set yields a two-year average home range of 5.170 ha with a standard deviation of 1.449 ha (Table 7).


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Seven ewes in southern Eagle Mountain yielded an average year-one home range of 2236 ha with a standard deviation of 650 ha, and an average year-two home range of 2354 ha with a standard deviation of 627 ha. Combining locations from both years into one data set yields a two-year average home range of 2971 ha with a standard deviation of 627 ha (Table 8).


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Ewe Utilization of Patch Fragments

The Eldorado Mountains contain only two desert bighorn habitat patches, and only one of those habitat patches contained ewe locations. Patch 2 (6,400 ha) contained 80.5% of all sheep locations during the two year period, while the remaining 19.5% of ewe locations were in matrix areas (Figure 7).
Figure 7. Map of the Eldorado Mountains, Clark County, Nevada, illustrating 2 desert bighorn habitat patches, and locations of 1840 ewes gathered between August 1993 and September 1995.
The Black Mountains contain 37 habitat patches, but 71.4% of ewe locations were located in only three separate patches. Patch seven (3.435 ha) contained 1.9%, patch 25 (9.999 ha) contained 53.3%, and patch 27 (8.167 ha) contained 16.2% of ewe locations. The remaining 28.6% of ewe locations were found in matrix areas (Figure 8).

Northern Eagle Mountain contains 9 habitat patches, but 67.6% of ewe locations were located in three separate patches. Patch 2 (133 ha) contains 0.7%, patch 5 (2.782 ha) contains 35.8%, and patch 9 (4.501 ha) contains 31.8% of ewe locations. The remaining 31.7% of ewe locations were found in matrix areas (Figure 9).

Southern Eagle Mountain only contains 2 habitat patches. Patch 11 (4.083 ha) contains 68.2% of ewe locations, while the remaining 31.8% of locations were found in matrix areas (Figure 10).

**Conclusions**

As a landscape becomes increasingly fragmented, landscape connectivity may be abruptly disrupted (With and Crist 1995). Percolation theory (Stauffer 1985) predicts that given a random distribution of a given cell type, once the distribution of that cell type reaches approximately 60%, there exists a high probability of those cells forming a continuous corridor from one end of a landscape to the other (With and Crist 1995). Below this critical threshold, habitat fragmentation, either natural or anthropogenic, has a reduced impact because the landscape already exists as a series of disjunct patches and intervening matrix areas; thus movement between patches is determined by an animal’s dispersal ability, and its ability to inhabit matrix areas. Above the critical threshold, habitat fragmentation may produce large losses of habitat because fragmentation may disrupt the large habitat patch that spans the entire length of the landscape, in essence, transforming...
Figure 8. Map of the Black Mountains, Inyo County, California, illustrating 39 desert bighorn habitat patches, and 364 ewe locations gathered between September 1992 and August 1994. Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Figure 9. Map of northern Eagle Mountain, Riverside County, California, illustrating 9 desert bighorn habitat patches and 713 ewe locations gathered between August 1993 and July 1995. Each patch is designated by a unique shade, but not all patches can be differentiated at this scale.
Figure 10. Map of southern Eagle Mountain, Riverside County, California, illustrating 2 desert bighorn habitat patches and 277 ewe locations gathered between August 1993 and July 1995. Both patches are designated by a unique shade, but only the larger patch is visible at this scale.
the landscape into a more disjunct system where suitable habitat changes from a large continuous habitat patch into a collection of smaller habitat patches totaling only a small fraction of the original habitat. With and Crist (1995) argued that the critical threshold in natural systems is not simply a result of the landscape structure, but involves the combination of landscape structure and species' interactions, and noted that the occurrence of critical thresholds has not yet been directly tested. Gardner et al. (1987) found that the distribution of forest patches shows that in at least some forests, patches are more aggregated than predicted by randomly generated landscapes, suggesting that real landscapes may have a lower critical threshold than theoretical random landscapes.

But if a species exists in a landscape that is not divided into separate, discrete habitat patches, and the habitat patches are arrayed in such a manner that individuals can easily reach most or all of the patches within a day, and the home range or minimum area requirements of the species encompasses multiple habitat patches, then the fragmentation threshold concept may not be in operation. Therefore it may not be an adequate predictor of a population level response to habitat fragmentation.

The average patch size for the Eldorado mountains is 3.221 hectares, and the average home range size varies from 997 to 1.196 ha. The average patch size for the Black Mountains is 591 ha, and the average home range size varies from 2.800 ha to 4.700 ha. The average patch size for northern Eagle Mountain is 2.046 ha, and the average home range size ranges from 4.000 to 5.200 ha. Finally the average patch size for southern Eagle Mountain is 2.046, and average home range is about 2.500 hectares. Thus in the Black Mountains and in northern and southern Eagle Mountain, ewe home ranges are larger than average patch size. In the Eldorados average patch size is larger than
average ewe home range. Landscapes where individual home ranges are larger than average patch size lend themselves to supporting the concept of a heterogeneously undivided landscape, because patches are more likely to contain a few individuals rather than entire populations. In order for the habitat patch arrays to function as islands, ewe home ranges would need to be much smaller than individual patches, and each patch would need to contain an entire population.

Examining ewe populations relative to individual habitat patches yields mixed results. The Black Mountains ewe population and the northern Eagle Mountain ewe population both inhabit multiple patches, while the Eldorado Mountains and southern Eagle Mountain ewe populations both inhabit single patches. But a closer examination of the data reveals that in the Black Mountains and southern Eagle Mountain, the occupied habitat patch is by far the largest in the range (See Chapter 3). The argument could be made that in these two mountain ranges, ewes are only inhabiting one patch, and thus still have other patches available to them, but it is misleading to argue this point because there are no other patches available in either mountain range that are similar in size. Thus, it appears that the landscape of these four ranges does not meet the divided habitat criteria of Addicott et al. (1987) and these ranges tend to support the concept of a heterogeneously undivided landscape.

The average distance between habitat patches is less than 1.000 m for all of the ranges, and is less than 400 m in three of the four ranges. Although most references in the bighorn sheep literature concern ram movements, Elenowitz (1983) noted a group of 2 ewes and 1 lamb moving over 35 km in one week. Obviously this average of over 5 km per day is not normal daily movement, but does address the ability of ewes to move.
relatively long distances. The average distances between patches are relatively trivial compared to the mobility of desert bighorn ewes. Thus in all four areas under investigation, ewes should be able to easily reach all habitat patches.

In conclusion it does appear that the landscapes supporting these four desert bighorn population exist in a heterogeneously undivided landscape. But it also appears that it is impossible to determine the effects of further habitat fragmentation in these areas. It appears that threshold effects may not play a role in the effects of fragmentation, but this prediction cannot be supported with any certainty. One difficulty lies with patch definition. By definition, heterogenous habitat must have more than one habitat type. Spatially explicit models usually refer to patch areas, areas inhabitable by the organism under question, and matrix areas, areas either uninhabitable by the organism, or inhabitable but imparting a lower fitness. But it is extremely difficult to determine if desert bighorn ewes are viewing the landscape with regards to patch boundaries and matrix areas, as these areas are currently defined. It is possible that the current patch definition is too generous, and thus large patches are masking smaller-scale movements occurring within patch boundaries. Ewes could be recognizing and reacting to landscape elements on a much smaller scale than currently believed. Aerial telemetry, especially based on a two-week time window, is very coarse data, and can not address movements made on less than a two week interval. Without movement data gathered on a much finer scale, both spatially and temporally, bighorn ewe perception of the landscape is still uncertain, and thus the effects of additional habitat fragmentation are unclear. It is impossible to determine from this data if threshold effects will come into play, or the mountain ranges are operating under a source-sink design, or to offer any reliable prediction of the effects
of further habitat fragmentation.

It can and must be noted that the presence of a very few, large habitat patches in each mountain range leads to additional questions about the scale of investigation. Senft et al. (1987) noted that ungulates may make behavioral decisions at a landscape level, at an individual plant level, and at any level in-between. Thus it is possible, perhaps even likely, that examining bighorn sheep populations in the Eastern Mojave Desert on a metapopulation scale, and designating entire mountain ranges as habitat patches, will yield different results. Bighorn sheep are such habitat generalists that the ideas of habitat patches and matrix areas may not be useful on an intra-mountain level. Critical thresholds of fragmentation may very well play a crucial role in desert bighorn population persistence at the metapopulation level, even though they do not appear to be playing a governing role at the intra-mountain level. At the metapopulation level, factors such as average patch size, and inter-patch distance may have a much more important role in population persistence. Bleich et al. (1996) stated that, presently, habitat fragmentation may be the most important crisis facing desert bighorn populations. Examining desert bighorn populations on a regional scale, and predicting what effects habitat fragmentation will have on a metapopulation will be, and should be, a topic of research for years to come.
Literature Cited


CHAPTER 5

CONCLUSIONS

The main focus of this research was to identify preferred desert bighorn habitat, develop a habitat model, and apply that model to four mountain ranges in the Eastern Mojave Desert containing populations of desert bighorn ewes. After the habitat model was applied, each range was examined individually to determine if the addition of a spatially explicit component to the habitat model increased our knowledge of ewe habitat choice. The specific area of concern was the detrimental effects habitat fragmentation might have on population persistence and viability.

The findings of the first paper illustrate that although 30 m elevation data yielded a more accurate depiction of the landscape in an absolute sense, 100 m data was still adequate for determining habitat quality. Desert bighorn have large home ranges, and by their very nature, are habitat generalists. These two conditions help explain why even though habitat components may be measured at a resolution of 30 m or finer, desert bighorn may not make short-term decisions on a 30 m scale of resolution. In fact, desert bighorn very likely make foraging and dispersal decisions on a hierarchical scale. Some decisions may be made on a scale of a few meters, while others may be made on a scale of a few hundred or even a few thousand meters. The results of this chapter illustrate that it
is nearly impossible to champion one data resolution over another in all circumstances because the utility of data resolution changes depending on the question under investigation. The correct scale of investigation cannot be determined without looking at what scale the process in question is operating on.

The motive behind the research in the second paper was to question the paradigm or traditional model of desert bighorn habitat. Desert bighorn habitat models have been developed for several mountain ranges, but it has been unclear if a single habitat model can function well when applied to multiple mountain ranges in a given region. It was determined that the traditional bighorn habitat model was inadequate when applied to the four target ranges in the Eastern Mojave Desert because of its unrealistic distance to permanent water requirement. It was also determined that although a single definition was formulated that worked well for three of the four ranges, a single habitat model could not be formulated that worked equally well on all four mountain ranges because of widely differing topographic values, and availability of permanent water. Additionally, it was determined that, at least in these four mountain ranges, occupied habitat patches appear to be larger than unoccupied habitat patches, but because of small sample sizes, there is no statistical support for this claim. In conclusion, more research should be conducted on this topic in the future, both at similar scales and at the larger, metapopulation scale (Levins 1969, Hanski and Gilpin 1991), to determine if desert bighorn have a minimum size requirement for habitat patches, and if in fact desert bighorn populations in the Eastern Mojave Desert are functioning as metapopulations.

The main objective of the third paper was to ascertain if it is possible to predict the effects of habitat fragmentation on ewe populations in four mountain ranges in the Eastern
Mojave Desert. A main thrust of conservation biology has been to elucidate the mechanisms of habitat fragmentation, and to predict the consequences of future habitat fragmentation, either natural or anthropogenic. If desert bighorn habitat exists as a scattered conglomeration of isolated habitat patches, and individuals exhibit a relatively low dispersal rate, then the habitat will most likely conform to the predictions of island biogeography (MacArthur and Wilson 1967, Diamond and May 1981) and metapopulation theory (Levins 1969, Hanski and Gilpin 1991). If habitat exists as a series of habitat patches interspersed with relatively inhabitable matrix areas, and individuals exhibit a high dispersal rate and incorporate multiple habitat patches into their home ranges, then the habitat is most likely functioning as heterogeneously undivided habitat (Addicott et al. 1987). The results of this research appear to suggest that on an intra-mountain scale, desert bighorn habitat exists in a heterogeneously undivided state, but on an inter-mountain or regional scale, may exist in a divided state, or as a metapopulation.

It is somewhat difficult to conduct a fine-grained study of desert bighorn habitat requirements and preferences using movement data gathered via aerial telemetry, especially when the data can only be gathered on a bi-weekly basis. However, one of the unstated goals of this research was to utilize methodology commonly available to desert bighorn researchers and managers. As long as the human population continues to increase in size, and as long as wildlife conservation issues continue to be relegated to a relatively low position in natural resource budgets, wildlife researchers and managers will have to increasingly rely upon remotely-sensed data. It does little good to attempt to develop habitat models that are dependent upon fine-grained location data, and fine-grained habitat component data, when it is unlikely that such data will be widely available to others.
dealing with similar issues. Thus, although it may seem odd to attempt to quantify desert bighorn habitat using aerial telemetry data, this is exactly the scenario that has been played out in the recent past, and most likely will continue to be conducted into the future.
Literature Cited


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          topographically suitable desert bighorn sheep habitat. Desert Bighorn
          Council Trans. 40:13-18

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   Committee Member, Dr. Lawrence Walker
   Committee Member, Dr. John Bissonette.
   Graduate Faculty Representative, Dr. Evangelos Yfantis

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ABSTRACT

Habitat Patch Dynamics of Desert Bighorn Sheep
*Ovis canadensis nelsoni* In The
Eastern Mojave Desert

by

Darren Del Divine

Dr. Charles L. Douglas. Examination Committee Chair
Adjunct Professor of Biology
University of Nevada, Las Vegas

The individual chapters of this Dissertation were designed to examine desert bighorn habitat, and the disjunct nature of that habitat. The findings of the first chapter illustrated that although 30 m elevation data yielded a more accurate depiction of the landscape, 100 m data was still adequate for determining habitat quality. The second chapter illustrated that the traditional bighorn habitat model was inadequate when applied to four Eastern Mojave Desert mountain ranges because of its unrealistic distance to permanent water requirement. It was also determined that a single habitat definition could not be formulated that worked equally well on all four mountain ranges because of widely differing topographic values, and distance from permanent water values. The findings of the third chapter suggested that on an intra-mountain scale, desert bighorn habitat exists in a heterogeneously undivided state, but on an inter-mountain scale, may exist in a divided state, or as a metapopulation.