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Desert bighorn movements and habitat use in relation to the proposed Black Canyon Bridge Project, Nevada

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DESERT BIGHORN MOVEMENTS AND HABITAT USE IN RELATION TO THE PROPOSED BLACK CANYON BRIDGE PROJECT: NEVADA

by

Donald William Ebert

A thesis submitted in partial fulfillment
of the requirements for the degree of

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The Thesis of Donald William Ebert for the degree of Master of Science in Biological Sciences is approved.

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ABSTRACT

In this study, I used information on topography and the distribution of resources in the Eldorado Mountains, Nevada, to characterize bighorn sheep (Ovis canadensis) habitat quality, and information on movements of radio-collared bighorn to estimate home range size and patterns of movement. Study results were used to evaluate potential impacts of three proposed highway alignments (Gold Strike Canyon, GSA; Sugarloaf Mountain, SLA; and Promontory Point, PPA) on bighorn sheep.

Seasonal preferences for aspect, slope, elevation, distance to water, distance to escape terrain, and land surface ruggedness (LSR) were studied for male and female bighorn sheep. Distinct differences in habitat selection existed between the sexes throughout most of the year. Only during the breeding season did ram preferences approach those of female bighorn sheep. While habitat selection varied between seasons and within seasons between years, general patterns were evident and could be used for distinguishing quality habitat. In general, ewes selected northern and eastern aspects, slopes over 40%, 400-600 m elevations, areas within 300 m of escape terrain, and areas with LSR index values between 300-750. Ewes averaged 1.1 km from water in summer with 90% of observations within 2.3 km. Rams preferred northern aspects, 20-40% slopes, elevations above 600 m, areas between 200-700 m of escape terrain, and areas with LSR index values between 150-450. Rams averaged 1.7 km from water in summer with 90% of observations within 2.9 km.

Total home range size for ewes and rams averaged 19.0 and 49.7 km^2, respectively. Mean seasonal home range size for ewes varied little between seasons (range 4.2 to 11.0 km^2) with significant range overlap between seasons. No distinct seasonal movement patterns were evident. Mean seasonal home range size for rams varied from 6.7 to 19.6 km^2. Larger home range sizes were associated with the breeding season as rams left their bachelor pastures in search of estrous females.

Due to the close proximity of the highway alignments to each other, little difference exists in their potential impacts to bighorn sheep. Analyses using geographic information systems, however, indicates SLA intrudes the least on high use areas, high quality habitat, and areas identified as lambing habitat of the three. Habitat loss due to potential habitat fragmentation will be greatest for GSA.

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INTRODUCTION

Human disturbance affects natural populations of organisms in a variety of ways. Construction of roads causes habitat destruction and habitat fragmentation that may lead to the decline of local animal populations if high quality habitat is lost or if movement patterns and spatial use of habitats is disrupted. To determine the influence of human disturbance, biologists must quantify the use of different portions of habitat and measure home range size and seasonal patterns of movement for potentially affected species. In this study, I use information on topography and the distribution of resources in the Eldorado Mountains, Nevada, to characterize habitat quality of bighorn sheep (Ovis canadensis), and movement of radio-collared rams and ewes to estimate home range sizes and pattern of movement. This biological information will be used to assess potential impacts to the local bighorn sheep population of three proposed roadways considered by the Bureau of Reclamation (BOR) to reroute vehicular traffic from Hoover Dam.

Hoover Dam, located approximately 48 km southeast of Las Vegas, NV, along the Colorado River, is one of the most popular tourist attractions in the American Southwest (Fig. 1). Considered an engineering marvel, tourism has increased at the dam almost annually since its completion in 1934. Records from the BOR (U.S. Bureau of Reclamation 1986) show that the daily average number of people taking the guided tour of Hoover Dam has increased from 818 people/day in 1937 to 1,808 people/day in 1984. Fulfilling predictions made in the report, this figure exceeded 2,000 people/day in 1989 with a daily average of 2,109 (BOR files). As was noted in the report, these numbers represent only the number of visitors who partook in the guided tour and are believed to represent only 15% of the total number of people that use the dam daily. Assuming the validity of this estimate, over 5.1 million people visitied, crossed, or otherwise used the dam in 1989, the year this study started.

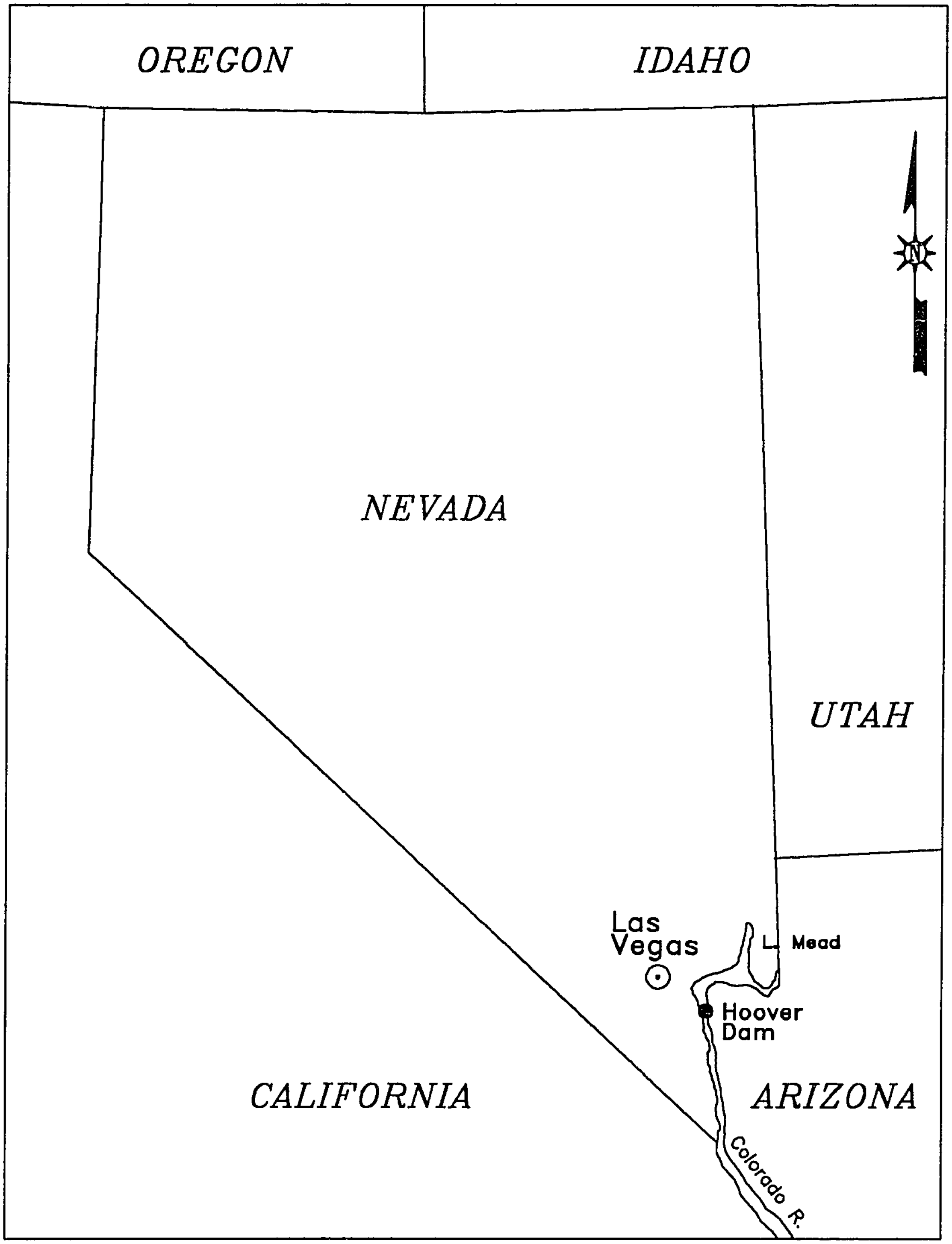

Figure 1. Location of Eldorado Mountains and Hoover Dam, Clark County, Nevada.

Hoover Dam also serves as an important travel corridor, connecting much of Arizona with Nevada and points further west. It's importance is augmented as it is the only Colorado River crossing near Las Vegas, NV. Davis Dam, located approximately 145 km down river, is the nearest alternative crossing to the south. Lee's Ferry, the closest alternative to the north, is over 400 km distant. As a consequence, Hoover Dam is heavily utilized by the commercial trucking industry as one of the shortest, most direct routes into and out of Las Vegas. This, combined with the rise in tourism, has led to dramatic increases in traffic volumes on the dam's crest in recent years.

In a report by the BOR (U.S. Bureau of Reclamation 1986), the average annual daily traffic volumes for Hoover Dam increased from approximately 1500 to approximately 6500 between the years 1960 and 1985. By 1989, it had increased to over 8,200 and reached 9,225 in 1991. Designed to "safely" accommodate approximately 320 vehicles/hour, the dam is now experiencing traffic volumes far greater than that on a frequent basis. Peak summertime traffic volume (1200 to 1300 hour) averaged 738 vehicles in 1985 and is expected to exceed 1100 vehicles by the year 2000. In 1991, the average hourly traffic count during the months of May through August exceeded the dam's design capacity by 120 vehicles.

As the number of hours increase where traffic volumes exceed the design capacity of the dam, the potential for serious pedestrian/vehicle conflict also increases. This situation is further aggravated by the steep grades, sharp turns, restricted visibility, and narrow roads associated with the dam and its approach roads; the increasing size of commercial trucks and recreational vehicles; and the transportation of hazardous materials (e.g. explosives, flammable fuels, caustic chemicals, and radioactive material) across the dam. Recognizing the substantial safety risks present in this situation, the BOR has begun exploring options to reduce the volume of traffic over Hoover Dam.

After consideration of several possibilities, the BOR has identified three alternative river crossings for further study (Fig. 2). All three crossings are located in close proximity to Hoover Dam and would require the construction of 3.6 km to 4.3 km of new road in Nevada, depending on

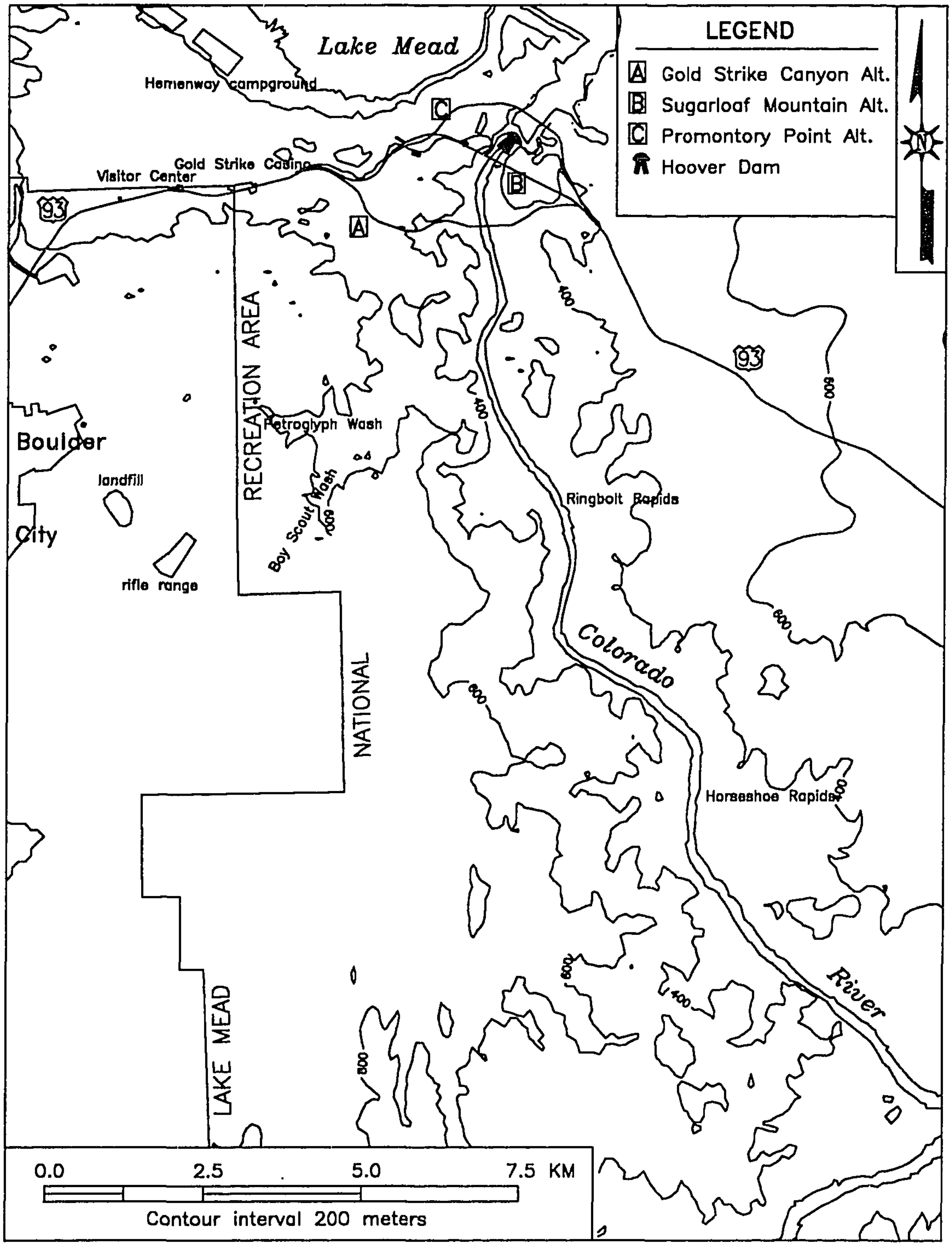

Figure 2. Location of primary study area with alternative highway alignments.

which alignment is selected. Concern for the placement of the proposed alignments, now known as the Black Canyon Bridge Project (BCBP), was expressed by the Nevada Department of Wildlife (NDOW) and the National Park Service (NPS) as each of the new approach roads would traverse the northern portion of the Eldorado Mountains and could impact bighorn sheep habitat.

Based on statewide helicopter surveys in 1976, McQuivey (1978) reported that the Eldorado herd was Nevada's second largest, with an estimated 410 individuals. Only the Sheep Range, located north of Las Vegas on the Lincoln and Clark county line, had a higher population estimate with a projected population of 732 bighorn sheep. Population estimates in the Eldorado Mountains have remained relatively constant throughout the intervening years with biannual estimates averaging 414 bighorn sheep during the past decade (range 367 to 450) (NDOW files).

The general distribution of bighorn sheep within the Eldorado Mountains has been described by Breyen (1971) (Fig. 3). Using the locations of beds and pellet groups along with random observations of bighorn sheep, Breyen determined the heaviest concentration of bighorn sheep use was between Hoover Dam and Nelson, NV, located near the center of the range approximately 35 km south of the dam. I made further refinements on the bighorn sheep distribution pattern by using the observation data obtained during the last five helicopter surveys. The majority of bighorn sheep observations recorded during these flights occurred between Hoover Dam and Burro Wash, located approximately 19 km south of Hoover Dam (ave. = 58.2%, range 31% to 72%). On average, then, nearly 60% of the bighorn sheep population in the Eldorado Mountains can be expected to be found within the northernmost quarter of the range, in the area of greatest concern.

The aesthetic and economic importance of the Eldorado herd should not be underestimated. McQuivey (1978) postulated that it, along with the River Mountain and Black Mountain herds, is one of the most observed and photographed populations in Nevada. Purdy (1981) would argue that, for many people, much of the appeal of Hoover Dam and that of Lake Mead National Recreation Area (LMNRA) is due to the presence of bighorn sheep in the area.

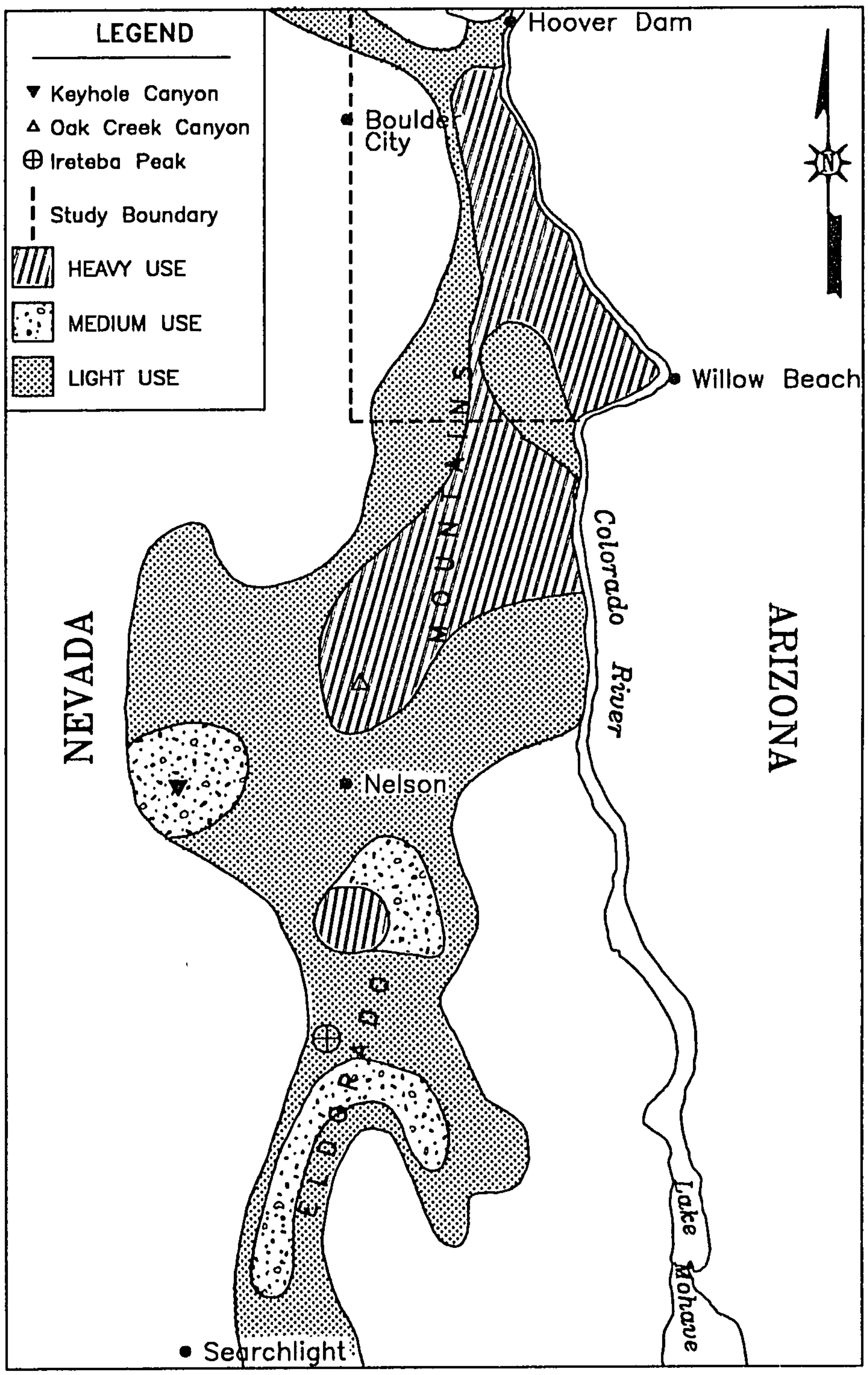

Figure 3. General distribution of bighorn sheep in the Eldorado Mountains (after Breyen 1971).

Economically, the Eldorado herd figures prominently into Nevada's hunting quotas. Between the years 1975 and 1989, 125 rams have been taken by hunters in the Eldorado Range accounting for 10.4% of the rams harvested in the state during that period (NDOW files). Since 1983, an average of 11.9 rams (range nine to 14) have been removed from the range annually.

Although the reasons may vary, bighorn sheep are considered a special and valuable resource. Proposals, such as the BCBP, that have a high potential for disrupting bighorn sheep habitat need to be evaluated carefully.

Thought to number between 1,500,000 to 2,000,000 at the beginning of the nineteenth century, fewer than 25,000 bighorn sheep remained by the mid-1900's (Buechner 1960). While some doubt exists as to the validity of the original population estimate, examination of past and present distributions of bighorn sheep clearly indicate that a large scale reduction in bighorn sheep numbers has occurred recently (McQuivey 1978, Brown 1989). While a number of factors have contributed to this rapid and sudden decline, most can be linked to the arrival and settlement of European man in western North America and his subsequent activities (Buechner 1960, Van Den Akker 1960, McQuivey 1978, Brown 1989). To halt and reverse this trend, proper management of these activities is necessary.

Construction of roads through bighorn sheep habitat has been implicated by a number of researchers as affecting bighorn sheep populations (Van Den Akker 1960, DeForge 1972, Ferrier 1974, Jorgensen 1974, Douglas 1976, McQuivey 1978, Olech 1979, Witham and Smith 1979, Miller and Smith 1985, Etchberger et al. 1989, Woods 1990, Cunningham and Hanna 1992). Indirectly, roads have allowed encroachment of such activities as livestock grazing, housing development, mining, hunting, and various outdoor recreational activities into bighorn sheep territory. Impacts from these intrusions have ranged from abandonment (DeForge et al. 1981, Blaisdell 1982, Sandoval 1988) to habituation (Hicks and Elder 1979, Hamilton 1982). Roads have directly impacted bighorn sheep populations through the destruction of critical habitat, bighorn sheep/motor vehicle collisions, and obstruction of movement corridors. While increases in indirect activities are not expected with construction of BCBP, the latter, more direct impacts are a cause of concern.

Bighorn sheep/motor vehicle collisions may be a significant cause of mortality in bighorn sheep populations. Records of highway mortalities occasionally appear in the literature to document past distribution and intermountain movements of bighorn sheep (Breyen 1971, McQuivey 1978), but comprehensive studies detailing the scope of the problem are unavailable. While only 13 road killed bighorn sheep have been reported in the Eldorado Range between 1983 and 1988 (NDOW files) it is felt that this number is a gross underestimate as numerous bighorn sheep collisions go unreported. In a report by Cunningham and Hanna (1992), 23 road killed bighorn sheep were documented in 27 months along a 5.5 km length of U.S. 93 in western Arizona. This nearly equalled the number of road mortalities documented (n = 24) on the same length of highway by the state's game and fish department in the 10 years prior to their work. Although this represented nearly a four-fold increase in the number of road killed bighorn sheep than expected from past records, the authors felt a number of road caused mortalities still went undetected despite their vigilance (S. Cunningham, Ariz. Game and Fish, pers. comm., 1992). The extent of the problem was further illuminated when Cunningham and Hanna (1992) determined that the probability of a ewe in their study area being struck and killed by a motor vehicle within a year can be as high as 27%.

A population may not be able to sustain itself under such pressure. Using population modeling on elk (Cervus elaphus) in the Bow Valley Elk Reserve (BVER) in Banff National Park, Alberta, Canada, Woods (1990) predicted a population crash from an estimated 900 animals to below 150 within 20 years given an anticipated 15% annual mortality rate due to road kills after road improvements on the Trans-Canada Highway. Holroyd (1979, in Woods 1990) suggested that moose (Alces alces) populations in the BVER might also crash without reducing the potential for road related mortalities. Woods (1990, p. 68) pointed out that "since moose populations are very small relative to elk, they would be more sensitive to rapid collapse". The same may be true with bighorn sheep populations.

While posing a potentially serious hazard to bighorn sheep as well as motorists, Reed et al. (1979) and Woods (1990) have shown that motor vehicle collisions with large ungulates can be significantly reduced by adequate fencing. If the road is fenced, the largest concern of the BCBP, will be its potential to obstruct bighorn sheep movement patterns and/or disrupt critical use areas.

It is generally accepted that bighorn sheep use different portions of their home range throughout the year. Geist (1971) categorized as many as six seasonal ranges for male Rocky Mountain bighorn sheep (Ovis canadensis canadensis) while identifying four for ewes. For desert bighorn sheep, the pattern of habitat use does not appear to be as complex, but several seasonal ranges have been identified (Leslie and Douglas 1979, Wilson et al. 1980, King and Workman 1983). In general, ewes are dispersed to the greatest extent during the cool months of winter and spring. The physiological water stresses associated with the hot summer months are absent and bighorn sheep are able to use forage in areas without freestanding water. Lambing usually takes place during this period and gravid females will move to areas of extremely precipitous terrain before giving birth. As ambient air temperatures increase, ewe movements become dictated by water availability. With the progression of hot summer months, bighorn sheep use is usually restricted to small areas adjacent to available water sources.

Mature rams typically remain spatially segregated from ewes during the majority of the year and occupy areas known as "bachelor pastures". These areas are somewhat removed from ewe habitat and generally have less topographic relief. This spatial separation may break down during the summer season as the need for water becomes critical. Depending on the number and locations of available water sources, however, rams and ewes may still remain separate. As ewes enter estrous, typically in mid to late summer, rams will join the ewe groups and begin travelling from band to band in search of receptive females. Ram movements during this period are often extensive and may include adjacent mountain ranges.

Ewes and rams show a high degree of fidelity in their use of seasonal ranges from one year to the next. Their movements between ranges follow traditional routes (Geist 1971, Festa-Bianchet 1986). Loss of any one of these areas is considered critical, as modern bighorn sheep show little exploratory behavior. As a result, compensatory movement into unfamiliar terrain does not occur as habitat is reduced (Geist 1971). With a diminished resource base, affected populations can be expected to decline.

As population size decreases, the risk of extinction increases (MacArthur and Wilson 1967). Four basic forces have been identified which contribute to this increased probability. They are: demographic stochasticity, environmental stochasticity, genetic stochasticity, and natural catastrophes (Schaffer 1981).

Demographic stochasticity concerns the random fluctuations in birth rates, death rates, sex ratios, and age structure within a population. These changes can be detrimental since they affect the number of individuals capable of breeding at any one time. With decreasing population size, even small fluctuations can have significant impacts.

Environmental stochasticity entails changes in forage quality and quantity, weather conditions, predator density, disease incidence, competitor density, and parasite abundance. These changes are, in effect, changes in the force and direction of natural selection. Fisher's (1930) fundamental theorem of natural selection states that a population's ability to respond to such selection is directly related to the amount of genetic variation within the population. As the population size is decreased, its gene pool is also reduced, resulting in a net loss of genetic variation. With small population sizes, responses to natural selection may be limited.

Genetic stochasticity involves alterations in gene frequencies as a result of genetic drift and inbreeding. Both inbreeding and genetic drift will lead to a loss of genetic variability within a population at a rate which is inversely proportional to the size of the population (Futuyma 1979). As genetic variability is lost, the degree of homozygosity in the population will increase, which in turn can result in decreased fecundity, decreased fertility, growth retardation, and/or abnormal development within the population (Allendorf and Leary 1986).

And lastly, natural catastrophes include droughts, floods, fires, severe storms and other natural disasters which occur periodically. The results of these occurrences on small populations is intuitively obvious. If the event is large enough, entire populations may be lost, regardless of any other factor.

Many of the problems small populations face can be overcome if immigration of new individuals occurs. It has been estimated that as few as one immigrant every generation is sufficient to maintain genetic variability within a population provided the migrant breeds successfully (Futuyma 1979). When gene flow is high relative to selection pressures, small populations can maintain the genetic characteristics of a population many times its number. Also, immigration can provide buffers against demographic stochasticity when immigration occurs at a rate high enough to counter high death rates and/or low birth rates. Even after a localized extinction from a natural catastrophe, migrants may successfully recolonize the impacted area, thus avoiding true extinction.

Fragmentation of habitat by roads and other mechanisms pose a two-pronged risk to extant populations. The first and most obvious is the direct loss of habitat. However, the second, more subtle effect, the increase in insularity of the remaining habitat patches, has equally serious consequences (Wilcox and Murphy 1985). Even when habitat loss is marginal, fragmentation may devastate a population if isolation becomes complete.

Obstruction of bighorn sheep movement corridors by road development has been documented in a number of studies. After reviewing past distributions of bighorn sheep populations in Nevada, McQuivey (1978) concluded that annual bighorn sheep migrations between several mountain ranges had ceased due to improvements of minor roads into major thoroughfares. Ferrier (1974) also commented on large losses of bighorn sheep habitat along the lower Colorado River in California and Arizona due to highway construction and increased traffic volumes. Krausman et al. (1989) suggested that movements of male bighorn sheep between mountain ranges may be restricted, in part, by the presence of roads and Witham and Smith (1979) and Witham et al. (1982) remark on the "artificial" isolation of the North Plomosa Mountains due to the construction of Interstate 10.

In several instances many of the direct impacts of roads on bighorn sheep populations might have been avoided with proper foresight and management. Construction of underpasses and/or overpasses in conjunction with fencing along highway corridors has proven successful in allowing continued use of seasonal ranges and/or critical use areas as well as reducing road related mortalities for elk (Woods 1990), mule deer (Odocoileus hemionus) (Reed et al. 1975, 1979, Ward et al. 1980), and mountain goats (Oreamnos americanus) (Singer and Doherty 1985). The success of such projects, however, is largely determined by prior knowledge and understanding of movement behavior and habitat utilization of the animals to be affected. Klein (1971), studying reindeer (Rangifer tarandus) in Scandinavia, noted that fences and bridges were largely ineffective at directing reindeer movements unless used in conjunction with traditional movement patterns. Miller et al. (1972) experienced similar difficulties in diverting barren-ground caribou (Rangifer tarandus groenlandicus) in north-central Canada from traditional migration routes. In another study, Ward et al. (1980) documented a reluctance in elk to use underpasses or bridge structures located near streams. They hypothesized that elk preferred to cross streams perpendicularly rather than travel parallel to them. In the same study, pronghorn antelope (Antilocapra americana) were rarely observed using underpasses despite the presence of several of these structures in areas of high antelope concentrations. As such, fencing along highway right-of-ways acted as an absolute barrier to antelope movement. It was undetermined if the reluctance of antelope to use the underpass structures was due to site-specific characteristics, underpass design, or an inherent behavioral trait of the species. These same underpasses were heavily utilized by mule deer and livestock.

Limited research (e.g. distribution and population estimates) has been conducted on the Eldorado Mountain herd. Information on movement corridors and habitat use patterns that are essential for planning and evaluating the proposed road alignments is currently not available. My objectives were to obtain pertinent data to avoid or mitigate possible impacts to the local bighorn sheep population.

By using movements of radio-collared bighorn sheep along with incidental observations of uncollared animals, I can test for the importance of various habitat factors on ewe and ram distributions as well as determine if seasonal variations in habitat selection patterns occur. The major factors hypothesized to influence bighorn sheep distributions are: aspect, slope, elevation, land surface ruggedness, distance from water, and distance from escape terrain. If strong correlations exist between one or more of these habitat factors and bighorn sheep distributions, the various road alternatives can be compared based on their impacts to those factors identified as important.

Movement patterns of radio-collared bighorn sheep will also be used to test if seasonal migrations within the Eldorado Mountains are occurring. Such movements are hypothesized as needs for water, shelter, and forage change for bighorn sheep throughout the year. If long-range movements are occurring, I would expect low levels of overlap between one or more seasonal home range areas and/or large distances separating seasonal centers of activity for a majority of radio-collared bighorn sheep. Any movement corridors identified will be assessed for possible disruption caused by the proposed highway alignments. If possible, habitat characteristics defining movement corridors will be identified.

As part of the study, I will test the effectiveness of the Cunningham (1989) habitat evaluation model to accurately predict bighorn sheep distribution patterns in the northern Eldorado Mountains. If a high correlation between the model's habitat quality ratings and actual bighorn sheep distribution patterns is observed, I will then use the model to predict changes in habitat quality ratings that result from the construction of each of the alternative highway alignments. Potential loss of habitat or changes in habitat quality ratings can then be compared between highway alignments.

The impacts of U.S. 93 on bighorn sheep distributions can also be tested. If bighorn sheep react adversely to heavily travelled roads, we can expect bighorn sheep use to be lower than expected based on the amount of available habitat adjacent to the highway and to increase with increasing distance from the highway. Given the close proximity of U.S. 93 to each of the three proposed highway alignments, reactions of bighorn sheep to the existing highway should provide an excellent predictor of bighorn sheep behavior following new road construction.

STUDY AREA

Location

The Eldorado Mountains are located in Clark County in southern Nevada (Fig. 1). They are bordered to the northwest by the River Mountains, to the west by the McCullough Range, and to the south by the Newberry Mountains. To the east, the Eldorado Mountains parallel the Colorado River and form its western bank. Promontory Point, which forms the northernmost extension of the Eldorado Mountains, juts out approximately two km into Lake Mead north of Hoover Dam. The range stretches approximately 60 km, from north to south, and covers nearly 930 km^2 (Breyen 1971). Although Longwell et al. (1965) considered the Eldorado Mountains to be one topographic unit, the range is commonly divided into two sections, the North and the South Eldorados, near Nelson, NV. The South Eldorados are also known as the Opal Mountains (Longwell et al. 1965). Separating the Eldorados from the surrounding ranges are three highways, U.S. 93 to the north, U.S. 95 to the west, and State Highway 68 to the south.

The primary study area lies within the northern portion of the North Eldorados (Fig. 2). Its boundaries extend from the Colorado River to the western edge of the range and from Promontory Point to Burro Wash, located approximately 21 km downriver. The width of the range varies along this length from approximately one km at Promontory Point to nine km near Willow Beach, AZ. The area encompasses roughly 12,000 ha. Large portions of the study area are located within the Hoover Dam Reservation, administered by the Bureau of Reclamation, and LMNRA. *Several sections of the study area also fall within the Boulder City Municipal Area which* abuts the northwestern portion of the range.

Topography

The topography of the North Eldorados is discussed in detail by Breyen (1971), while Longwell et al. (1965) provides a description of the geology of the area. The North Eldorados consist mostly of Tertiary volcanic rocks with some Pre Cambrian metamorphic rocks in limited areas. Soils in the study area are sparse and not well developed. Elevations vary from 197 m along the Colorado River to 973 m among the rolling hills southeast of Boulder City.

The area can be thought of as being divided into two sections by a series of north-south running bluffs which begin in an area east of Boulder City and extend south a distance of 24 km. The topography to the west of the bluffs consists mostly of rolling hills and wide gentle washes. Cliffs and other topographic features that comprise escape terrain are essentially lacking in the area. These hills gradually dissipate into the flat desert of the Eldorado Valley as one moves westward. To the east, the terrain is vastly different. Ending abruptly, the bluffs drop off precipitously, often over 200 m, into an area of maze-like ridges and narrow, steep-sided washes. This rigorous terrain continues for one to eight km until it terminates at the edge of Black Canyon. Here, again, the terrain drops off steeply to the banks of the Colorado River. Escape terrain is abundant throughout the eastern section and can be thought of as forming a nearly continuous band from Promontory Point to Burro Wash.

An anomalous east-west running ridge, extending 3.5 km west from the north-south bluffs, is located at the northwestern edge of the range. To the north, this ridge is cut by several drainages that empty into Hemenway Wash. The southern exposure, however, has less topographic relief and surface irregularities. While ewes are occasionally sighted along this ridge, extensive use by male bighorn sheep has been documented. Located almost exclusively within the Boulder City Municipal Area, this ridge forms the closest extension of the Eldorado Range to the River Mountains (1.5 km). Several housing developments, however, separate the two.

Vegetation

Three vegetational communities have been identified within the confines of the study area: creosotebush - bursage scrub, desert wash, and stream riparian. Detailed descriptions of these communities are provided by Bradley and Deacon (1965). The vast majority of the vegetation found within the study area is comprised of the creosotebush - bursage scrub community. Bursage (Ambrosia dumosa) and creosotebush (Larrea tridentata) are codominants in this association with Krameria parvifolia (little-leaved ratany), Sphaeralcea ambigua (desert-mallow), Ephedra nevadensis (Mormon tea), and Encelia farinosa (brittlebush) also common.

The desert wash community is also prevalent in the area, being found along many of the drainages that dissect the area. While sharing many of the same species with the creosotebush - bursage community, additional species such as Hymenoclea salsola (cheesebush), Gutierrezia spp. (snakeweed), Bebbia juncea (sweet bush), and Acacia greggii (catclaw) are also found. This greater diversity may be due, in part, to the greater availability of water usually found within drainages.

The stream riparian community is extremely limited in its distribution. It is found primarily along the river where sandbars have accumulated and at the mouths of some side canyons. While not quantified, it is believed to make up less than 1% of the available vegetation. Dense thickets of Tamarix ramosissima (saltcedar) dominate many of these areas.

Water

Water is not thought to be a limiting resource for bighorn sheep in the northern portion of the Eldorado Mountains (McQuivey 1976). The range abuts both the Colorado River and several kilometers of Lake Mead shoreline providing numerous points of access. Of the approximate 12,000 ha within the study area, over 7,000 ha are within 3.2 km of these two water sources. The 3.2 km distance is considered critical as few desert bighorn sheep are found greater than this away from water during the hot summer months (Leslie and Douglas 1979). The average distance bighorn sheep move from water in the cooler months is 9.7 km (Hansen 1972). Virtually all of the mountainous terrain located north of Burro Wash is found within this zone.

Other permanent water sources known to occur within the study area include four hot springs, each producing small running streams, and several artificial water sources. Figure 4 shows the locations of all known permanent water sources.

In addition to the permanent sources, countless catchments or tinajas are scattered throughout the study site providing an inestimable number of ephemeral water sources.

Climate

Precipitation and temperature patterns recorded at the NPS Ranger Station at Boulder Beach, NV (elev. 507 m) have been reported as being nearly identical to those in the northern portion of the Eldorado Mountains (Breyen 1971). Precipitation patterns in the area are typical of those in southern Nevada with long periods of drought interspersed with localized, often heavy, rainfalls. Rain patterns are highly variable from year to year, but the majority of precipitation occurs between the months of July and March (Fig. 5.). Annual precipitation at the ranger station for 1990 and 1991 was 10.26 cm and 18.34 cm, respectively.

Showing a more stable pattern are annual temperature regimes (Fig. 6). The area experiences a brief winter season, where daily minimum temperatures seldom drop below 0 ^{o}C, but this quickly gives way to a prolonged, hot summer season. Air temperatures exceeding 38 ^{o}C may occur as early as late April and can last well into the first or second week of October. At the Boulder Beach Ranger Station, NV, winter (December to February) minima and summer (June to August) maxima averaged 2.1 ^{o}C and 40.3 ^{o}C , respectively, for 1990 and 1991.

Human Impacts

A variety of human activities occur throughout the study area. U.S. 93 traverses the extreme northern portion of the range separating Promontory Point from the remainder of the Eldorado Mountains. Several pullouts, parking lots, scenic overlooks, and dam-related structures occur along this corridor in addition to a major hotel/casino complex. Paved and dirt roads

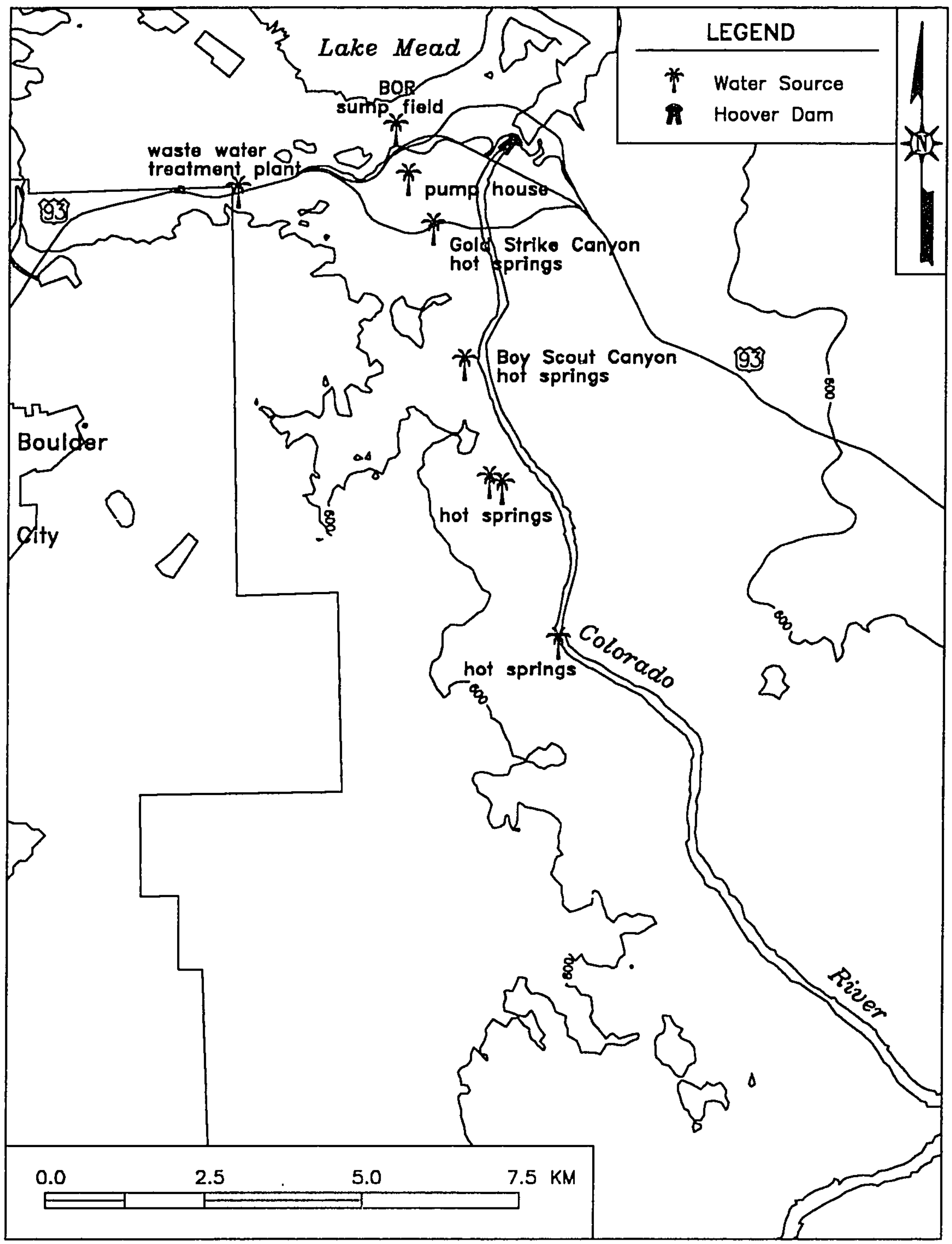

Figure 4. Locations of known permanent water sources in primary study area.

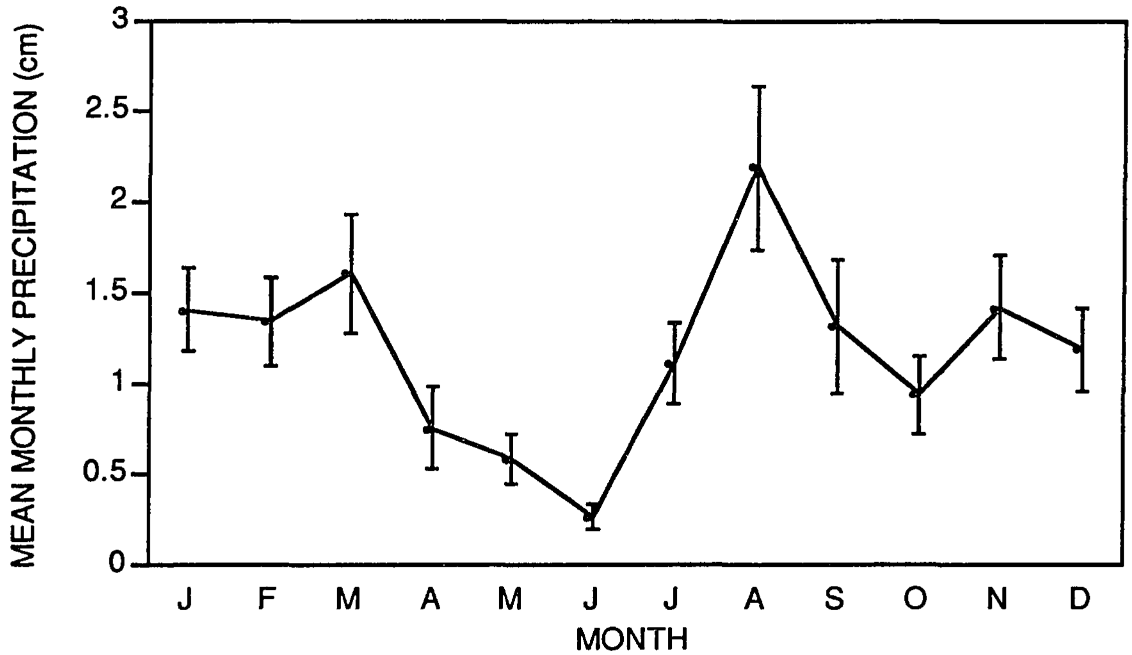

Figure 5. Mean monthly precipitation (cm) and standard error bars for the northern Eldorado Mountains, Nevada, for 1954-1989.

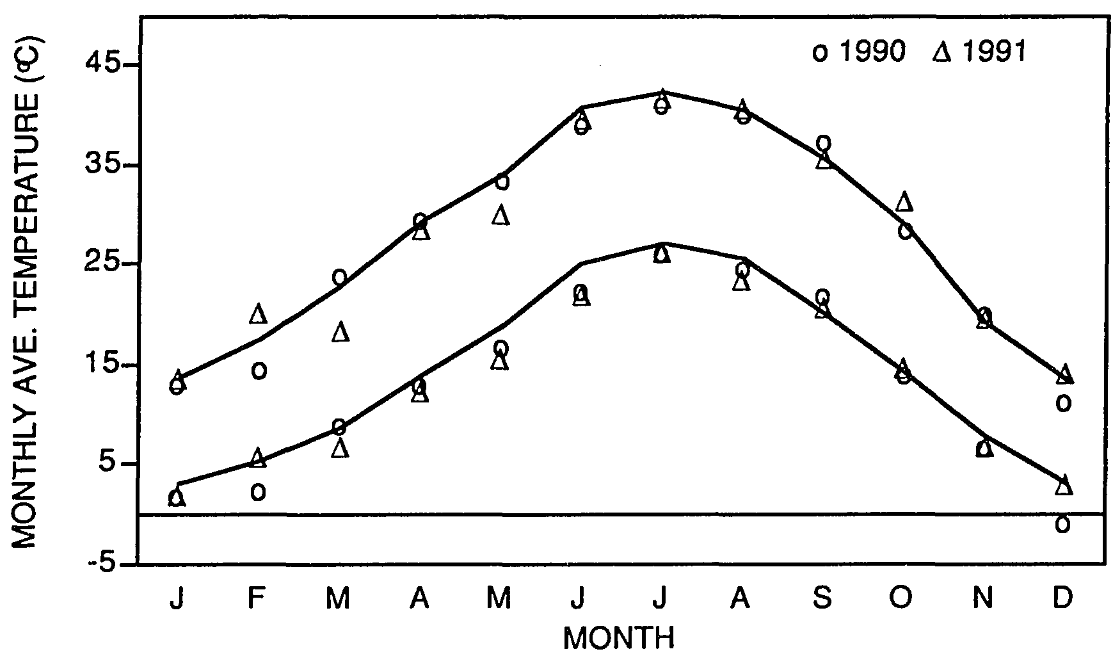

Figure 6. Mean monthly high and low temperatures (°C) for the northern Eldorado Mountains, Nevada, for 1990 and 1991 compared to the average monthly high and low temperatures for the 5 previous years (1985-1989).

crisscross the area to service the dam and the numerous electrical transmission lines emanating from the area. Many of these service roads are open to the public and provide easy access to the periphery of the range. In addition to the service roads, many off-road vehicle and motocross trails dissect the area and receive regular use. While off-road travel is restricted within LMNRA, evidence of its occurrence is frequently encountered within the study area. Several washes leading to the interior of the range are frequently used by hikers and occasionally by horseback riders for day hikes and overnight trips. Those leading to the hot springs in Boy Scout and Gold Strike Canyons receive heavy use. Along the Colorado River, many side canyons and sandbars are used as popular picnic spots and overnight camping areas by boaters and canoeists. Hunting is permitted within the borders of LMNRA and poaching occasionally occurs (Bob McKeever, NPS, pers. comm., 1989).

Although mining is not currently occurring within the study area, signs of past operations are numerous. With the establishment of the Eldorado Canyon mining district near Nelson, NV, in 1857, the Eldorado Mountains became one of the first ranges in Nevada to be extensively mined (Longwell et al. 1965). Activity occurred throughout much of the range until the late 1930's (Breyen 1971). Mining in the area may also have occurred, by Mexicans or Spaniards, prior to modern records (Vanderburg 1937 in Breyen 1971).

Proposed Highway Alignments

The Bureau of Reclamation has proposed three alternative river crossings to reduce traffic congestion on Hoover Dam. Each proposed alignment leaves U.S. 93 east of Gold Strike Casino approximately 4.7 km from Hoover Dam. The Gold Strike Canyon alignment (GSA) enters Gold Strike Canyon at this point and follows the canyon's contours for much of its 3.6 km distance (Figs. 2,7). As the canyon continues to deepen, the alignment leaves the canyon and moves to the top of the north canyon wall. Traversing the remaining distance to the river, GSA crosses the Black Canyon gorge approximately 1.6 km down river from the dam.

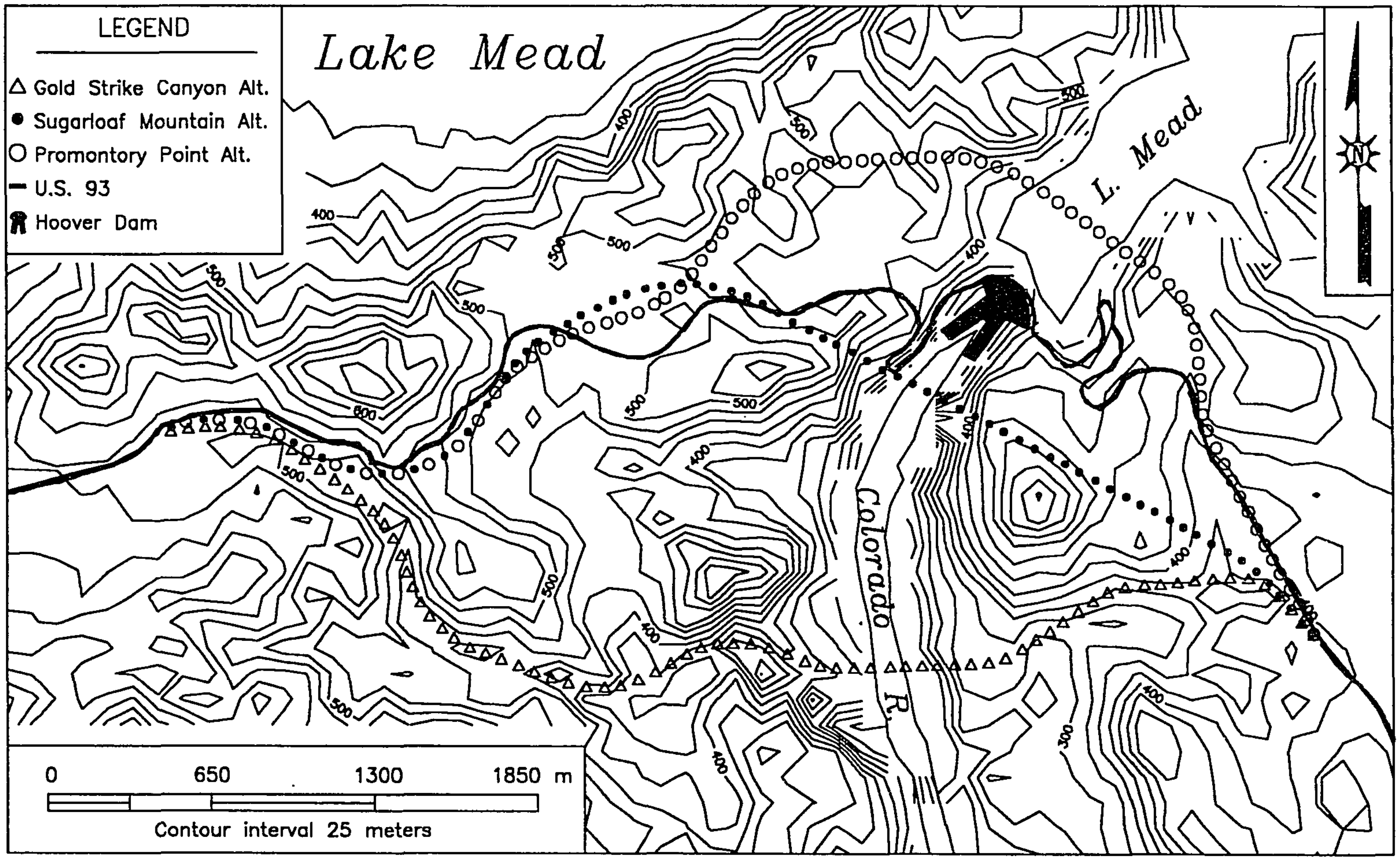

Figure 7. Location of proposed highway alignments.

The Sugarloaf Mountain alignment (SLA) closely parallels existing U.S. 93 for much of its distance (Figs. 2,7). After leaving U.S. 93, SLA travels to the south of the highway seldom greater than 100 m distant from the existing highway. After 2.3 km, SLA crosses U.S. 93, where the BOR warehouse complex is presently located, and begins a gentle curve to the southeast. It again crosses U.S. 93, approximately 1.4 km from Hoover Dam, before reaching its bridging structure. The Sugarloaf alignment would cross the Colorado River approximately 0.6 km south of the dam. Total distance of the alignment in Nevada equals 3.6 km.

The third proposed alternative, the Promontory Point alignment (PPA), shares much of the same right of way as SLA (Figs. 2,7). Leaving U.S. 93, PPA follows SLA for 2.2 km. As SLA passes the BOR warehouse complex and begins its turn toward the river, PPA swings to the northeast and sets itself on a course to cross Black Canyon 0.25 km north of the dam across a narrow section of Lake Mead. The PPA would require construction of 4.3 km of approach road within Nevada.

Access to the dam by visitors and service personnel would still be by the existing highway. An interchange would be constructed at the point of departure for GSA allowing for access to the old highway. For PPA and SLA, the interchange would occur at the site of the existing BOR warehouse complex. The bypassed section of U.S. 93 would remain intact.

METHODS

Bighorn Sheep Capture

Bighorn sheep were captured in two operations. The first occurred during the week of 27 September 1989 to 2 October 1989, when 19 ewes and 14 rams were fitted with radio collars equipped with mortality sensors (Telonics, Inc., Mesa, Ariz.) and released. An additional six ewes and six rams were captured and equipped with collars on 8 - 9 May 1990. All bighorn sheep were captured by use of a hand-held net gun (Coda Enterprises, Mesa, Ariz.) fired from a Bell Jet Ranger helicopter (deVos et al. 1984). Age estimates were determined by counting horn rings (Geist 1966). All bighorn sheep captures occurred within 10 km of Hoover Dam in the primary study area (Fig. 2).

Locating Bighorn Sheep

Relocation flights began on 17 October 1989. Flights, using the National Park Service's Cessna 206, were scheduled once every seven days, but ranged from one to 21 days due to inclement weather or aircraft availability. Flight starting times were rotated between morning and afternoon hours and flight patterns were varied to randomize observations. The aircraft was equipped with a removable, belly-mounted, modified-H type antenna as described by LeCount and Carrel (1980). A programmable scanner was used for monitoring. Both scanner and antenna were manufactured by Telonics, Inc. Due to the inaccessibility of much of the study area, visual sightings from the air were highly desirable and extra effort was directed at achieving this goal. Non-visual point locations were obtained by circling an animal's position until signal strength was equal along the circle's circumference. The center of the circle was then plotted as the animal's location (Kenward 1987). By placing surplus collars within the study area, I determined non-visual point locations to have a mean error of 67.5 m (s.d. = 29.0 m, n = 4). Information on date, time, temperature, location, number of bighorn sheep present, collared bighorn sheep present, and, when possible, group composition (i.e. ram only, ewe-juvenile group, or mixed group) were recorded and maintained on separate records for each observation. Collared rams aged at 3+ years and class III uncollared rams (Geist 1971) were classified as adults. Bighorn sheep locations were plotted on U.S.G.S. 1:24000 scale 7.5 minute series maps and recorded as Universal Transverse Mercator (UTM) grid coordinates. Groups of bighorn sheep greater than or equal to 100 m distant from each other were recorded as separate observations. To minimize disturbance to bighorn sheep, flights were flown at altitudes 100 m or more above ground (Krausman and Hervert 1983, Miller and Smith 1985).

Ground surveys, using a hand-held, modified-H antenna and programmable receiver, were conducted weekly to supplement aerial relocation data. Because of location errors associated with radio triangulation (Heezen and Tester 1967, Springer 1979, Lee et al. 1985, Saltz and Alkon 1985) only visual observations were recorded. In addition to information collected during aerial surveys, sex and age of uncollared bighorn sheep were classified according to Geist (1971). Observations were made with 8 x 32 binoculars or a Celestron C90 spotting scope with an 18 mm ocular.

Successive observations of radio-collared bighorn sheep were separated by a minimum of 24 hours to reduce autocorrelation between observations (i.e. to obtain independent sample data). Swihart and Slade (1985a, b) discussed the importance of obtaining independent sample data for use in statistical measures of home-range size. Independence of observations is also a critical assumption in many statistical tests including chi-squared tests of independence, t-tests, and ANOVA's (Neter et al. 1990). To ensure that an animal's position at time $t + k$ is not a function of its position at time t, k must be long enough that an animal is able to traverse its home range in the specified time interval (Swihart and Slade 1985a). Given adequate time, then, the probability of observing an animal in any portion of its home range will be equal. To determine this time interval or time to independence (TTI), Swihart et al. (1988) indicated that a size-dependent time scale exists for terrestrial mammals, in conjunction with foraging mode, that governs the rate of space use. For noncentral place foragers such as bighorn sheep, the authors determined that TTI $= 354M^{0.22}$, where M is the animal's mass in kilograms and TTI is measured in minutes. Using this formula and 90.7 kg as the weight of a large ram (Hansen and Demming 1980, Remington 1982), I calculated a minimum of 954 minutes or 15.9 hours as the time interval necessary to eliminate autocorrelation between successive observations. To be conservative, I increased this time interval to 24 hours. This time period appears to be adequate to assure independence as even lambs of the year have been observed to travel 30 km or more within this time period (Elenowitz 1982).

Habitat Evaluation

Geographic Information System

A raster based, PC operated, computer software package entitled Professional Map Analysis Package (pMAP) (SIS 1986) was used for all geographic information system (GIS) analyses. U.S.G.S. 1:24000 scale 7.5 minute series maps were obtained for the study area and gridded along UTM grid lines into one hectare cells (100 m x 100 m). The one ha cell size was chosen as I felt it was small enough to provide adequate resolution for suitable habitat evaluation yet large enough to allow a sufficient margin of error while plotting bighorn sheep locations. A base elevation map was entered into the GIS program by estimating the elevation of each cell's mid-point to the nearest 1.5 m. Percent slope and aspect of each cell were calculated from the elevation map by the software program. Percent slope was calculated as the maximum slope value between the center cell and each of its eight neighbors. Aspect was determined by the orientation, in azimuths, of the maximum slope. Additional base maps consisting of existing roads and trails, housing developments and other man-made structures, and permanent water sources were digitized from U.S.G.S. 1:24000 scale 7.5 minute series maps and entered into the system. Maps of the proposed highway alignments were digitized from engineering drawings supplied by the U.S. Bureau of Reclamation (Colorado River Bridge - Hoover Dam. Phase B - Corridor Studies. U.S. Bureau of Reclamation. rev. Dec. 1991).

Habitat Use

Locations for each group of bighorn sheep observed were digitized and entered into the GIS program. For each observation, slope (0-20, 21-40, 41-60, 61-80, or ≥ 81%) and aspect (N, E, S, W, or level, ≤ 10% slope) were obtained along with distance from permanent water (±100 m) and elevation (200-300, 301-400, 401-500, 501-600, 601-700, or ≥ 701 m). A land surface ruggedness index (LSRI) (0-150, 151-300, 301-450, 451-600, 601-750, or ≥ 751) was determined by summing slope values of the observation cell with those of its eight neighbors. This provided a measure of the topographic relief or "ruggedness" of the immediate area similar to that described by Beasom et al. (1983), but compatible with a GIS system (see appendix A). Distances (0, 1-100, 101-200, 201-300, 301-500, 501-700, 701-900, or ≥ 901 m) from observed locations to escape terrain were also obtained through GIS analysis. Escape terrain was defined as areas with ≥ 60% slopes (Dunn 1991, Cunningham and Hanna 1992).

Chi-squared goodness of fit tests were performed to test the null hypothesis that bighorn sheep used habitat in direct proportion to its availability for slope, aspect, elevation, distance to escape terrain, and LSRI (Neu et al. 1974). If significance was detected ($P \leq 0.05$), 95% confidence intervals for the difference between two proportions, adjusted for simultaneous inference (significance level = $a/2k$, k = no. of components), were constructed to determine which components were selected, avoided, or used in proportion to their availability (McClave and Dietrich 1988). This technique was used by Krausman et al. (1989) for bighorn sheep and Ordway and Krausman (1986) for mule deer instead of the more widely used method of Neu et al. (1974), which does not permit calculation of a simultaneous Bonferroni confidence interval when percentage use within a category is zero. Chi-squared tests for independence were used to test for differences in use between seasons and between seasons over years (Zar 1974). Seasons analyzed were: winter (December to February), spring (March to May), summer (June to August), and fall (September to November). Separate analyses were performed for each sex. The sequential Bonferroni test was used in these and all other analyses to control the group-wide type-I error rates (Rice 1988).

Porter and Church (1987) pointed out the potential effects of constructing arbitrary study boundaries in habitat use/availability studies. Accurate assessment of available habitat is necessary to avoid spurious results. By calculating the distance between successive observations by sex for each collared bighorn sheep over the course of the study I obtained data that allowed me to estimate a probability radius in which a bighorn sheep would likely be found given its previous location. The distance that contained 75% of all recorded movements (i.e. the 75th percentile) was chosen as an accurate representation of potential movement. Calculation of available habitat, then, was done by plotting the locations of all observations separately by sex and drawing this radius around each point. Amounts of the various habitat components contained within this area were then determined by GIS analysis.

A single-factor ANOVA was used to determine if mean distance from water varied between seasons (Zar 1974). If mean distance was found to be unequal ($P \leq 0.05$), the Games-Howell multiple comparison procedure (Games and Howell 1976 in Abacus Concepts 1989) was used to evaluate which pair(s) of means are significantly different. Unpaired t-tests were used to compare seasonal means between sexes (Zar 1974). A 0.05 significance level was used in all tests.

Habitat Evaluation Model

The primary study area was evaluated for bighorn sheep suitability by a rating system developed by Cunningham (1989). The system evaluates five basic habitat components which are judged to be critical to bighorn sheep ecology. They are: natural topography, vegetation type, precipitation, water availability (type and use), and human use. Each habitat component is subdivided into various categories with scores assigned based on the category's potential value to desert bighorn sheep and its distance from various other habitat components. Scores for natural topography, vegetation type, and human use range in value from 0 to 20 points. For precipitation, scores range from one to five points. Values for the water component range from -8 to 20 points. For a detailed breakdown of each category score within the different habitat components see Cunningham (1989). Summing for all five components, a maximum score of 85 is possible for any one area . Based on its cumulative score, an area is then classified as either poor, fair, good, or excellent quality habitat. The four categories of predicted bighorn sheep use are defined as follows:

Total score	Classification
45 or less	Poor quality
46 - 60	Fair quality
61 - 73	Good quality
74 - 85	Excellent quality

Scores for the evaluation of potential bighorn sheep habitat were modified from those initially proposed by Cunningham (1989). Following suggestions by S. Cunningham (Ariz. Game and Fish Dept., pers. comm., 1992), scores were lowered from those initially proposed to more accurately depict habitat conditions within the Eldorado Mountains. Similar scores were used by Cunningham and Hanna (1992) in their evaluation of the Black Mountains, Arizona, an area directly across the Colorado River from the Eldorado Mountains.

Initially designed to evaluate four km^2 blocks of terrain, modifications to the Cunningham habitat evaluation model (1989) were made to use the one ha cell resolution used in the GIS analysis. For the model's precipitation, vegetation, and water components, no major modifications were needed. Scores for these components were assigned based on Cunningham's (1989) criteria. However, scores were assigned to one ha cell areas as opposed to four km^2 blocks. Changes to the human use and natural topography components were more extensive and are discussed below.

In Cunningham's initial model, the impact of a man-made structure or human activity influences the value of an entire four km^2 block. In many instances, this greatly exaggerates the actual effect of the structure, activity, etc. on the local bighorn sheep population. To give an example, in Cunningham's system, a section of habitat that contained a heavily travelled highway would receive a human use score of 0 out of a possible 20 points regardless of the length or location of the highway within the habitat block. In so doing, the best possible rating for this section of habitat would be fair quality despite the possible favorable conditions of other habitat components. By analyzing the habitat in smaller sections, a more realistic zone of influence may be achieved.

To modify Cunningham's human use component, I first evaluated each man-made structure or activity in my study area and categorized it as either high density human use and/or economic potential, medium density human use and/or economic potential, or low density human use and/or economic potential following criteria supplied by Cunningham (1989). I then determined if the structure or activity precluded bighorn sheep use of the area by destruction of habitat and/or construction of barriers (e.g. paved parking lot, building structure, paved roadway, fenced exclosure). Scores were then assigned as follows:

0	High, medium, or low density human use and/or economic value Habitat unavailable.
4	High density human use and/or economic value. Habitat available.
7	Medium density human use and/or economic value. Habitat available.
10	Low density human use and/or economic value. Habitat available.

The values selected followed Cunningham's (1989) numeric values and increments to indicate increased value for bighorn sheep.

Increasing scores were then assigned to the surrounding cells to reflect the diminishing influence of the human disturbance with increased distance from it. Scores were assigned to the buffering cells as follows:

Human use designation	Score Distance from human disturbance 100 m	200 m	300 m	400 m
High density human use and/or economic potential	7	10	15	20
Med. density human use and/or economic potential	10	15	20	20
Low density human use and/or economic potential	15	20	20	20

Again, the values selected followed Cunningham's (1989) numeric values and increments to indicate increased value for bighorn sheep. Where zones of influence overlapped, the score associated with the greater disturbance was assigned.

The other significant modification to Cunningham's method involved analysis of the natural topography component. Delineation of different topographic categories was done by use of LSRI values as opposed to subjective outlines (see appendix A). Cells with LSRI values of 0 to 150 were designated as level to slightly undulating surfaces. Values of 151 to 300 were classified as rolling hills while LSRI values > 300 were considered steep areas. Cells with LSRI values > 450 were further classified as steep terrain interspersed with cliffs and ledges. Boundary values for the different topography categories were based on land surface ruggedness index value selection patterns for adult male bighorn sheep, female bighorn sheep without lambs, and female bighorn sheep with lambs.

Home Range

The general definition of home range was given by Burt (1943) as the area used by an individual in its normal activities of foraging, mating and caring for its young. Krausman (1985) expanded this definition to include areas used by an individual for resting and avoiding predators. Burger (1985) reviewed many of the common methods used in describing an individual's home range and analyzed their utility for bighorn sheep studies. For the purposes of this study, home ranges were calculated as minimum convex polygons (MCP) (Mohr 1947). It is recognized that this method is strongly affected by outliers and has a sample size bias. To its advantage, however, is it is easily calculated and interpreted, its only assumption is that an animal's distribution is convex, and it has been widely used in other bighorn sheep studies (Leslie and Douglas 1979, Elenowitz 1984, Ough and deVos 1984, Krausman 1985, Sanchez et al. 1988, Krausman et al. 1989, Scott et al. 1990, Cunningham and Hanna 1992). Home range area was obtained by the computer program HOME RANGE (Ackerman et al. 1989). Home ranges were adjusted, when appropriate, by removing any portion of Lake Mead enclosed within the polygon and/or any areas located across the Colorado River which acted as an absolute barrier to bighorn sheep movements. These areas were considered "voids" as they were inaccessible to the Eldorado bighorn sheep herd and termed "null habitats" following Krausman et al. (1989). Area of the adjusted home range was determined by the GIS program by summing the area of cells within the interior of the polygon with 1/2 the area of the perimeter cells. Accuracy of this technique was examined by comparing the areas of 211 polygons calculated by the HOME RANGE program with those determined by the GIS method. While statistically significant ($t = -6.81$, 210 df, $P \leq 0.0001$), the GIS method produced only marginally larger measures of area than those of the HOME RANGE program (mean difference = 1.5 ha, s.e. = 0.22 ha). As the area of the polygons ranged from 35.6 to 4835.3 ha, this difference was regarded as inconsequential. In addition to total home range, seasonal home ranges were calculated for each bighorn sheep with nine or more observations within a season. A repeated measures ANOVA with two within-subject factors (year and season) and one between-subjects factor (gender) was performed to analyze the effects of year, season, and sex on home range sizes. A multivariate approach was used for solving the general linear model. As a consequence, bighorn sheep with incomplete data sets (i.e. bighorn sheep that did not have eight seasons of home range data) were excluded from the analysis. If the null hypothesis of equality was rejected ($P \leq 0.05$), contrasts, defined prior to conducting the analysis, were constructed to determine the nature of the inequalities within each sex for each season and year combination. An unpaired t-test was used to compare total home range between sexes as the multivariate approach did not permit the construction of contrasts which contained an interaction between a within and a between subjects factor (Zar 1974). A 0.05

significance level was used to test for significance. Tests for differences in seasonal home range size between sexes were not performed.

Harmonic mean core areas (Dixon and Chapman 1980, as modified by Ackerman et al. 1989) were also computed using the HOME RANGE program for bighorn sheep collared greater than or equal to one year. This was done to supplement information gained from the MCP's by delineating "central areas of consistent or intense use" (Kaufmann 1962 in Ackerman et al. 1989). Ackerman et al. (1989) discuss the influence of scale (units/inch) and grid density selection on harmonic mean home range and core area estimates and provided formulae for optimizing their selection. While the authors suggest selecting a convenient scale to determine the grid density for each animal, I took the opposite approach by setting the number of grid points on the x and y axes to the maximum values allowed by the program (x = 72, y = 32) and obtained individual scale settings for each animal. The principal advantage of using a convenient scale is for plotting home range boundaries, which can be easily overlaid on reference maps or aerial photographs of similar scale. The disadvantage of this method however is that one scale may not be adequate to cover the range of distributions of the study group and that different grid densities are usually obtained for different animals. These different grid densities can then result in different levels of resolution for harmonic mean home range or core area boundaries. By using a constant grid density, each harmonic mean core area boundary will have the same level of resolution. I then manipulated the plot data provided by HOME RANGE for use with computer program SURFER (Golden Software, Golden, CO) for georeferencing. Harmonic mean core areas were adjusted, when appropriate, similar to adjusted MCP's. An unpaired t-test was performed to test for differences in harmonic mean core areas between sexes.

Seasonal, yearly, and overall activity centers were determined for each animal. The center of activity was defined as the harmonic mean center (Dixon and Chapman 1980).

Affects of Highway 93 on Bighorn Sheep Distribution

The distribution of female bighorn sheep observations were examined to determine the influence of U.S. 93 on bighorn sheep use of adjacent habitat. An approach was adapted similar to that used by Perry and Overly (1977) and Rost and Bailey (1979) in their studies on mule deer and elk. For their analyses, they compared the density of fecal-pellet groups along transects running perpendicular to roads and distance from roads. They concluded road avoidance when pellet-group densities increased with increasing distance from roads. Critical to their conclusion was the assumption pellet-group density was directly related to animal use levels. In my study, I examined the distribution of female bighorn sheep in relation to suitable habitat adjacent to U.S. 93. Suitable habitat was defined as areas rated as good or excellent quality by the modified Cunningham habitat evaluation model. In order to test the null hypothesis that U.S. 93 did not affect bighorn ewe distributions, I evaluated the habitat as if the highway did not exist. To simulate pristine conditions, all cells were assigned the maximum score of 20 in the Human Use component. The number of observations within 100 m of the highway was then determined along with the amount of suitable habitat within that zone. This was repeated for each 100 m zone up to a distance of 1.6 km from U.S. 93. A chi-squared goodness of fit test was then performed to test whether or not the number of observations within a zone occurred in direct proportion to that zone's available habitat (Neu et al. 1974). If significance was detected ($P \leq 0.05$), 95% confidence intervals for the difference between two proportions, adjusted for simultaneous inference, were constructed to determine which zones were selected, avoided, or used in proportion to their availability (McClave and Dietrich 1988). The analysis was performed separately for each year of the study. For purposes of the analysis, I assumed that areas rated good or excellent quality by the modified Cunningham method realistically depicted ideal bighorn sheep habitat, that the vast majority of female bighorn sheep movements occurred within these areas, and that ewe distribution is random within suitable habitat. The analysis did not include male bighorn sheep locations as areas occupied by rams were separated from U.S. 93 by unsuitable habitat.

The effect of U.S. 93 on lamb distribution was also examined by measuring distances (±100 m) from lamb observations to the highway during the spring season (March to May). The minimum distance measured during this time was then assumed to be the minimum buffer necessary to maintain lambing ground integrity.

Distribution and Movements of Bighorn Sheep along Proposed Alignments

Use of habitat adjacent to each alignment was determined by two methods. The first involved counting the number of observations of bighorn sheep within 0.5 km and 1.0 km of each alignment. A chi-squared goodness of fit test was then performed to test the null hypothesis that observed bighorn sheep use adjacent to the proposed alignments was equal between alignments. Expected number of bighorn sheep observations within each zone examined was weighted by the amount of suitable habitat within that zone. Partitioning of the overall chi-squared analysis into component chi-squared analyses was performed if the null hypothesis was rejected ($P \leq 0.05$) (Zar 1974). Analyses were performed separately for each sex.

The second method consisted of constructing a relative use map which depicted areas of high, high-moderate, low-moderate, low, and no bighorn sheep use. Using the GIS program, a map was generated that showed the total number of bighorn sheep observations that occurred within each cell over the course of the study. A second map was then generated from the first that totalled the number of observations within 0.5 km of each cell. Cells with no observations within that radius were designated as no use zones. The remaining cells were divided into their respective use categories by use of quartiles. The upper and lower quartiles were designated high and low use zones, respectively, while the interquartile range was divided into high-moderate and low-moderate use zones by the median. The amount of overlap between each proposed alignment and relative use zone was then determined and compared between alignments.

Bighorn sheep movements across the proposed right of ways were documented by direct observations and by use of relocation data on radio-collared animals. To delineate specific movement corridors, bighorn sheep observed within 0.5 km of any alignment during ground surveys were monitored for one hour or more. Movement routes were plotted on U.S.G.S. 1:24000 scale 7.5 minute series maps. Movements across the alignments observed during aerial surveys were also recorded.

To assess differences in the number of crossings between alignments, a chi-squared goodness of fit test was performed to test the null hypothesis that each alignment was crossed an equal number of times. To eliminate observer's bias due to differences in accessibility of the different alignments, only the number of crossings determined by relocation data were used. Number of crossings for each alignment was calculated by connecting successive relocations with a straight line. If the line intercepted a proposed alignment it was counted as a crossing. As each alignment traversed nearly the entire width of suitable habitat, it was assumed that movements through the area occurred across the alignment and not at its distal end. Chi-squared goodness of fit tests were also conducted to determine if rams and ewes crossed each alignment in equal amounts and if number of crossings were equal for each season of the year for each sex. A significance level of 0.05 was used in all tests.

RESULTS

Relocations and Home Range

A total of 45 desert bighorn sheep (20 males and 25 females) were captured and collared in two capture operations (Table 1). Although relocation surveys began in the latter part of October 1989, the first full season of study did not begin until 1 December 1989. Data collected prior to that date were not used in any analyses.

Between 1 December 1989 and 30 November 1991, 105 aerial and 81 ground surveys were conducted for a total of 896 field hours. During that time, my field assistants and I observed 2,909 groups of bighorn sheep involving 3,625 relocations of radio-collared bighorn sheep and 275 observations of uncollared bands (Tables 2 and 3). Aerial observations accounted for 80% (n = 2344) of all observations. Of those, 67.7% (n = 1586) were visual observations. Figures 8 - 15 show the location of bighorn sheep observations by sex for each season.

With the exception of three rams (two adults and one yearling), all bighorn sheep movements were located within the primary study area. Ram B563, captured and collared in the Eldorado Mountains on 8 May 1990, was observed in the River Mountains on 11 May 1990. The yearling remained in the River Mountains until 30 April 1991 where it was, once again, observed in the Eldorado Mountains. By 10 May 1991, B563 had returned to the River Mountains and continued to be located within that range for the remainder of the study. With only two observations within the Eldorado Mountains, B563 was excluded from further analyses.

Rams A920 and A790 were located most often within the primary study area, but made movements south of Burro Wash during the rutting seasons of 1990 and 1991, respectively. Ram A920 travelled to the extreme southern end of the Eldorado Mountains where, from approximately 7 September 1990 to 7 December 1990, it concentrated its activities in the Ireteba Peak area approximately 40 km south of Hoover Dam. Due to battery failure in A920's radio collar prior to the start of the 1991 rut, I was unable to determine if this movement pattern was repeated

Table 1. Summary of bighorn sheep captured and collared in the Eldorado Mountains, Nevada, 1989 - 1990.

Sheep Number	Sex	Estimated Birth Yr.	Date of Capture	Months Observed	Cause of Loss
A462	F	1987	27 Sep 89	24	
A488	F	1984	27 Sep 89	0	Probable fall
A513	F	1986	27 Sep 89	24	
A563	F	1985	28 Sep 89	0	Unknown
A613	F	1987	28 Sep 89	1	Collar failure
A638	F	1984	28 Sep 89	19	Natural mortality
A662	F	1985	28 Sep 89	24	
A710	F	1985	28 Sep 89	17	Natural mortality
A720	F	1985	28 Sep 89	24	
A741	F	1986	28 Sep 89	24	
A759	F	1984	29 Sep 89	3	Natural mortality
A771	F	1983	29 Sep 89	0	Capture mortality
A780	F	1983	29 Sep 89	24	
A811	F	1987	29 Sep 89	24	
A821	F	1985	1 Oct 89	24	
A870	F	1987	1 Oct 89	4	Probable predation
A890	F	1986	1 Oct 89	1	Unknown
A930	F	1986	2 Oct 89	24	
A114	F	1985	2 Oct 89	24	
A136	F	1987	9 May 90	6	Probable predation
B488	F	1986	8 May 90	19	
B759	F	1988	9 May 90	19	
B771	F	1989	8 May 90	19	
B870	F	1988	9 May 90	19	
B890	F	1987	8 May 90	19	
A086	M	1988	2 Oct 89	24	
A161	M	1986	8 May 90	19	
A439	M	1986	27 Sep 89	24	
A539	M	1985	28 Sep 89	0	Hunter mortality
A589	M	1985	28 Sep 89	3	Probable predation
A730	M	1983	28 Sep 89	24	
A790	M	1986	28 Sep 89	24	
A830	M	1983	1 Oct 89	24	
A840	M	1982	1 Oct 89	24	
A860	M	1986	1 Oct 89	0	Hunter mortality
A880	M	1988	1 Oct 89	3	Unknown
A910	M	1984	1 Oct 89	24	
A920	M	1982	2 Oct 89	17	Collar failure
A940	M	1985	2 Oct 89	24	
A963	M	1988	2 Oct 89	24	
B539	M	1988	8 May 90	19	
B563	M	1989	8 May 90	19	
B589	M	1986	8 May 90	19	
B860	M	1989	8 May 90	19	
B880	M	1986	8 May 90	19	

Table 2. Seasonal, yearly, and total number of locations for female bighorn sheep in the Eldorado Mountains, Nevada, between 1 December 1989 - 30 November 1991.

Sheep	1989-1990				Annual	1990 - 1991				Annual	Total
Number	Dec-Feb	Mar-May	Jun-Jul	Aug-Nov	Total	Dec-Feb	Mar-May	Jun-Jul	Aug-Nov	Total	n
A462	10	16	14	14	54	15	14	15	13	57	111
A513	14	17	15	16	62	16	14	15	13	58	120
A613	3	•	•	•	3	•	•	•	•	•	3
A638	10	18	14	14	56	16	14	7	•	37	93
A662	10	15	13	14	52	16	15	17	14	62	114
A710	10	12	13	10	45	13	6	•	•	19	64
A720	9	12	12	10	43	12	13	14	12	51	94
A741	11	18	13	14	56	16	16	16	13	61	117
A759	9	•	•	•	9	•	•	•	•	•	9
A780	11	12	11	10	44	12	13	14	13	52	96
A811	15	17	15	12	59	14	14	19	13	60	119
A821	15	17	16	14	62	15	15	17	12	59	121
A870	18	6	•	•	24	•	•	•	•	•	24
A890	3	•	•	•	3	•	•	•	•	•	3
A930	23	23	17	16	79	19	16	18	13	66	145
A114	15	18	14	14	61	18	15	16	13	62	123
A136	•	5	14	10	29	•	•	•	•	•	29
B488	•	3	16	17	36	14	13	16	13	56	92
B759	•	4	16	12	32	19	16	15	13	63	95
B771	•	4	14	13	31	12	15	17	14	58	89
B870	•	4	16	13	33	14	14	14	12	54	87
B890	•	5	16	14	35	16	14	14	14	53	93
Total	186	226	259	237		257	237	244	195		1841

Table 3. Seasonal, yearly, and total number of locations for male bighorn sheep and uncollared bighorn sheep groups in the Eldorado Mountains, Nevada, between 1 December 1989 - 30 November 1991.

Sheep	1989-1990				Annual	1990 - 1991				Annual	Total
Number	Dec-Feb	Mar-May	Jun-Jul	Aug-Nov	Total	Dec-Feb	Mar-May	Jun-Jul	Aug-Nov	Total	n
A086	23	18	17	14	72	18	16	17	12	63	135
A439	15	15	13	14	57	15	13	17	14	59	116
A589	11	•	•	•	11	•	•	•	•	•	11
A730	11	12	14	13	50	15	13	15	12	55	105
A790	9	14	16	12	51	16	13	17	12	58	109
A830	14	19	21	13	67	15	13	16	14	58	125
A840	21	18	19	17	75	19	12	21	12	64	139
A880	13	•	•	•	13	•	•	•	•	•	13
A910	16	18	16	12	62	19	13	19	13	64	126
A920	12	18	12	10	52	18	10	5	4	37	89
A940	14	20	18	15	67	20	16	19	12	67	134
A963	19	18	15	16	68	19	13	17	13	62	130
B539	•	5	19	18	42	19	15	16	12	62	104
B589	•	5	15	13	33	17	12	19	11	59	92
B860	•	5	16	14	35	17	14	17	13	61	96
B880	•	4	16	11	31	19	13	16	13	61	92
A161	•	3	17	15	35	17	14	14	12	57	92
Total	178	192	244	207		263	200	245	179		1708
Uncollared sheep	87	30	32	26		31	27	20	22		275

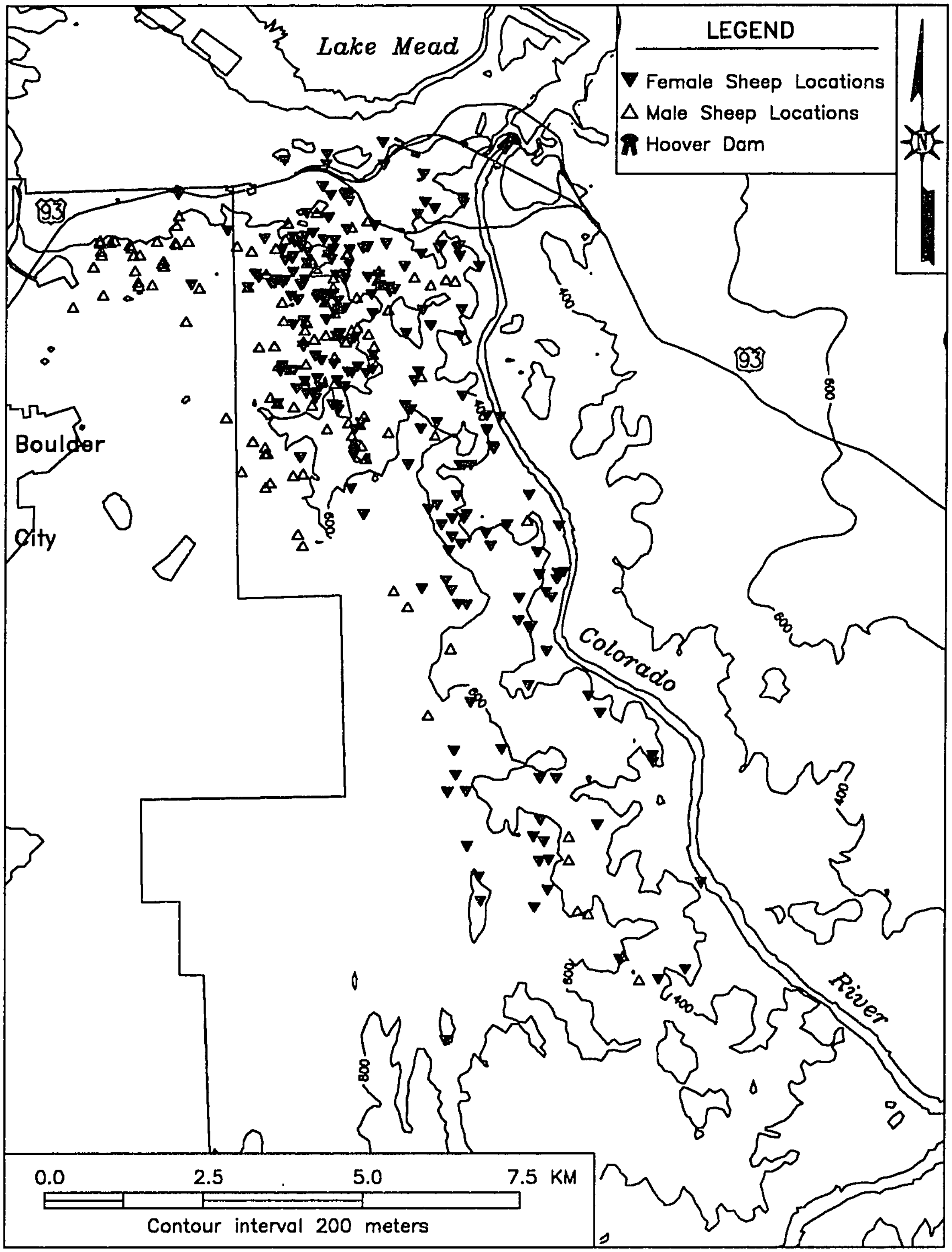

Figure 8. Location of bighorn sheep observations from 1 December 1989 - 28 February 1990.

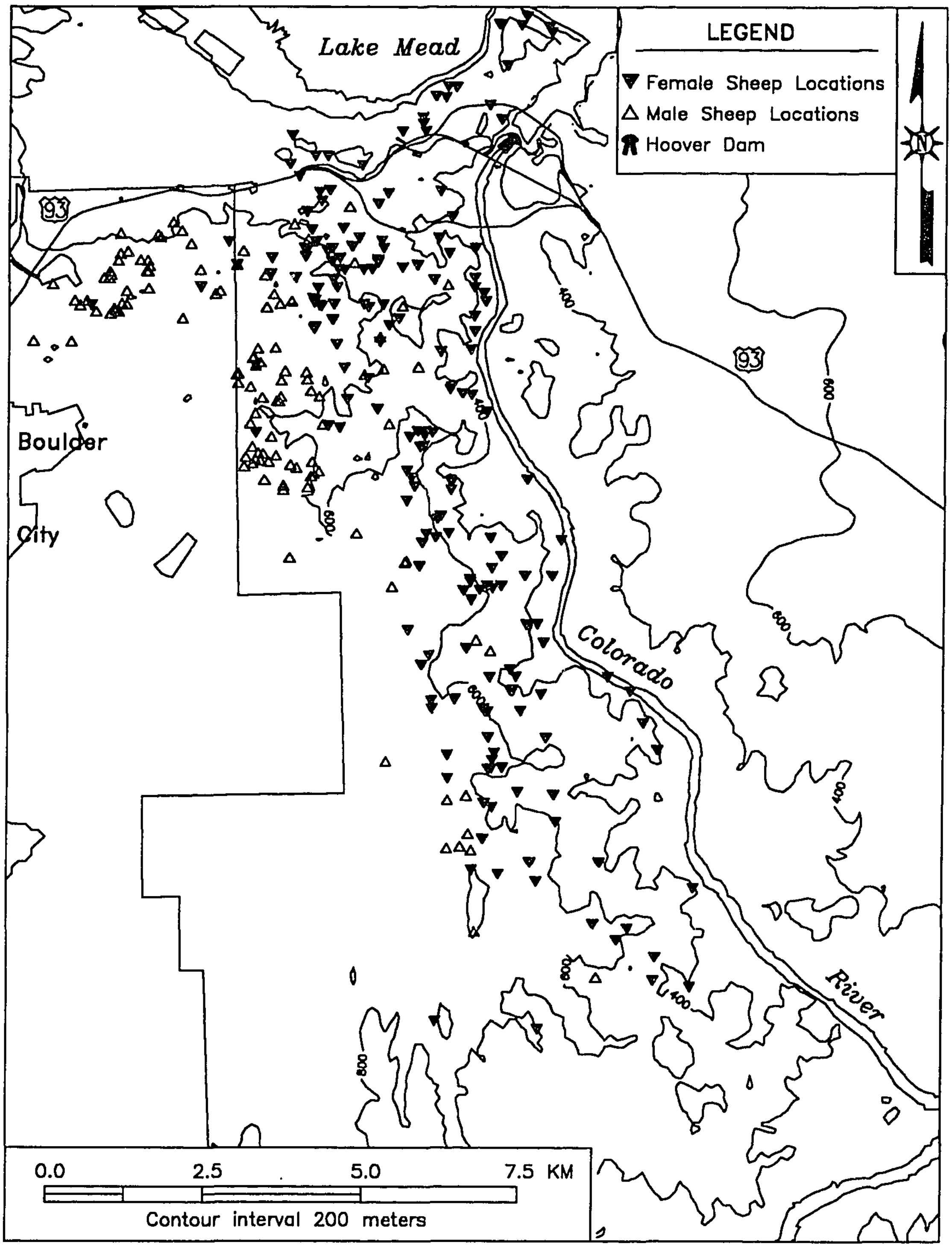

Figure 9. Location of bighorn sheep observations from 1 March 1990 - 31 May 1990.

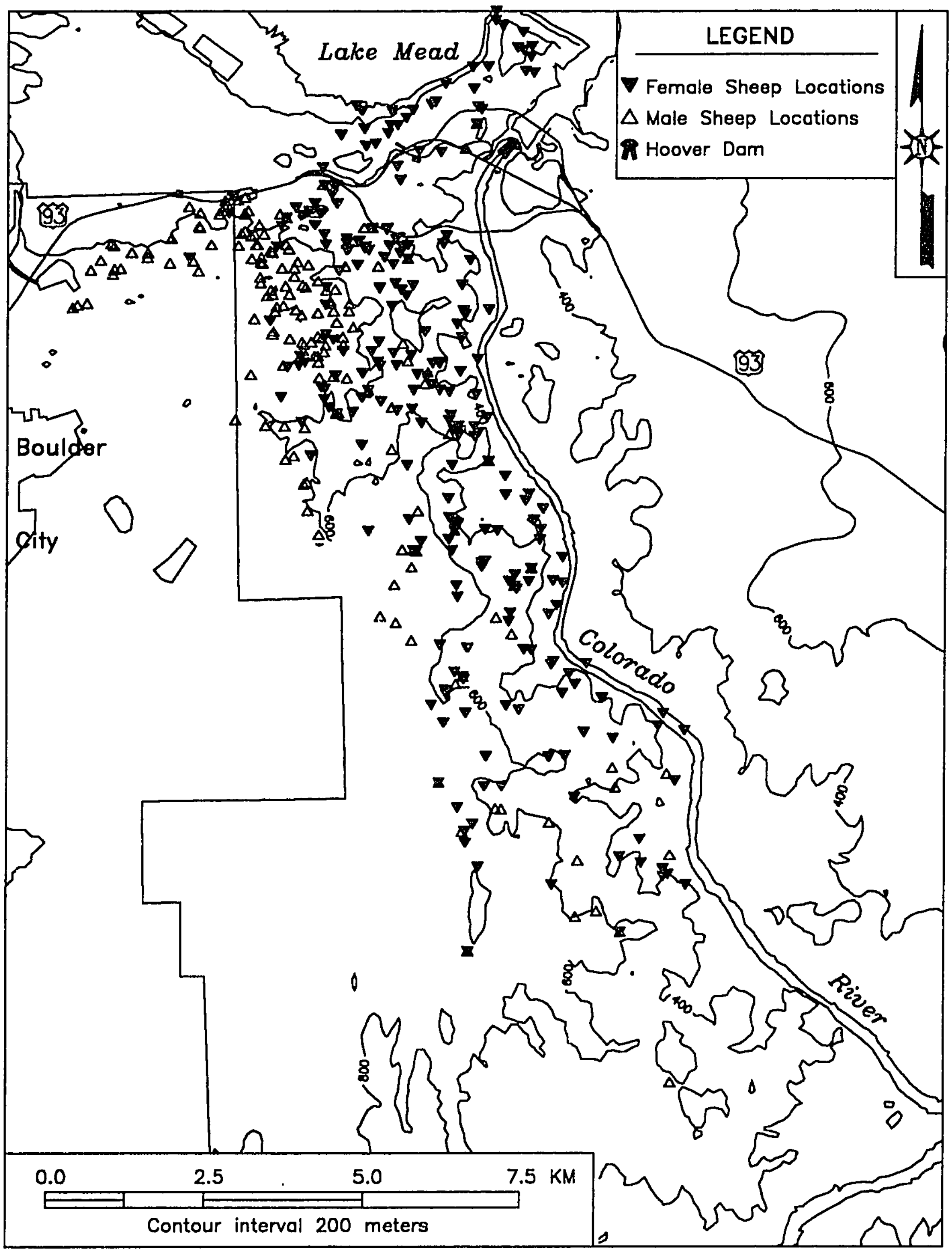

Figure 10. Location of bighorn sheep observations from 1 June 1990 - 31 August 1990.

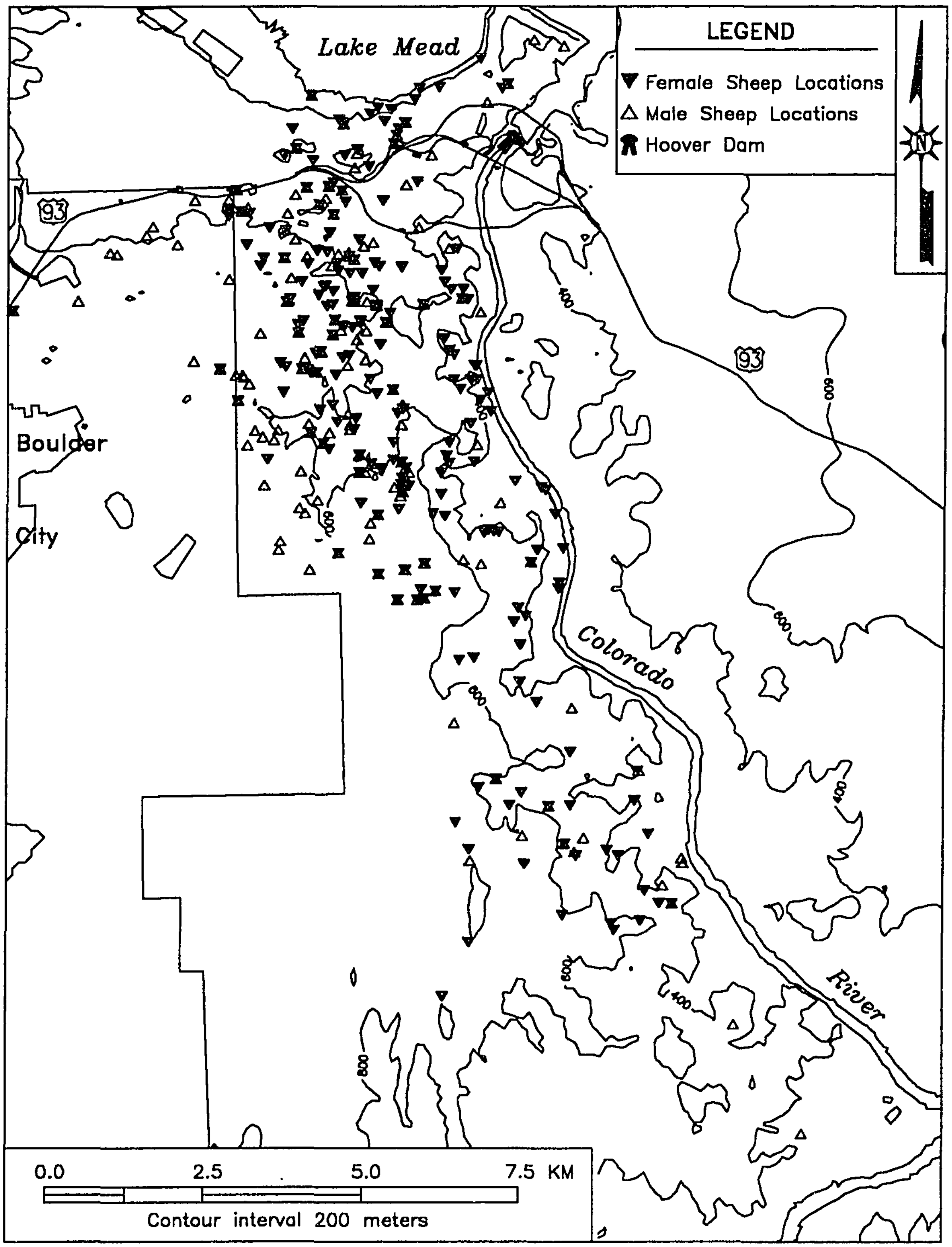

Figure 11. Location of bighorn sheep observations from 1 September 1990 - 30 November 1990.

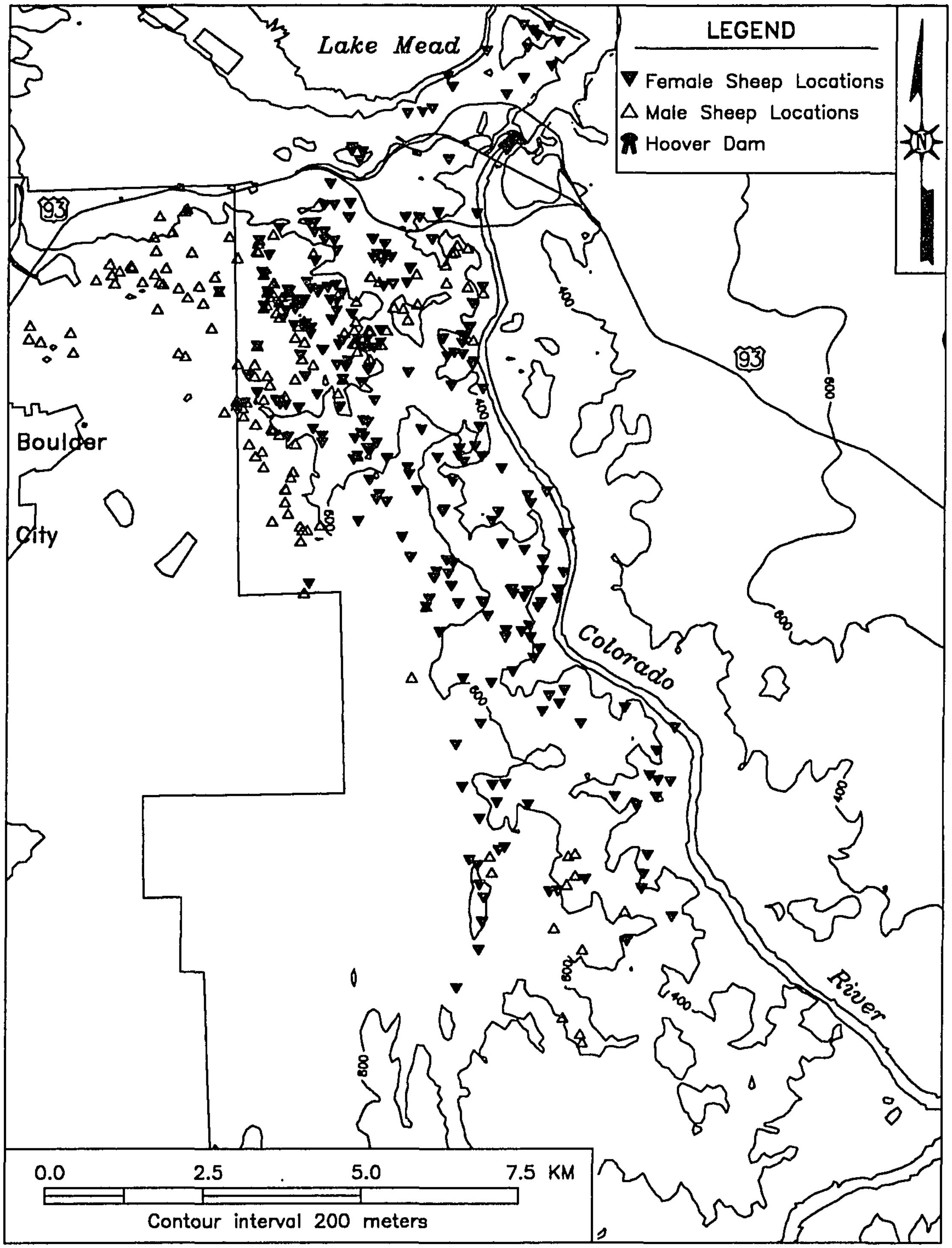

Figure 12. Location of bighorn sheep observations from 1 December 1990 - 28 February 1991.

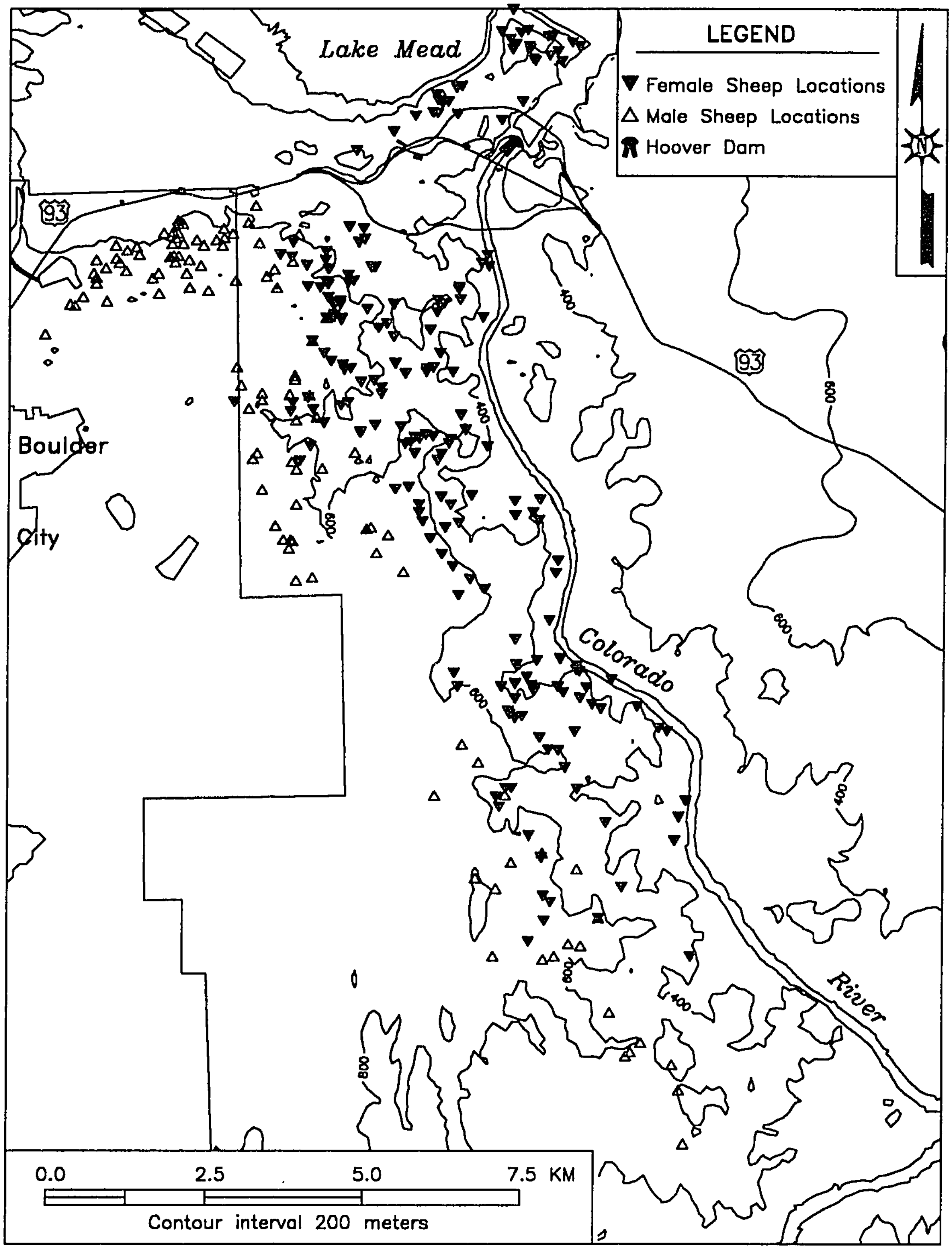

Figure 13. Location of bighorn sheep observations from 1 March 1991 - 31 May 1991.

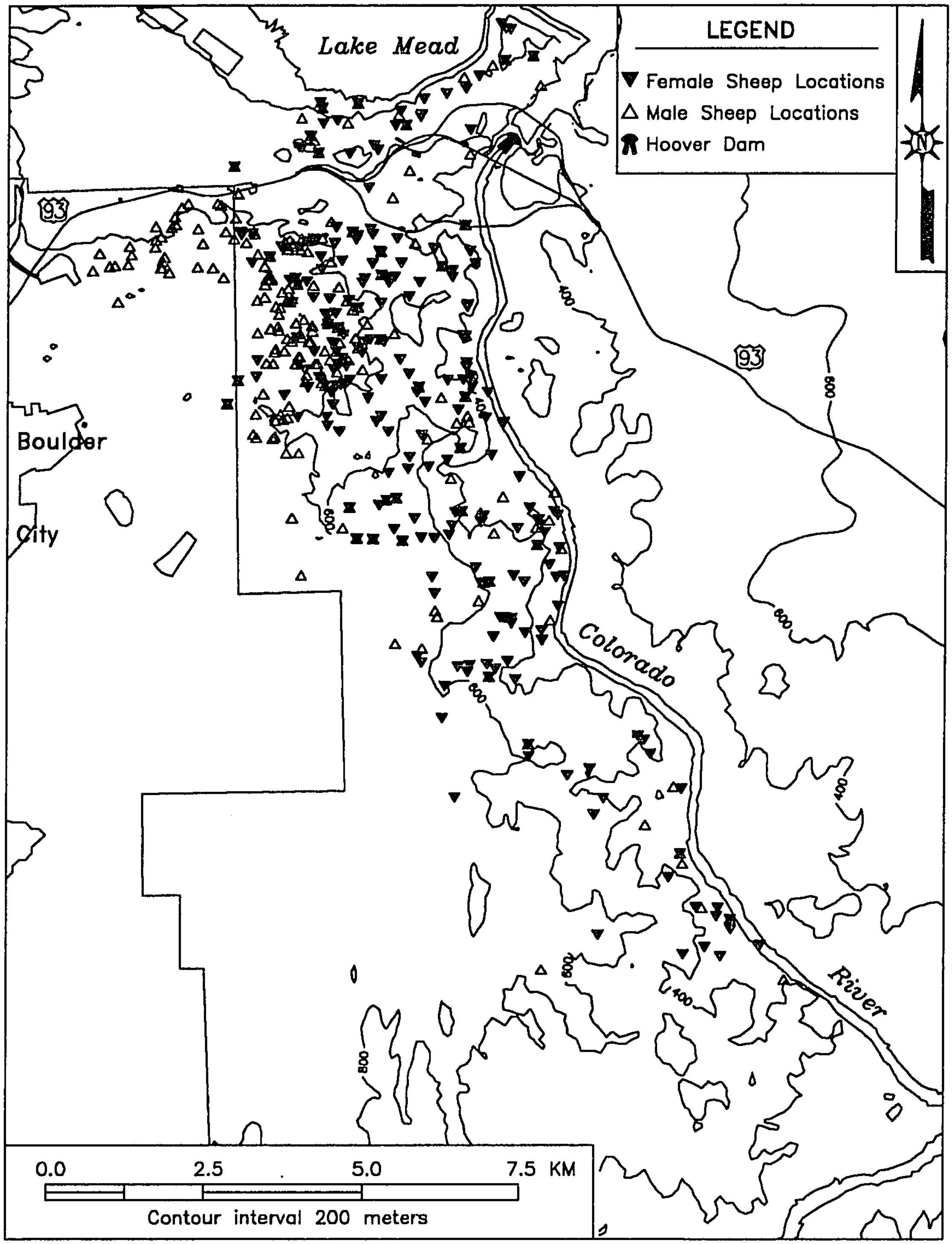

Figure 14. Location of bighorn sheep observations from 1 June 1991 - 31 August 1991.

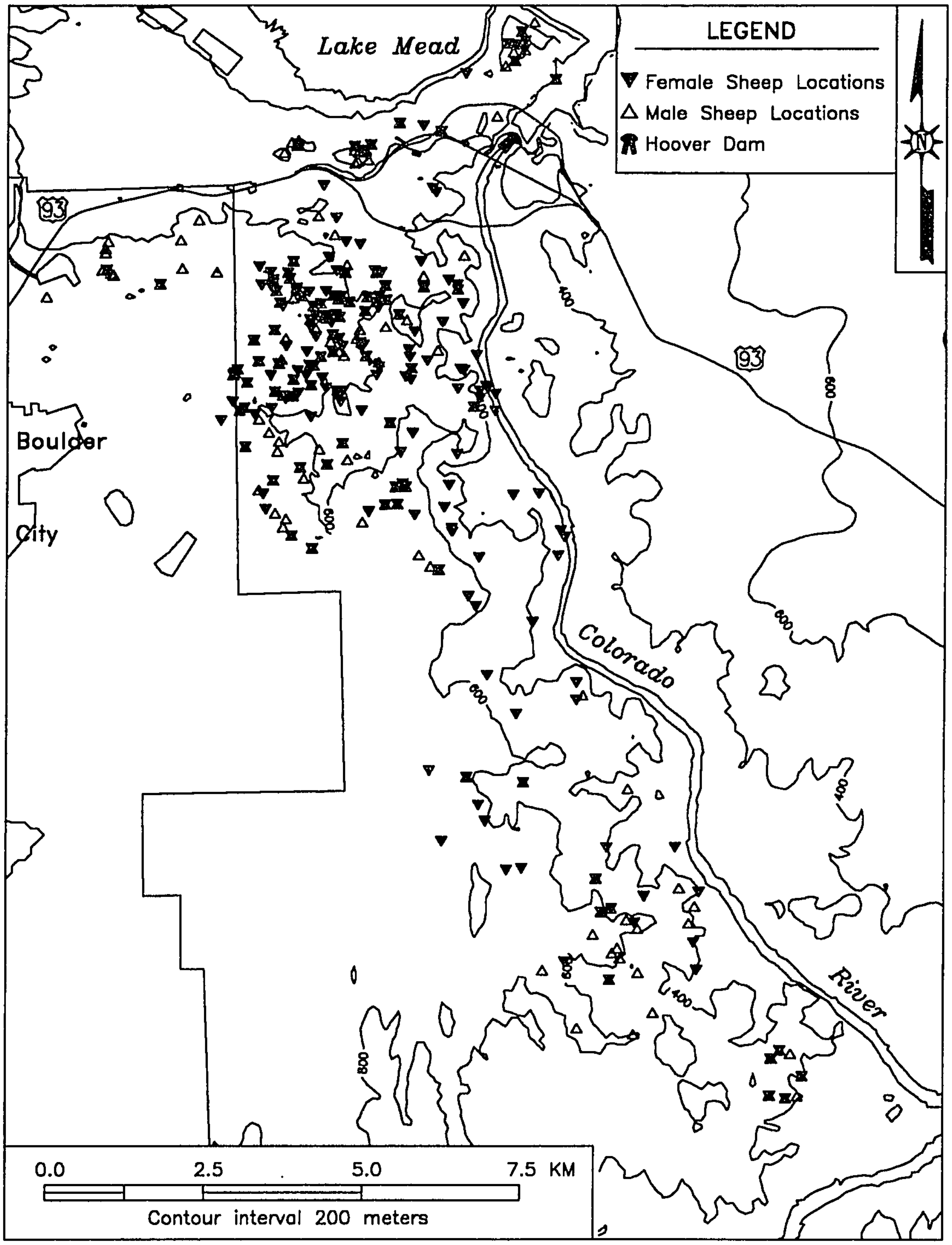

Figure 15. Location of bighorn sheep observations from 1 September 1991 - 30 November 1991.

the following year. Ram A790 left the primary study area on approximately 21 August 1991 and returned approximately one month later. In the interim, A790 explored the area between Nelson, NV. and Burro Wash.

As the movements of these two rams extended beyond the limits of the GIS database, I was unable to compensate for inclusion of null habitats. Seasonal home range data for A920 for the winter of 1990-1991 and for A790 during summer and fall 1991 were not used in the home range analysis. The same situation was encountered while calculating total home range size and harmonic mean core areas; data for A920 and A790 were not included in those analyses. I realize that this will bias estimates toward smaller home ranges, but also recognize the limitations of the MCP for accurately depicting home range use for such widely distributed observations. The calculated home ranges for A920 and A790 during these periods include vast tracts of land unused by the bighorn sheep, thereby falsely inflating the estimates of mean home range size. While I feel justified in making these exclusions, a study of longer duration is necessary to validate this position.

Mean seasonal home ranges for adult male bighorn sheep ranged from a low of 6.7 km^2 during the winter of 1989-1990 (range 2.4 to 15.4 km^2) to a high of 19.6 km^2 for summer 1991 (range 3.3 to 40.6 km^2). Total home range averaged 49.7 km^2 (range 31.5 to 60.5 km^2) while harmonic mean core area averaged 36.1 km^2 (range 20.0 to 66.5 km^2). For female bighorn sheep, mean seasonal home range size varied from a low of 4.2 km^2 during the winter of 1989-1990 (range 0.6 to 12.4 km^2) to a high of 11.0 km^2 during the following spring (range 4.0 to 19.6 km^2). Total home range size was smaller for female bighorn sheep than those recorded for adult males (t = 10.82, df = 27, $P \leq 0.0001$), averaging 19.0 km^2 (range 8.2 to 30.3 km^2). Harmonic mean core areas were also smaller (t = 7.09, df = 27, $P \leq 0.0001$), averaging 12.5 km^2 (range 4.4 to 22.0 km^2).

A repeated measures ANOVA with two within-subject factors (year and season) and 1 between subjects factor (gender) was performed to analyze the effects of year, season, and sex on home range size. Only bighorn sheep with complete home range data (i.e. eight complete seasons of data with nine or more observations per season) were used in the analysis. Test results showed that mean seasonal home range was not equal between sexes or between years or between seasons within a sex ($F = 3.7$, Greenhouse-Geisser epsilon (G-G) = 0.0233, Hunyh-Feldt epsilon (H-F) = 0.0180, df = 3, $P = 0.018$). For female bighorn sheep, mean seasonal home range varied little between seasons or between years. The exception to this, however, was spring 1990 where the mean home range size was larger (mean = 11.1 km^2, range 4.0 to 19.6 km^2) than that observed for any other season (pairwise contrasts, $P \leq 0.05$). Mean seasonal home range for ewes during summer 1991, also had a marginally larger mean home range size (mean = 7.8, range 2.0 to 12.9 km^2) than winter 1989-90 (mean = 4.7 km^2, range 1.6 to 12.4 km^2) (G-G = 0.0464, H-F = 0.0383, df = 1, $P = 0.0277$).

With the exception of the fall season, mean seasonal home ranges for mature rams were similar between years for each season. Summer home ranges were significantly larger than winter ranges while spring home ranges were intermediate between the two. Mean seasonal home range for fall 1990 was similar to summer home ranges while the mean seasonal home range the following fall was similar to those observed in winter. This difference may be explained by an earlier start and finish of the rut in the study's second year.

Seasonal home range size, total home range area, and harmonic mean core areas for female and male bighorn sheep are provided in tables 4 and 5, respectively. Figure 16 illustrates the relationship of home range size between season, year, and sex.

Habitat Evaluation

Habitat Availability

Distance from previous observation was measured for 1,805 ewe relocations and 1,670 collared ram sightings (Fig. 17). The distance containing 75% of all ewe movements was 2.2 km (range 0.0 to 7.6 km) and 2.3 km for rams (range 0.0 to 31.0 km). For convenience, 2.3 km was

Table 4. Home range size (km^2) and harmonic mean core area (km^2) for female bighorn sheep in the Eldorado Mountains, Nevada, between 1 December 1989 - 30 November 1991. Seasonal home range was calculated for bighorn sheep with nine or more observations/season. Total home range and core area was calculated for sheep radio-collared greater than or equal to one year.

Sheep	Estimated	1989-1990				1990-1991					Core
Number	Birth Yr.	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Total	Area
A462	1987	1.6	14.6	6.8	10.7	11.3	9.5	6.9	4.3	25.1	14.8
A514	1986	2.6	10.3	9.4	9.5	8.7	7.6	12.9	7.7	22.0	12.2
A638	1984	2.4	10.4	7.6	8.3	5.4	7.7	•	•	16.1	12.1
A662	1985	2.7	15.8	9.8	6.1	9.6	8.1	12.5	3.3	21.8	16.2
A710	1985	5.1	10.5	6.0	5.9	2.9	•	•	•	16.3	10.9
A720	1985	5.2	8.1	5.8	2.3	5.1	6.6	5.3	7.7	15.1	9.6
A741	1986	5.9	19.6	8.5	4.5	9.6	3.5	5.5	3.1	25.5	19.0
A759	1984	0.6	•	•	•	•	•	•	•	•	•
A780	1983	12.4	14.6	8.6	7.3	6.1	11.0	12.5	12.4	28.8	22.0
A811	1987	4.1	4.3	1.2	2.3	2.9	3.3	2.0	3.2	8.2	4.4
A821	1985	3.3	4.0	3.5	5.5	5.4	2.7	5.1	1.8	10.5	6.3
A870	1987	4.2	•	•	•	•	•	•	•	•	•
A930	1986	2.3	9.7	5.2	3.3	3.4	8.4	5.4	3.3	17.8	13.5
A114	1985	6.8	9.8	10.2	5.5	3.3	6.2	9.9	3.9	19.1	12.5
A136	1987	•	•	8.4	8.6	•	•	•	•	•	•
B488	1986	•	•	8.4	7.4	4.8	1.7	9.4	2.6	16.1	11.3
B759	1988	•	•	1.8	5.5	5.5	5.9	1.9	9.2	14.4	6.0
B771	1989	•	•	14.0	5.6	10.5	14.2	12.2	6.9	30.3	17.7
B870	1988	•	•	11.2	9.6	7.7	3.3	5.9	1.9	14.7	6.0
B890	1987	•	•	7.1	5.3	5.6	5.9	7.4	7.3	21.2	17.4
Mean		4.2	11.0	7.4	6.3	6.3	6.6	7.7	5.2	19.0	12.5
S.E.		0.78	1.32	0.76	0.57	0.66	0.83	0.96	0.8	1.48	1.22
n		14	12	18	18	17	16	15	15	17	17

Table 5. Home range size (km^2) and harmonic mean core area (km^2) for male bighorn sheep in the Eldorado Mountains, Nevada, between 1 December 1989 - 30 November 1991. Seasonal home range was calculated for bighorn sheep with nine or more observations/season. Total home range and core area was calculated for sheep radio-collared greater than or equal to one year.

Sheep	Estimated	1989-1990				1990-1991					Core
Number	Birth Yr.	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Total	Area
A439	1986	2.7	4.5	16.2	13.8	3.7	2.9	3.3	4.9	31.5	36.2
A589	1985	15.4	•	•	•	•	•	•	•	•	•
A730	1983	2.4	17.5	19.6	7.7	6.3	14.6	33.6	3.2	53.4	28.7
A790	1986	7.4	14.6	22.2	20.5	8.9	20.6	94.5[b]	108.2[b]	206.2[b]	130.7[b]
A830	1983	7.0	17.8	16.1	7.7	3.3	18.8	14.8	10.7	46.1	39.4
A840	1982	3.1	4.1	7.9	21.8	11.2	16.5	15.2	0.4	59.6	40.8
A880	1988	5.3	•	•	•	•	•	•	•	•	•
A910	1984	8.1	6.6	18.5	23.6	7.2	16.0	14.9	7.1	57.8	66.5
A920	1982	8.8	22.5	11.0	41.0	172.5[b]	8.8	•	•	381.8[b]	232.2[b]
A940	1985	6.3	15.6	13.8	12.7	8.2	8.0	23.7	6.4	37.6	20.1
A963	1988	2.1[a]	9.5[a]	4.0[a]	3.7[a]	5.4[a]	17.7[a]	15.0	2.9	40.4	31.0
A086	1988	2.4[a]	6.1[a]	6.3[a]	3.0[a]	3.9[a]	35.6[a]	40.6	10.9	50.2	36.9
B539	1988	•	•	9.7[a]	6.3[a]	16.5[a]	26.4[a]	14.5	9.0	60.5	43.1
B589	1986	•	•	10.7	21.6	11.1	11.5	19.0	23.7	51.2	20.0
B860	1989	•	•	8.9[a]	12.0[a]	9.3[a]	8.2[a]	15.2[a]	7.4[a]	24.7[a]	19.4[a]
B880	1986	•	•	26.1	8.6	18.0	26.8	21.4	22.5	57.2	42.7
A161	1986	•	•	23.6	15.2	20.6	6.3	19.6	14.0	50.3	28.0
Mean[c]		6.7	12.9	16.9	17.6	9.9	13.7	19.6	9.6	49.7	36.1
S.E.[c]		1.21	2.45	1.74	2.93	1.79	2.11	2.80	2.13	2.65	3.60
n[c]		10	8	11	11	10	11	12	12	12	12

[a]Juvenile ram: less than 3 years of age.
[b]Unable to adjust for exclusion of null habitats.
[c]Does not include juvenile ram home ranges or areas containing null habitats.

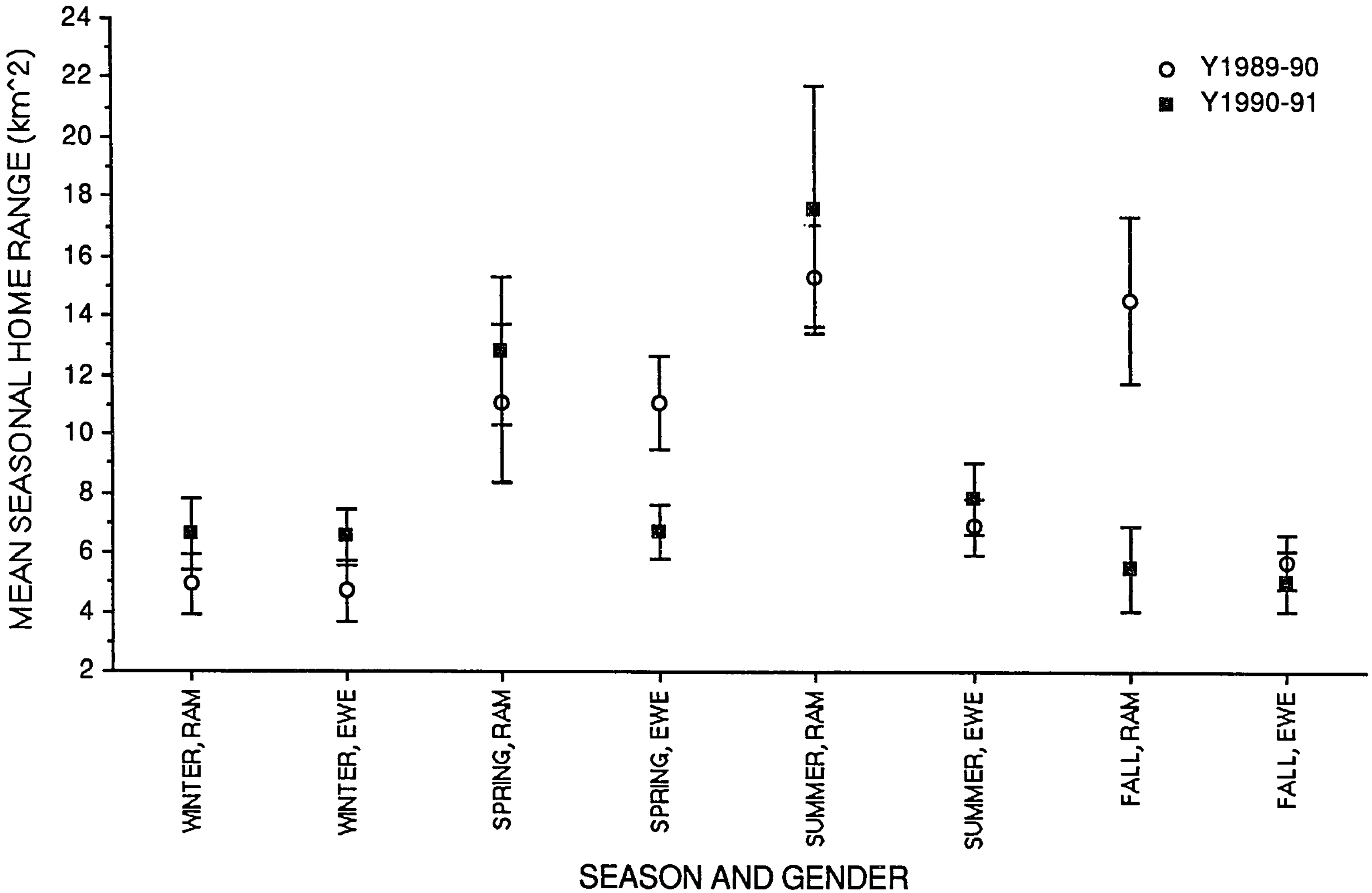

Figure 16. Mean seasonal home range and standard error bars by gender, season, and year. The repeated measures ANOVA derived seasonal means from collared bighorn sheep with eight complete seasons of home range data.

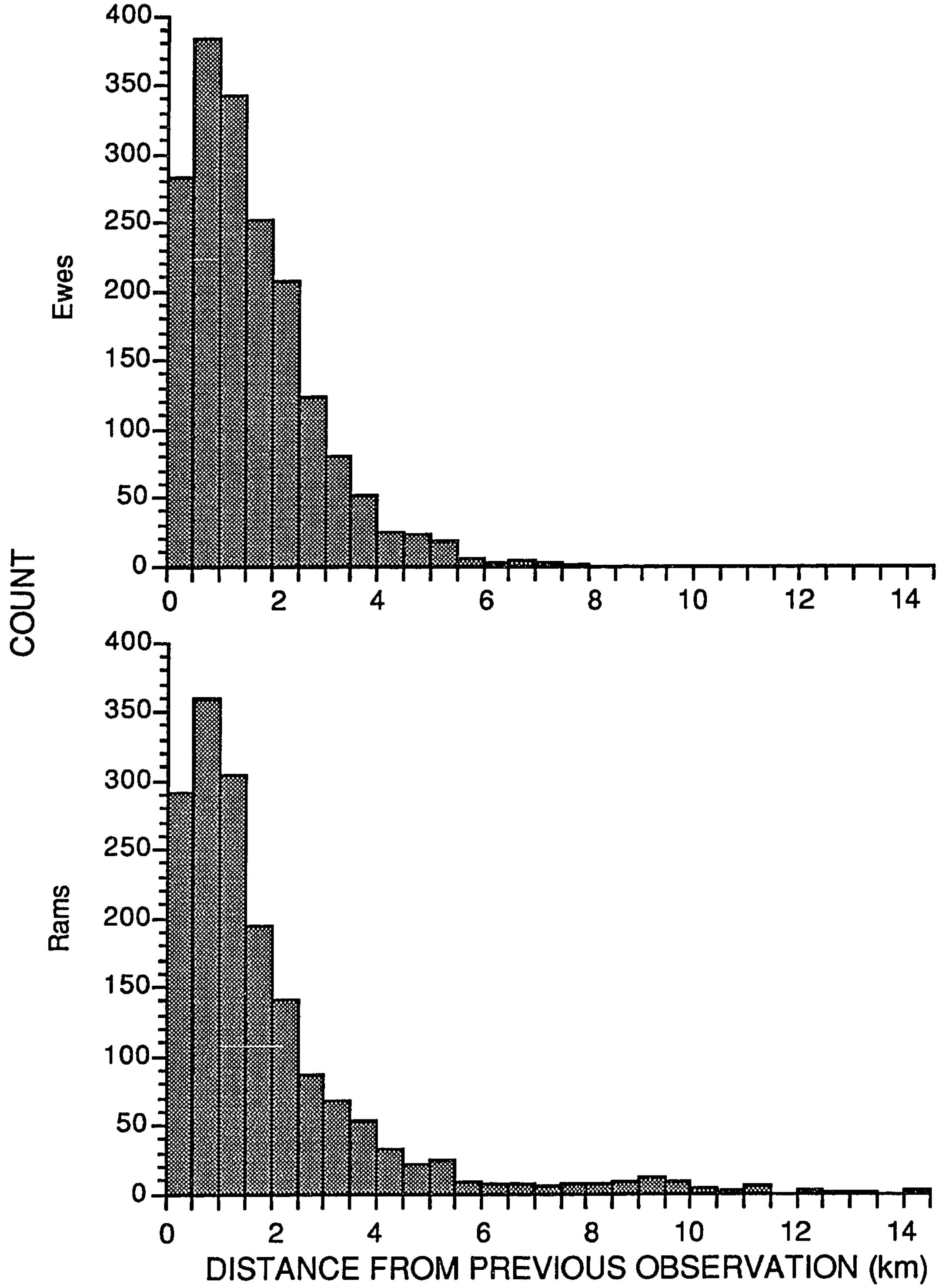

Figure 17. Frequency distribution of distance from previous observation for female and male bighorn sheep.

used as the potential movement radius for both sexes. Total area within this radius or "available habitat" is 12,969 ha and 14,352 ha for female and male bighorn sheep, respectively.

Habitat Use

Aspect

Ewes

Aspects were not used in proportion to their availability in any season of any year (chi-square, df = 4, $P \leq 0.05$). In all seasons, level areas were avoided while northern aspects were selected in all but three seasons: winter 1989, winter 1990, and fall 1991 (Fig. 18, Table 6). Eastern aspects were selected in winter 1989, spring 1990 and fall 1991. Southern aspects were used in proportion to their availability in all seasons while use of western aspects was proportional to its availability in all seasons but spring 1990, when it was avoided.

Use between years was similar for winter, spring, and summer seasons (chi-square, df = 4, $P > 0.05$). Pooled data show eastern aspects selected during winter with eastern and northern aspects selected in spring (Fig. 18, Table 6). Northern aspects were selected in summer. Level areas were avoided for all three seasons. During the fall season, aspect use was significantly different between years (chi-square = 14.4, df = 4, $P = 0.0061$). Level areas were avoided in both years with use of northern slopes occurring in greater proportion in 1990 than 1991 and eastern slopes used in greater proportion in 1991.

Rams

Rams did not use aspect classes in proportion to their availability in any season of any year (chi-square, df = 4, $P \leq 0.05$). In all seasons, level areas were avoided (Fig. 19, Table 6). Northern aspects were selected for in the summer seasons as well as during winter 1989, fall 1990, and summer 1991. Western slopes were selected in spring and summer of 1990. Southern and

Table 6. Aspect use by bighorn sheep in the Eldorado Mountains, Nevada. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = $a/2k$, k = no. of components). Blank spaces indicate use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

		1989-1990				1990-1991				Years Combined			
Aspect	% available	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
EWES													
North	19.8		S	S	S		S	S			S	S	*
East	25.9	S							S	S	S		*
South	12.0												*
West	12.8		A										*
Level	29.5	A	A	A	A	A	A	A	A	A	A	A	*
RAMS													
North	19.2	S		S	S		S	S		S	S	S	*
East	25.5						A				A		*
South	13.2												*
West	11.3		S	S							S		*
Level	30.8	A	A	A	A	A	A	A	A	A	A	A	*

* use between years significantly different ($p \leq 0.05$)

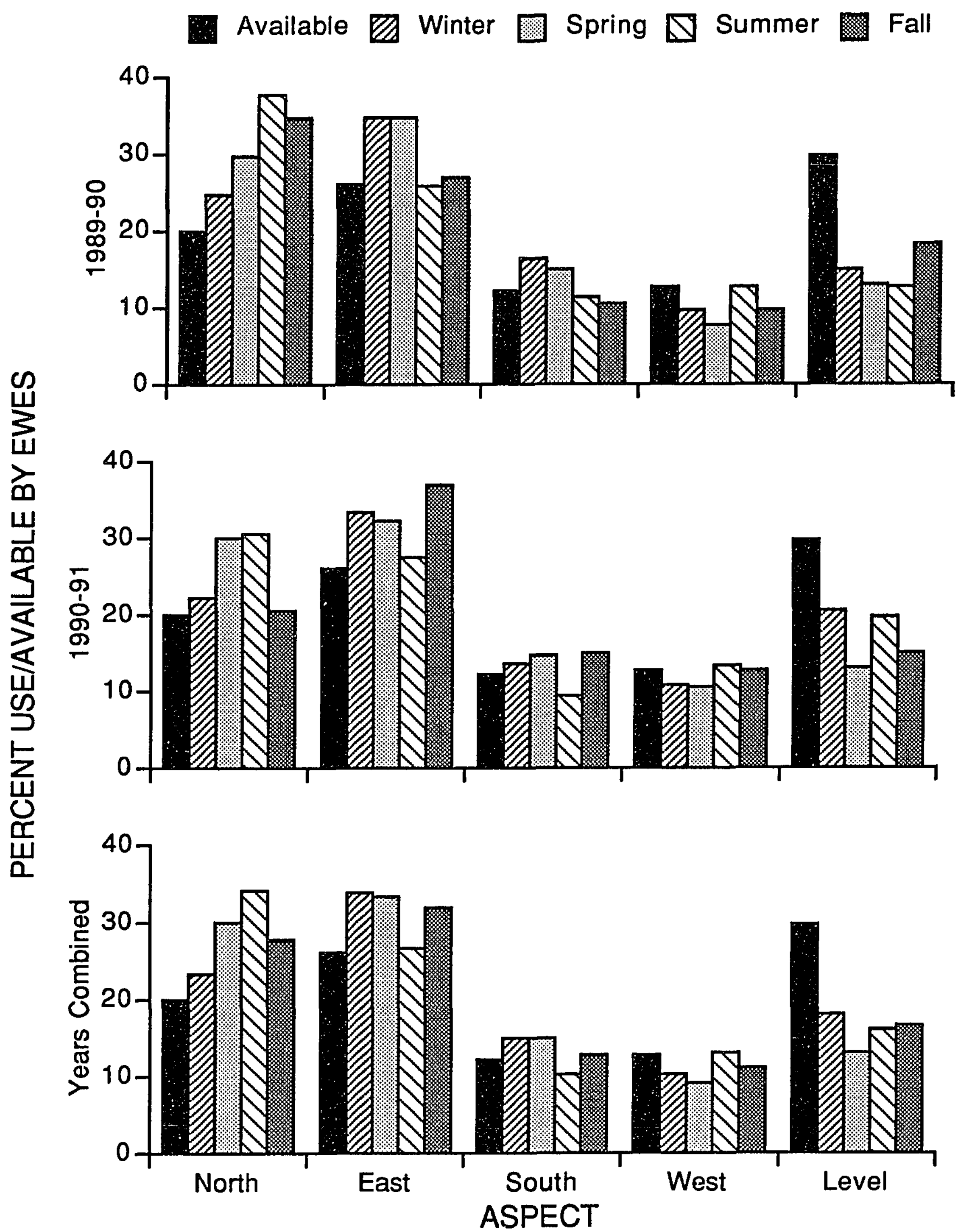

Figure 18. Percentage use of aspect by female bighorn sheep compared to availability by season, year, and years combined.

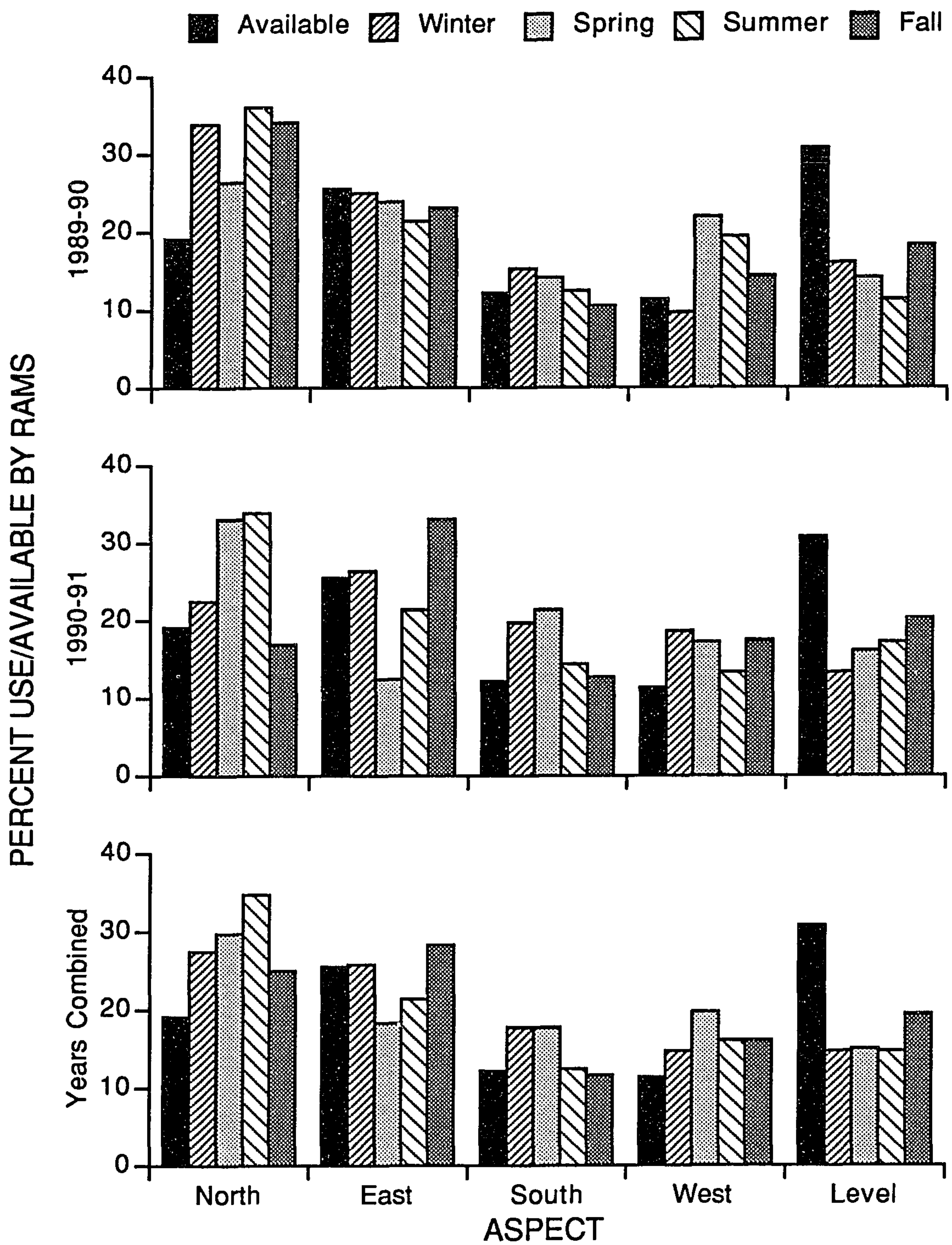

Figure. 19. Percentage use of aspect by male bighorn sheep compared to availability by season, year, and years combined.

eastern slopes were never used in greater proportion than their availability. Use of eastern aspects was avoided in spring 91.

Use between years was similar for winter, spring, and summer seasons (chi-square, df = 4, $P > 0.05$). Pooled data show selection for northern aspects and avoidance of level areas in all three seasons (Fig. 19, Table 6). Eastern aspects are avoided while western aspects were selected during spring. During the fall season, aspect use was significantly different between years (chi-square = 13.57, df = 4, $P = 0.0088$). Level areas were avoided in both years with use of northern slopes occurring in greater proportion in 1990 than 1991 and use of eastern slopes was greater in 1991.

Slope

Ewes

Female desert bighorn sheep did not use slope class proportional to availability in any season of any year (chi-square, df = 4, $P \leq 0.05$). In all seasons, areas with slopes ≤ 20% were used less than expected while areas with 41 to 60% slopes were used more than expected (Fig. 20, Table 7). Areas with 61 to 80% slopes were used in greater proportion than available in all seasons except fall 1991 where use was proportional to availability. Use of areas with 21 to 40% slopes occurred in proportion to availability in all seasons except fall 1991 when it was selected. Slopes of 81% or greater were selected in spring and summer of 1990, winter 1989-90, and spring 1991.

Use between years was similar for all seasons (chi-square, df = 4, $P > 0.05$). Combining years, slopes of 41 to 60% and 61 to 80% were selected in all seasons (Fig. 20, Table 7). Areas with slopes ≥ 81% were used more than expected in winter, spring, and summer, but used proportional to availability during fall. Use of 21 to 40% slopes did not differ from expected in any season while areas with slopes of 20% or less were avoided in each season.

Table 7. Use of slope class by bighorn sheep in the Eldorado Mountains, Nevada. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = a/2*k*, *k* = no. of components). Blank spaces indicate use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

		1989-1990				1990-1991				Years Combined			
Slope Class	% available	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
EWES													
≤ 20% slope	35.6	A	A	A	A	A	A	A	A	A	A	A	A
21-40%	29.5								S				
41-60%	18.9	S	S	S	S	S	S	S	S	S	S	S	S
61-80%	9.9	S	S	S	S	S	S	S		S	S	S	S
≥ 81% slope	6.1		S	S		S	S			S	S	S	
RAMS													
≤ 20% slope	36.8	A	A	A	A	A	A	A	A	A	A	A	A
21-40%	28.5	S	S	S	S	S	S	S	S	S	S	S	S
41-60%	19.4			S								S	
61-80%	9.8						A				A		
≥ 81% slope	5.5		A				A				A		

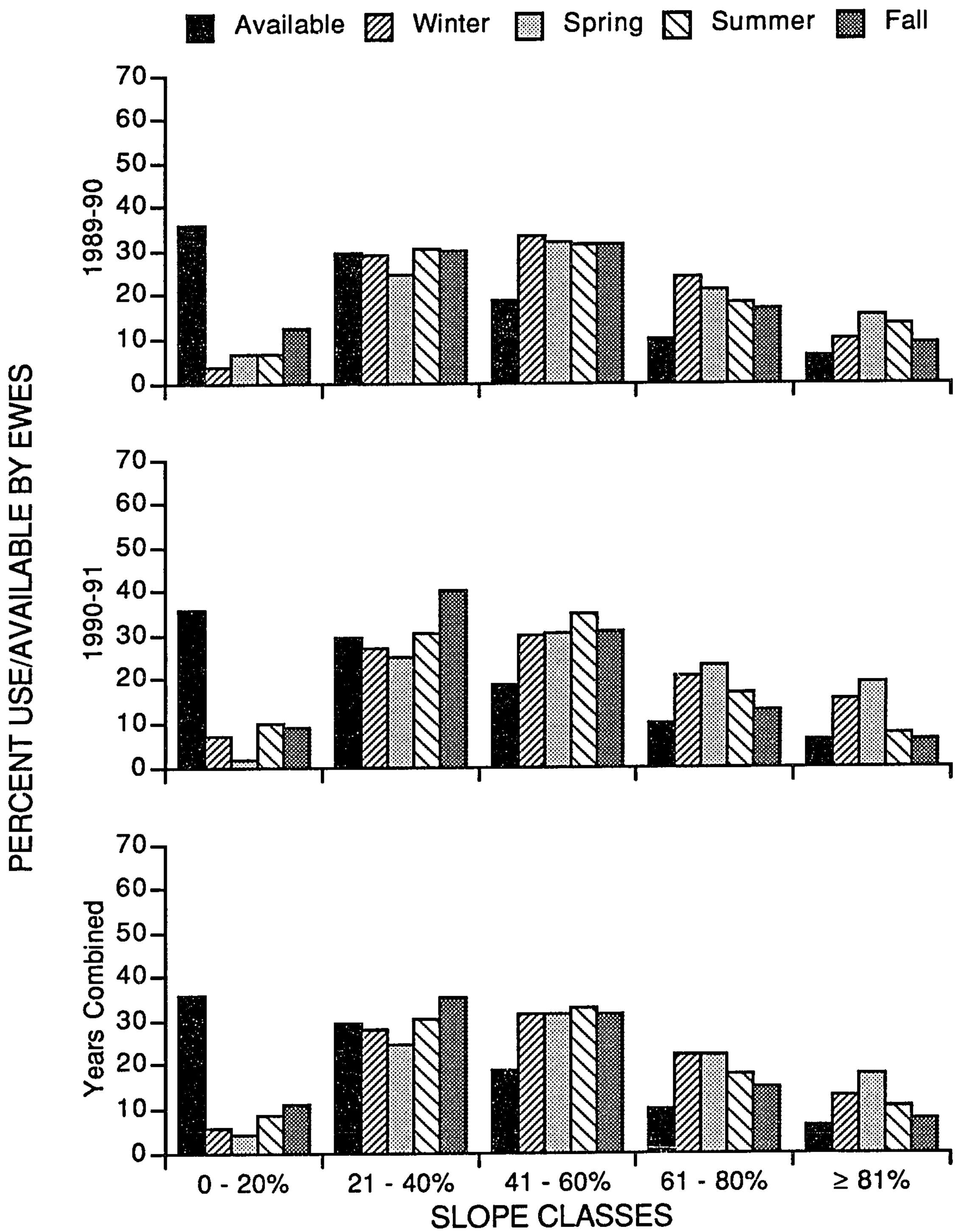

Figure 20. Percentage use of slope class by female bighorn sheep compared to availability by season, year, and years combined.

Rams

Slope classes were not used by male desert bighorn sheep in proportion to availability in any season of any year (chi-square, df = 4, $P \leq 0.05$). Areas with slopes ≤ 20% were avoided in all seasons while slopes of 21 to 40% were used more than expected (Fig. 21, Table 7). Slopes of 41 to 60% were selected in summer 1990 and 1991. During spring 1990 and 1991, slopes ≥ 81% were avoided. Slopes of 61 to 80% were also used less than expected in spring 1991.

Use of slope classes was similar between years for each season for male bighorn sheep (chi-square, df = 3 for spring, df = 4 for all other seasons, $P > 0.05$). Pooled data indicate avoidance of slopes ≤ 20% and selection of 21 to 40% slopes in all seasons (Fig. 21, Table 7). Areas with slopes of 41 to 60% are used more than expected in summer while 61 to 80% slopes and slopes ≥ 81% were used less than expected in spring.

Elevation

Ewes

Elevation classes were used proportional to availability in both winters as well as spring 1990 and fall 1991 (chi-square, df = 5, $P > 0.05$) (Fig 22, Table 8). Use between years for the summer season was similar with 401 to 500 m and 501 to 600 m elevation zones being used more than expected and elevations above 601 m avoided. Fall 1990 showed a similar pattern with female bighorn sheep selecting the 501 to 600 m elevation zone and avoiding the 601 to 700 m elevation zone. Use of the 401 to 500 m zone in fall was proportional to availability, however. No elevation zone was used more than expected in spring 1991, but the 200 to 300 m and 601 to 700 m elevation zones were avoided.

Use of elevation classes between years was similar for winter, spring, and summer seasons (chi-square, df = 5, $P > 0.05$). Combining data, use of the 501 to 600 m elevation zone was more than expected base on availability for all three seasons (Fig 22, Table 8). The 401 to 500 m zone was also used in greater proportion than available during the summer season while

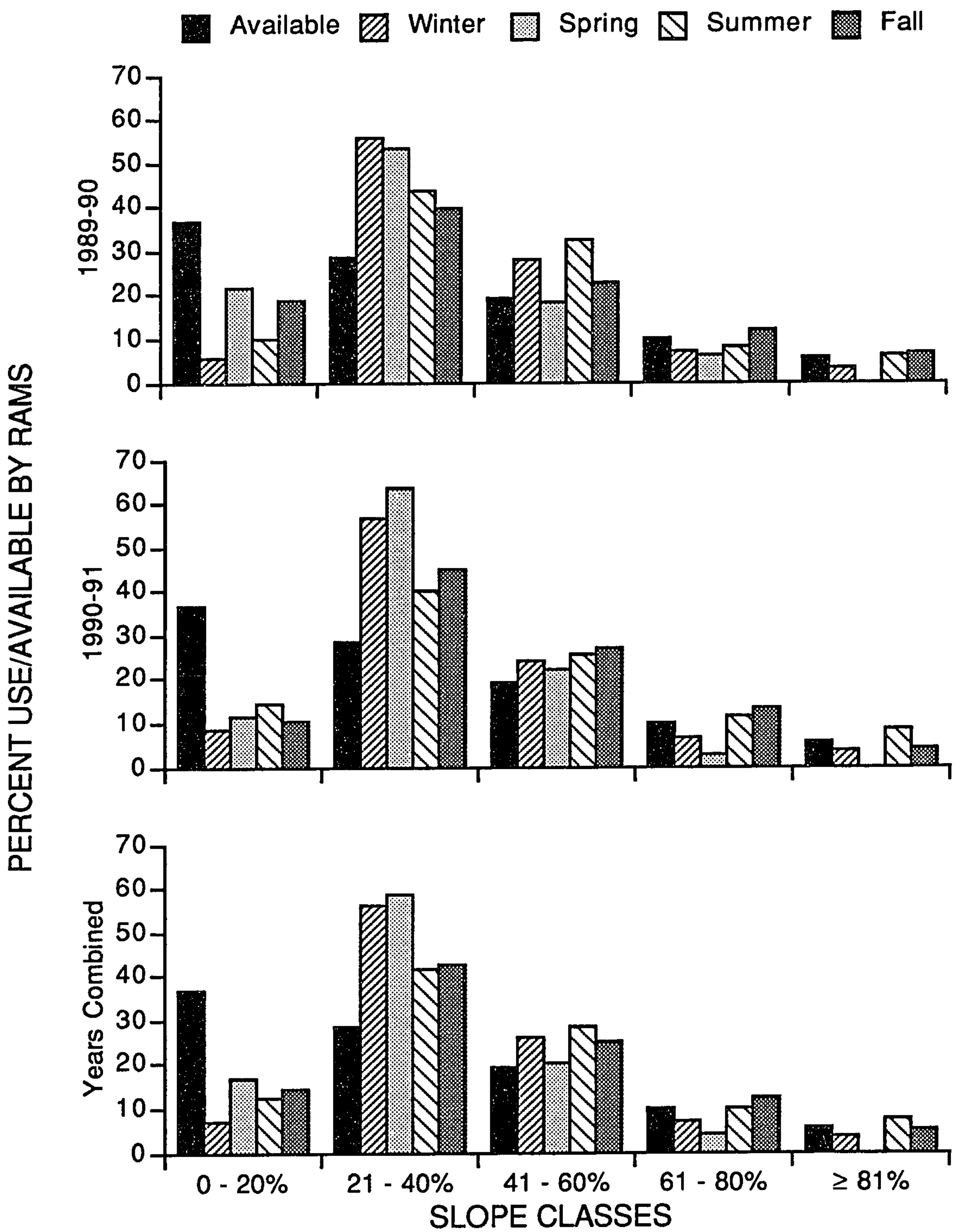

Figure 21. Percentage use of slope class by male bighorn sheep compared to availability by season, year, and years combined.

Table 8. Elevation use by bighorn sheep in the Eldorado Mountains, Nevada. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = a/2k, k = no. of components). Blank spaces indicate use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

		1989-1990				1990-1991				Years Combined			
Elevation (m)	% available	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
EWES													
200-300	4.0						A						*
301-400	9.0												*
401-500	18.4			S				S				S	*
501-600	16.7			S	S			S		S	S	S	*
601-700	29.2			A	A		A	A			A	A	*
≥ 701	22.7			A				A				A	*
RAMS													
200-300	5.6	A	A	A	A	A	A		A	A	A	A	*
301-400	11.3	A	A	A	A	A	A	A	A	A	A	A	*
401-500	18.8	A	A	A	A	A	A	A	A	A	A	A	*
501-600	16.3				S								*
601-700	27.7	S	S	S		S	S	S	S	S	S	S	*
≥ 701	20.3		S			S				S	S	S	*

* use between years significantly different ($p \leq 0.05$)

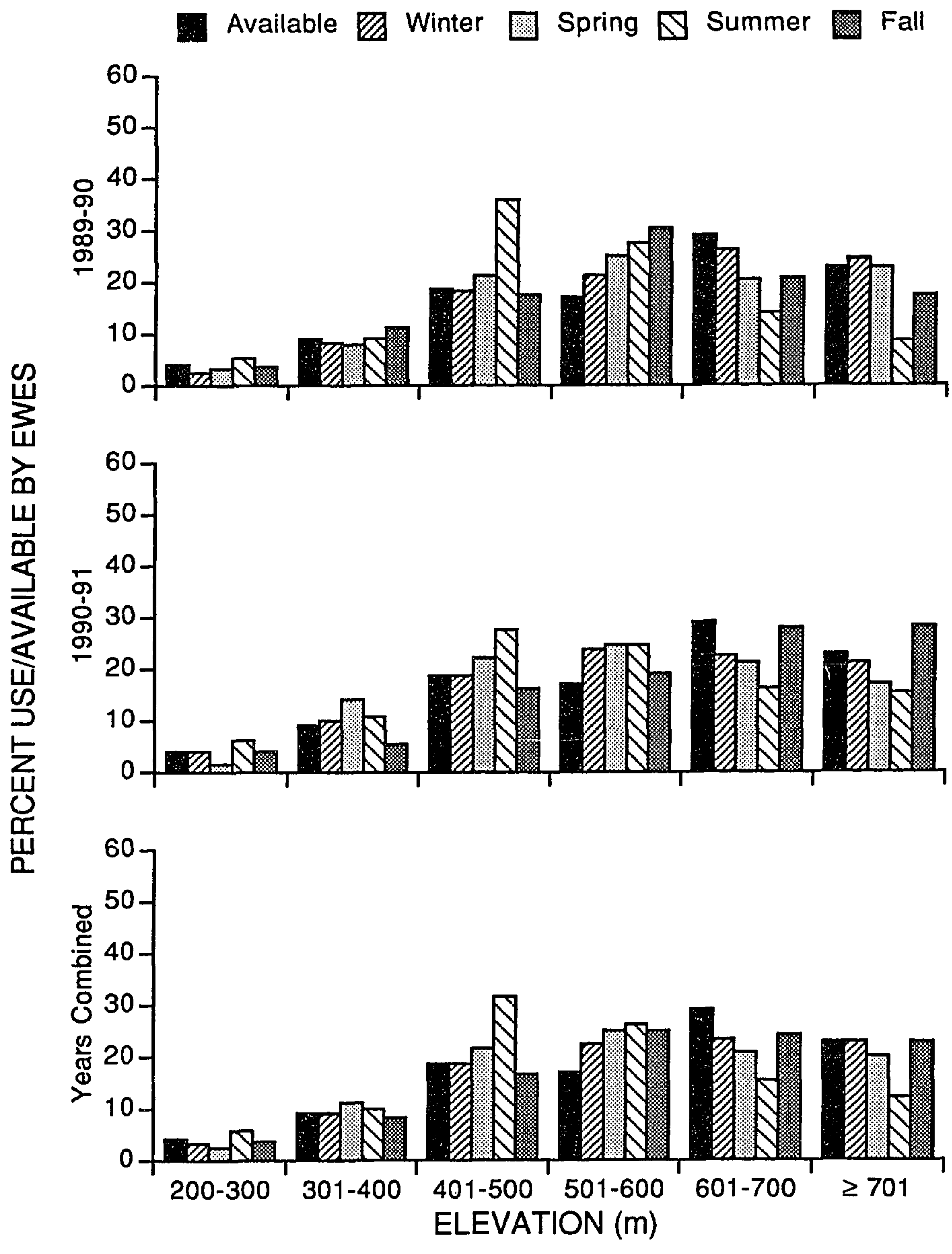

Figure 22. Percentage use of elevation by female bighorn sheep compared to availability by season, year, and years combined.

the 601 to 700 m and ≥ 701 m zones were avoided. Avoidance of the 601 to 700 m elevation zone was also documented in the spring season. Use of elevation zones between years for the fall season was significantly different (chi-square = 17.3, df = 5, $P = 0.0039$). Use of the 301 to 400 m and 501 to 600 m elevation zones occurred in greater proportion in 1990 than 1991 while the ≥ 701 m zone was used more than expected in 1991.

Rams

Male bighorn sheep did not use elevation zones in proportion to their availability in any season of any year (chi-square, df = 5, $P \leq 0.05$). Use was less than expected in the 301 to 400 m and 401 to 500 m elevation zones for all seasons (Fig. 23, Table 8). Use was less than expected in the 200 to 300 m elevation zone in all but summer 1991. The 601 to 700 m zone was selected in all seasons except fall 1990 when the 501 to 600 m zone was used in greater proportion than available. The ≥ 701 m elevation zone was used more than expected in spring 1990 and winter 1989-90.

Use between years was similar for winter, spring, and summer seasons (chi-square, df = 5, $P > 0.05$). Pooled data shows elevation zones 200 to 300 m, 301 to 400 m, and 401 to 500 m were avoided in all three seasons while the 601 to 700 m and ≥ 701 m elevation zones were selected (Fig. 23, Table 8). Use of the 501 to 600 m zone was proportional to availability in each of the three seasons. Elevation zone use during fall was significantly different between years (chi-square = 14.1, df = 4, $P = 0.0069$). Use was more than expected in the 501 to 600 m elevation zone in 1990.

Distance from Escape Terrain

Ewes

Female desert bighorn sheep did not use habitat near escape terrain in proportion to availability in any season of any year (chi-square, df = 7, $P \leq 0.05$). Areas ≥ 701 m from escape

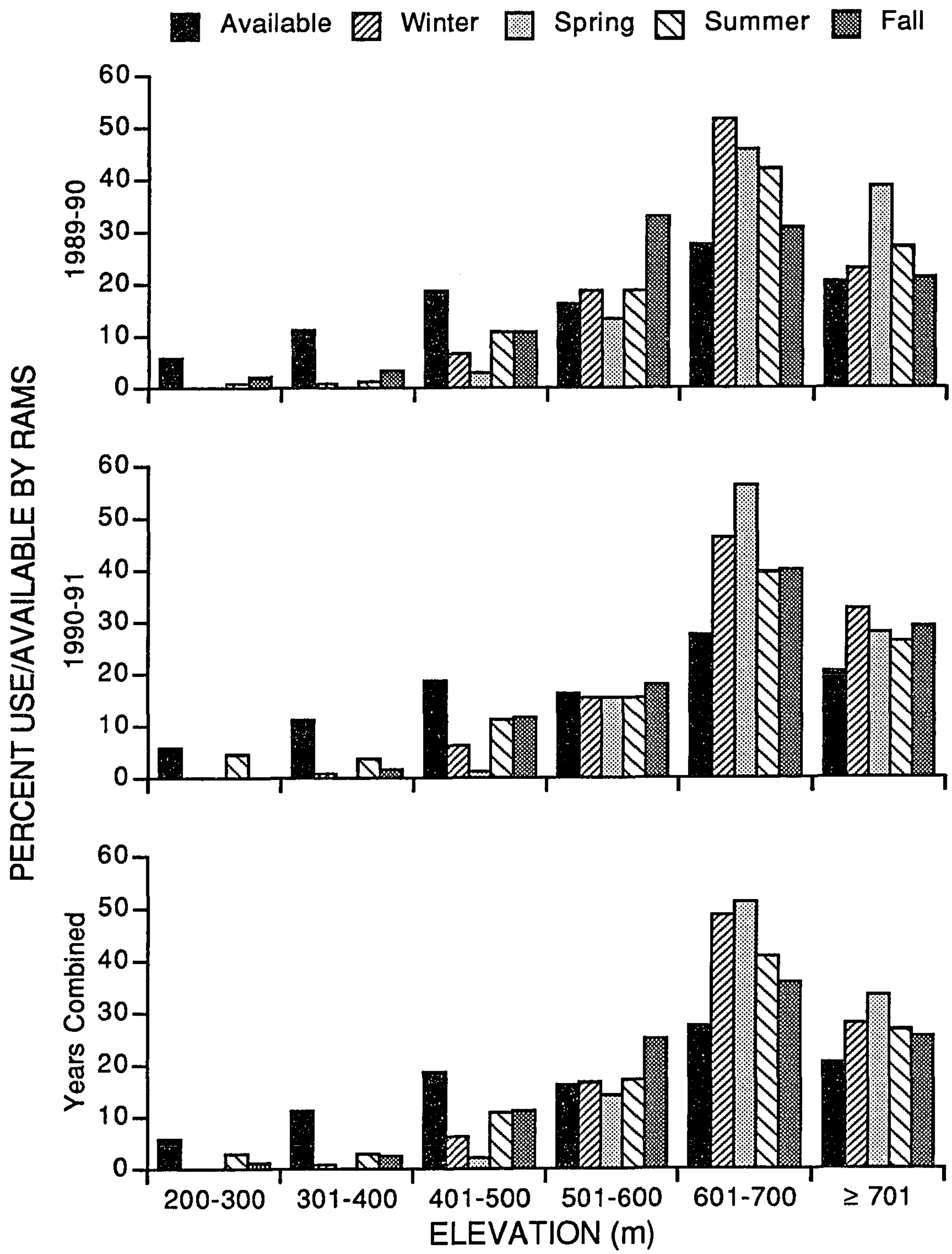

Figure 23. Percentage use of elevation by male bighorn sheep compared to availability by season, year, and years combined.

terrain were avoided in all seasons studied (Fig. 24, Table 9). Areas ≥ 501 m were avoided in all seasons except winter 1990-91 and fall 1991 when use was proportional to availability. During summer 1990 and spring 1991, areas 301 to 500 m distant from escape terrain were also avoided. Cells with maximum slope values ≥ 60% (i.e. escape terrain) and areas within 100 m of escape terrain were selected in all seasons except fall 1991. In fall 1991, areas within 100 m of escape terrain were used greater than expected while cells rated as escape terrain were used in proportion to availability. Areas within 101 to 200 m of escape terrain were also selected during summer 1991.

Use between years was similar for each season (chi-square, df = 5 for spring and summer, df = 6 for fall and winter, $P > 0.05$). Using pooled data, use of cells rated as escape terrain and areas within 100 m of escape terrain was greater than expected based on availability (Fig. 24, Table 9). During summer and fall seasons, cells 101 to 200 m distant from escape terrain were also used more than expected. Areas ≥ 501 m distant from escape terrain were avoided in all four seasons. During spring and summer seasons, areas 301 to 500 m from escape terrain were also avoided.

Rams

Use of habitat near escape terrain for male desert bighorn sheep did not occur in proportion to availability in any season of any year (chi-square, df = 7, $P \leq 0.05$). Areas ≥ 901 m from escape terrain were avoided in all seasons (Fig. 25, Table 9). Surprisingly, cells rated as escape terrain were avoided during spring 1990 and 1991. Areas within 100 m of escape terrain were also avoided during spring 1991, but selected during summer 1990 and fall 1991. Areas 301 to 500 m distant from escape terrain were selected most often, being used more than expected in winter 1989-90, spring 1990, fall 1990, and spring 1991. The 201 to 300 m zone was also used more than expected during winter 1990-91 as well as the 501 to 700 m zone during winter 1990-91 and spring 1991.

Table 9. Use of habitat near escape terrain by bighorn sheep in the Eldorado Mountains, Nevada. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = $a/2k$, k = no. of components). Blank spaces indicate use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

Distance from		1989-1990				1990-1991				Years Combined			
escape terrain (m)	% available	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
EWES													
0	16.6	S	S	S	S	S	S	S		S	S	S	S
1-100	18.6	S	S	S	S	S	S	S	S	S	S	S	S
101-200	8.8							S				S	S
201-300	6.2												
301-500	9.7			A			A				A	A	
501-700	7.5	A	A	A	A		A	A		A	A	A	A
701-900	7.1	A	A	A	A	A	A	A	A	A	A	A	A
≥ 901	25.5	A	A	A	A	A	A	A	A	A	A	A	A
RAMS													
0	15.9		A				A			A	A		
1-100	18.9			S			A		S		A	S	S
101-200	9.1												
201-300	6.0					S				S		S	
301-500	9.0	S	S		S		S			S	S	S	S
501-700	6.9					S	S			S	S		
701-900	6.6												
≥ 901	27.6	A	A	A	A	A	A	A	A	A	A	A	A

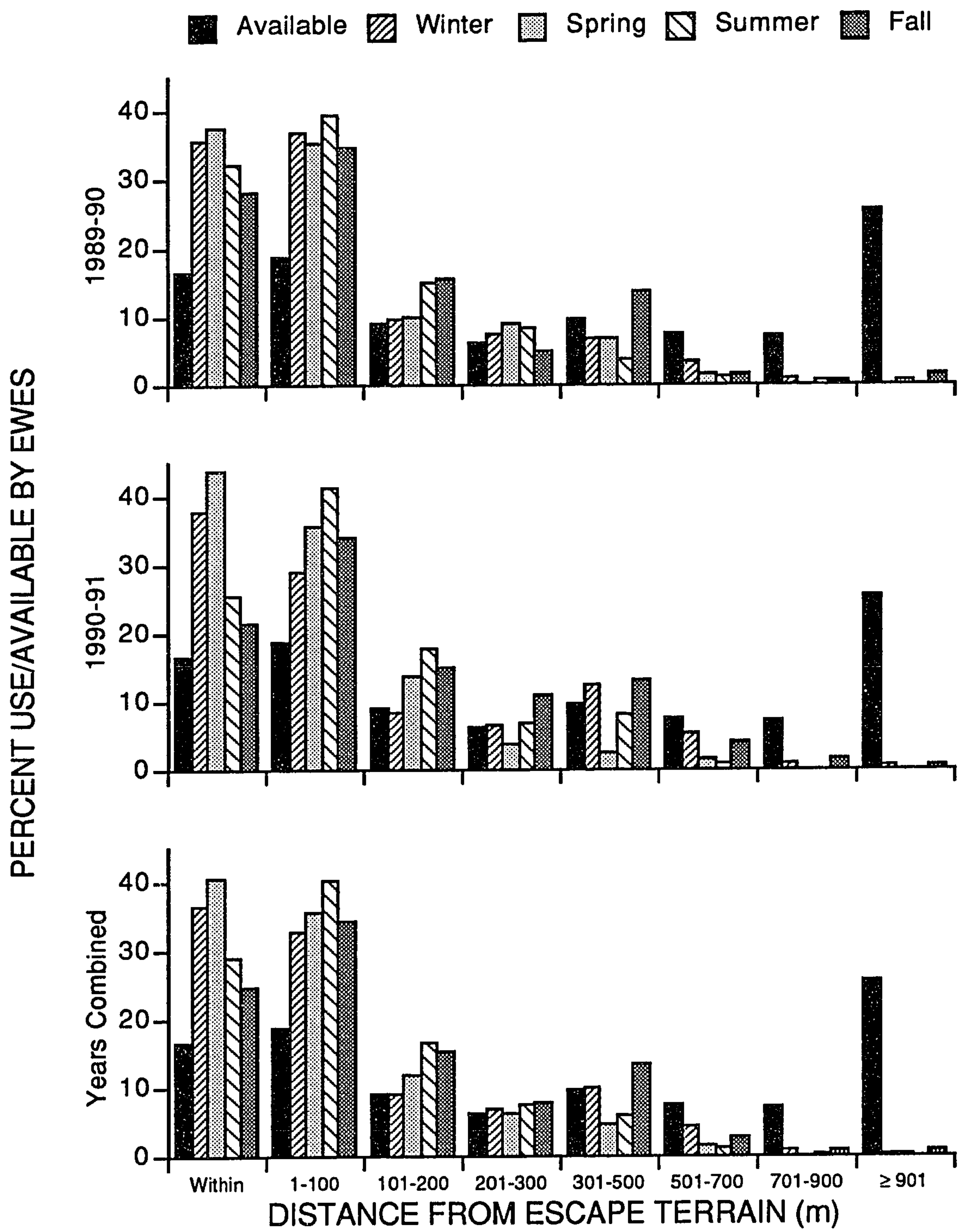

Figure 24. Percentage use of habitat near escape terrain by female bighorn sheep compared to availability by season, year, and years combined. Cells with slopes ≥ 60% are defined as escape terrain.

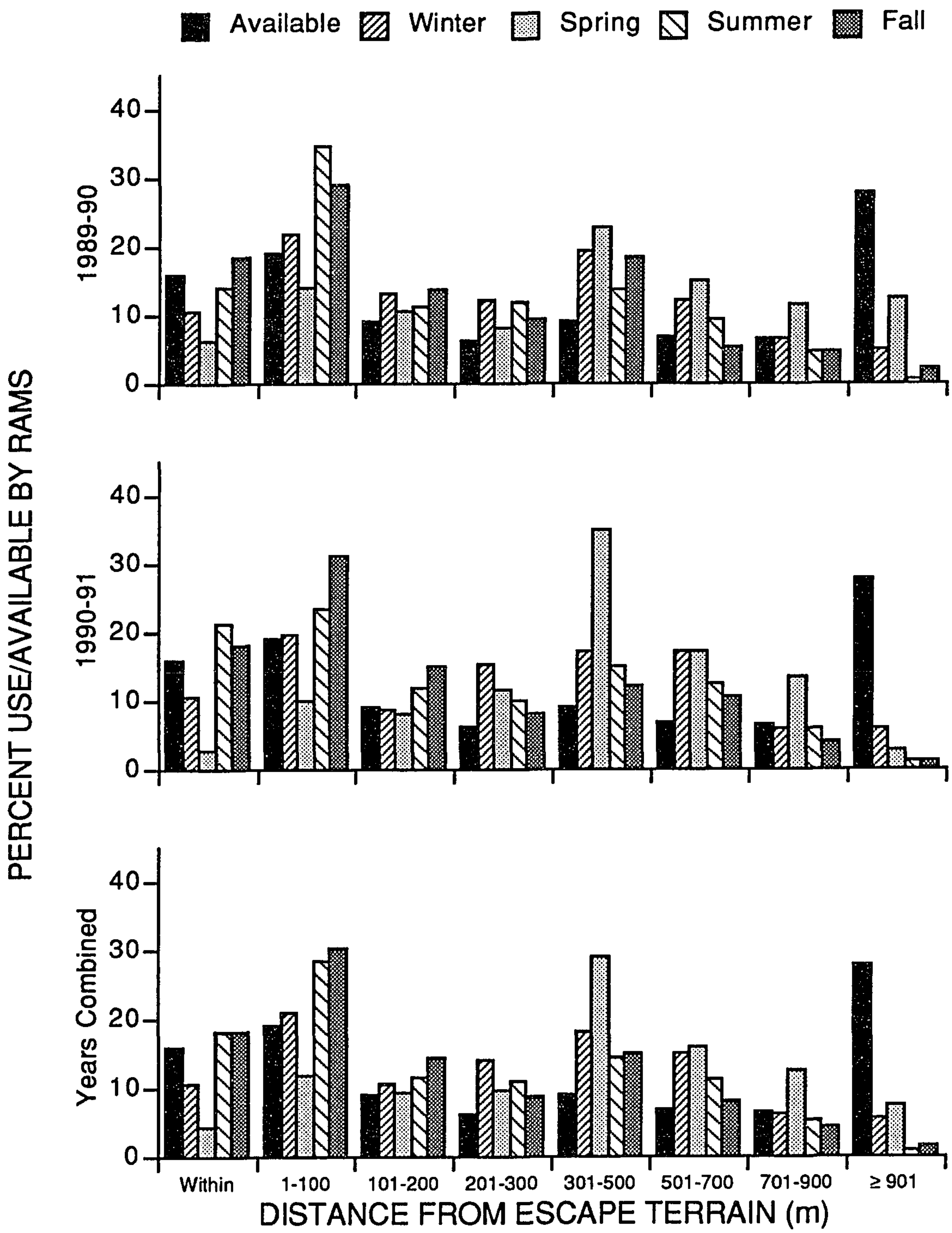

Figure 25. Percentage use of habitat near escape terrain by male bighorn sheep compared to availability by season, year, and years combined. Cells with slopes ≥ 60% are defined as escape terrain.

Use of habitat near escape terrain was similar between years for each season for male desert bighorn sheep (chi-square, df = 7, $P > 0.05$). Pooling data, areas ≥ 901 m from escape terrain were used less than expected in each season while cells rated as escape terrain were avoided during winter and spring (Fig. 25, Table 9). The 101 to 200 m zone was also avoided during spring, but use was greater than expected during the summer and fall seasons. Areas 301 to 500 m distant from escape terrain were selected throughout the year while the 201 to 300 m zone was used more than expected during winter and summer and use was more than expected for the 501 to 700 m zone in the winter and spring seasons.

Land Surface Ruggedness Index

Ewes

Land surface ruggedness index (LSRI) classes were not used proportional to availability in any season of any year by female desert bighorn sheep (chi-square, df = 5, $P \leq 0.05$). Cells in the 0 to 150 and 151 to 300 classes were used less than expected in each season studied while cells with LSRI values between 301 to 450 were used more than expected (Fig. 26, Table 10). The 451 to 600 class was also used more than expected in all seasons except fall 1991 when use was in proportion to availability. And finally, the 601 to 750 class was selected frequently, being used more than expected during winter 1989-90, spring 1990, summer 1990, winter 1990-91, and spring 1991.

Use of LSRI class was similar between years for each season (chi-square, df = 5, $P >$ 0.05). Using pooled data, the 0 to 150 and 151 to 300 classes were avoided in all four seasons while the 301 to 450 and 451 to 600 classes were used more than expected (Fig. 26, Table 10). Use of the 601 to 750 class was also more than expected in all but the fall season. In the spring, the ≥ 751 class was also used in greater proportion than availability.

Table 10. Use of Land Surface Ruggedness Index (LSRI) class by bighorn sheep in the Eldorado Mountains, Nevada. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = $a/2k$, k = no. of components). Blank spaces indicate use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

		1989-1990				1990-1991				Years Combined			
LSRI Class	% available	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
EWES													
0-150	27.5	A	A	A	A	A	A	A	A	A	A	A	A
151-300	25.7	A	A	A	A	A	A	A	A	A	A	A	A
301-450	21.8	S	S	S	S	S	S	S	S	S	S	S	S
451-600	15.7	S	S	S	S	S	S	S		S	S	S	S
601-750	5.9	S	S	S		S	S			S	S	S	
≥ 751	3.4										S		
RAMS													
0-150	29.1	A	A	A	A	A	A	A	A	A	A	*	A
151-300	24.6		S				S			S	S	*	
301-450	21.8	S	S	S	S	S	S	S	S	S	S	*	S
451-600	16.0		A				A				A	*	S
601-750	5.5	A	A	A		A	A			A	A	*	
≥ 751	3.0	A	A	A			A		A	A	A	*	

*use between years significantly different ($p \leq 0.05$)

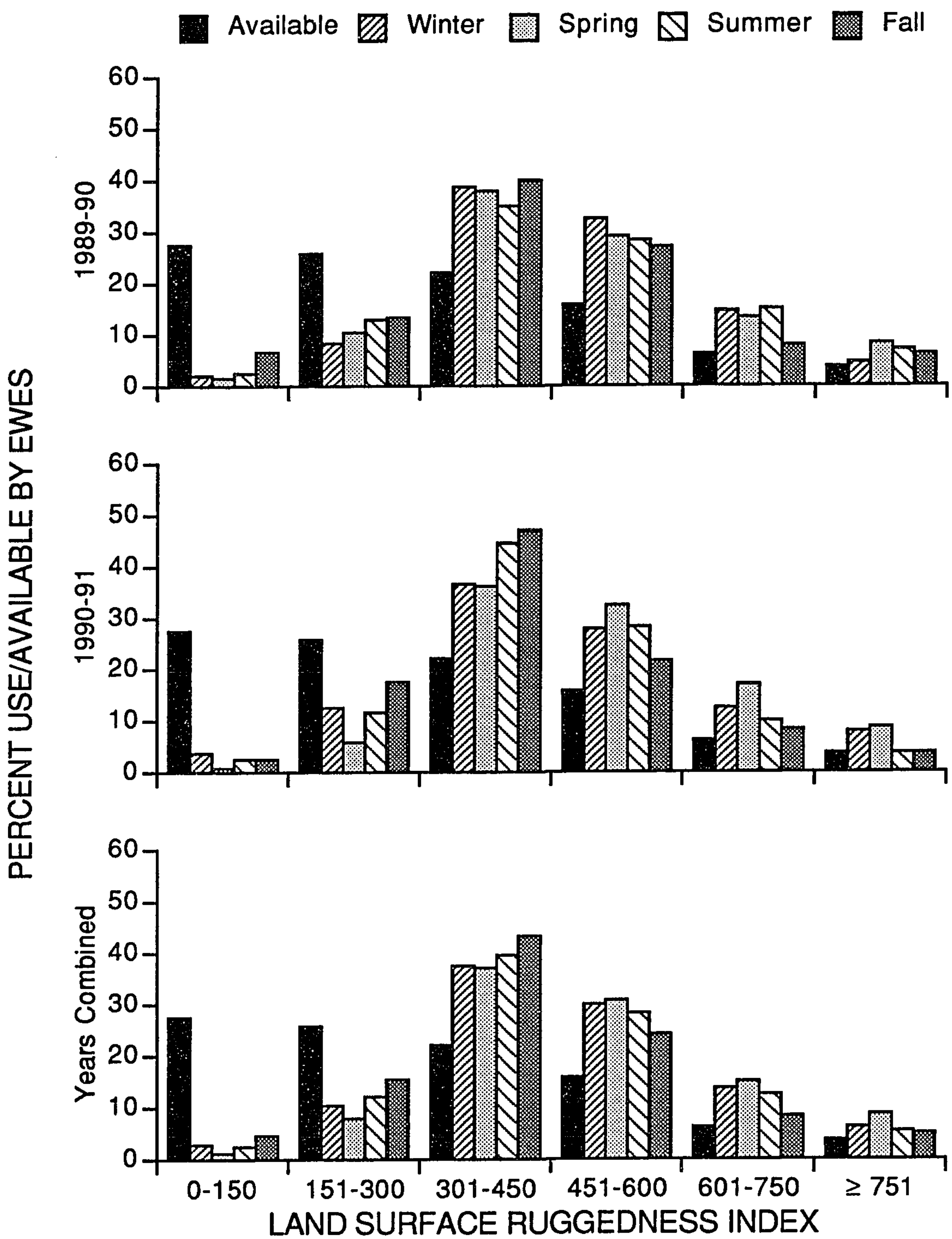

Figure 26. Percentage use of land surface ruggedness index (LSRI) class by female bighorn sheep by season, year, and years combined. A cell's LSRI value is determined by summing the maximum slope values of all cells in the surrounding 3 x 3 cell neighborhood.

Rams

Male desert bighorn sheep did not use LSRI class in proportion to availability in any season of any year (chi-square, df = 5, $P \leq 0.05$). Use of the 0 to 150 class was less than expected in all seasons studied (Fig. 27, Table 10). The 151 to 300 class was selected in spring of both years while the 301 to 450 class was used more than expected in each season of each year. Use of the 451 to 600 class occurred less than expected during spring of both years and the 601 to 750 class was frequently avoided, being used less than expected in winter 1989-90, spring 1990, summer 1990, winter 1990-91, and spring 1991. Use of the ≥ 751 class was also frequently less than expected, being avoided in winter 1989-90, spring 1990, summer 1990, spring 1991, and fall 1991.

Use of LSRI classes between years was similar for winter, spring, and fall seasons (chi-square, df = 2 for winter and spring, df = 5 for fall, $P > 0.05$). Pooling data, areas with gentle topographies (i.e. 0 to 150 class) were avoided in all three seasons (Fig. 27, Table 10). The 151 to 300 and 301 to 450 classes were used more than expected during the winter and spring seasons while the 301 to 450 and 451 to 600 classes were used in greater proportion than available during fall. The 451 to 600 class was avoided during spring and use of the 601 to 750 and ≥ 751 classes was less than expected in both winter and spring seasons. During the summer season, use of LSRI class was significantly different between years (chi-square = 15.8, df = 4, P = 0.0033). Use of the 451 to 600, 601 to 750, ≥ 751 classes occurred in greater proportion in 1991 than 1990.

Distance from Water

Figure 28 shows the mean seasonal distance from water for female and male desert bighorn sheep. For female bighorn sheep, mean distance from water ranged from only 1.0 km in summer 1990 (range 0.0 to 4.2 km) to 1.7 km during fall 1991 (range 0.0 to 3.8 km). Despite the small spread, mean distance from water differed significantly between seasons (F = 11.8, df = 7, P

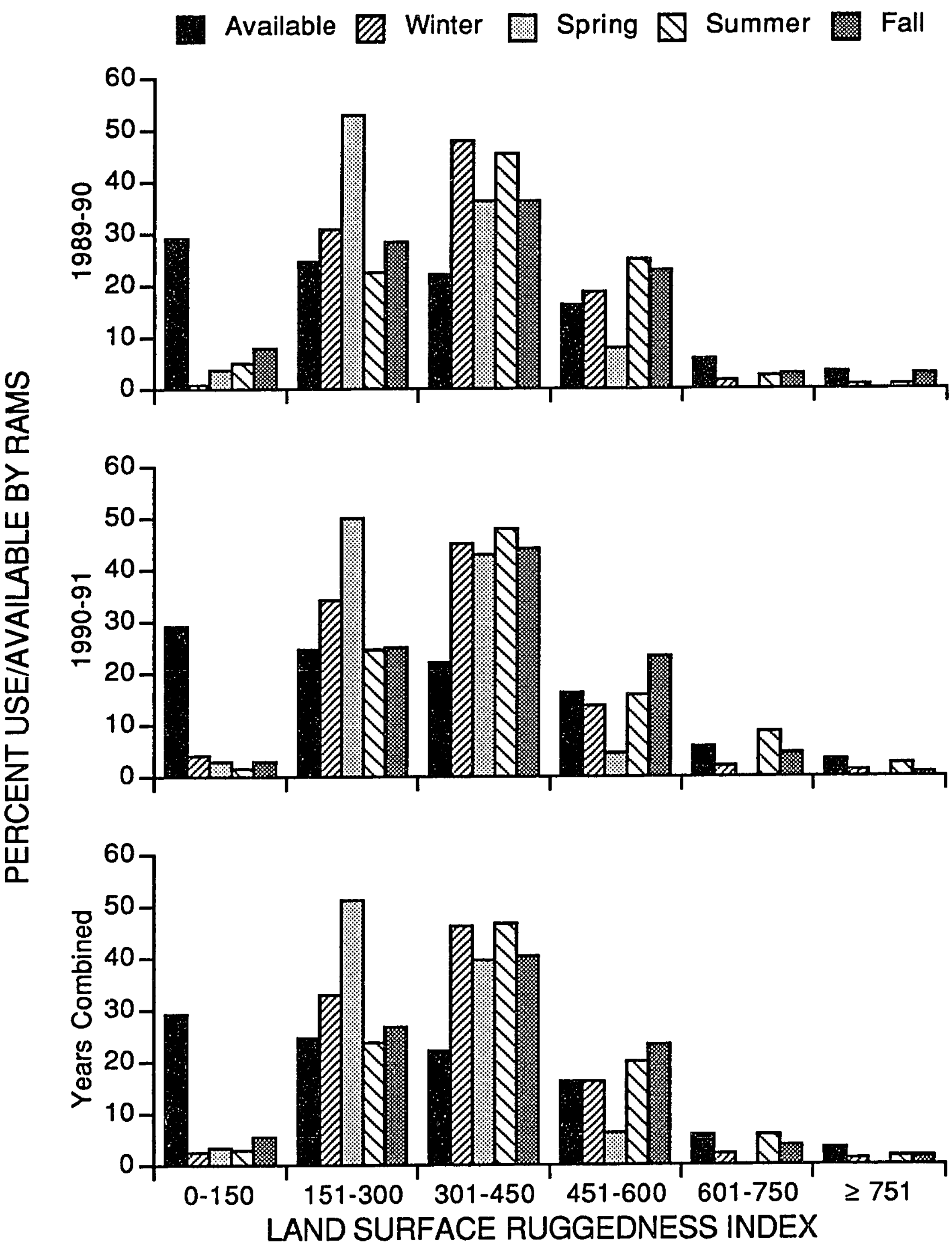

Figure 27. Percentage use of land surface ruggedness index (LSRI) class by male bighorn sheep by season, year, and years combined. A cell's LSRI value is determined by summing the maximum slope values of all cells in the surrounding 3 x 3 cell neighborhood.

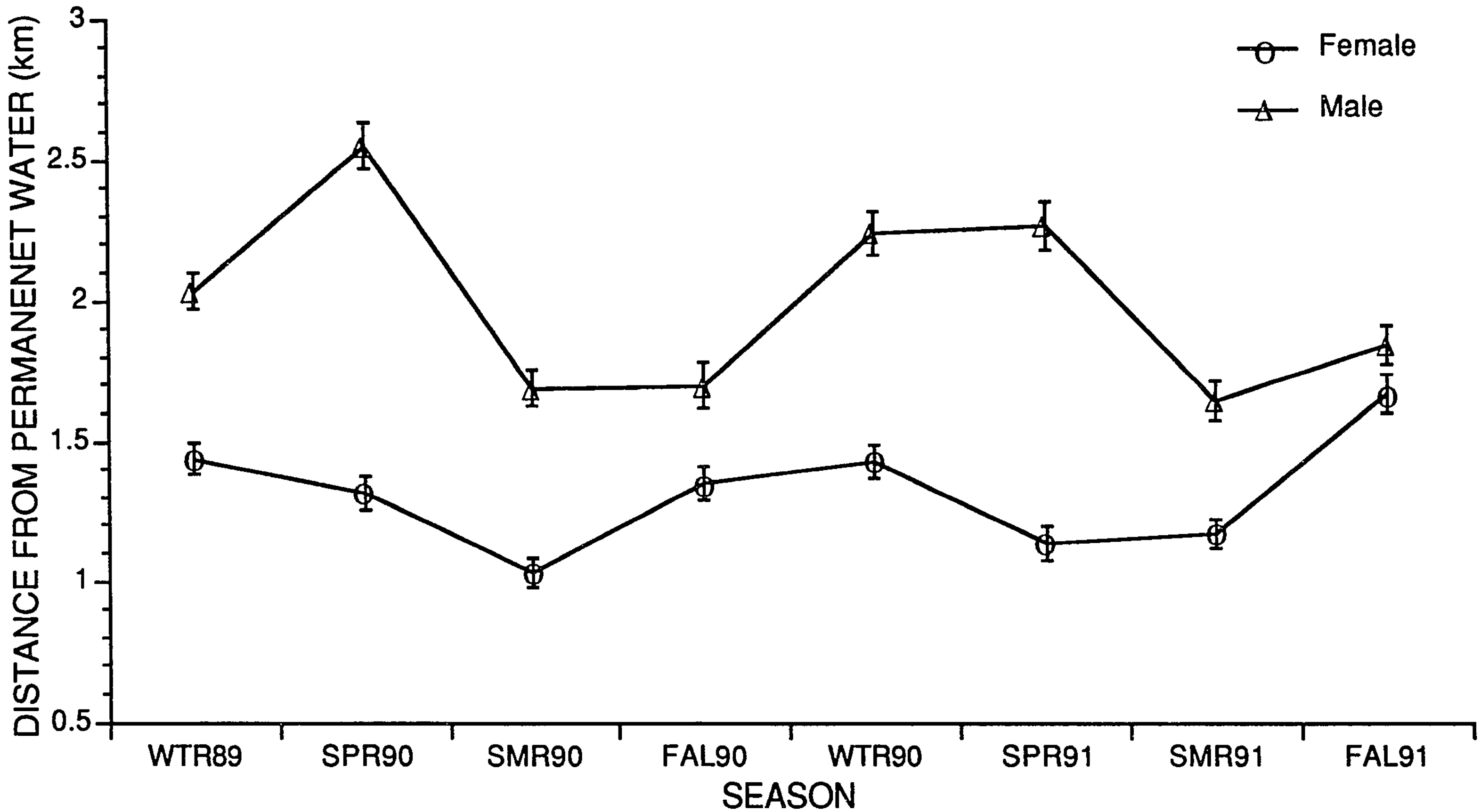

Figure 28. Mean seasonal distance from permanent water with standard error bars for female and male bighorn sheep.

≤ 0.0001). Ewes, on average, could be found closer to water during summer 1990 and 1991 and spring 1991 than in fall 1991 or in either winter. Ewes seldom ventured far from water in any season, however, as 90% or more of all ewe sightings occurred within a three km radius of water within any particular season. During the summer seasons, 90% of all ewe locations were within 2.3 km of water.

Rams were found significantly farther from permanent water sources than ewes in all seasons with the exception of fall 1991 (unpaired t-tests, $P \leq 0.05$). Mean seasonal distance from water for male bighorn sheep ranged from 1.6 km in summer 1991 (range 0.0 to 5.1 km) to 2.6 km in spring 1990 (range 0.6 to 4.2 km). Mean distance differed seasonally ($F = 18.4$, $df = 7$, $P \leq 0.0001$) with summer and fall distances significantly shorter than those in spring. Winter distances were also farther than those observed in summer 1990 and 1991 and fall 1990. Paradoxically, the greatest distance a ram was observed from water (5.1 km) occurred during summer 1991.

Habitat Evaluation Model

The primary study area was evaluated for bighorn sheep suitability using the revised Cunningham habitat evaluation model (Cunningham 1989) (Fig. 29). Over 55% of all ewe observations were located within good quality habitat while an additional 33.6% were found within areas rated as excellent quality (Fig. 30, Table 11). Of the 192 sightings recorded outside of good or excellent quality habitat, all but five were located within 300 m of these areas (Table 12). Less than 0.5% of all ewe sightings occurred in an area rated as poor quality habitat.

Adult male bighorn sheep showed a strong affinity for areas rated as good quality habitat (Fig. 31, Table 11). Out of 1,208 observations, 840 sightings, or 69.5% of total observations, occurred within this habitat class. Sightings within excellent and fair quality habitats occurred in approximately equal numbers with 170 and 189 respective observations. Areas rated as poor quality habitat were seldom used with less than 1% of total ram observations occurring within this

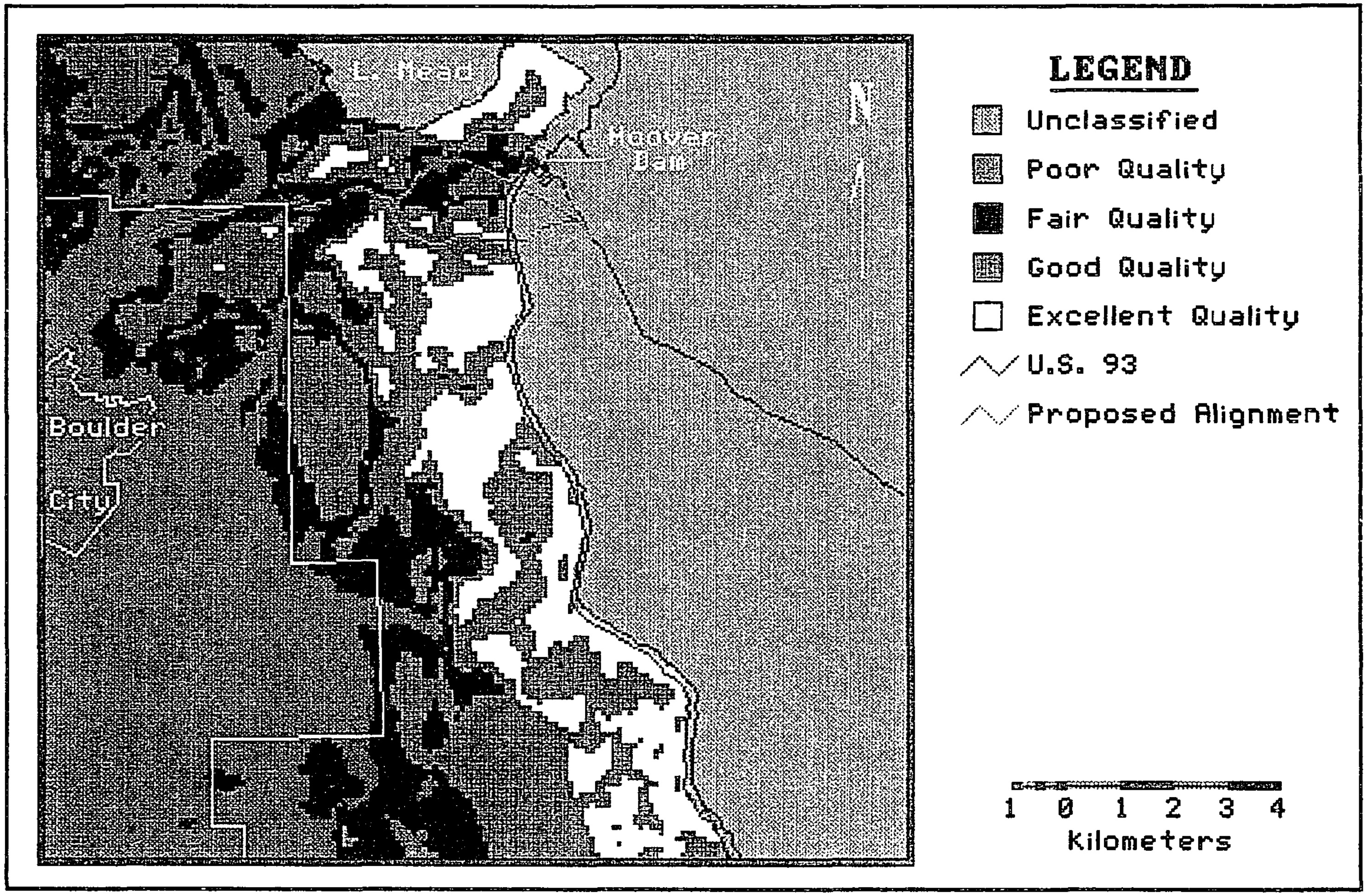

Figure 29. Areas of predicted bighorn sheep use based on the modified Cunningham habitat evaluation model (Cunningham 1989).

Table 11. Number of sheep observations within areas of predicted bighorn use based on the modified Cunningham habitat evaluation model (Cunningham 1989).

Habitat Classification	Ewes No. of obsv.	Ewes %	Rams No. of obsv.	Rams %	Lambs No. of obsv.	Lambs %
Poor quality	6	0.3	9	0.7	0	0.0
Fair quality	186	10.5	189	15.7	3	3.4
Good quality	981	55.6	840	69.5	32	36.4
Excellent quality	593	33.6	170	14.1	53	60.2
Total	1766	100.0	1208	100.0	88	100.0

Table 12. Distance (m) from good or excellent quality habitat by bighorn sheep in the Eldorado Mountains, Nevada, between 1 December 1989 - 30 November 1991. Distances recorded for lambs are measured from excellent quality habitat during the spring season (Mar-May).

Distance from good or excellent habitat (m)	Ewes No. of obsv.	Ewes Cumulative Count	Ewes Cumulative %	Rams No. of obsv.	Rams Cumulative Count	Rams Cumulative %
0	1574	1574	89.1	1010	1010	83.6
1-100	142	1716	97.2	125	1135	94.0
101-200	28	1744	98.8	49	1184	98.0
201-300	17	1761	99.7	18	1202	99.5
301-400	4	1765	99.9	4	1206	99.8
401-500	0	1765	99.9	0	1206	99.8
≥ 501	1	1766	100.0	2	1208	100.0

Distance from excellent habitat (m)	Lambs No. of obsv.	Lambs Cumulative Count	Lambs Cumulative %
0	53	53	60.2
1-100	20	73	83.0
101-200	10	83	94.3
201-300	2	85	96.6
301-400	1	86	97.7
401-500	1	87	98.9
≥ 501	1	88	100.0

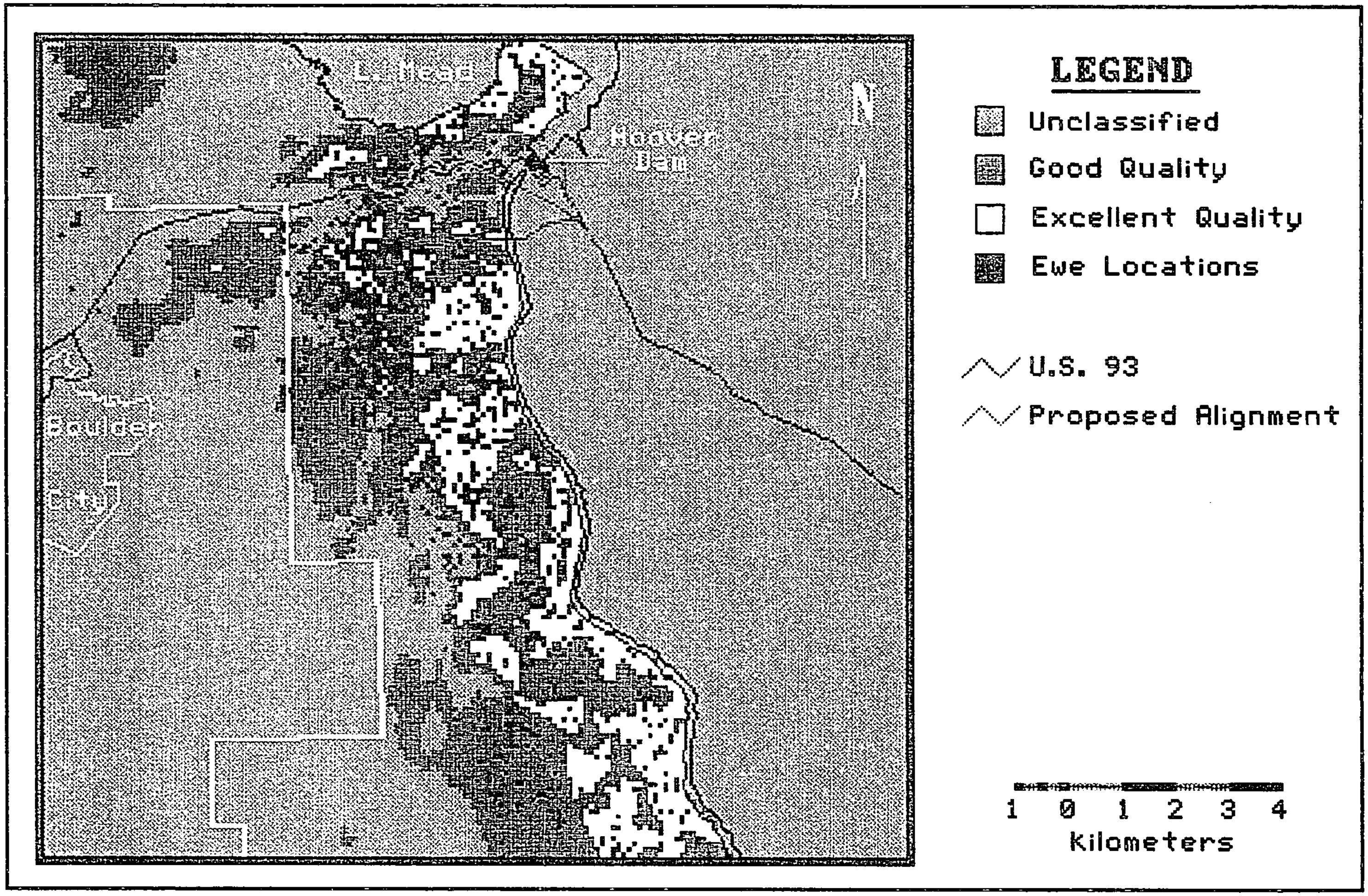

Figure 30. Female bighorn sheep observation in relation to good and excellent quality habitat.

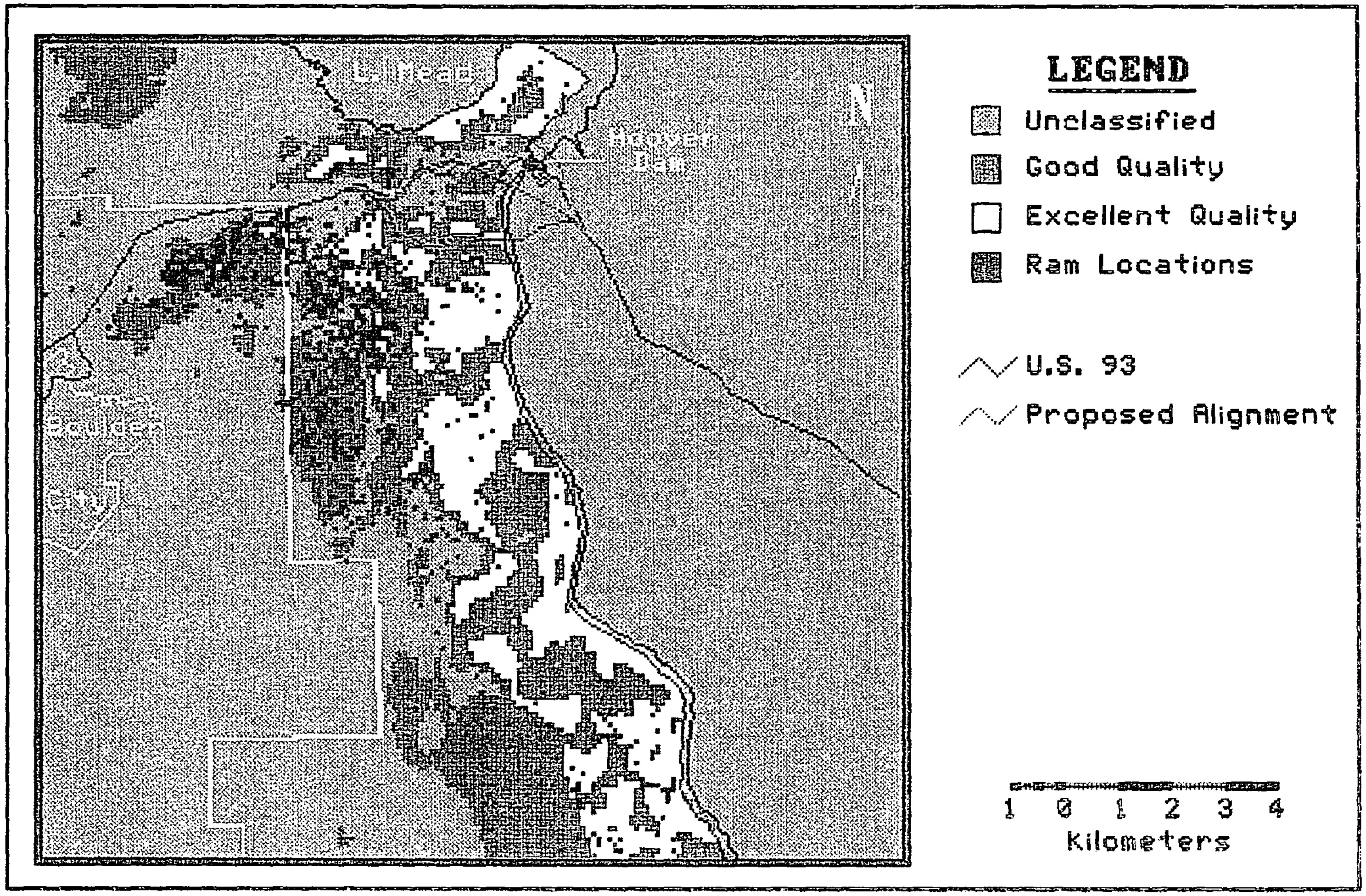

Figure 31. Male bighorn sheep observations in relation to good and excellent quality habitat.

class. Adult rams, like ewes, were rarely observed far from areas rated as good or excellent quality habitat (Table 12).

Areas rated as excellent quality habitat proved to be a good predictor for lamb usage (Fig 32, Table 11). Approximately 94% of lamb observations during the spring lambing season occurred within this class or within 200 m from it (Table 12). No lamb observations were made within areas rated as poor quality habitat.

Affects of Highway 93 on Bighorn Sheep Distribution

Two hundred and forty-nine sightings of female bighorn sheep occurred within good to excellent quality habitat within 1.6 km of U.S. 93 during the first year of the study (Table 13). An additional 183 were sighted the following year (Table 13). Chi-squared goodness of fit tests indicate that use of good to excellent quality habitat adjacent to the highway was not proportional to its availability for either year ($P \leq 0.05$). However, evidence for rejecting the null hypothesis of equal use was only marginal for the first year (chi-square = 25.3, df = 15, $P = 0.046$). In fact, construction of 95% confidence intervals for the difference between two proportions failed to identify a significant difference between observed and expected use in any of the use categories during 1989-90. Construction of 95% confidence intervals on percentage use (Neu et al. 1974) yielded identical results. While results from the second year showed clearer evidence for disproportionate use (chi-square = 67.7, df = 15, $P \leq 0.0001$), actual avoidance of the highway was inconclusive (Table 13). While the zone immediately adjacent to the highway (0 to 100 m) was avoided, so was the 401 to 500 m zone. Use was proportional to availability in all other zones with the exception of the 1501 to 1600 m zone where use was greater than expected.

Distance from U.S. 93 was measured for 88 lamb observations during spring lambing season. Only one observation was within 500 m of the highway. This sighting occurred on 24 May 1991 when the lamb sighted was estimated at three to four months of age.

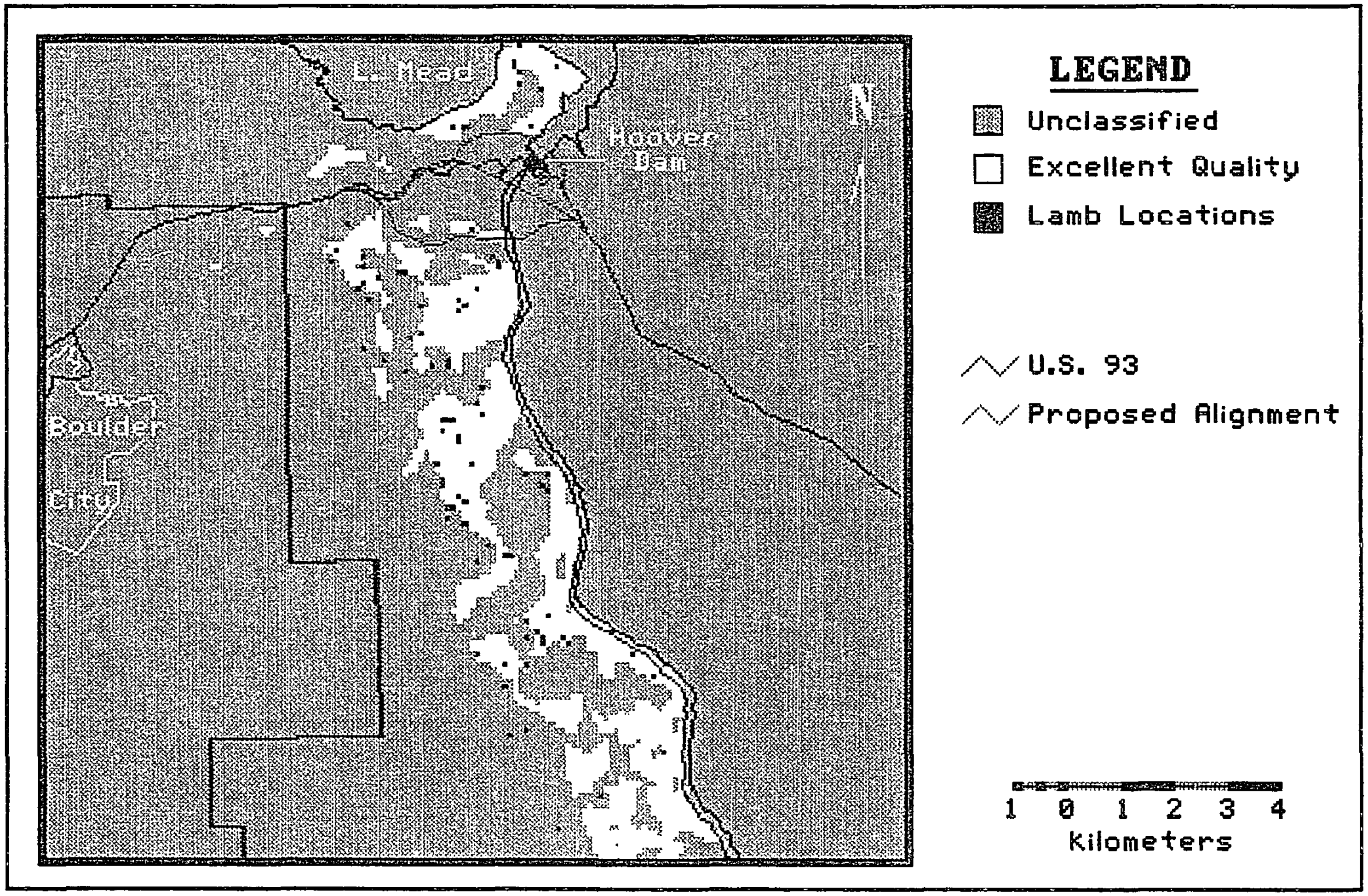

Figure 32. Bighorn sheep lamb observations in relation to excellent quality habitat.

Table 13. Use of suitable habitat adjacent to U.S. 93 by female desert bighorn sheep in comparison to its availability. Chi-squared goodness of fit tests were performed to determine if use was in proportion to availability (Neu et al. 1974). Selection (S) and avoidance (A) were determined by constructing 95% confidence intervals for the difference between 2 proportions (McClave and Dietrich 1988), adjusted for simultaneous inference (significance level = $a/2k$, k = no. of components). (N) indicates use was in proportion to availability. The sequential Bonferroni test was used to control the table-wide type-I error rates (Rice 1988).

Distance from highway (m)	Total area available (ha)	1989-1990 Number of bighorn observed	1989-1990 Number of bighorn expected	1989-1990 Analysis of use	1990-1991 Number of bighorn observed	1990-1991 Number of bighorn expected	1990-1991 Analysis of use
0-100	206	21	28	N	4	21	A
101-200	106	12	15	N	10	11	N
201-300	104	16	14	N	11	10	N
301-400	119	18	16	N	12	12	N
401-500	119	13	16	N	4	12	A
501-600	122	14	17	N	9	12	N
601-700	130	11	18	N	9	13	N
701-800	138	11	19	N	12	14	N
801-900	119	14	16	N	10	12	N
901-1000	113	14	16	N	11	11	N
1001-1100	105	16	14	N	9	10	N
1101-1200	95	20	13	N	12	10	N
1201-1300	87	17	12	N	14	9	N
1301-1400	86	19	12	N	18	9	N
1401-1500	88	16	12	N	15	9	N
1501-1600	80	17	11	N	23	8	S
Total	1817	249	249		183	183	

1989-1990: $X^2 = 25.3$, df = 15, $P = 0.04$ **1990-1991**: $X^2 = 67.7$, df = 15, $P \leq 0.0001$

Distribution and Movements of Bighorn Sheep along Proposed Alignments

Due to a lack of animals collared in the vicinity of the proposed Promontory Point and Sugarloaf Mountain highway alignments during the first capture operation, recorded bighorn sheep use prior to the second capture operation was judged to be biased. As such, only observations recorded after spring 1990 were used in assessing possible differences between the proposed road alignments in the following analyses.

Use of Adjacent Habitat

Numbers of observations within 0.5 km of the proposed alignments was equivalent between alignments for both female and male desert bighorn sheep (Table 14). Use of habitat by either sex was also equivalent between alignments for areas within 1.0 km of the proposed right of ways.

Approximately equal numbers of radio-collared bighorn sheep were observed in proximity to each alignment (Table 14).

Areas of Relative Use

Figure 33 depicts areas of relative bighorn sheep use within the primary study area. Number of observations within 0.5 km of any one cell ranged from 0 to 193. The median number of observations was 15 with five and 36 recorded sightings delimiting the lower and upper quartiles, respectively.

Portions of each alignment overlap with high and high-moderate use areas (Fig. 33, Table 15). PPA has the greatest amount of overlap with GSA second. SLA has the least impact within these categories.

Table 14. Comparison between proposed highway alignments of bighorn sheep use of adjacent habitat. Numbers in parentheses indicate number of radio-collared bighorn sheep observed within proximity zone.

	PROPOSED ALIGNMENT						
	Gold Strike Canyon		Sugarloaf Mountain		Promontory Point		Total
Area within 0.5 km of alignment (ha)	450		460		536		1446
No. of ewe observations[a]	103	(7)	87	(5)	106	(5)	296
Expected no. of obsv.	92		94		110		296
$X^2 = 2.0$, d.f. = 2, $p = 0.38$							
No. of ram observations[a]	45	(8)	40	(9)	47	(9)	132
Expected no. of obsv.	41		42		49		132
$X^2 = 0.5$, d.f. = 2, $p = 0.76$							
Area within 1.0 km of alignment (ha)	917		898		991		2806
No. of ewe observations[a]	211	(8)	167	(6)	197	(6)	575
Expected no. of obsv.	188		184		203		575
$X^2 = 4.6$, d.f. = 2, $p = 0.10$							
No. of ram observations[a]	103	(12)	83	(13)	93	(13)	279
Expected no. of obsv.	91		89		99		279
$X^2 = 2.3$, d.f. = 2, $p = 0.32$							

[a]Does not include observations for winter (Dec-Feb) 1989-90 or spring (Mar-May) 1990.

Table 15. Overlap of proposed highway alignments with relative bighorn sheep use areas.

	Number of 100m x 100m (ha) cells intersected		
Relative	PROPOSED ALIGNMENT		
Use Area	Gold Strike Canyon	Sugarloaf Mountain	Promontory Point
None	0	0	0
Low	0	6	0
Low-moderate	2	4	6
High-moderate	25	21	36
High	20	17	14
Total	47	48	56

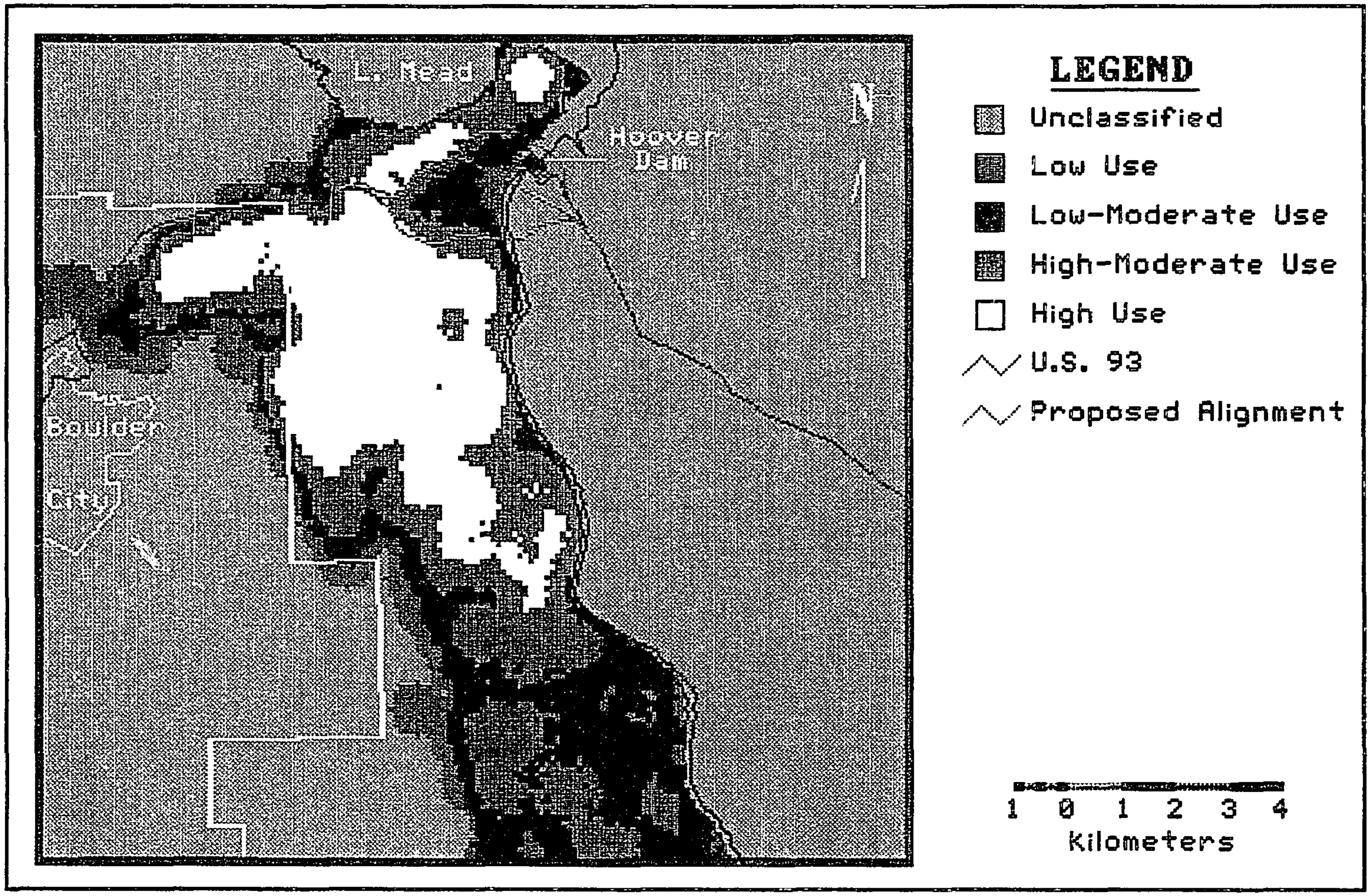

Figure 33. Areas of relative bighorn sheep use within the primary study area.

Movements Across Proposed Alignments

Visual Observations

Due to the difficult access to portions of the proposed highway alignments, man-power limitations, and constraints on field time, few bighorn sheep crossings of the proposed highway alignments were observed. Of the crossings recorded, only a small percentage occurred along the same path as a previous observation. Overall number of observed crossings was similar between alignments with nine, 10, and 10 crossings for GSA, SLA, and PPA, respectively. Locations and number of observed crossings are provided in Figure 34.

Relocation Data

Number of crossings as determined by relocation data was similar between alignments for both sexes (chi-square, $P > 0.05$). Telemetry data indicated that mature rams crossed GSA, SLA, and PPA 28, 22, and 24 times, respectively (Table 16). The number of crossings recorded for radio-collared ewes were consistently higher than those for rams although the differences were not statistically significant (chi-square, $P > 0.05$). Ewes were documented as crossing GSA, SLA, and PPA a total of 44, 35, and 41 times, respectively (Table 16).

Time of year appeared to have no influence on ewe movements as contingency table analysis indicated the number of crossings was similar between seasons for each of the separate alignments ($P > 0.05$). Mature rams, on the other hand, showed distinct seasonality in their movement patterns although sample size was too small for statistical testing. Of the 74 documented adult ram crossings, all occurred in summer and fall.

Movement patterns for radio-collared bighorn sheep in the vicinity of the proposed highway alignments are provided in Figures 35 - 46.

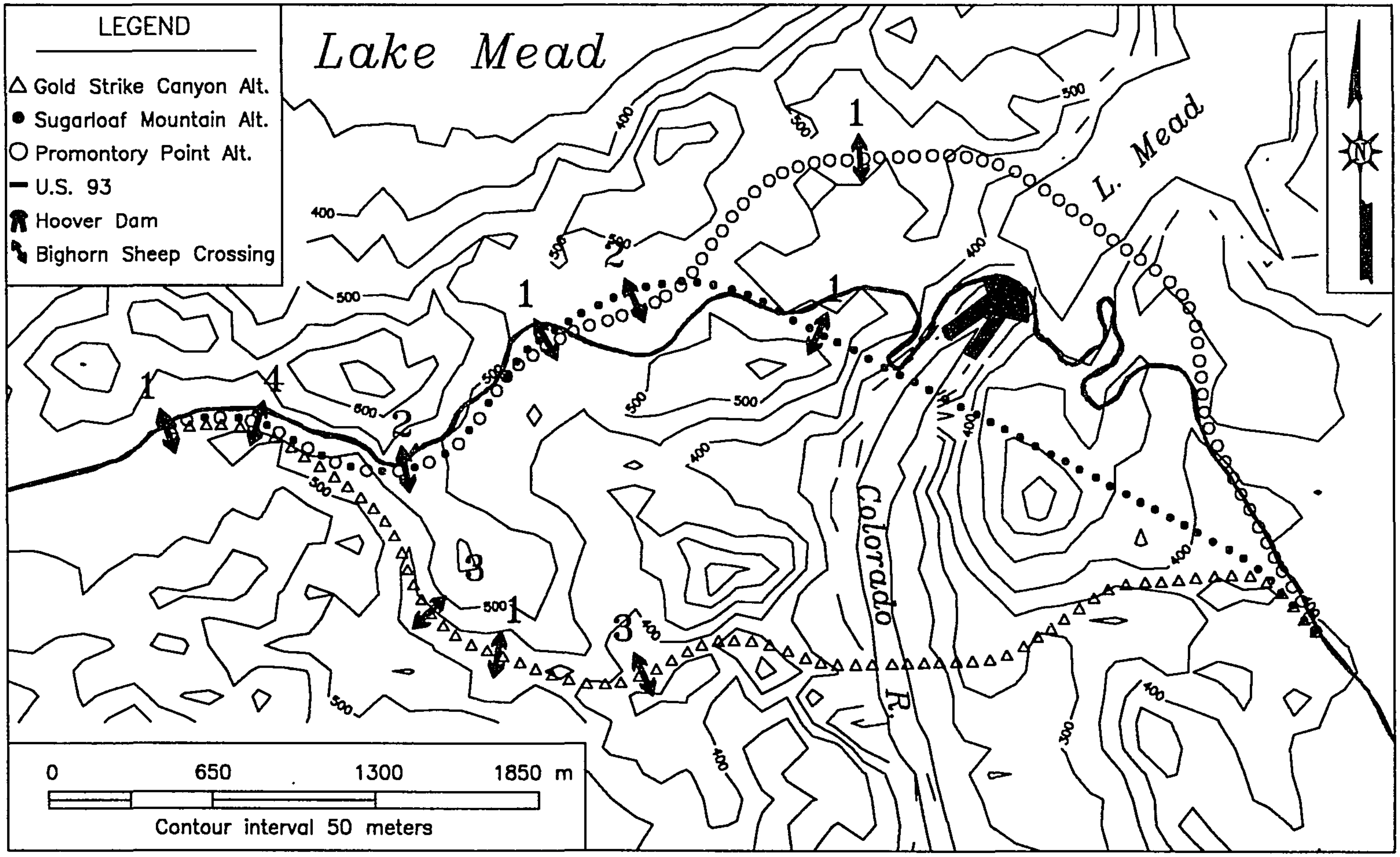

Figure 34. Number and location of bighorn sheep crossings of the proposed highway alignments.

Table 16. Number of crossings of proposed highway alignment by bighorn sheep by year and by season as determined by relocation data.

	1989-1990												1990-1991											
	Dec-Feb			Mar-May			Jun-Aug			Sep-Nov			Dec-Feb			Mar-May			Jun-Aug			Sep-Nov		
EWES	G	S	P	G	S	P	G	S	P	G	S	P	G	S	P	G	S	P	G	S	P	G	S	P
A811	5			5			2						2											
A821										2	2	2	2											
A930				6	6	8	4	2	2							2	2	2						
B488	•	•	•	•	•	•	2	2	2	7	7	7	1	1	1			2	7	7	7	1		
B759	•	•	•	•	•	•			2	2	2	2	7	7	7	1	1	3				2	2	2
Total	5			11	6	8	8	4	6	11	11	11	12	8	8	3	3	7	7	7	7	3	2	2
RAMS																								
A830																			2	2	2			
A840							2	2		2	2	2							1	1	1			
A940										4	2	2							5	2	2	1	2	2
A963				2[a]	2[a]	2[a]													1	1	1			
A086				4[a]	4[a]	4[a]	4[a]	2[a]	2[a]	2[a]						4[a]	4[a]	4[a]	2	2	2	2	2	4
B539	•	•	•	•	•	•	3[a]	1[a]	1[a]	1[a]	1[a]	1[a]							3	3	3	1	1	3
B880	•	•	•	•	•	•													2[a]					
Total[b]							2	2		6	4	4							14	11	11	4	4	9

G = Gold Strike Canyon Alignment, S = Sugarloaf Mountain Alignment, P = Promontory Point Alignment

[a]Juvenile ram: < 3 years of age.

[b]Does not include juvenile rams.

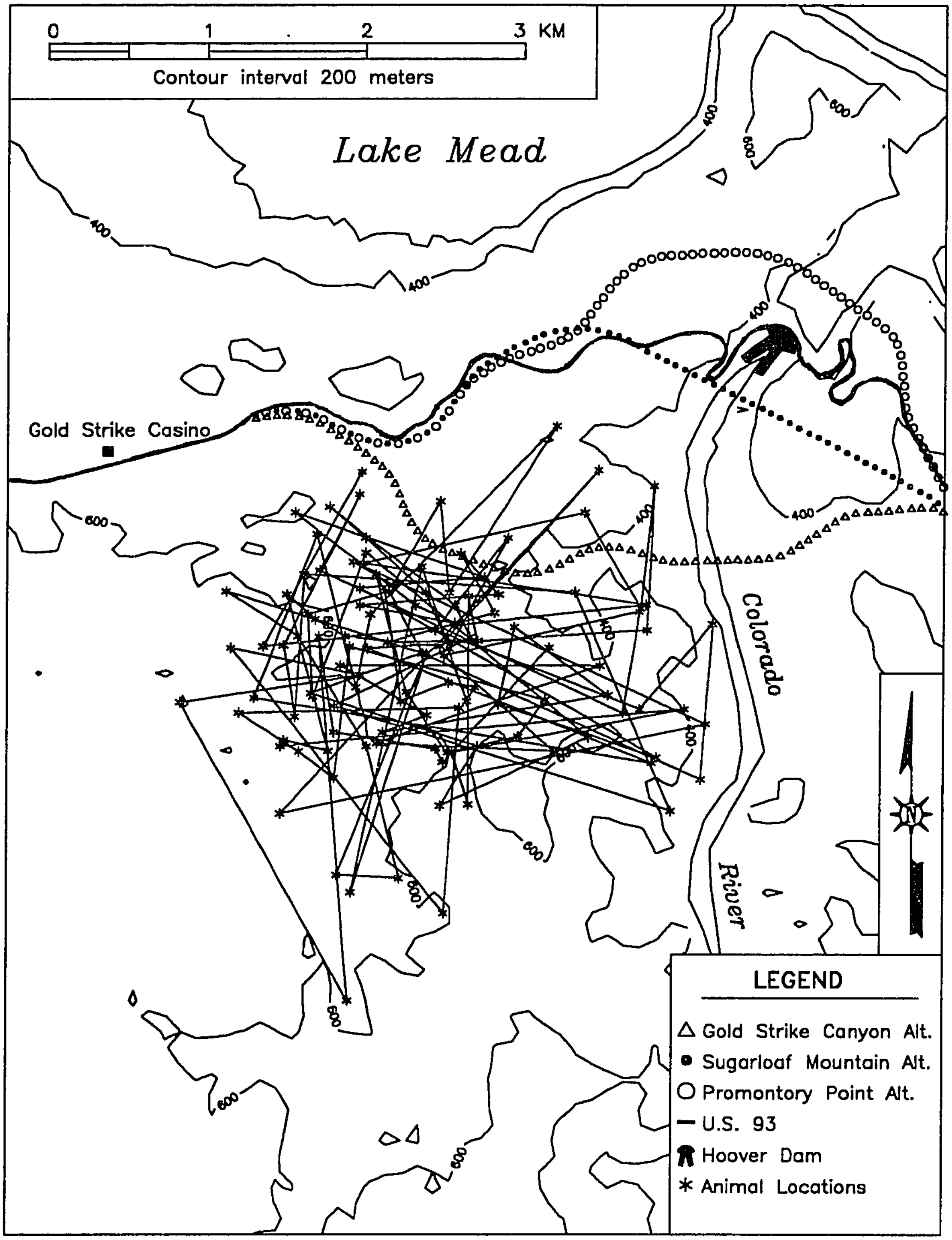

Figure 35. Movement of female bighorn sheep, A811, from 1 December 1989 - 30 November 1991.

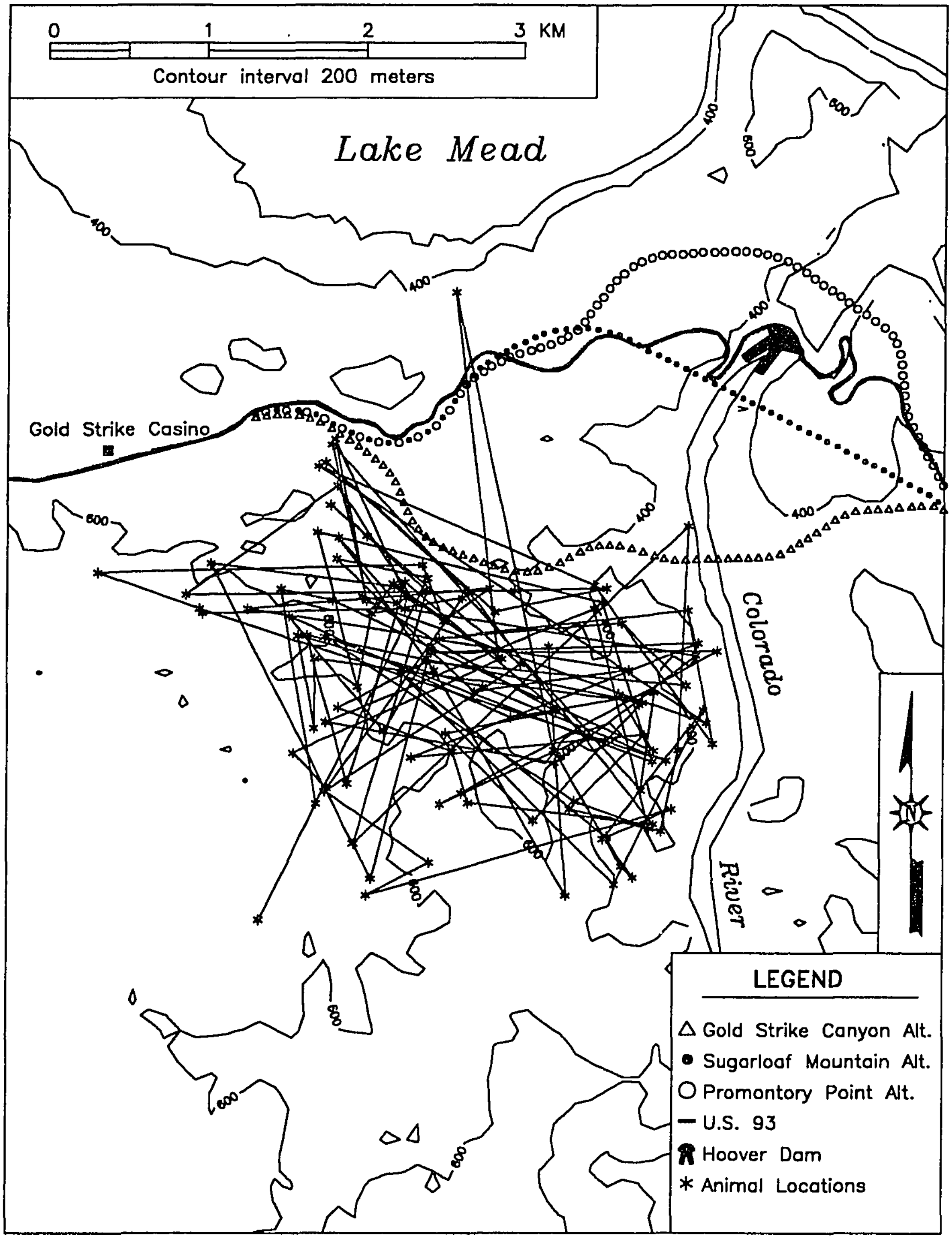

Figure 36. Movement of female bighorn sheep, A821, from 1 December 1989 - 30 November 1991.

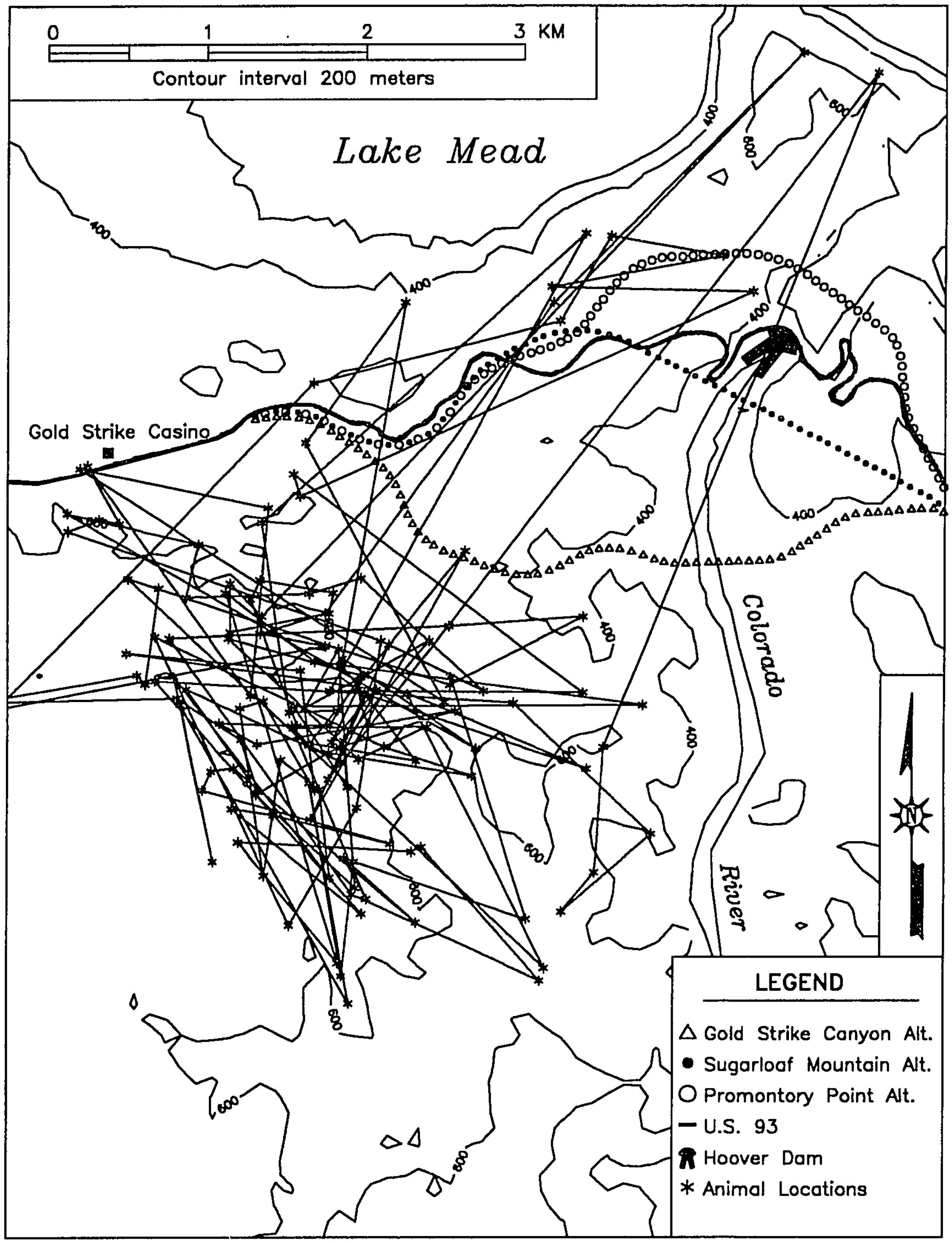

Figure 37. Movement of female bighorn sheep, A930, from 1 December 1989 - 30 November 1991.

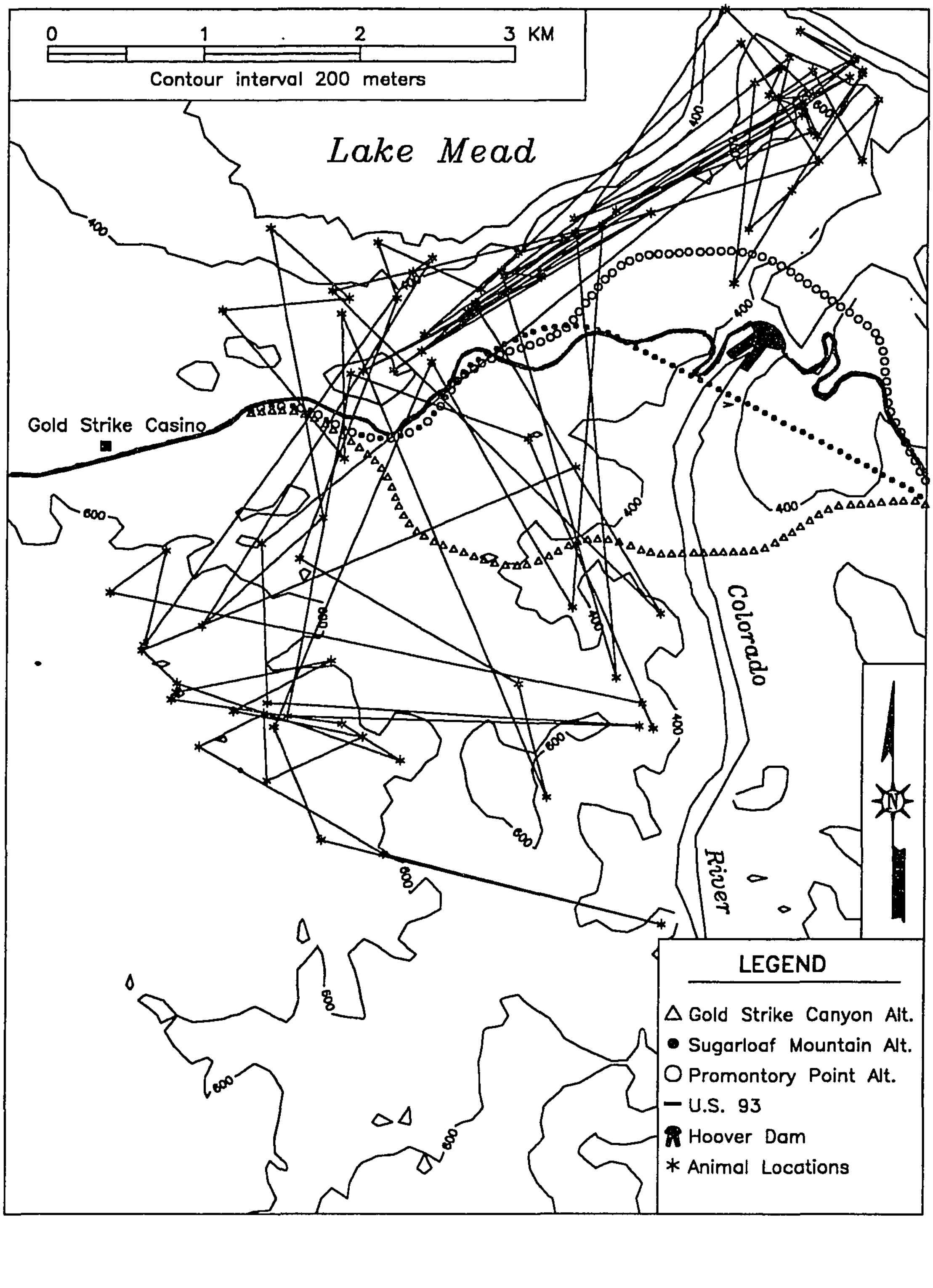

Figure 38. Movement of female bighorn sheep, B488, from 1 June 1990 - 30 November 1991.

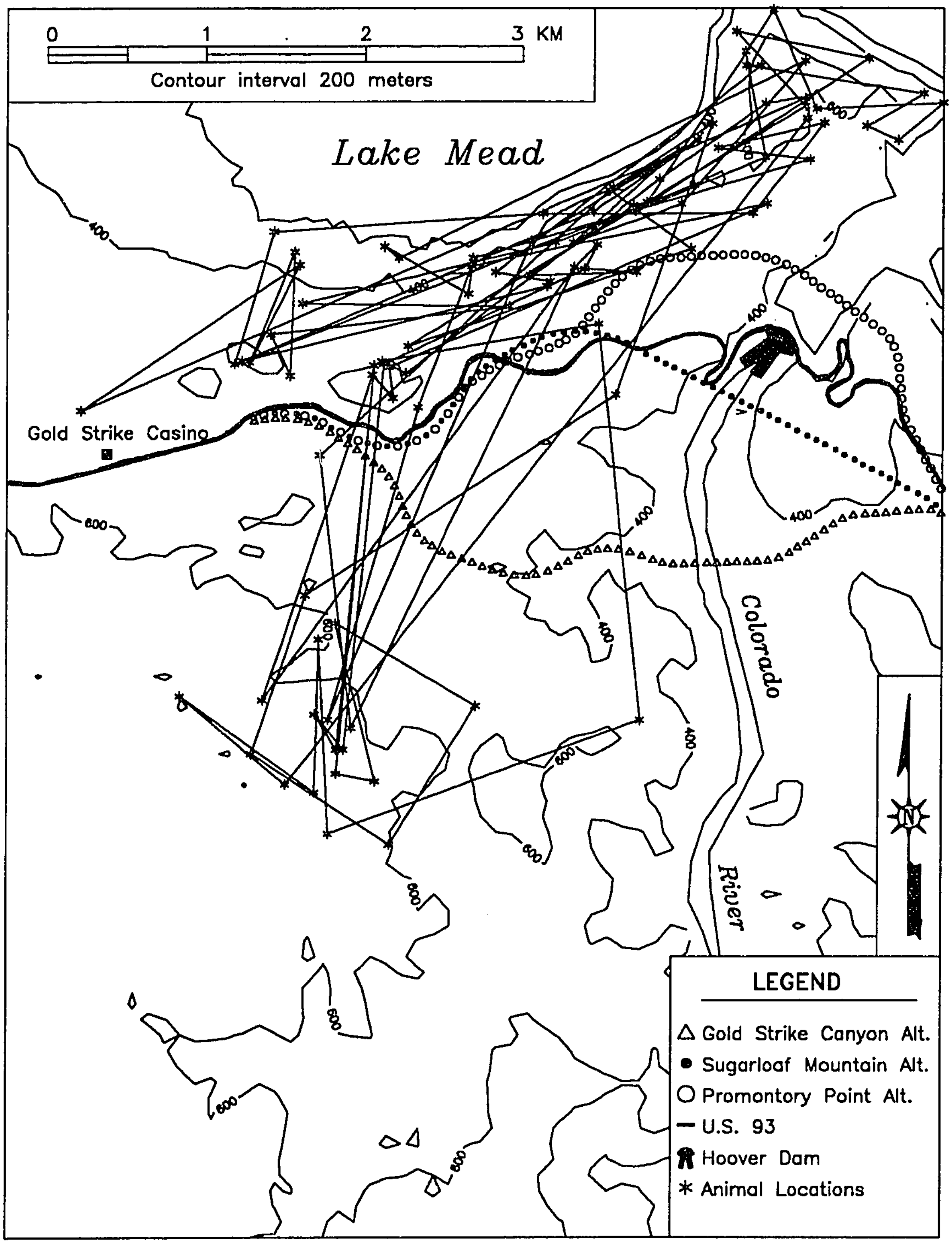

Figure 39. Movement of female bighorn sheep, B759, from 1 June 1990 - 30 November 1991.

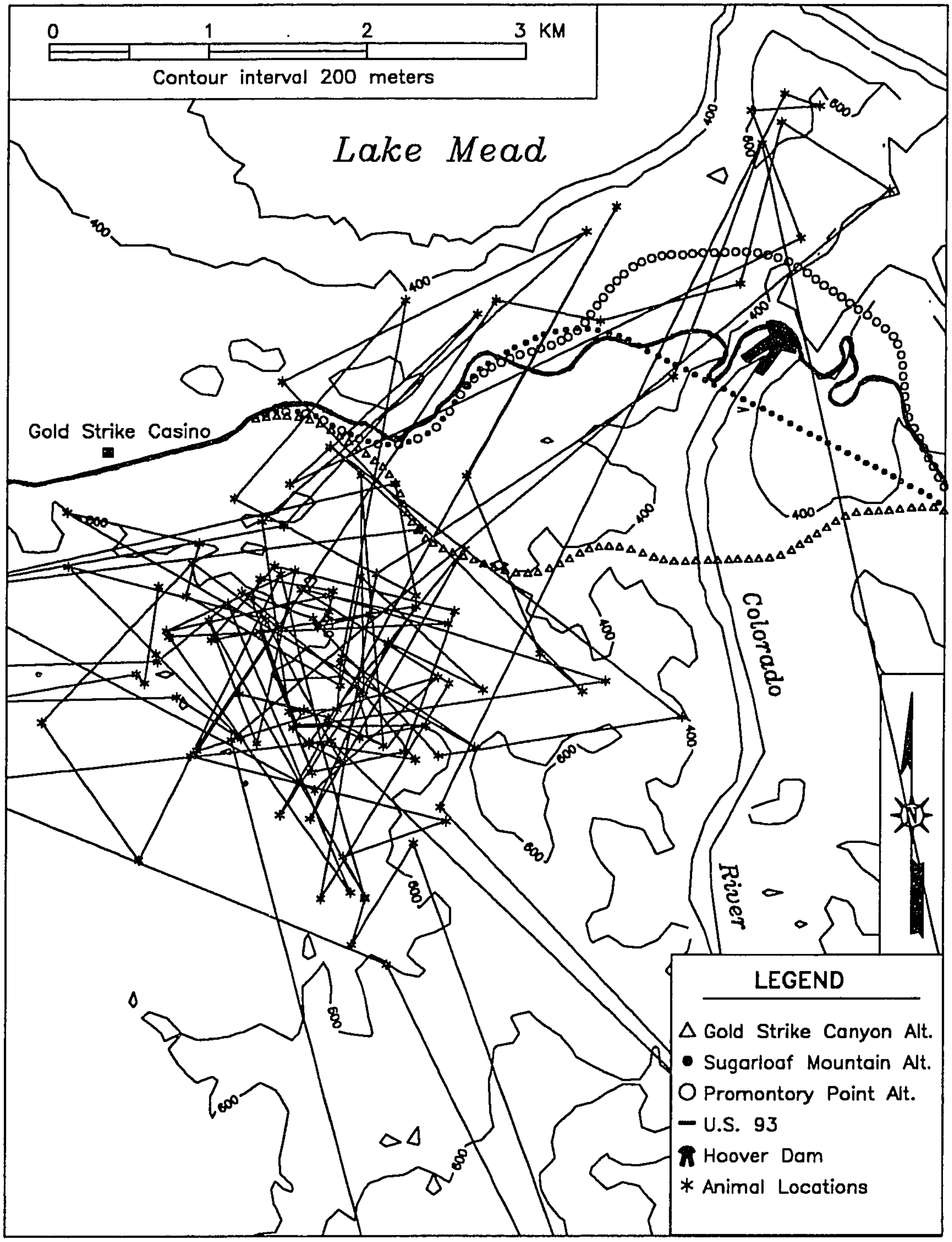

Figure 40. Movement of male bighorn sheep, A086, from 1 December 1989 - 30 November 1991.

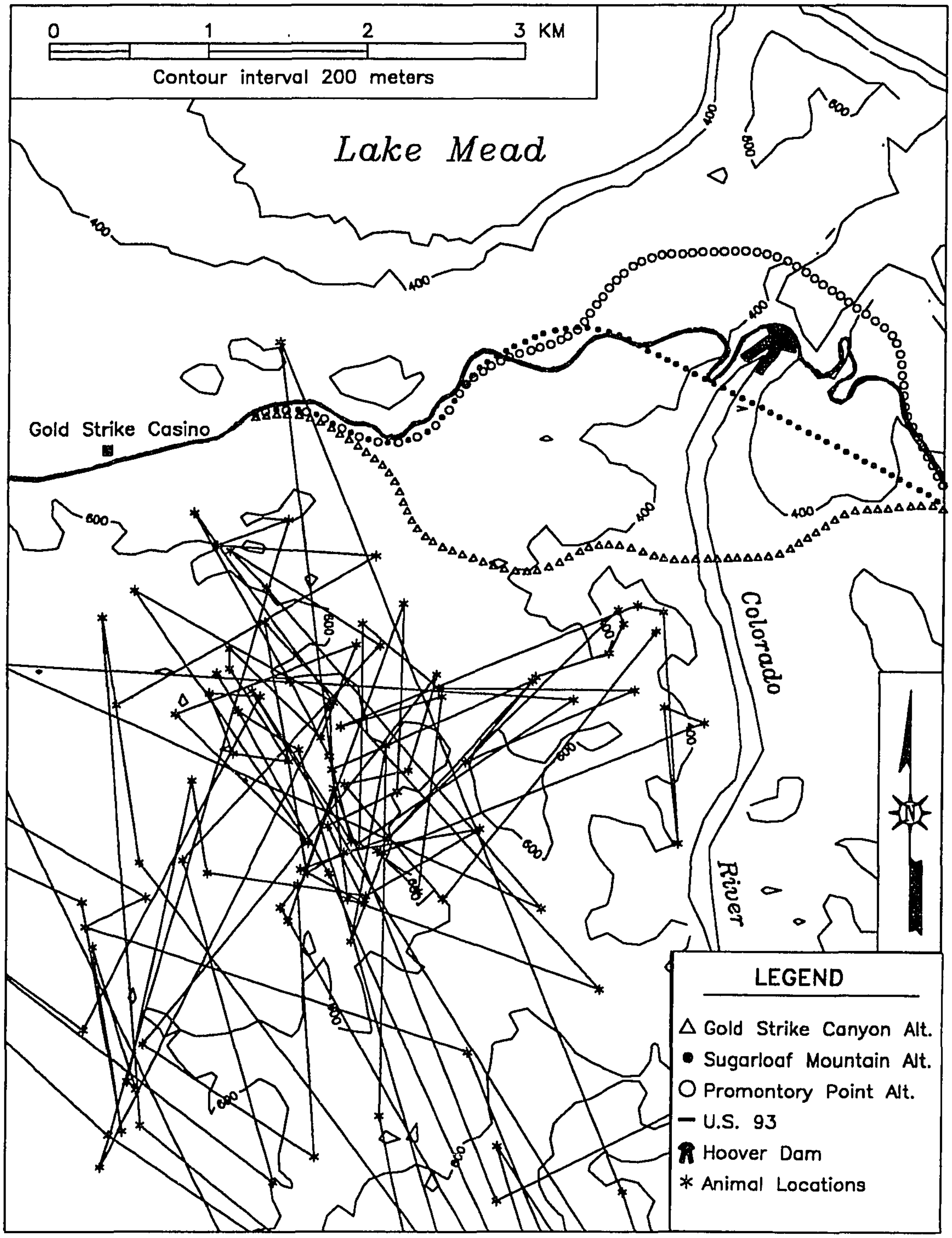

Figure 41. Movement of male bighorn sheep, A830, from 1 December 1989 - 30 November 1991.

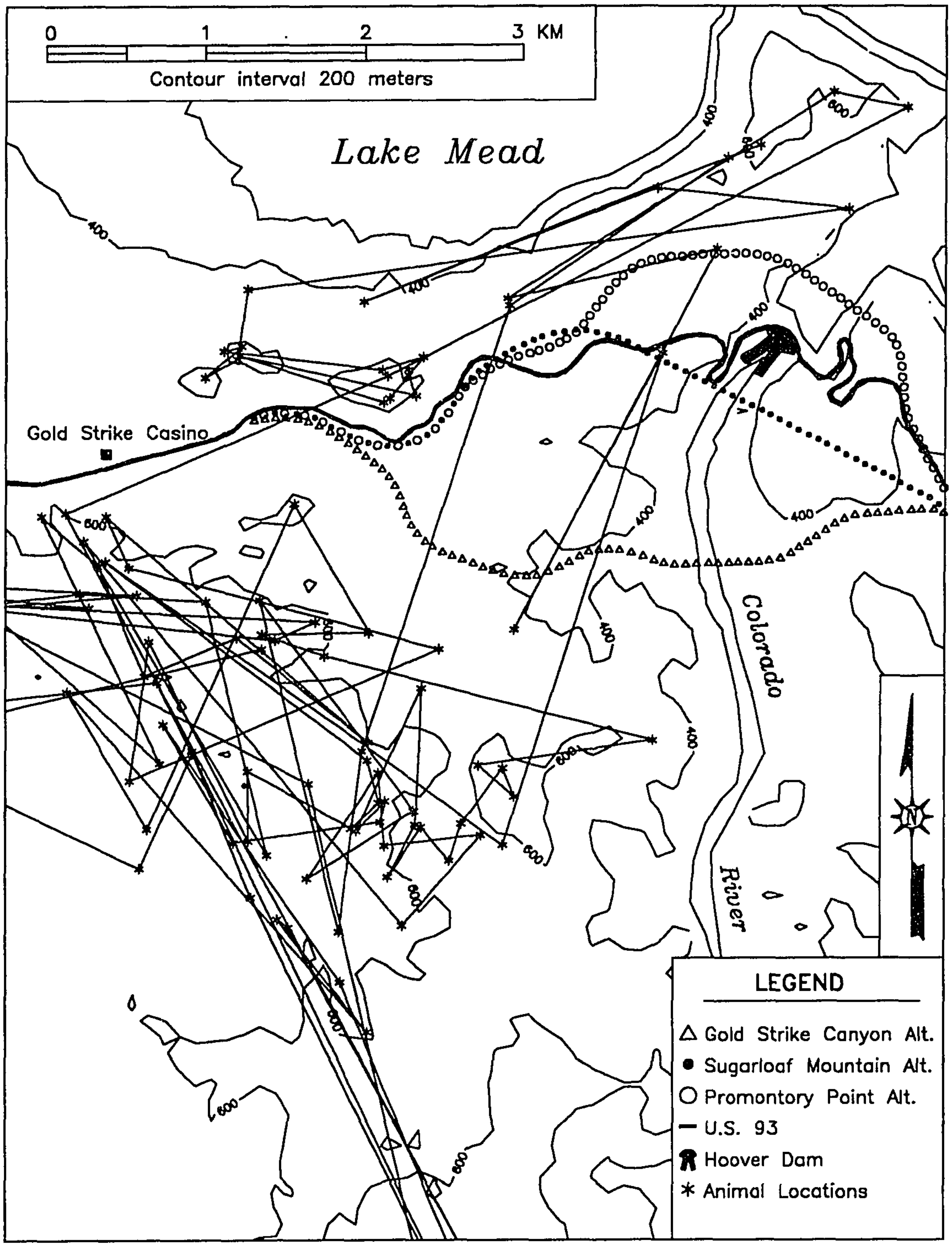

Figure 42. Movement of male bighorn sheep, A840, from 1 December 1989 - 30 November 1991.

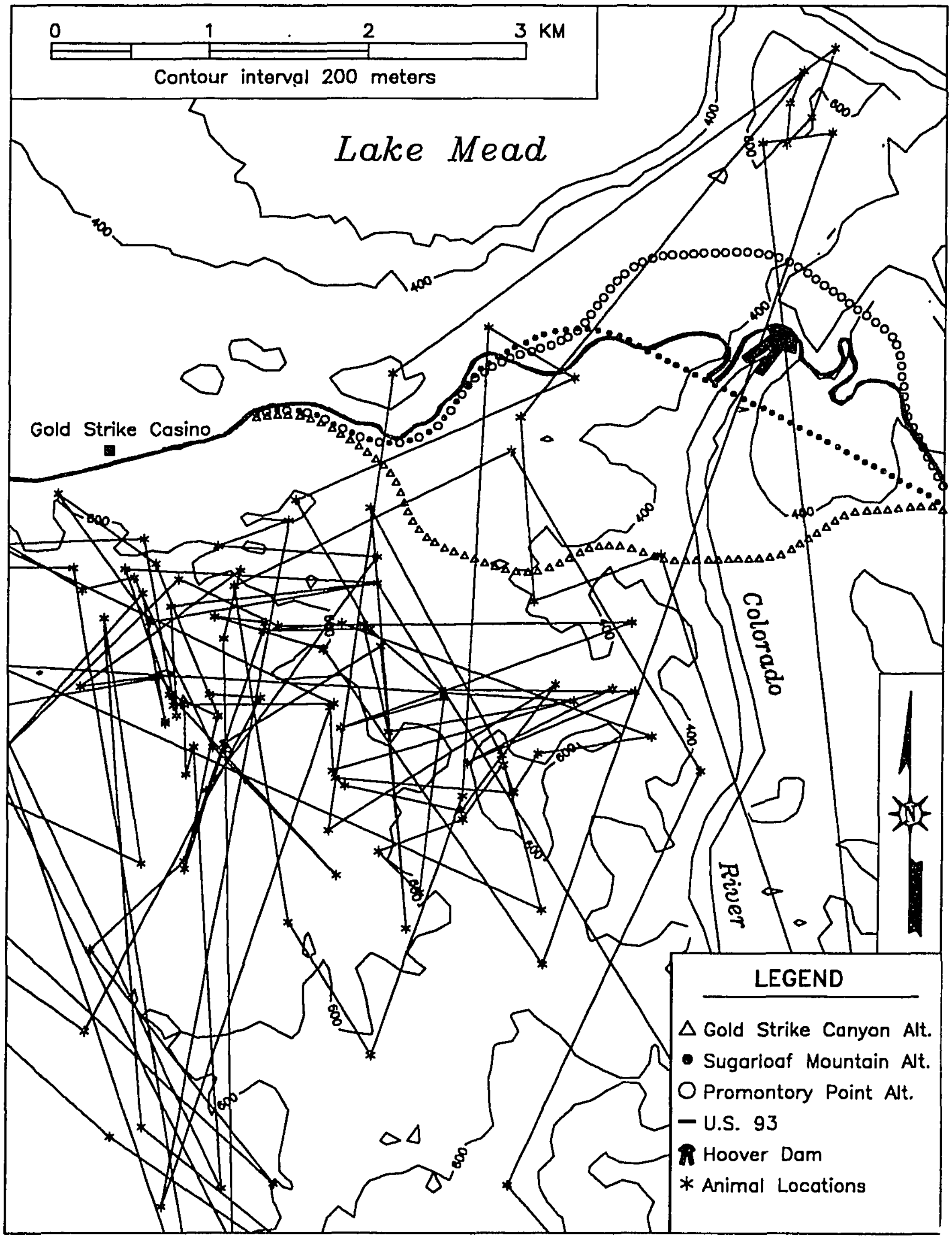

Figure 43. Movement of male bighorn sheep, A940, from 1 December 1989 - 30 November 1991.

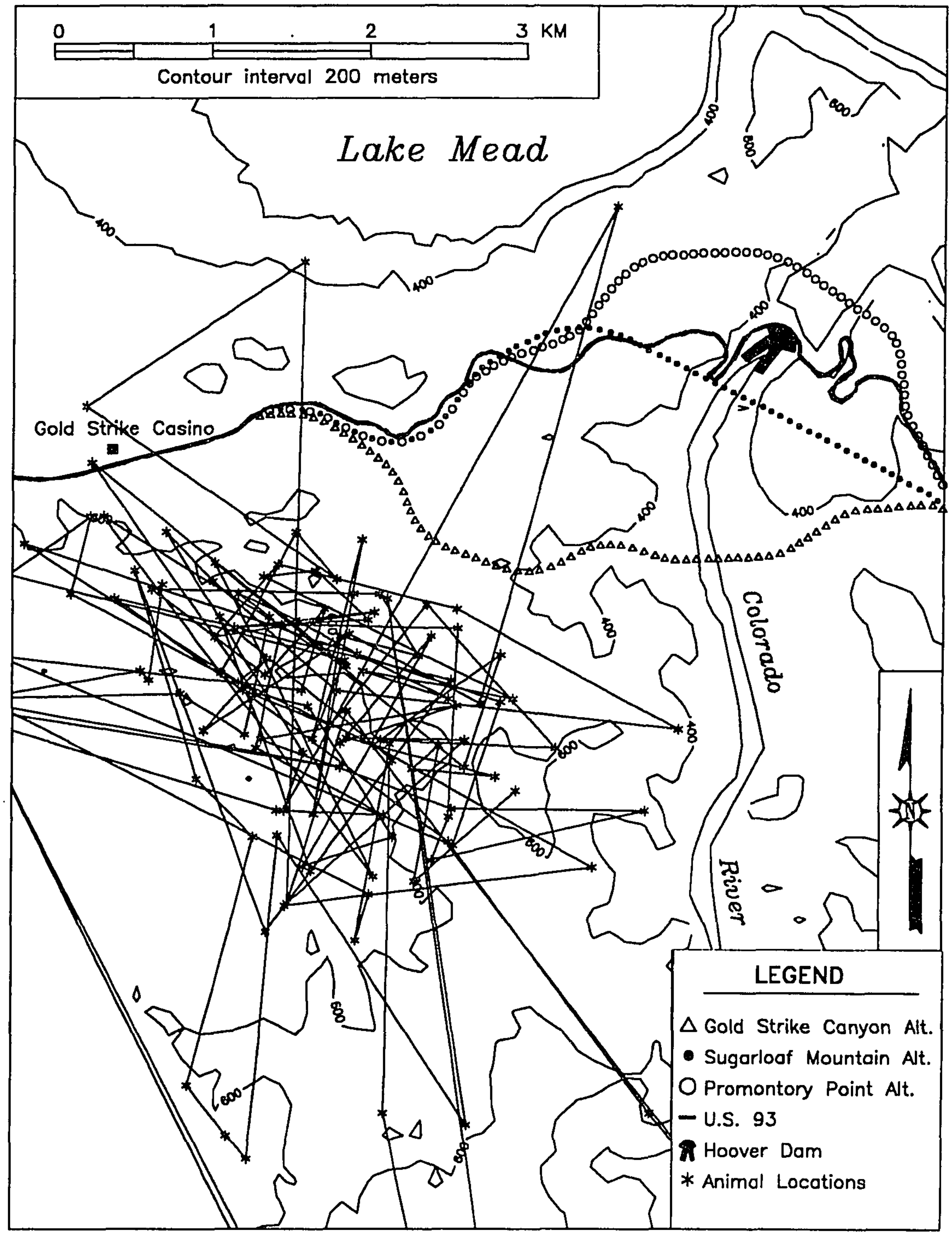

Figure 44. Movement of male bighorn sheep, A963, from 1 December 1989 - 30 November 1991.

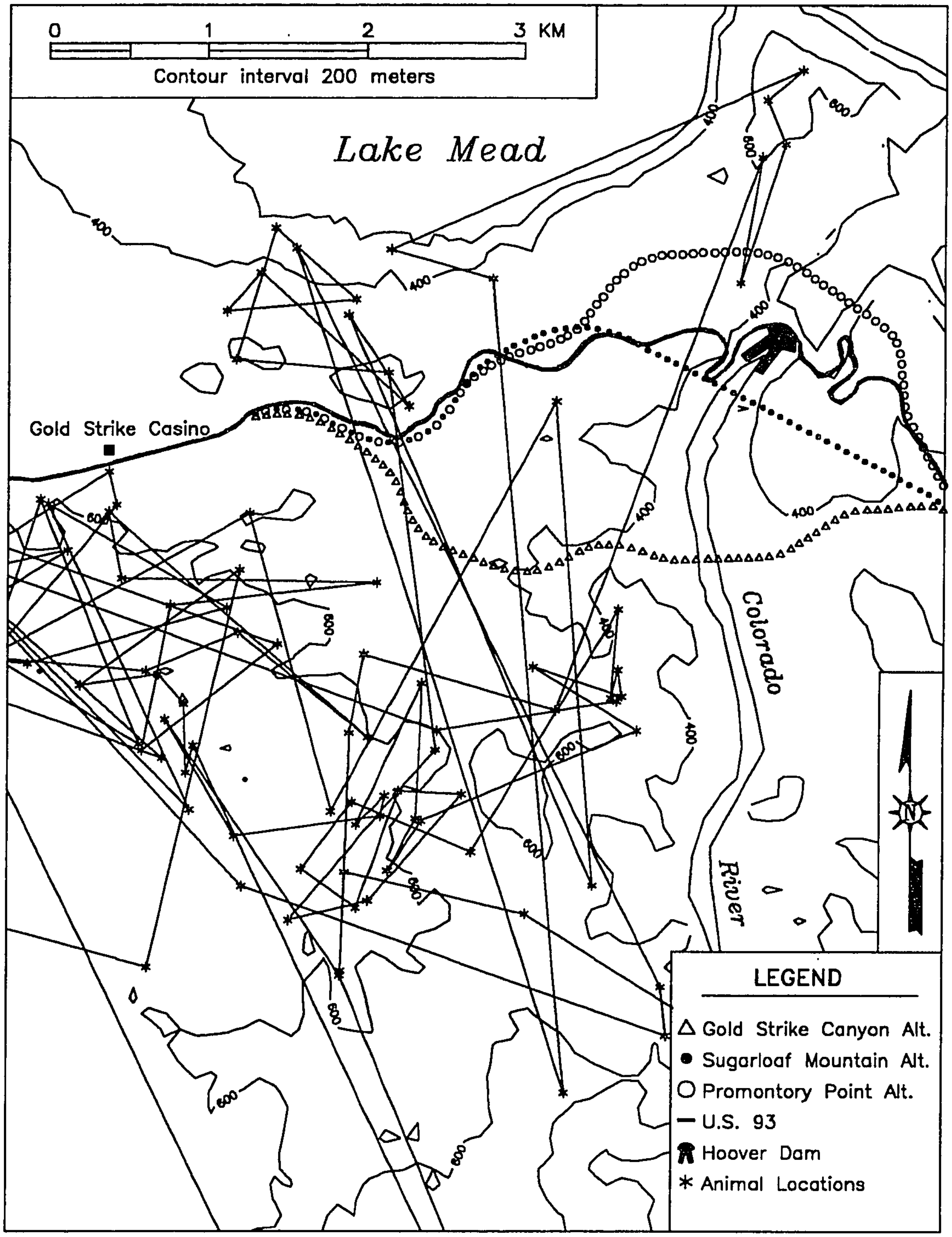

Figure 45. Movement of male bighorn sheep, B539, from 1 June 1990 - 30 November 1991.

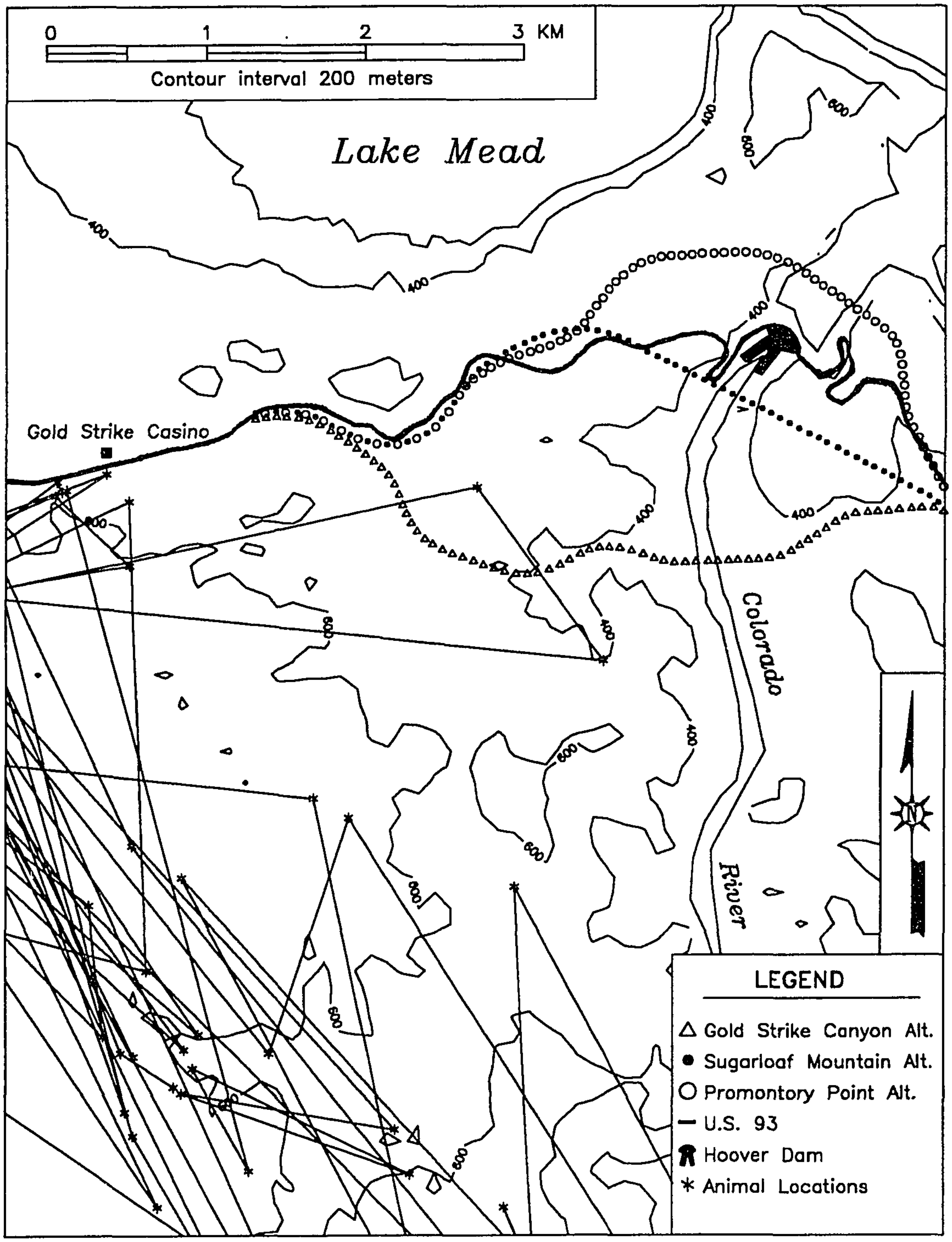

Figure 46. Movement of male bighorn sheep, B880, from 1 June 1990 - 30 November 1991.

DISCUSSION

General

Little has been written concerning the distribution of desert bighorn sheep within the Eldorado Mountains. Breyen (1971) conducted the first detailed study of the subject. Using NDOW helicopter surveys (1969 to 1970), personal field observations, and distribution and abundance of bighorn sheep pellet groups and bed sites, he concluded that the Eldorado herd consisted of two separate groups. The major portion of the herd was located north of Nelson, Nevada and made wide use of the "rugged steep and rocky terrain between the edge of the deep bluff and the river." Bighorn sheep use was reported as heavy in this region throughout most of the year, with use becoming more concentrated in areas immediately adjacent to the river during the hot, dry summer months. Areas identified as receiving heavy use included Oak Creek Canyon, just north of Nelson, and the "immediate edge of the north-south running deep bluff."

The second major group of bighorn sheep in the Eldorados was found concentrated in the Tule Spring area, south of Nelson. Breyen reports that bighorn sheep use remained localized to the east and northeast of the spring for much of the year but expanded during winter to include the Ireteba Peaks and Copper Mountain. McQuivey (1976), using much of the same bighorn sheep observation data as Breyen, reported similar distribution patterns for the Eldorado herd.

Present distribution of bighorn sheep in the northern portion of the Eldorado Mountains above Burro Wash conforms to that reported by Breyen (1971). Heavy concentrations of bighorn sheep can still be found along the edge of the north-south running bluff east of Boulder City and in the rugged, rocky terrain between the bluffs and the Colorado River. Promontory Point, while not mentioned by Breyen (1971), receives heavy use by ewe-juvenile groups throughout the year and by mature rams during the fall. The exclusion of Promontory Point from Breyen's description was probably an oversight on Breyen's behalf and not a recent range expansion by bighorn sheep. McQuivey (1976) reports bighorn sheep use on Promontory Point during the early 1970's.

Rams and ewes remain separate throughout most of the year, only intermingling during the fall rutting season. Habitat use by female bighorn sheep is largely restricted to the rugged terrain between the bluff and the river and along the bluff's edge. Rams, however, appear less dependent on steep, rocky slopes as a mechanism for defense and are able to exploit more of the rolling terrain to the west. While ewe use of the more rugged terrain may be directly related to a greater dependence on escape terrain among female bighorn sheep to avoid predation, the separation of rams from ewes throughout the nonbreeding season may also be a mechanism to reduce intersexual competition for limited resources within the range. Although I did not test for this hypothesis during the study, spatial segregation as a method of resource partitioning has been demonstrated in other ungulate species (McCullough et al. 1989). Spatial segregation between sexes during the nonbreeding season is common among bighorn populations (Leslie and Douglas 1979, Witham and Smith 1979, Wilson et al. 1980, Tilton and Willard 1982, King and Workman 1983, Cunningham and Hanna 1992).

Two primary "bachelor pastures" were identified during this study. Both are located more than one km distant from the proposed highway alignments. The first is located along a prominent east-west ridge in the northwest portion of the Eldorado range. The ridge parallels U.S. 93 and terminates at the edge of Boulder City. Evaporation ponds from a water treatment plant located across the highway from Gold Strike Casino provide an intermittent water source throughout the year. Rams inhabiting this area are thus able to remain separate from ewe-juvenile groups through the hot summer months. The second area of concentrated ram use is located in a set of low lying hills bounded to the south and southeast by Boy Scout Wash and to the north and northeast by Petroglyph Wash. Several rams occupy this area throughout most of the year despite a lack of permanent water in the immediate vicinity. Numerous natural catchments are available, however, which can provide water for a week or more after a rain shower. Permanent water sources can be found within three to four km.

During the rutting season, rams leave the bachelor pastures in search of estrous females. Mature rams were first observed in the company of ewes on 14 August in 1990 and on 29 July in 1991. Breyen (1971) reported mid-August as the start of the breeding season during 1970. While in rut, rams enter the steep, rocky terrain between the bluff and the river and travel between groups of female bighorn sheep. Ram movements during this time are extensive, but are largely confined to areas north of Burro Wash, including Promontory Point. Only two radio-collared rams (one in each year) ventured south of the wash during the fall breeding season (see above). Radio-collared ewes also restrict their movements to areas north of Burro Wash. On only two occasions were radio-collared ewes observed south of the wash. In both instances, the ewes were seen foraging on the edge of the bluff approximately one km south of the wash. This limited movement south of Burro Wash is in contrast with Breyen's (1971) conclusion that bighorn sheep north of Nelson constitute one group of bighorn sheep. Interactions between bighorn sheep north of the wash and those to the south appear to be limited despite no obvious barrier to movement. This suggests that three or more "subpopulations" of bighorn sheep inhabit the Eldorado Mountains. Further study is warranted to elucidate group dynamics within this range.

Female bighorn sheep, as a group, exploit the entire expanse of steep, rocky terrain between the bluff and the river. Within that area, however, individual ewes tend to restrict their activities to specific home ranges. In addition, distinct areas appear to be used by specific bands of ewes. Although there is overlap in use areas, ewes from one area were seldom seen in the company of ewes from another area. Interestingly, ewes from the same use area also maintained loose associations among each other. It is expected that the new highway alignment, regardless of which alternative is selected, will have a greater impact on the female portion of the population as use areas of several ewes are intersected by one or more proposed highway alignments.

In examining the degree of association among radio-collared ewes, I used Cole's (1949) formula to determine a coefficient of association (CA). The formula is defined as:

$$\frac{2ab}{a+b}$$

where a is the number of times animal A was observed throughout the season, b is the number of times animal B was observed throughout the season, and ab is the number of times that animals A and B were observed together throughout the season. Using this formula a value of one would indicate a perfect association between two animals or the probability that A and B would be seen together all the time. Knight (1970) states that coefficient values ≥ 0.50 show attraction between animals as opposed to random associations.

Coefficients of association for female bighorn sheep collared greater than or equal to nine months (n = 15) ranged from 0.00 to 0.31 (mean = 0.03). Only one pair of ewes had a coefficient ≥ 0.20. The low association values observed in the Eldorado range are among the lowest reported in the literature. In the nearby River Mountains, Leslie and Douglas (1979) reported a mean association value for adult female bighorn sheep of 0.28. Cunningham and Hanna (1992), obtained mean coefficients of association of 0.07, 0.11, and 0.29 for three groups of bighorn sheep across the Colorado River in the Black Mountains of Arizona. While the first two groups had association values similar to those found in the Eldorado Range, the authors attribute the low values to small sample size and a short monitoring period. Elenowitz (1984), studying a group of recently transplanted bighorn sheep, calculated substantially higher coefficients (CA ≥ 0.50) than those in this study. Similarly high coefficients were reported by Watts (1979), Axtell (1988), and Sanchez et al. (1988).

Leslie and Douglas (1979) postulated that group cohesion is a function of population density. As density increases the probability of bighorn sheep associating with one another also increases. This greater interaction, the authors suggest, may lead to a breakdown of group cohesion. Chilelli and Krausman (1981), however, found no group integrity within the Harquahala or Little Harquahala Mountains where bighorn sheep densities are low. Population density within the River Mountains was reported as 2.84 bighorn sheep/km^2 whereas the Harquahala and Little Harquahala Mountains have bighorn sheep densities of 0.13 to 0.14 bighorn sheep/km^2 and 0.11 bighorn sheep/km^2, respectively. Based on NDOW's 1990 population estimate, bighorn sheep density within the Eldorado Mountains is 0.85 bighorn sheep/km^2. In the northern Eldorado Mountains, however, bighorn sheep density is nearly twice that observed for the mountain range as a whole. Using the greatest number of bighorn sheep observed during any one survey and the amount of good and excellent quality habitat north of Burro Wash, I calculated a density of 1.61 bighorn sheep/km^2 for the northern portion of the range.

Cunningham (Ariz. Game and Fish Dept., pers. comm., 1992) questions the yardstick many researchers use to judge group cohesion. Association values of 0.50, he argues, are too stringent of a requirement to evidence attraction and suggests values closer to 0.30 are more realistic. While this may be so, I also suggest sampling strategy may influence association values. Intuitively, group cohesion studies will only be valid if members of the same group, if it exists, are monitored. By randomly selecting a relatively small number of bighorn sheep within a large area, it is possible to select bighorn sheep entirely from different groups. This is particularly true if actual group size is small. The low association values found in the Eldorado Mountains could possibly be explained by this scenario. It could also explain the high coefficients found in recently transplanted populations (Elenowitz 1984, Axtell 1988) and remnant herds (Watts 1979).

An established lambing area common to the majority of female desert bighorn sheep appears to be lacking in the northern Eldorado Mountains. Lambing is believed to occur throughout the area as gravid ewes remain within their customary use areas throughout the lambing season. The need to travel to areas providing adequate security, in the form of escape terrain, and seclusion appears to be negated, as large tracts of remote, rugged terrain are found in abundance throughout the area. The close proximity of the Colorado River also enhances the suitability of much of the area as potential lambing sites. The lack of a common lambing ground is similar to that found by Leslie and Douglas (1979). Lambs were observed in the vicinity of both PPA and GSA (discussed below).

Lambing period is similar to that found in surrounding areas. Newborn lambs were first observed in the Eldorado Mountains on 3 March 1990 and on 7 March 1991. Nine of 19 radio-collared ewes were suspected of having lambs in 1990. That ratio increased to 11 of 17 in 1991. Leslie and Douglas (1979) documented lambs in the River Mountains as early as 1 January, but continued to observe newborn lambs well into April. Cunningham and Hanna (1992) reported lambing activity from February to June. Within the Eldorado Mountains, Breyen (1971) noted the majority of lambing took place between February and March.

Unlike rams, ewes showed little seasonal movement patterns. Seasonal home ranges overlapped extensively with only slight shifts in seasonal centers of activity (mean distance apart = 1.9 km, range 0.1 to 5.1 km). Mean distance between seasonal centers of activity was similar for each change of season ($F = 0.112$, $df = 3$, $P = 0.95$). Breyen (1971) and McQuivey (1976), however, both reported extensive seasonal movements of bighorn sheep within the Eldorado Mountains. Breyen (1971) reported movement toward water during hot summer months while McQuivey (1976) also remarked on elevational movements between the winter and summer seasons. While subtle shifts in distance from water and changes in elevation were detected between seasons, none could be classified as major. In addition, seasonal home range size for females was relatively constant throughout the study. Contraction of home range during summer months as reported by Breyen (1971) and McQuivey (1976) did not occur.

Bighorn sheep movements between the Eldorado Mountains and the neighboring ranges have been discussed by Breyen (1971), McQuivey (1976, 1978), and Leslie and Douglas (1979). Sheep were historically observed to cross into the Newberry Mountains as well as into the Highland Ranges although these movements appeared to be limited in scope. Movements into these ranges was not documented during the present study although this may be more a function of bighorn sheep being collared in the northern portion of the Eldorado Mountains only and not an actual lack of inter-mountain movement.

To the north, historic records indicate extensive bighorn sheep movements between the Eldorado and River mountains. Prior to the 1940's, seasonal migrations between the Eldorado and River mountains were thought to have occurred annually. As the River Mountains contained no permanent water source, bighorn sheep were prohibited from residing in the range year-round. During the hot, inhospitable months bighorn sheep moved out of the range, but returned with milder weather. Construction of artificial water sources in the River Mountains in the 1940's eliminated the physiological motivation for bighorn sheep to move out of the range and then returned with the onset of milder weather. Although bighorn sheep became increasingly dependent on the artificial water sources through the years, movements between the Eldorado and River mountains continued until the mid-1970's. At that time, increased traffic and human encroachment along historic migration routes was thought to have eliminated all movement between the ranges. Leslie and Douglas (1979) report that no bighorn sheep were observed moving into or out of the River Mountains during the three years of their study and McQuivey (1978) noted an absence of highway mortalities along U.S. 93 along with a lack of recorded bighorn sheep crossings between the two ranges in the five years prior to his report.

During the present study, movements between the two ranges were observed, but limited in number. Only seven crossings were recorded during 26 months of observation. Of those, only two were actually observed. The other five exchanges involved relocations of radio-collared bighorn sheep. Of particular note was the movement of 11 uncollared bighorn sheep (one class I ram, one class II ram, four ewes, and five lambs) from the Eldorado Mountains into the River Mountains. All other crossings, as far as I can ascertain, involved rams only. It is believed that this group originally came from the River Mountains as they were first observed in the Eldorado Mountains in an area where ewes and lambs are traditionally absent.

Three highway mortalities were recorded along U.S. 93 over the course of the study. Based on their locations, two may have been the result of movements between the Eldorado and River mountains. The first involved a seven to nine year old ram. It was struck and killed approximately 1.5 km west of the Alan Bible Visitor Center. Only one km of desert wash separates the Eldorado and River mountains at this location. The second mortality, involving an adult ewe, occurred approximately two km further west; in the vicinity of Hemenway Park. Again, the gap separating the two ranges at this location is approximately one km. The third and last mortality occurred several kilometers from the River Mountains, approximately one km east of Gold Strike Casino, where the carcass of an adult female bighorn sheep was discovered alongside the highway. This area is part of a major movement corridor between the main portion of the Eldorado Mountains and Promontory Point.

Home Range

While several studies have used MCP to evaluate home range, few have employed it uniformly. Leslie and Douglas (1979), Scott et al. (1990), Ough and deVos (1984), and Cunningham and Hanna (1992) have all produced estimates of total home range for individual bighorn sheep based on a minimum of one year's worth of observation, but total length of study, interval between successive observations, and method of survey varied widely. Leslie and Douglas (1979), Krausman (1985), Sanchez et al. (1988), and Krausman et al. (1989) have also examined home ranges for one or more seasons throughout the year, but have delineated the seasons using different criteria. Leslie and Douglas (1979) produced a seasonal breakdown based on phenological and behavioral changes observed throughout the year. Krausman (1985), Sanchez et al. (1988), and Krausman et al. (1989) based their definition of season on arbitrary dates; frequently dividing the year into even intervals. In addition, differences exist between the studies as to the significance of outlying observations. Sanchez et al. (1988) classified points that were greater than 1/4 of the distance between the two most distant points or greater than two km from any other location point as exploratory and excluded them from the analysis. Many other authors made no distinction between exploratory and non-exploratory movements and included all location points in their definition of home range. As each of these various differences can profoundly influence the estimation of home range size using MCP, caution is necessary when comparing estimates of one study with those of another.

Despite differences in technique, the majority of studies reported similar findings for female desert bighorn sheep. Leslie and Douglas (1979), in the River Mountains, reported a mean total home range of 16.9 ± 1.51 km^2 (SE). In the Cabeza Prieta National Wildlife Refuge (CPNWR), Scott et al. (1990) determined a mean total home range of 22.0 ± 4.1 km^2 (SE). Similar findings were reported by Cunningham and Hanna in the Black Mountains for two of three ewe groups with 13.8 ± 3.4 km^2 (sd) and 18.4 ± 5.4 km^2 (sd), respectively. The third group had a significantly larger mean home range size at 45.5 ± 6.7 km^2 (sd). In southwestern Arizona, Ough and deVos (1984) reported a mean total home range size for female desert bighorn sheep of 28.0 km^2. With the exception of Cunningham and Hanna's (1992) third group, total home range for ewes in the Eldorado Mountains were similar to that documented in other studies.

Seasonal home ranges in the Eldorado Mountains for female desert bighorn sheep were consistent with those reported by Krausman (1985) and Krausman et al. (1989) for ewes in the Harquahala Mountains, Arizona. Comparable ranges were also described by Leslie and Douglas (1979) for spring (4.8 ± 1.21 km^2 SE) and summer (6.5 ± 0.48 km^2 SE) and by Sanchez et al. (1988) for summer (7.0 ± 0.56 km^2 SE). In contrast, seasonal home ranges for female desert bighorn sheep in the Little Harquahala Mountains, Arizona, were significantly larger than those observed in this study (Krausman 1985, Krausman et al. 1989).

In contrast to ewes, mean total home range for male desert bighorn sheep varies widely between studies (Leslie and Douglas 1979, Ough and deVos 1984, Scott et al. 1990, Cunningham and Hanna 1992). Typically larger than those reported for female bighorn sheep, total home range size for rams have been documented as small as 32.5 ± 4.32 km^2 (SE) in the

River Mountains (Leslie and Douglas 1979) to over 274 km^2 in southwestern Arizona (Ough and deVos 1984). However, for many of these studies sample sizes are small. Leslie and Douglas (1979), Ough and deVos (1984), and Scott et al. (1990) used four or fewer adult male bighorn sheep in estimating home range size. At this low level, the inclusion or exclusion of one or two animals can greatly influence the mean. In a clear example, Scott et al. (1990), in CPNWR, reported a mean home range estimate of 115.1 ± 70.1 km^2 (SE) for four adult male bighorn sheep. By excluding one ram, the authors were able to lower this figure to 46.8 ± 22.9 km^2 (SE). Cunningham and Hanna (1992), using nine radio-collared adult rams, obtained a total home range estimate of 70.7 ± 23.1 km^2 (sd). While slightly higher, this estimate is comparable to that found for adult rams in the Eldorado Mountains.

Krausman (1985) and Krausman et al. (1989) are among the few studies that have examined seasonal home ranges for adult male desert bighorn sheep. Krausman (1985) collected seasonal data for four years in the Harquahala and Little Harquahala mountains. Krausman et al. (1989) used data from Krausman (1985), but collected an additional year of data. Although seasonal ranges varied between years, the five year average for each season in each mountain range was larger than those found in the Eldorado Mountains.

Heavy bighorn sheep use occurs in the area of the proposed alignments. Female bighorn sheep occupy the area year-round. Adult male bighorn sheep are typically found west and south of the alignments, but enter the area during the fall rutting season. Five ewes and seven rams have home ranges which are intersected by one or more of the proposed highway alignments. Of these, four ewes (80%) and six rams (86%) have home ranges which are intersected by all three proposed highway alignments. Home ranges of the remaining bighorn sheep are intersected by GSA only. An additional seven rams and three ewes have home ranges within one km of GSA while PPA and SLA have an additional six rams and one ewe with home ranges less than one km distant. Based on home range data alone, impacts to the Eldorado

Mountain herd from construction of the Black Canyon Bridge Project would be similar regardless of which alignment was chosen.

Consideration of harmonic mean core areas does little to help distinguish differences between the proposed highway alignments. For female desert bighorn sheep, outlines of harmonic mean core areas were similar to those determined by MCP. As such, five ewes had harmonic mean core areas intersected by one or more proposed highway alignments. All three alignments traversed portions of three harmonic mean core areas while GSA entered an additional two. Similarities between harmonic mean core area boundaries and MCP, as found here, can be expected when bighorn sheep activity is distributed uniformly.

Harmonic mean core areas determined for male bighorn sheep bore little resemblance to the "central areas of consistent or intense use" they were intended to delimit. Despite an average of 112 point locations per ram, the number of observations was not sufficient to adequately delineate core area boundaries given the wide-ranging movements and irregular home range patterns of breeding males. In almost all cases, core area boundaries included vast tracts of unused areas, and in two instances, harmonic core areas were larger than home range estimates. Evaluation of potential impacts of the BCBP on male bighorn sheep based on core area criteria was judged to be deceptive (five rams, which were never observed to cross any of the alignments, had core areas that contained one or more proposed highway alignments) and will not be used in the final analysis.

Habitat Evaluation

Habitat Use

Aspect

Bighorn sheep have shown a preference for virtually all points of the compass. Elenowitz (1984) reported preferred use of southern and western slopes in the Peloncillo Mountains, New Mexico. Dunn (1984), in Death Valley National Monument, California, noted higher than expected use of northern and southern aspects. In the Santa Catalina Mountains, Arizona, bighorn sheep made heavy use of northern, northwestern, and western aspects (Gionfriddo and Krausman 1986), while in Waterton Canyon, Colorado, Risenhoover and Bailey (1985) reported selection of eastern to southwestern slopes.

Several factors can influence aspect use. Holl and Bleich (1983), in the San Gabriel Mountains, California, found female bighorn sheep preferred southern exposures during the winter-spring period as did Tilton and Willard (1982) in the Cabinet Mountains, Montana. The authors hypothesized that lack of persistent snow and increased exposure to the sun made southern slopes more appealing for foraging and thermal regulation. Benefits gained from increased solar radiation did not preclude use of other aspects, however. Holl and Bleich (1983) noticed that north-facing slopes were used in early winter, in particular, when germination of winter annuals on southern exposures was late due to insufficient fall precipitation. Contrary to Holl and Bleich's (1983) expectations, female bighorn sheep selected southern slopes during the summer season as well. The authors concluded that other habitat components in addition to thermal cover were influencing aspect selection. In Waterton Canyon, Colorado, Risenhoover and Bailey (1985) also found that bighorn sheep avoided north-facing slopes during the winter-spring period. Vegetation, in this case, and not snow cover was thought to be the determining factor. North-facing slopes in Waterton Canyon are generally characterized as having dense, tall vegetation which limit bighorn sheep visibility. Bighorn sheep, which rely heavily on their eyesight for predator detection and avoidance (Geist 1971), typically avoid such areas (Risenhoover and Bailey 1985, Fairbanks et al. 1987, Armentrout and Brigham 1988, and Etchberger et al. 1989). In desert environs, shade is a critical component in determining bighorn sheep activity (Leslie and Douglas 1979). Gionfriddo and Krausman (1986) attributed shade as the prime determinant in bighorn sheep selection of north facing slopes during summer in the Catalina Mountains, Arizona. Although the authors noted adequate shade was available on all aspects, it was most consistently found on northern slopes. Cunningham and Hanna (1992) also noted higher than expected use of northern aspects by bighorn sheep in the Black Mountains, Arizona.

Additional variables such as proximity to escape terrain, proximity to water sources, and season also influence aspect use. Dunn (1984) found higher than expected use on both northern and southern aspects during summer in Death Valley National Monument, California. He attributed the high use of southern slopes to a large number of observations of ewe groups along a precipitous, south-facing wall. The use of northern aspects was largely influenced by a high number of observations at a particular spring. Entry to the spring was almost entirely from the north. Change of season can have a profound effect on aspect selection. As seasons change, changes occur in precipitation patterns, ambient air temperatures, forage availability, and water availability. It is not surprising then that several authors report differences in aspect use with changing seasons (Holl and Bleich 1983, Dunn 1984, Cunningham and Ohmart 1986, Fairbanks et al. 1987, Cunningham and Hanna 1992).

Aspect use, then, is dependent on the interaction of biotic and abiotic components in the environment and not a function of aspect per se. A priori decisions on aspect use by a particular herd should not be made based on other studies, but determined for a particular area through field evaluations. In the northern Eldorado Mountains, female bighorn sheep were observed to use northern and eastern aspects while avoiding level areas. Adult male bighorn sheep selected northern and western slopes and avoided level areas. Shade was probably an important factor in aspect selection in the Eldorado Mountains as both adult rams and ewe-juvenile groups selected north-facing slopes. Although not quantified, the amount of thermal cover in the form of rocks (i.e. large boulders) and shrubs in the study area is meager. Relief from solar radiation is provided mostly from large topographic features such as ridgelines, rock outcrops, and steep slopes. As such, shade is found predominantly on northern aspects. The use of eastern aspects by female bighorn sheep and western aspects by adult males may also be explained by topographic features. The steep, rocky terrain favored by female bighorn sheep is found largely to the east of the north-south running bluffs. Eastern aspects predominate in this area as the area rapidly descends to the Colorado River to the west. The use of this area by ewe-juvenile groups and its general avoidance by adult rams is consistent with the different habitat preferences exhibited by the sexes documented in other studies (Leslie and Douglas 1979, Gionfriddo and Krausman 1986). Adult rams, preferring gentler, more rolling terrain, were typically found along the western slopes of the bluffs.

By determining bighorn sheep selection and avoidance of certain habitat components (e.g. aspect), it should be possible to estimate the potential impacts of new construction, in this case, the three proposed alignments, by determining the amount of preferred habitat lost either directly, through habitat destruction, or indirectly, through behavioral avoidance. By comparing this figure between the three alignments, differences among the alignments may become evident and statements regarding the preference of one alignment over another can be empirically based.

The amount of habitat lost directly is straightforward and easy to calculate. By overlaying the proposed highway alignments on maps detailing habitat components, the amount of selected habitat covered by the roadways can be readily determined and compared. Use of computers and GIS software greatly increases the speed and accuracy of this procedure.

Calculation of areas lost due to indirect effects, while often considerable, is typically more difficult to assess. In the past, habitat lost indirectly has been estimated by drawing a uniform buffer around the disturbance and totaling the area within its borders. Frequently, little attention is paid to the quality of the habitat within the zone and its importance to the animal(s) of concern. This technique tends to oversimplify the problem and should be regarded as unrealistic.

For bighorn sheep, the quality of the habitat is an important factor in determining the effects of a disturbance on a population (Hicks and Elder 1979, MacArthur et al. 1982, Holl and Bleich 1983). It has been speculated that bighorn sheep found in areas of high quality habitat, i.e., in areas with ample forage and escape terrain, are more likely to tolerate a disturbance then those in marginal habitats. Investigating the effects of human activity on bighorn sheep distributions in the John Muir Wilderness in the Sierra Nevada Mountains, California, Hicks and Elder (1979) found that food resources and not human presence dictated bighorn sheep use. In areas where bighorn sheep and humans overlapped, bighorn sheep use of meadows was positively correlated with vegetative cover and percentage of preferred forage species present. No correlation was found between human use and bighorn sheep activity. Holl and Bleich (1983), in the San Gabriel Mountains, California, found a similar relationship between bighorn sheep use and human activity. In areas where human activity was thought to preclude bighorn sheep use, Holl and Bleich found those areas to contain marginal bighorn sheep habitat; areas unlikely to sustain a resident population regardless of human activity. Those areas judged to be optimum bighorn sheep habitat supported bighorn sheep activity despite concurrent human use.

While quality of habitat is an important determinant in assessing the potential impacts of disturbance on a population, it is not the only consideration. Etchberger et al. (1989) noted that current bighorn sheep use in the Pusch Ridge Wilderness in the Santa Catalina Mountains, Arizona is two times farther from human disturbance than abandoned historic habitat despite similar habitat characteristics. Ferrier (1974) and DeForge et al. (1981) also document losses of bighorn sheep populations from areas of high quality habitat which they attribute to human encroachment.

Numerous researchers have recognized that it is not the presence of humans, per se, that disturbs bighorn sheep, but the type of human activity and its frequency that affects bighorn sheep distributions (Geist 1971, Jorgensen 1974, Hicks and Elder 1979, Kovach 1979, Leslie and Douglas 1980, Hamilton 1982, MacArthur et al. 1982, Krausman and Hervert 1983, Miller and Smith 1985, Stanger et al. 1986). Under normal conditions, aircraft appear to have little impact on bighorn sheep. Using heart rates as an indicator of stress, MacArthur et al. (1982) noted no responses in heart rate when either fixed-wing aircraft or helicopters, were flown greater than or equal to 400 m distant from bighorn sheep. Miller and Smith (1985) and Krausman and Hervert (1983) also reported negligible disturbance to bighorn sheep when fixed-wing aircraft were flown greater than 100 m above ground level. Strong reactions, defined as bighorn sheep movement greater than 100 m accompanied by changed behavior in response to stimuli, were elicited, however, when aircraft flew at lower levels. Disturbance to bighorn sheep from traffic also appears to be minimal. MacArthur et al. (1982) documented increased heart rates in less than one in 10 bighorn sheep passed by a vehicle. In observations where heart rates increased, distance from vehicle had a greater effect on heart rate response than did either type of vehicle (car, truck, motorbike, snowmobile, or grader) or frequency of successive vehicle passes (MacArthur et al. 1982). The vast majority of reactions caused by vehicles occurred when vehicle passes were less than or equal to 25 m from the animal (MacArthur et al. 1982). Minimum disturbance to bighorn sheep from passing cars and trucks was also documented by Miller and Smith (1985). In nearly all of their observations, bighorn sheep responded with slight or no reaction to moving traffic. As in MacArthur et al. (1982), distance from disturbance may have played an important role as the majority of observations occurred on steep slopes and ridgelines far above the related roadways. In the same study, parked vehicles evoked stronger reactions than moving traffic among adult rams. This is similar to observations reported for bighorn sheep in response to passing river boats in Cataract Canyon, Utah (Stanger et al. 1986). Stanger et al. (1986), studying bighorn sheep behavior patterns prior to and during rafting season, detected no difference in bighorn sheep behavior when river boats travelled in a predictable manner. Only when rafters altered their behavior, e.g., approaching the shore, whistling, or turning sharply nearby, did bighorn sheep become disturbed. Miller and Smith (1985) speculated that female bighorn sheep were not affected by parked vehicles because they were found at higher elevations at considerable distance from roadside disturbance. They also suggested rams may be more susceptible to human disturbance due to a history of hunting. In nearly all studies, bighorn sheep reacted strongly when approached by humans walking (Hicks and Elder 1979, Kovach 1979, Hamilton 1982, MacArthur et al. 1982, Holl and Bleich 1983, Miller and Smith 1985). Hicks and Elder

(1979) noted, as did Kovach (1979) and MacArthur et al. (1982), that reactions were particularly strong when bighorn sheep were approached from above.

While bighorn sheep may be able to habituate to certain disturbances, the frequency or duration of the disturbance may ultimately determine whether bighorn sheep will continue to use or abandon an area. Hamilton (1982) found that human use of a trail near a mineral lick did not preclude bighorn sheep use of the lick despite peak use of the trail occurring during the same time period as peak use of the lick. She did find, however, that bighorn sheep altered their behavior to avoid people at the lick. Bighorn sheep were never observed at the lick when people were in the immediate vicinity, but waited a minimum of one hour after a group passed by before approaching. Hamilton (1982) concluded that increases in trail use to one or more groups per hour would eliminate bighorn sheep use of the mineral lick. Similar changes in behavior in response to disturbance have been reported in other studies (Jorgensen 1974, Leslie and Douglas 1980, Campbell and Remington 1981).

To evaluate areas lost indirectly due to disturbance in a more realistic manner, a method taking the above factors into account needs to be employed. Because the modified Cunningham habitat evaluation model (Cunningham 1989) directly addresses many of these concerns and was shown to be a good predictor of bighorn sheep use based on existing conditions in the northern Eldorado Mountains (see below), I have chosen to employ it to evaluate the changes in habitat likely to occur due to construction of an alternative roadway. The model was run separately for each proposed alignment, incorporating the alignment as an existing roadway, and the resulting changes in habitat classifications for the area were recorded. Areas that changed from excellent or good quality habitat to fair or poor quality habitat were considered lost. The amount of preferred habitat component contained within the lost habitat was then determined. Two scenarios were considered in the evaluation: (1) bighorn sheep movements across the highway occur after construction of the alignment, and (2) bighorn sheep movements are obstructed after construction. If bighorn sheep movements become obstructed, I assume that movements to and from the Promontory Point area will cease. I also assume that an isolated Promontory Point area will be unable to sustain a viable bighorn sheep population (Holl and Bleich 1983, Berger 1990) and that the entire area will be lost from the Eldorado Mountain herd. Because the area of potential impact for each of the proposed alignments is contained almost exclusively within ewe-juvenile habitat, only habitat components important to female bighorn sheep are evaluated. Adult rams do enter the area, but only during the late summer - fall breeding period. During this time, habitat use for male bighorn sheep is generally similar to that observed for ewe-juvenile groups.

Based on the modified habitat evaluation model, construction of SLA results in the least amount of preferred aspect lost if bighorn sheep movements across the roadway continue. Just four ha of east and north aspects are disturbed under this scenario with construction of SLA as compared to 17 ha and 23 ha for PPA and GSA, respectively. Considerably more habitat is lost given the alternative scenario, but the results are generally similar. If movements across the alignment are obstructed, GSA has the greatest impact with 412 ha of preferred aspect lost while SLA and PPA lose 328 ha and 317 ha, respectively.

Elevation

Similar to aspect, selection of elevation is dependent on a number of biotic and abiotic components. Presence or absence of snow (Tilton and Willard 1982, Holl and Bleich 1983, Dunn 1984), location and availability of water (Holl and Bleich 1983, Cunningham and Ohmart 1986), distribution of escape terrain (Cunningham and Hanna 1992), forage availability, and season (Holl and Bleich 1983, Dunn 1984, Elenowitz 1984, Cunningham and Ohmart 1986) can all have an influence on elevation selection. In fact, determining which elevations are preferred simply identifies where critical habitat components are ideally juxtaposed and has little to do with the actual distance above sea level. To give an example, knowing that bighorn sheep preferred areas between 1,500 m and 1,800 m in one mountain range does little to help distinguish bighorn sheep habitat in a mountain range that is below 1,000 m in elevation. While studies of elevation preference are important for determining the existence of elevational migrations or for identifying areas of bighorn sheep use, results, with the exception of trends, should be confined to the particular mountain range where the study was conducted.

In the Eldorado Mountains, female bighorn sheep preferred elevations ≥ 501 m and ≤ 600 m throughout most of the year, but also made frequent use of the 401-500 m elevation zone during summer. Areas ≥ 601 m, while used in proportion to availability during fall and winter, were avoided during spring and summer. Adult male bighorn sheep were typically found at higher elevations than ewes.

Use of lower elevations during the dry, summer months by female bighorn sheep is probably a result of ewes moving closer to the Colorado River for easier access to water. Similar movements to lower elevations related to water availability were observed in the San Gabriel Mountains, California (Holl and Bleich 1983) and in Carrizo Canyon, California (Cunningham and Ohmart 1986). Lambing may also have contributed to the use of lower elevations by female bighorn sheep during summer as the low, broken terrain near the river provides abundant shelter and protection from predators. Movement into extremely rugged terrain during lambing is consistent with findings from other studies (Leslie and Douglas 1979, Cunningham and Ohmart 1986, Cunningham and Hanna 1992). Gionfriddo and Krausman noted use of lower elevations by ewes with lambs than female bighorn sheep without offspring during summer in the Santa Catalina Mountains, Arizona (1986).

Selection of higher elevation zones by rams is consistent with different habitat preferences between the sexes. Areas at higher elevations contained less broken, steep terrain than areas near the river making them more desirable to adult male bighorn sheep (Leslie and Douglas 1979, Gionfriddo and Krausman 1986). Segregation by elevation was also documented by Tilton and Willard (1982) with adult rams located at higher elevations than ewe-juvenile or young ram groups, although distinctions between elevation use and sex were not so clear in other studies (Gionfriddo and Krausman 1986, Cunningham and Hanna 1992).

Because the 401-500 m elevation zone is selected by female bighorn sheep during summer when the need for water or shelter may be critical for continued viability of the herd, impacts to this elevation zone by the proposed highway alignments are considered the most sensitive. Potential impacts to the 501-600 m zone, due to its preferred use by ewes throughout the year, were also examined.

If movements continue after construction, SLA will have the least amount of impact of the three alignments examined. Nine hectares of the critical 401-500 m elevation zone will be lost if this alignment is selected. Only an additional two ha are lost when the 501-600 m zone is included. Losses of these elevation zones from construction of the other alternative alignments are nearly three and four times higher for GSA and PPA, respectively. Should construction of a new highway block movement to the Promontory Point area, impacts to the 401-500 m elevation zone are similar between SLA and PPA with 233 and 217 ha lost respectively. Construction of GSA will result in the greatest loss with 521 ha affected. Impacts caused by the three alignments to the 501-600 m elevation zone, are similar to those of the 401-500 m zone with SLA and PPA impacting 170 and 171 ha, respectively, and GSA causing the loss of 203 ha.

Slope

Although the presence of steep slopes does not necessarily mean the presence of bighorn sheep, the presence of bighorn sheep typically means the presence of steep slopes. Steep slopes are widely recognized as a vital component of bighorn sheep habitat (Wilson et al. 1980, Holl and Bleich 1983, Risenhoover and Bailey 1985, Fairbanks et al. 1987). In conjunction with visibility, forage quality and quantity, and in most cases, water availability, it is a major determinant in defining bighorn sheep habitat (Hansen 1980, Armentrout and Brigham 1988, Cunningham 1989). Although bighorn sheep will make use of level areas, they are generally not far from steep, rugged areas (see below).

Slope is usually measured in terms of percentage elevation gain for a given horizontal distance travelled. In this system, a 100% slope is equivalent to a 45° angle. Methods for measuring slope, however, varies from study to study. In most cases, one of two methods are employed: (1) measuring slope from U.S.G.S. topographic maps by use of a slope indicator, or (2) field measurements. A third variation involves gridding the study area into equal-sized cells and then assigning a slope value for the entire cell. Cell slopes are determined either by measuring the dominant slope within the cell or by comparing the elevational differences between the target cell and each of its eight neighbors. In the latter case, a minimum, maximum, average, or fitted slope can be assigned. This approach is utilized by raster-based, GIS programs. The size of the cell is an important consideration when employing this method. Cells too small may not accurately reflect the prevailing slope of the area whereas cells too large may generalize too many landscape features. Because of the different techniques utilized in measuring slope, comparisons between studies should be done with caution.

Two factors appear to have substantial influence on slope selection: season, and sex. Male bighorn sheep are typically found on less steep slopes than female bighorn sheep (Leslie and Douglas 1979), however, season can significantly influence this. Tilton and Willard (1982), studying winter habitat selection in the Cabinet Mountains, Montana, noted adult rams preferred 36-60% slopes while female bighorn sheep made use of 36-80% slopes. Conversely, Gionfriddo and Krausman (1986) reported no difference in slope usage among the sexes during summer in the Santa Catalina Mountains, Arizona. In their study, both sexes preferred slopes of 59-79%, while avoiding slopes < 40% and > 120%. In a year-round study by Cunningham and Hanna (1992), the authors found that ewes generally used steeper slopes than rams during spring and summer, but had similar slope usage in fall and winter. My study revealed that rams had only subtle shifts in slope usage during the year while slope usage among ewes changed significantly between seasons. In three groups of female bighorn sheep studied, slope usage was generally similar within a particular group for summer, fall, and winter seasons, but movements onto steeper slopes were observed during spring. Similar movement patterns among bighorn sheep were reported by Cunningham and Ohmart (1986) and Elenowitz (1984). Lambing and an increased need for security may dictate use of steeper slopes in spring. Gionfriddo and Krausman (1986) noted that ewes with lambs were found on steeper slopes than ewes without lambs in the Santa Catalina Mountains, Arizona.

While Cunningham and Hanna (1992) reported similar movement patterns among ewe groups, use of percent slope was significantly different between groups. Of the three groups studied, one group of ewes was consistently found on less steep slopes than the other two. Confounding the difference in slope usage between the sexes, the ewe group using less steep slopes also used slopes less steep than those observed for rams in all seasons but spring. This apparent anomaly may have been a special adaptation for ewes to avoid coyote (Canis latrans) predation near the Colorado River (S. Cunningham, Ariz. Game and Fish Dept., pers. comm., 1992). Coyotes, which are less adapted to the arid environment than bighorn sheep, must remain in the vicinity of the Colorado River to avoid dehydration. Female bighorn sheep, can venture farther from water, and can minimize their risk of predation by foraging away from the river. Without the presence of coyotes, less steep slopes can be exploited.

Slope usage by bighorn sheep in the Eldorado Mountains is similar to that reported in other studies. Rams prefer less steep slopes (21-40%) than ewes throughout the year, but also select 41-60% slopes during the fall breeding season. Use of 41-80% slopes was documented for ewes in all seasons with slopes ≥ 81% used more than expected in winter, spring, and summer. Both sexes avoided slopes ≤ 20%.

Losses of slopes ≥ 41% will effectively decrease the habitat available for female bighorn sheep in the northern Eldorado Mountains. Under the assumption of continued movement, SLA will have the least amount of impact with eight ha of preferred slope lost. Construction of GSA or PPA will result in the loss of substantially higher amounts of selected slope classes with 42 and 33 ha affected, respectively. If construction of new highway obstructs bighorn sheep movements, SLA would still be preferred over GSA with 163 less hectares of preferred slope lost. Differences between SLA and PPA are negligible under this scenario.

Distance from Escape Terrain

Escape terrain is commonly defined as "steep, rocky terrain on which mountain sheep would be able to safely outmaneuver or outdistance predators" (Gionfriddo and Krausman 1986). It has long been recognized as a vital component of bighorn sheep habitat (Cary 1911, Honess and Frost 1942, Vaughan 1954) and its importance in determining the use and distribution of bighorn sheep populations cannot be overstated. Although it is not the only factor influencing bighorn sheep distributions (Krausman and Leopold 1986, Etchberger et al. 1989), the presence or absence of escape cover does affect the use of water (Leslie 1977) and forage (Breyen 1971), and influences travel route selection (Ough and deVos 1984) and lambing grounds (Leslie and Douglas 1979, Elenowitz 1984, Cunningham and Ohmart 1986). Holl and Bleich (1983) found that escape terrain directly affects ewe population size in the San Gabriel Mountains, California. The authors found that a linear relationship exists between the amount of escape terrain available and ewe population size and that a minimum amount of escape cover is necessary before female bighorn sheep can inhabit an area. Wakelyn (1987) also observed that areas with more habitat on or near escape terrain had larger populations of bighorn sheep than areas with less escape cover.

Studies of bighorn sheep behavior show that bighorn sheep are seldom far from escape cover. Kovach (1979), in the White Mountains, California, observed that bighorn sheep spent a significant amount of time either in, or in close proximity (35 m or less) to good escape cover. Gionfriddo and Krausman (1986), in the Santa Catalina Mountains, Arizona, documented preferred use of areas ≤ 50 m from escape terrain and noted that over 80% of all observations were within 20 m of steep and rocky terrain. And although Holl and Bleich (1983) did not directly measure distance from escape terrain, they estimated that all ewes observations were within 200 m of escape terrain in the San Gabriel Mountains, California.

It is generally accepted that female bighorn sheep are generally found within more precarious terrain (i.e. within areas classified as escape terrain) than adult rams (Wilson et al. 1980), however studies measuring distance from escape terrain between the sexes have returned inconsistent results. Tilton and Willard (1982), studying bighorn sheep in the Cabinet Mountains, Montana, observed that ewes were found farther from cliffs than were rams, while Gionfriddo and Krausman (1986) found no difference in distance to escape cover between sexes in the Santa Catalina Mountains, Arizona. Cunningham and Hanna (1992), studying bighorn sheep in the Black Mountains, Arizona, detected no consistent pattern in distance from escape terrain between three different ewe groups and a band of adult rams.

Perhaps more important than sex, group size and season can significantly influence the distance bighorn sheep are found from escape terrain. Risenhoover and Bailey (1985) noted that small groups of bighorn sheep (one to five animals) were rarely observed greater than 100 m distant from escape terrain while large groups (10 or more bighorn sheep) used areas > 100 m distant more than expected. The authors speculate that large groups are more likely to detect approaching predators than smaller groups and, thus, can forage at greater distances from escape cover without substantially increasing their risk of predation. Increased security with increasing group size was also documented by MacArthur et al. (1982). Differences in distance from escape terrain between seasons has been reported by Fairbanks et al. (1987), Elenowitz (1984), and Cunningham and Hanna (1992). In all studies, bighorn sheep were found closest to escape terrain during spring while winter typically found bighorn sheep the most distant.

Use of habitat near escape terrain in the Eldorado Mountains is similar to that found in other studies. Ewes selected areas ≤ 100 m from escape cover in all seasons, however, the greatest percentage of observations within 100 m was recorded in spring (75%). Areas > 300 m from escape terrain were avoided in spring and summer while use of areas > 500 m was less than expected in fall and winter. Female bighorn sheep were generally found farthest from escape terrain in fall with only 59% of observations less than or equal to 100 m from escape terrain. Rams were less dependent on escape terrain than ewes. Percentage of ram observations less than or equal to 100 m from escape terrain ranged from 16% in spring to 48% in fall. Areas classified as escape terrain were avoided by rams during winter and spring. Only during the rut were areas ≤ 100 m from escape terrain used more than expected.

While ewes were observed to range at distances over one km from escape terrain in three of four seasons, over 80% of ewe observations in any one season were less than or equal to 300 m from escape cover. Encroachments inside this 300 m zone, therefore, was considered directly affecting bighorn sheep habitat and was used it in my examination of potential impacts. Given continued bighorn sheep movement after construction, SLA continues to have the least amount of impact with 12 ha of quality habitat disturbed. Impacts due to the construction of GSA and PPA, under this same scenario, are roughly four times greater with 50 ha and 47 ha lost, respectively. If movements across the new alignment cease, GSA will have the greatest impact with 707 ha effectively lost. Construction of GSA results in approximately 200 more hectares lost than construction of either SLA (523 ha) or PPA (502 ha).

Land Surface Ruggedness

Beasom et al. (1983) point out that "land surface ruggedness is a vital component of habitat for many wildlife species". Indeed, this is especially true for bighorn sheep. Being relatively slow on open ground, bighorn sheep rely heavily on their agility among steep and rocky terrain as their primary means of predator avoidance (Geist 1971). Dependence on this habitat component for defense is such that bighorn sheep distribution is limited by the occurrence of precipitous terrain (Wilson et al. 1980). The recognition of this component's importance in bighorn sheep ecology is underscored by the almost universal analysis of slope use in bighorn sheep habitat studies (Ferrier and Bradley 1970, Holl and Bleich 1983, Elenowitz 1984, Risenhoover and Bailey 1985, Krausman and Leopold 1986, Fairbanks et al. 1987, Etchberger et al. 1989, and others). Yet, measurement of slope is not the same as measurement of land surface ruggedness (LSR). Slope provides only a superficial measure of the potential ruggedness of a particular area. In most cases only information from the spot where the animal was sighted is known. Measurement of this type of slope use tells us very little about the peaks, valleys, crags, and ridges that may be found immediately adjacent to the animal's location.

Until recently, no easy, direct method existed for quantifying LSR (see appendix A). As such, few studies have incorporated LSR as part of their habitat evaluations. To my knowledge, Krausman and Leopold (1986) and Etchberger et al. (1989) are the only two studies which have addressed the issue with regards toward bighorn sheep. In both studies, LSR was examined along with several other biotic and abiotic components in an attempt to discriminate between abandoned and currently used bighorn sheep habitat. As far as I know, I am the first to examine LSR selection among bighorn sheep based on use and availability studies. Caution should be used when applying these results to other areas unless the method for determining LSR is similar (see appendix A).

To mitigate loss of habitat among female bighorn sheep, impacts to areas with land surface ruggedness index (LSRI) values > 300 should be minimized. Resultant changes in habitat quality classifications show SLA to have the least potential impact if bighorn sheep movements continue unimpeded post-construction. Under this assumption, construction of SLA would result in the loss of 10 ha of preferred LSRI classes as compared to loses of 50 ha and 45 ha for GSA and PPA, respectively. With blocked movement, construction of GSA will result in the largest loss of preferred habitat (682 ha).

Distance from Water

Many factors influence habitat use and distribution of desert bighorn sheep populations. The amount and distribution of escape terrain, the quality and abundance of palatable forage, the type and degree of human disturbance, and the presence or absence of competing species all contribute to one degree or another to the suitability of an area for bighorn sheep (Cunningham

1989). Perhaps one of the most critical elements for determining bighorn sheep use, however, is the presence and availability of water.

While some populations are able to exist year-round in mountain ranges devoid of freestanding water (Krausman et al. 1985), the majority of bighorn sheep herds are dependent on its occurrence for their survival. This dependence is particularly acute during the hot, dry, summer months when ambient air temperatures frequently rise above bighorn sheep body temperatures. Turner (1973) found that under these circumstances, bighorn sheep are unable to prevent water loss solely through physiological and behavioral adaptations and must supplement water intake by actively drinking.

Needing to drink an estimated minimum of 4% of body weight in water per day for survival during periods of high heat stress (Turner and Weaver 1980), desert-dwelling bighorn sheep have adapted by restricting their summer movements to a small radius around water. Leslie and Douglas (1979) found that 84% of bighorn sheep observations from June through August in the River Mountains, Nevada, were within 3.2 km of permanent water. This compares to just 47% of observations within the same radius during the cool winter months. Cunningham and Ohmart (1986) also noted restrictive movements around water during summer in Carrizo Canyon, California. Bighorn sheep there were seldom sighted greater than two km from water during this period. Bighorn sheep in the Peloncillo Mountains, New Mexico, perhaps reflecting a better dispersion of water sources, were seldom observed farther than 1.6 km from water during any portion of the year. Still, bighorn sheep use in the Peloncillo Mountains was significantly closer to water in summer (mean = 833 m ± 103 SE) than during winter (mean = 1166 m ± 170 SE).

Leslie and Douglas (1979) found yearlings and female bighorn sheep with lambs to be more reliant on water sources during periods of no precipitation and extreme temperatures than adult males. Rams were able to range farther from water during summer and visits to water were less frequent. As ambient air temperatures decreased and forage quality improved, rams were able to disperse from water sources sooner (Leslie 1978). In contrast, Dunn (1984), in the

Cottonwood Mountains, Death Valley National Monument, found rams closer to water during summer months than female bighorn sheep. The author pointed out, however, that his findings do not necessarily indicate a greater dependence on water by males than females. Noting a greater number of water sources within ram habitat, Dunn attributed the difference in figures to a decreased probability of rams being far from water at any one time. In any event, the vast majority of ewe observations were still within four km of water, indicating dependence on it.

As in other studies, bighorn sheep in the Eldorado Mountains are found close to permanent water sources. Figures for this range, however, can be deceptive as a significant portion of mountainous terrain north of Burro Wash lies within 3.2 km of either the Colorado River or Lake Mead. Given the strong affinity of bighorn sheep for rugged terrain, it is unlikely bighorn sheep would be found far from water in the north Eldorado's regardless of their physiological needs. As such, distance data from this study, despite the close proximity of bighorn sheep to water, should be viewed with caution and not be used for predictions in other desert ranges.

While distance from water, overall, may not adequately reflect water dependency among bighorn sheep in the Eldorado Mountains, it may still be possible to detect differences in physiological needs between seasons and between sexes. Results from this study support those of Leslie and Douglas (1979); rams were found farther from water than ewes in all seasons save fall 1991, where distance from water was equal. Although this could be argued as evidence for a greater dependence on water among female bighorn sheep, I feel a simpler explanation is provided by examining differences in habitat selection between the sexes. Ewes have repeatedly shown a higher affinity for rugged terrain than rams (Leslie and Douglas 1979, Tilton and Willard 1982, Cunningham and Hanna 1992). As such, ewes in the northern Eldorado Mountains exploit to a greater extent the strip of broken terrain adjacent to the Colorado River. Separated from the river by this rugged section of terrain and lacking significant inland water sources, rams can be expected to be located farther from water than ewes based on topography alone. While differences in physiological needs may exist between the sexes, my results are inconclusive.

Movements toward water during periods of high heat stress were more conclusive than differences between sexes. Observations that both rams and ewes were located closer to permanent water sources during summer than during cool winter months are consistent with other studies (Leslie and Douglas 1979, Elenowitz 1984). Pronounced movements in the direction of water during periods of heat stress, however, were only evident for male bighorn sheep. Ewe movements were more subtle with only slight, although statistically significant, differences observed in mean distance from water (approximately 400 m). It is unclear, however, if this movement is related to an increased need for water among ewes during summer or is caused by some other factor. As the majority of ewe habitat is already within easy reach of water, the need to move closer to water sources, regardless of increased need for water, seems unnecessary.

Movements off of the north-south running bluffs by ewes into more rugged terrain near the river for lambing may also explain the observed seasonal movement patterns. Evidence for this alternative explanation is provided in the paucity of observations of radio-collared ewes at known water sources. While distance from water decreased during summer, only a handful of radio-collared ewes were observed near known water sources during the same period. In fact, most radio-collared ewes maintained a relatively substantial distance from water throughout this period and were never observed in the vicinity of known water sources. It is possible, however, given the frequency of field observations, that quick sallies to water may have been missed.

Observed distances of female bighorn sheep from water during spring 1991 also contributed to the conjecture that bighorn sheep movements may have been related to lambing or other needs and not associated with water stress. Although ambient air temperatures were considerably more moderate during spring 1991 than in either summer 1990 or summer 1991, mean distance from water for this period was not significantly different from that observed for either summer. The moderate temperatures during spring lead me to believe that diminished forage production and decreased plant water content, which have been identified as necessitating movements toward water (Leslie and Douglas 1979), had yet to occur and therefore did not contribute to these spring movements.

Because of the critical need for water during summer, disturbances at water sources are considered highly sensitive. Changes in time of use, duration of visit, and frequency of visits to water sources have been documented due to nearby construction activities (Leslie 1978, Leslie and Douglas 1980, Campbell and Remington, 1981, DeForge and Scott 1982) and vehicular traffic (Jorgensen 1974, Douglas 1976, Olech 1979). Campbell and Remington (1979) note that such perturbations can result in increased energy costs among bighorn sheep and may lead to a decrease in reproductive output. Depending on the severity and duration of the disturbance, the authors contend, continuing viability of the population may ultimately be threatened.

Disturbances at water sources may also result in the loss of large tracts of available habitat if the disturbance precludes bighorn sheep use and the area is abandoned. Such abandonments in Death Valley National Monument, California, resulted in a severe population decline as the Black Mountain herd was fragmented into two disjunct groups and several important movement corridors into neighboring ranges were lost (Douglas 1988). A similar decline in bighorn sheep numbers resulted from similar situations at Joshua Tree National Monument, California (Douglas 1976).

Impacts due to disturbance are not necessarily confined to the affected water source. Neighboring sources, if any are present, may also be impacted if bighorn sheep shift their use patterns away from the disturbance to nearby water supplies. Leslie and Douglas (1980) caution that such movements may jeopardize the fragile plant-herbivore equilibrium at adjacent water sources and result in a lowering of the area's carrying capacity. If the range deteriorates, stress among bighorn sheep may increase which in turn may lead to lower disease resistance (DeForge 1981). In addition, overcrowded conditions at the remaining water sources aid in the transmission of disease (Dobson and May 1986).

Because of the potential deleterious impacts to bighorn sheep populations, conflicts between human and bighorn sheep at water sources should be minimized. While some guidelines have been developed to mitigate potential disturbances (McQuivey 1978, Wilson et al. 1980, Smith and Krausman 1988), it is largely unknown at what distance a certain level of disturbance becomes disruptive. Given all three of the proposed alignments are located within two km of water, some level of disturbance seems inevitable regardless of which alignment is selected. However, due to the abundance of water available in the northern Eldorado Mountains, those disturbances are anticipated to be slight.

Construction of SLA will, most likely, cause the least amount of disturbance of the three proposed routes provided bighorn sheep movements are unobstructed by the new highway. Despite the entire length of SLA being within 1.3 km of water, only 12 ha of habitat will convert from good or excellent quality habitat to fair or poor quality habitat post-construction under this scenario. GSA and PPA, similarly located in close proximity to water, will lose approximately 50 ha and 48 ha, respectively.

A currently used water source is located within the habitat lost for each alignment. For SLA and PPA, new construction threatens continued use of the sump field located adjacent to the northeast corner of the BOR warehouse. As current construction plans consider the relocation of the warehouse for the Sugarloaf and Promontory Point alternatives for construction of a major road interchange in the area, I assume the sump field will also be removed. In the event the warehouse remains, access to the sump field for bighorn sheep is still expected to be restricted as the nearness of the new highway will, most likely, significantly increase disturbance levels at that location. Loss of this water source, however, does not appear to represent a serious liability given the close proximity and easy access of Lake Mead. In addition, the importance of this water source to bighorn sheep located south of existing U.S. 93 appears to be negligible with little observed use of the field by bighorn sheep from that area.

Use of the hot springs in Boy Scout Canyon as a watering source for bighorn sheep may be jeopardized by construction of GSA. Currently, use is confined to a small area within the canyon approximately 900 m from the Colorado River where small seeps and springs are first encountered. Larger springs and pools are located farther down canyon, however, their use by bighorn sheep is hampered by dense vegetation and heavy recreational use of the area. As GSA rises out of the deepening canyon and travels along its northern slope, the proposed right-of-way passes within a few hundred meters of the upper water source. Due to the close proximity of the roadway and its position above the springs, I suspect use of this source will diminish. But, again, potential effects from this loss on bighorn sheep distribution and numbers are anticipated to be minimal. Current use of the springs by bighorn sheep was observed to be light and its importance as a critical water supply is questionable due to the close proximity of the Colorado River. Frequent disturbance by hikers travelling to the larger pools down canyon also contributes to this area's perceived low evaluation.

If bighorn sheep movements to and from the Promontory Point area discontinue due to construction of new highway, impacts experienced by the bighorn sheep population will be a result of lost forage and cover as opposed to decreased water access. Sufficient water and adequate access will still exist along the Colorado River to meet the needs of all the bighorn sheep within the northern Eldorado Mountains.

Habitat Evaluation Model

Modifications made to the Cunningham habitat evaluation model (1989) made it an excellent predictor for desert bighorn sheep use in the northern Eldorado Mountains. Virtually all bighorn sheep observations occurred in areas classified as good or excellent quality habitat or were in close proximity to such areas. In addition, and perhaps more importantly, areas classified as good or excellent quality habitat corresponded well with the observed distribution pattern of bighorn sheep. Of the 8555 ha cells classified as high quality habitat, approximately 60%

contained at least one bighorn sheep observation or was immediately adjacent to one. This figure increases to over 80% if I count the number of cells classified as good or excellent quality habitat within 500 m of a bighorn sheep observation. While certainly satisfactory, I feel my accuracy at distinguishing bighorn sheep habitat was greater than this. Areas classified as high quality habitat (i.e. good or excellent quality habitat) which occurred at a distance from bighorn sheep observations were largely confined to the southern portion of the study area. This was to be expected as the collaring and observation efforts were concentrated in the northern regions immediately adjacent to the proposed road alignments. If the southern sector had been similarly sampled, I expect the number of cells classified as good or excellent quality habitat within 500 m of a bighorn sheep observation would have been closer to 90 or 95%. The high level of correspondence leads me to believe that changes in habitat classifications recorded after inclusion of proposed alignments within the model should be considered as realistic and that such changes can credibly predict potential changes in bighorn sheep distribution and use patterns.

Few cells currently classified as high quality habitat are traversed by SLA's proposed right-of-way. Of the 48 cells intersected by the alignment, no cells classified as excellent quality are encroached upon while just six cells of good quality habitat are affected. It is not surprising, then, that changes in habitat classifications after inclusion of SLA in the model results in just 12 ha of habitat changing from good or excellent quality habitat to poor or fair quality habitat (i.e. areas lost from use).

Loss of habitat for both GSA and PPA is substantially higher than that calculated for SLA as their proposed right-of-ways traverse significantly more high quality habitat. Intercepting 33 cells of good quality habitat and four cells classified as excellent quality, GSA will eliminate 50 ha of high quality habitat from present bighorn sheep use. A similar loss of premium habitat is expected for PPA as 48 ha will be reclassified from good or excellent quality to poor or fair quality habitat. PPA's right-of-way crosses 16 cells currently classified as good quality habitat as well as five cells designated excellent quality.

Losses discussed above are considered minimum estimates. Implicit in the model is the assumption that bighorn sheep will continue to move freely across the completed right-of-way. Obstruction of such movements, however, would result in larger amounts of habitat lost. Complete blockage of movement will, most likely, result in the loss of all areas north of the new highway regardless of which alignment is selected. Given this latter scenario, GSA will have the largest impact with 745 ha of good or excellent quality habitat lost. Approximately 200 ha less of high quality habitat is lost by blockage from either SLA (561 ha) or PPA (540 ha).

While it is difficult to say with certainty how the degradation of habitat will affect the Eldorado bighorn sheep population, it is generally accepted that loss of habitat results in a proportional population reduction. Holl and Bleich (1983) found a linear relationship in the amount of escape terrain available and the number of female bighorn sheep utilizing an area. If I assume a similar linear relationship exists between number of bighorn sheep in an area and amount of high quality habitat available, it may be possible to make some reasonable projections on potential impacts. With a density of 1.61 bighorn sheep/km^2 in the northern Eldorado Mountains, it is assumed an estimated 62 ha of high quality habitat is necessary to support one bighorn sheep in the area. Based on this figure, construction of SLA, given unimpeded movement, may have little or no effect on population size due to the marginal amount of high quality habitat lost. Impacts from GSA and PPA are also anticipated to be light with a potential loss of one bighorn sheep from the overall population each, given the same scenario.

If movements discontinue, however, potential losses from the population become an item of concern. Construction of GSA, with an estimated loss of 745 ha of high quality habitat, may cause the extirpation of 12 bighorn sheep from the Eldorado population. Exacerbating this situation, I assume the majority of these bighorn sheep will be female, given the location of the lost habitat. Female bighorn sheep contribute disproportionately to the reproductive potential of the herd. Losses from construction of either SLA or PPA are not anticipated to be as severe as

GSA. Estimated losses for both alignments are approximately nine bighorn sheep each; again, mostly female.

Based on the strong association between lamb locations and areas classified as excellent quality habitat, I examined the relationship between the proposed alignments and this habitat class. As lambs appear to be dependent on excellent quality habitat, disturbance to this class is considered particularly damaging. Of the three proposed alignments, SLA is expected to have the least amount of impact within this category. With much of its right-of-way already transversing areas of high human use, cells currently classified as excellent quality habitat (i.e. lambing habitat) are relatively distant. No portion of SLA is within 200 m of an area classified as excellent quality habitat. The 200 m buffer is considered particularly noteworthy as lambs were rarely observed greater than this distance from excellent quality habitat. GSA and PPA have 64% and 29% of their alignments within this zone, respectively. Degradation of excellent quality habitat due to new highway construction is also minimized through construction of SLA. Six cells classified as excellent quality habitat were reclassified to lower levels after SLA was included in the model. This compares to 41 cells and 38 cells reclassified for GSA and PPA, respectively.

Although a distinction was made between good and excellent quality habitat throughout this analysis, I should point out that these terms are misleading descriptors insofar as used within this study area. Areas classified as excellent quality habitat are, indeed, areas of importance, however I feel this classification more accurately delineates areas of critical importance (e.g. lambing grounds) as opposed to "ideal" bighorn sheep habitat. Indeed, it is not unreasonable to assume "ideal" habitat for adult male bighorn sheep was found within areas classified as good quality habitat and not areas classified as excellent quality based on the former's heavy use documented for rams. In addition, ewes used both good and excellent quality habitat more than expected based on its availability throughout the study (chi-square, df = 3, $P \leq 0.05$). I mention this apparent weakness in the classification system to forestall any temptation to consider areas classified as good quality habitat as second-class areas with diminished conservation value.

Mitigation measures for the northern Eldorado Mountains should be directed at maintaining the integrity of both these classifications to minimize disturbance to bighorn sheep.

Affects of Highway 93 on Bighorn Sheep Distribution

Distribution of female desert bighorn sheep does not appear to be affected by U.S. 93. Despite a slight trend toward increased use of areas distant from U.S. 93, use was not less than expected for any given distance interval save the 0-100 m and 401-500 m zones during the second year of study. Only the 1501-1600 m distance interval was used more than expected based on availability, and again, for only one year of study. I consider these shifts in use patterns as minor fluctuations in habitat usage and not actual selection or avoidance of particular areas.

Results in the northern Eldorado Mountains differ from the general consensus that bighorn sheep react adversely to roads (DeForge 1972, Ferrier 1974, Jorgensen 1974, McQuivey 1978, Krausman et al. 1979, Witham and Smith 1979, DeForge et al. 1981, Cunningham 1982 in Sanchez et al. 1988, Witham et al. 1982). However, research by both MacArthur et al. (1982) and Miller and Smith (1985) also indicate that disturbance to bighorn sheep from passing cars and trucks and highway noise is minimal. My observations support this latter conclusion as numerous bighorn sheep were spotted in close proximity to and in direct line of sight of U.S. 93. Indeed, on several occasions, groups of bighorn sheep were observed foraging immediately adjacent to the highway's shoulder with little or no overt reaction to passing vehicles. On two occasions, ewes with lambs (four to five months old) fed within 1.5 m of moving traffic. On both occasions, traffic volume was heavy with an average of 13 vehicles passing by each minute including passenger cars and vans, tour buses, recreational vehicles, and commercial tractor-trailers. Only when a vehicle slowed down or stopped nearby in an attempt by people to take photographs or obtain a better look at the animals, did the bighorn sheep interrupt their feeding behavior and move away at a walk.

Reactions of bighorn sheep to human disturbance is largely determined by the type of encounters experienced between humans and bighorn sheep over time (Geist 1971, Miller and Smith 1985). When such encounters are predictable and non-threatening (e.g. moving traffic), bighorn sheep may habituate to the disturbance (Geist 1971, Leslie and Douglas 1980, Hamilton 1982, Hicks and Elder 1982, Stanger et al. 1986). Such habituation appears to have occurred along U.S. 93. This result, however, was somewhat unexpected, given the high volume of traffic using the highway. Rost and Bailey (1979), studying elk and mule deer in the Rocky Mountain region, found that habitat use adjacent to roads was inversely related to the amount of vehicle traffic along the road. Heavily travelled roads were more likely to be avoided by both elk and mule deer than roads less used. The authors note, however, that the degree of avoidance was affected by the type and availability of surrounding habitat. It was hypothesized that high quality habitat, when readily available and distant from roads, allowed elk and mule deer to better avoid roads. In depauperate areas, elk and deer were forced to forage closer to roads to avoid malnutrition. Similar distribution patterns around roads for elk and mule deer in the Blue Mountains of Washington were found by Perry and Overly (1972). Elk avoided all roads, from primitive to main, with the greatest distance away measured along roads with the most vehicle use. Mule deer, however, only avoided roads heavily travelled and only when sufficient cover was absent. Although cover allowed elk to forage closer to roads, it did not totally eliminate traffic effects on elk distributions. To my knowledge, influence of traffic volume on bighorn sheep distribution has not been studied. However, analysis of historic and present distributions of bighorn sheep populations have led some researchers to conclude such a relationship exists (Ferrier 1974, McQuivey 1978).

If this is the case, why have female bighorn sheep adapted to the presence of U.S. 93 and not abandoned the area? I suspect that the juxtaposition of forage, cover, and water in the surrounding area allows for a relatively high level of tolerance among ewes to human disturbance. Similar conditions exist across the Colorado River in the Black Mountains of Arizona with a similar amount of bighorn sheep activity in proximity to U.S. 93 (Cunningham and Hanna 1992). The role of topography in determining bighorn sheep reactions to disturbance is well documented (Hicks and Elder 1979, MacArthur et al. 1982, Holl and Bleich 1983). The gradual build-up of traffic along U.S. 93 over the past 59 years may also have contributed to the present habituation of female bighorn sheep. Bighorn sheep may have adapted to the presence of the highway soon after completion of Hoover Dam when traffic volumes along U.S. 93 were substantially lower then present levels (U.S. Bureau of Reclamation 1986). Acceptance of the highway as a non-threatening presence was then passed on from one generation to the next. Increases in traffic volume over the years, therefore, could have been imperceptible to successive generations of bighorn sheep. Hamilton (1982) documented a rapid habituation to road disturbance by bighorn sheep in the San Gabriel Mountains, California, when traffic volumes were moderate.

Given the close proximity of the three proposed road alignments to U.S. 93 and the fact that each alignment is located within similar habitat as the existing highway, I expect bighorn sheep to habituate to the new highway equally as well. A few words of caution, however. Traffic speed and traffic volume are anticipated to increase along the new road alignment from levels currently experienced on U.S. 93 (U.S. Bureau of Reclamation 1986). Such increases may surpass limits which now allow bighorn sheep to cross U.S. 93 successfully and with relative frequency. Obstruction of bighorn sheep movements by the new highway would effectively deny access to the Promontory Point area and is considered the most serious potential impact of the new highway (see above). Of equal concern, construction of a new highway adds one more disturbance to an already heavily disturbed area. While tolerance for such disturbance has been exhibited by bighorn sheep presently inhabiting the area, historic patterns are no guarantee of future behavior. Additional disturbance may still result in habitat abandonment (see Van Dyke et al. 1986 and Brody and Pelton 1989 for a discussion on the influence of road density on home range selection).

Although ewes have apparently habituated to U.S. 93, insufficient data existed to test for possible avoidance of the highway by gravid females during spring lambing season. Such avoidance was expected due to the need for seclusion during birthing (Leslie and Douglas 1979). Sightings of newborn lambs (less than three months old), however, appear to confirm this requirement as all were 500 m or more from U.S. 93 despite the existence of potential lambing habitat in proximity to the highway. Based on these findings, I assume at least a 500 m buffer from disturbance is necessary to ensure successful lambing. Comparisons between the three proposed highway alignments and observed lamb distributions shows SLA as encroaching the least on existing lambing grounds. Of the 48 cells traversed by SLA, only four are within the crucial 500 m buffer zone. Encroachments into the zone by GSA and PPA equals 13 and 23 cells each, respectively.

Distribution and Movements of Bighorn Sheep along Proposed Alignments

Use of Adjacent Habitat

The close proximity of the proposed alignments to each other contributed to the failure to detect differences in bighorn sheep use adjacent to the alignments as measured by the number of observations within 0.5 km and 1.0 km of the respective alignments. Distance between GSA, the southernmost alignment, and PPA, the northernmost alignment, averages just 1.1 km (range = 0.0 - 2.3 km). As a result, considerable overlap occurs between proximity zones for all alignments. For PPA and SLA the situation is particularly acute with approximately two km of each alignment, or about 1/2 of their respective lengths in Nevada, shared between the two.

Although not statistically significant, use of areas adjacent to SLA by both male and female bighorn sheep was consistently lower than that observed for GSA and PPA. This was consistent with expectations as SLA passes through greater amounts of area classified as poor or fair quality habitat than does either GSA or PPA.

As judged by the number of radio-collared bighorn sheep in proximity to each alignment, a similar number of bighorn sheep will be affected by new highway construction regardless of which alignment is chosen. Again, this is a function of the close proximity of the alignments to each other.

Areas of Relative Use

In conjunction with habitat modeling, the study area was evaluated in regards to actual bighorn sheep distribution. Areas were rated as high use, high-moderate use, low-moderate use, and low use based on the number of observations within a 0.5 km radius of each cell in the study area. This methodology was adapted due to the small cell size used in my analysis. Although my field assistants and I documented close to 3000 observations in two years of study, the vast majority of cells where bighorn sheep observations occurred contained just one observation apiece. Using just the number of observations per cell as a criteria for distinguishing the cell's relative importance to bighorn sheep fails to distinguish between cells at the periphery of the range where habitat conditions are frequently marginal from those at the interior. In addition, cells containing bighorn sheep observations were frequently separated from similar cells by cells which contained no documented use. Although it can be assumed bighorn sheep movements occurred through these vacant cells, they were indistinguishable from cells where no actual use occurred. By extending a buffer around each cell and counting the number of observations within that area, I was able to recognize vacant cells that had a high probability of bighorn sheep use. By identifying such cells, it was then possible to obtain an accurate estimation of bighorn sheep use.

Examination of relative use zones in relation to the proposed highway alignments continues to indicate SLA as the preferred alignment. Of the three alignments, SLA traverses the least amount of area classified as high or high-moderate use (38 cells) followed by GSA (45 cells) then PPA (50 cells).

Interestingly, a zone of low to low-moderate use is found outlined by the triangle formed by PPA, GSA, and the Colorado River (Fig. 33). I was at first concerned that problems existed in the sampling effort to collar bighorn sheep from that area. Capture operations were restricted from the zone due to the heavy concentration of high voltage transmission lines in the area. Although efforts were made to collar animals immediately adjacent to the area, I suspected that bighorn sheep inhabiting the area avoided capture. However, examination of movements by radio-collared bighorn sheep confirmed the conclusion that the area was not used extensively by bighorn sheep. Ewes collared both north and south of the triangular area travelled to the opposite side of the zone, but mostly by skirting its western edge. Rams, which had opportunity to enter the area during the rut were seldom observed there. If uncollared ewes were indeed inhabiting the area, I suspect one or two collared rams would have revealed their presence to me at this time.

It is unclear why the zone is used only sporadically by bighorn sheep. When the human disturbance factor is removed from the habitat evaluation model, much of the area is classified as excellent quality habitat (Fig. 47). Given the apparent high degree of habituation to disturbance observed among bighorn sheep in the area, I would therefore expect bighorn sheep use within the zone to be at higher levels than those observed. The lack of use, therefore, is in conflict with my conclusions based on bighorn sheep response to U.S. 93. Although the test results failed to detect any avoidance, the heavy concentration of disturbance within the area is apparently affecting bighorn sheep behavior to some degree. Further study is needed to resolve this disagreement.

Movements Across Proposed Alignments

Visual Observations

Despite the low number of bighorn sheep crossings witnessed along the proposed highway alignments, a number of conclusions can be drawn from them. First, no apparent

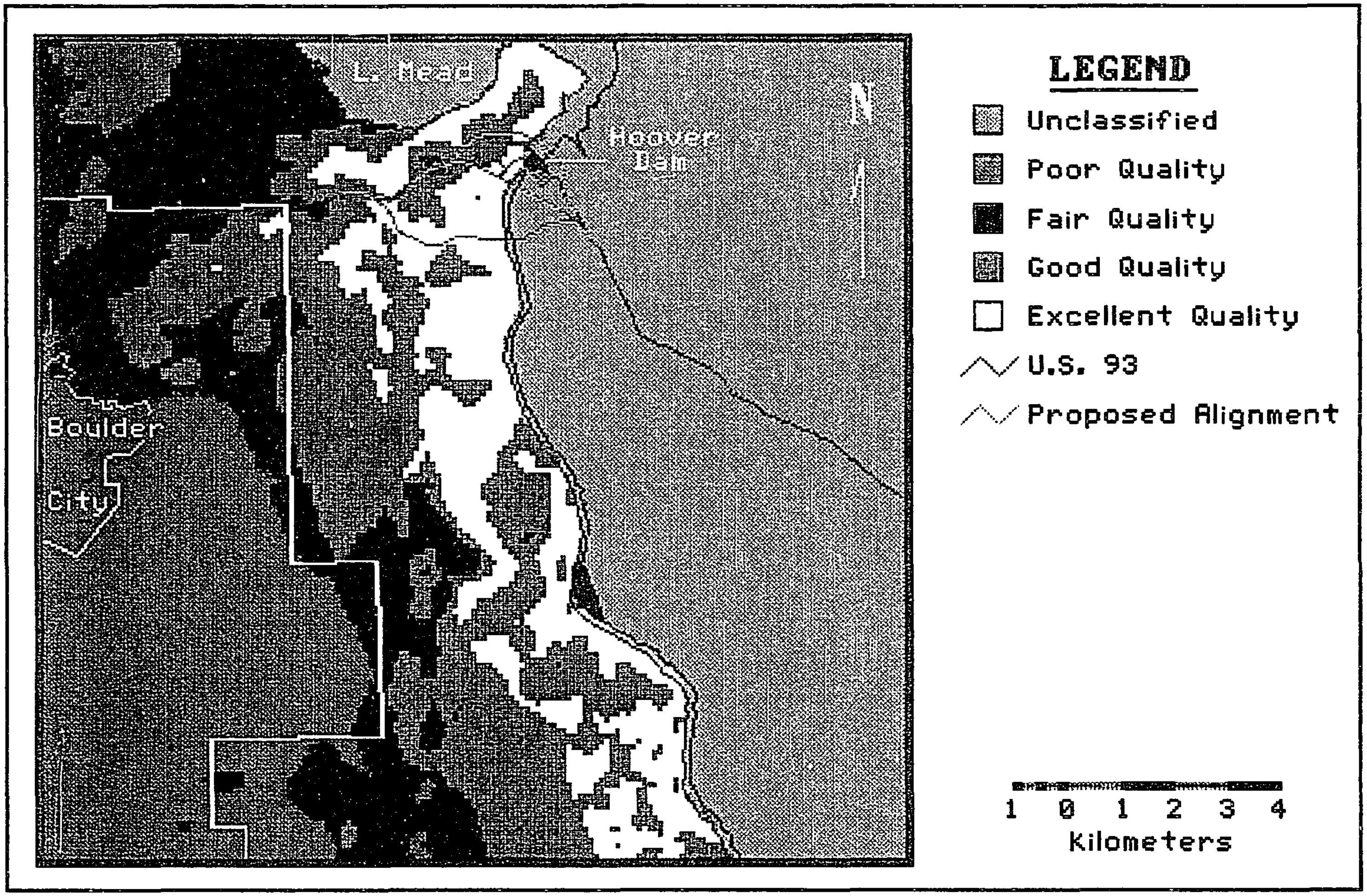

Figure 47. Areas of predicted bighorn sheep use based on the modified Cunningham habitat evaluation model with human disturbance removed (Cunningham 1989).

difference exists between alignments based on the number of crossings observed. Each alignment was crossed by bighorn sheep approximately an equal number of times. This observation lends support to my conclusion that bighorn sheep use adjacent to the alignments is similar between alignments. Second, for all three alignments, bighorn sheep crossings occur along the entire length of the alignment. No single trail or area is used exclusively as a crossing point for any of the three alignments. Movements such as these, diffused over a wide area, can be expected when suitable habitat is available and the area lacks a specific biological attraction point to focus movements (e.g. mineral lick, point water source). Even within marginal habitat, bighorn sheep movement corridors are not confined to narrow bands, but expand to fill areas of acceptable habitat (Ough and deVos 1984). Third, for PPA and SLA, the majority of documented crossings occur along the shared length of alignment located between Gold Strike Casino and the BOR warehouse complex. Although comprising only 1/2 of their respective lengths, this stretch of alignment accounts for 70% of crossings observed for each of the respective alignments. This conforms to expectations based on the distribution of motor vehicle/bighorn sheep collisions along U.S. 93 since 1963 (NDOW records) and my relative use map (Fig. 33), which indicates a band of high use for that particular area. And lastly, Gold Strike Canyon serves as an important source of forage and thermal cover for local bighorn sheep. Locations identified as crossing points for Gold Strike Canyon were actually locations where bighorn sheep were observed to enter or exit the canyon. While in the canyon, bighorn sheep would often meander along the wash bottom foraging on available plant cover. Exits usually occurred some distance away from the point of entry via a different route. During summer, bighorn sheep were frequently observed bedded near the canyon bottom where shade was available throughout much of the day. Movements along PPA and SLA were more transient in nature.

Relocation Data

Similar to the measure of bighorn sheep use adjacent to the proposed alignments, the close proximity of the alignments to each other influenced the results here. No difference was detected between alignments in the number of crossings documented for either male or female bighorn sheep. This is attributable to the large number of shared crossings documented between alignments. In the vast majority of cases, successive relocations of a bighorn sheep which document an alignment crossing reveal that the bighorn sheep had, in fact, crossed all three. For SLA, this was the rule rather than the exception. In virtually all documented crossings of this alignment (55 of 57), bighorn sheep travelled from north of PPA to south of GSA or vice versa. The crossing of SLA appears to be incidental to this movement. While percentage of shared crossings for GSA (76.4%) and PPA (84.6%) are also high, the occurrence of a higher portion of unshared crossings may indicate a higher level of bighorn sheep activity in their vicinity as compared to SLA. This conclusion is supported by documented bighorn sheep use as revealed by the relative use map (Fig. 33).

Lines connecting successive location points should not be considered as representing true routes of travel. This is particularly true when time intervals between observations are large, such as used in this study, when distance travelled between points can be grossly underestimated (Reynolds and Laundre 1990). However, by "connecting the dots", general movement patterns may become evident and provide useful information for management decisions. Such trends were apparent in the area of the alignments.

Although movements into the triangle outlined by PPA, GSA and the Colorado River did occur, they are limited. To the north, movement patterns generally parallel PPA, remaining mostly to the north of PPA, between the alignment and Lake Mead's shore line. Bighorn sheep movements extend westward in this area to just west of the BOR warehouse complex where bighorn sheep make extensive use of a series of rough peaks located between the warehouse and Gold Strike Casino. Here bighorn sheep may turn to the south and move into the area south of U.S. 93. Once across the highway, bighorn sheep movements radiate outward, but remain generally to the west and south of Gold Strike Canyon. Bighorn sheep moving in the opposite direction follow basically the same route. The high use category in the relative use map (Fig. 33) roughly corresponds to the observed movement corridor.

The three proposed alignments run roughly parallel to the majority of bighorn sheep movements. PPA and GSA, however, infringe more on areas of greater bighorn sheep activity than does SLA. The potential for disrupting existing movement patterns is, therefore, considered higher for these two alignments. Construction of SLA is the preferred alternative based on this analysis.

SUMMARY

The close proximity of the proposed road alignments to each other and their similarities in length blurred many of the distinctions between the three alternatives considered for the Black Canyon Bridge Project. Home range data provided little information to help differentiate alignments as a similar number of bighorn sheep with home ranges within one km was documented for each proposed roadway. Chi-squared goodness of fit tests comparing the number of bighorn sheep observations within 0.5 km and 1.0 km of the respective alignments to one another revealed no difference for either male or female bighorn sheep use adjacent to the proposed right-of-ways. Similar examination of the number of bighorn sheep crossings of the proposed roadways for both sexes failed to detect any difference between the alignments. Closer examination of such analyses, however, revealed a subtle but consistent pattern of disparity between the alignments. In almost all cases, numbers recorded for the Sugarloaf Mountain alignment (SLA) were lower than those noted for either the Gold Strike Canyon alignment (GSA) or the Promontory Point alignment (PPA). This observation led to speculation that impacts to bighorn sheep would be minimized by construction of SLA.

Distinct differences between the alignments became more apparent with the application of advanced geographic information systems (GIS) techniques. Construction of a relative use map provided a detailed illustration of bighorn sheep observation densities in the area of the proposed roadways. Subtle differences detected earlier between the alignments were emphasized by this approach. Located in proximity to the proposed alignments was a region of low to low-moderate bighorn sheep use. This area corresponded roughly with a triangle formed by PPA, GSA, and the Colorado River. SLA, which is positioned between the other two alignments, essentially bisects this triangle, and, as a consequence, traverses notably fewer cells classified as high or high-moderate use than either GSA or PPA. Although insufficient evidence existed to statistically reject the hypothesis of equal bighorn sheep use between alignments, suspected differences in use appear to be real.

Further support for this conclusion and a probable explanation for the observed bighorn sheep distribution is provided by a derived habitat quality map. Using a modified Cunningham habitat evaluation model, each 100 m x 100 m cell in the study area was assigned a quality grade based on the cell's juxtaposition with various biotic and abiotic components. Roughly corresponding to the area in question was a collection of cells classified as poor to fair quality habitat. Overlays of the proposed right-of-ways on the habitat quality map revealed that, indeed, close to 90% of SLA is contained within these cells. This value compared to just 21.3% for GSA and 62.5% for PPA. The lower use observed in the area surrounding SLA was consistent with expectations as bighorn sheep showed a decided avoidance of poor and fair quality habitat.

The close correspondence of bighorn sheep observations with habitat quality ratings showed the modified Cunningham habitat evaluation model to be an excellent predictor of bighorn sheep habitat use. Predictions of changes in habitat quality based on the incorporation of the respective alignments into the model were therefore considered realistic and accurate. Two analyses were conducted for predicting changes. The first, assumed bighorn sheep movements would continue unobstructed across the proposed right-of-ways following construction. In this evaluation, SLA continues to have the least potential for disrupting existing bighorn sheep activity based on the amount of good and excellent quality habitat reclassified to either fair or poor quality habitat. Loss of quality habitat following construction of SLA is anticipated to be 4 x less than that of either GSA or PPA. The second analysis assumed the new roadway would act as an absolute barrier to bighorn sheep movements. Under this scenario, impacts of SLA and PPA were judged to be similar while construction of GSA results in the greatest potential disturbance. If bighorn sheep movements become obstructed, a potential of 12 bighorn sheep may be lost from the population following construction of GSA. An estimated nine individuals will be lost due to construction of either PPA or SLA.

Within habitat lost (i.e. areas reclassified from good or excellent quality habitat to fair or poor quality habitat), the amount of various preferred habitat components for female bighorn sheep were determined. Only ewe preferences were examined as rams rarely entered the area of the alignments except during the rut when male habitat selection closely mimicked that of female bighorn sheep. For all components (slope, elevation, aspect, distance from escape terrain, and land surface ruggedness), construction of SLA minimized losses of selected habitat provided bighorn sheep movements across the alignment continued post-construction. If movements become impeded, loss of selected habitat is minimized by construction of PPA, however, impacts by SLA are only slightly greater. Under the no-movement scenario, construction of GSA results in the greatest amount of potential disturbance to all habitat components. Although seasonal variations exist, over the course of the year ewes select northern and eastern aspects, elevations of 400-600 m, slopes > 40%, cells with land surface ruggedness index values > 300, and areas < 300 m of escape terrain.

Threats to water sources from proposed highway alignments are considered slight. No known water source is jeopardized by SLA, while PPA and GSA threaten one water source each. Both water sources are considered marginal in both quality and volume and of questionable value to bighorn sheep. The close proximity of the threatened water sources to alternative water supplies further diminishes their significance as essential water stores.

A specific lambing ground common to all ewes within the northern Eldorado Mountains was not observed. Lambing occurred throughout the region, coinciding with the occurrence of steep, rocky terrain. Potential impacts to existing lambing grounds by the proposed alignments was evaluated in two ways. The first involved measuring the minimum distance between U.S. 93 and known lamb locations during the spring lambing period. This distance was assumed to be the minimum buffer needed from highway disturbance to ensure successful lambing. Five hundred m was the minimum distance measured. Based on this criteria, SLA was judged to be the least intrusive of the three alignments while PPA encroached the most. The second evaluation took advantage of the observed close association between lamb observations and the excellent quality habitat classification. Of the 88 lamb sightings recorded during the two years of study, over 94% occurred in or within 200 m of this habitat class. Measuring the loss of excellent quality habitat after construction, SLA was again found to be the least intrusive of the three alignments with PPA still the most.

Insufficient evidence existed to reject the hypothesis that female bighorn sheep distributions were unaffected by U.S. 93. The highway has been in existence for nearly 60 years which may account for its acceptance among bighorn sheep today. Even still, the results were unexpected given the high volumes of traffic travelling on U.S. 93 and the heavy human pedestrian activity (e.g. turnouts, scenic overlooks, shuttle bus parking, commercial buildings) associated with the area. Given the observed level of habituation exhibited by bighorn sheep to U.S. 93, similar tolerance of new highway is anticipated.

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APPENDIX A

Quantifiying land surface ruggedness: a GIS approach

QUANTIFYING LAND SURFACE RUGGEDNESS: A GIS APPROACH

Introduction

Rugged terrain has long been recognized as a principal characteristic of bighorn sheep (Ovis canadensis) habitat (Cary 1911, Honess and Frost 1942, Vaughan 1954). By exploiting such areas, bighorn sheep have been able to reduce their risk to predation (Geist 1971), competition (Dunn 1984), and human disturbance (Hicks and Elder 1979).

Their dependence on broken terrain, however, can be limiting. Numerous studies have noted bighorn sheep habitat use is primarily restricted to areas within100 m of steep, rocky terrain which serves as escape cover. Risenhoover and Bailey (1985) obtained a negative correlation between foraging efficiency and distance to escape terrain and MacArthur et al. (1979) speculated that elevated stress levels were associated with increased distance from escape terrain. Given such restrictive use patterns, food and water sources otherwise located a short distance from bighorn sheep populations may not be utilized (Leslie 1977).

It is small wonder then that when researchers began modeling optimal bighorn sheep habitat requirements, topography figured prominently (Ferrier and Bradley 1970, Hansen 1980). While these early models provided a rough estimation of habitat suitability, many parameters used and especially those for land surface ruggedness (LSR) were subjective descriptions and coarse-grained approximations. More recent models (Armentrout and Brigham 1988, Cunningham 1989) refined many parameters and added relevant others, but assessments for LSR remained essentially unchanged. Without incorporation of an objective assessment of LSR, the utility of these models to accurately predict habitat use patterns may be decreased.

Beasom et al. (1983) developed a relatively rapid and effective method for quantifying LSR. By counting intersections between contour lines in an area and points on a regularly spaced grid, an index for ruggedness is calculated. The number of intersections reflects the degree of roughness.

The underlying assumption of the index is that the total length of all contour lines which traverse an area is a direct function of the "ruggedness" of the area. This appears to be a valid assumption as total length, being a function of the number and lengths of contour lines in an area, takes into account many of the complex variables (e.g. surface irregularities and elevational changes) that comprise "ruggedness".

While providing a valuable tool for habitat evaluations, Beasom et al.'s index does not lend itself to easy implementation with a computer-based geographic information system (GIS). My objective is to develop a technique for quantifying LSR that uses the increased resolution capabilities of GIS and maintains the desired correlation with total contour length.

Methods

The Colorado River Black Canyon area near Hoover Dam in the Lake Mead National Recreation Area was selected as the test location (Fig. 1). The site supports a large population of bighorn sheep and provides a wide variety of terrain classes. U.S.G.S. 1:24000 scale 7.5 minute series maps were obtained for the area and gridded into one ha cells (100 m x 100 m). Elevation values for each cell were estimating by determining the elevation at the cell's mid-point to the nearest 1.5 m and entered into the Professional Map Analysis Package (pMAP) (SIS 1986), the GIS software program used for all analyses. Two hundred cells were then selected at random for model development. To assess the overall terrain of an area, a three x three cell window (nine ha, 22.2 acres), encompassing the target cell and its eight neighbors, was chosen as the unit of study. Contour lines within each nine ha window were measured and totaled. The lengths were standardized to that expected for 3.04 m contour intervals (Beasom et al. 1983). Figure 2 illustrates several neighborhoods and their associated values.

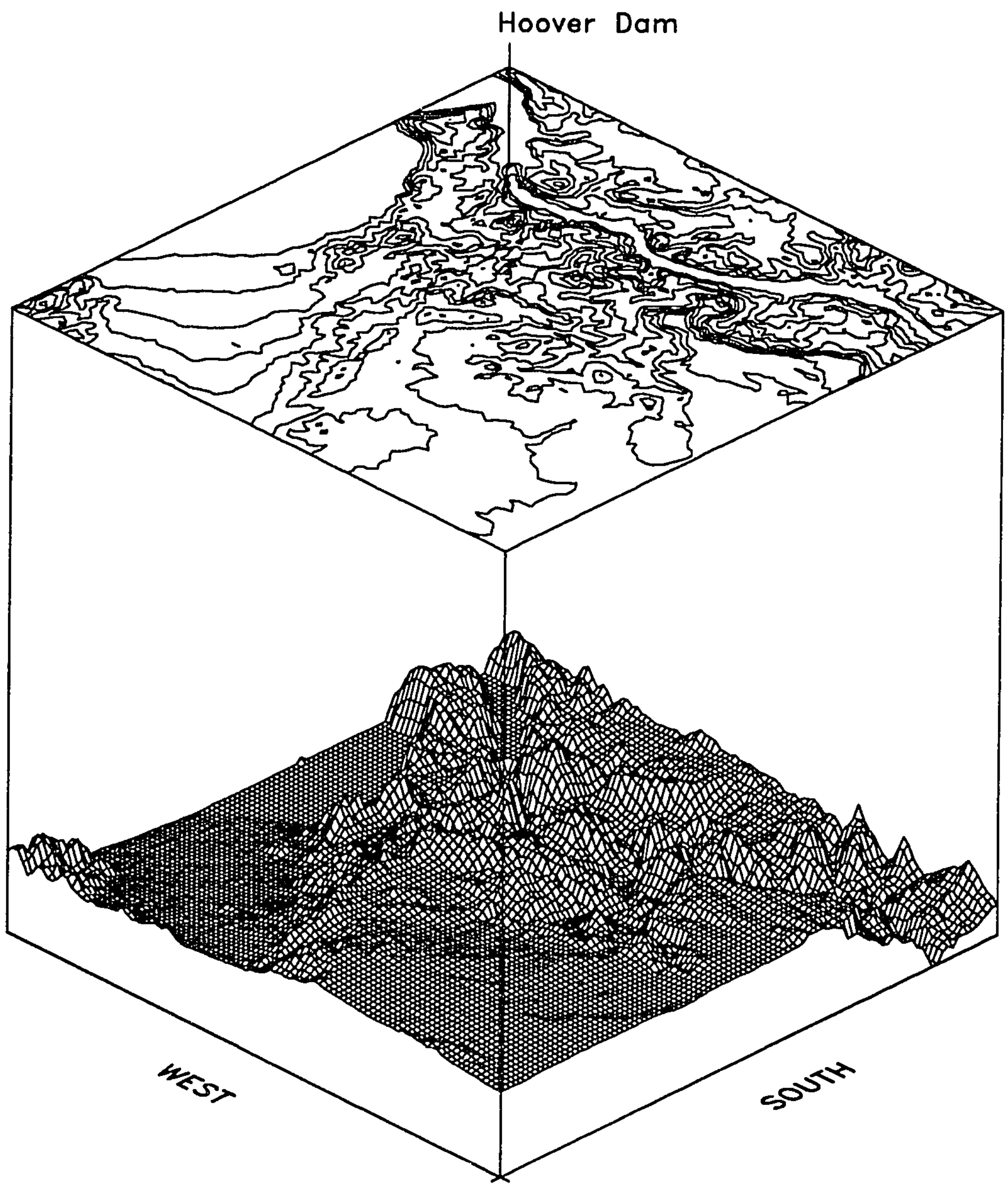

Figure 1. Black Canyon study area, Lake Mead National Recreation Area, Clark Co., NV, Mohave Co., AZ: two-dimensional (above) and three-dimensional (below) representations.

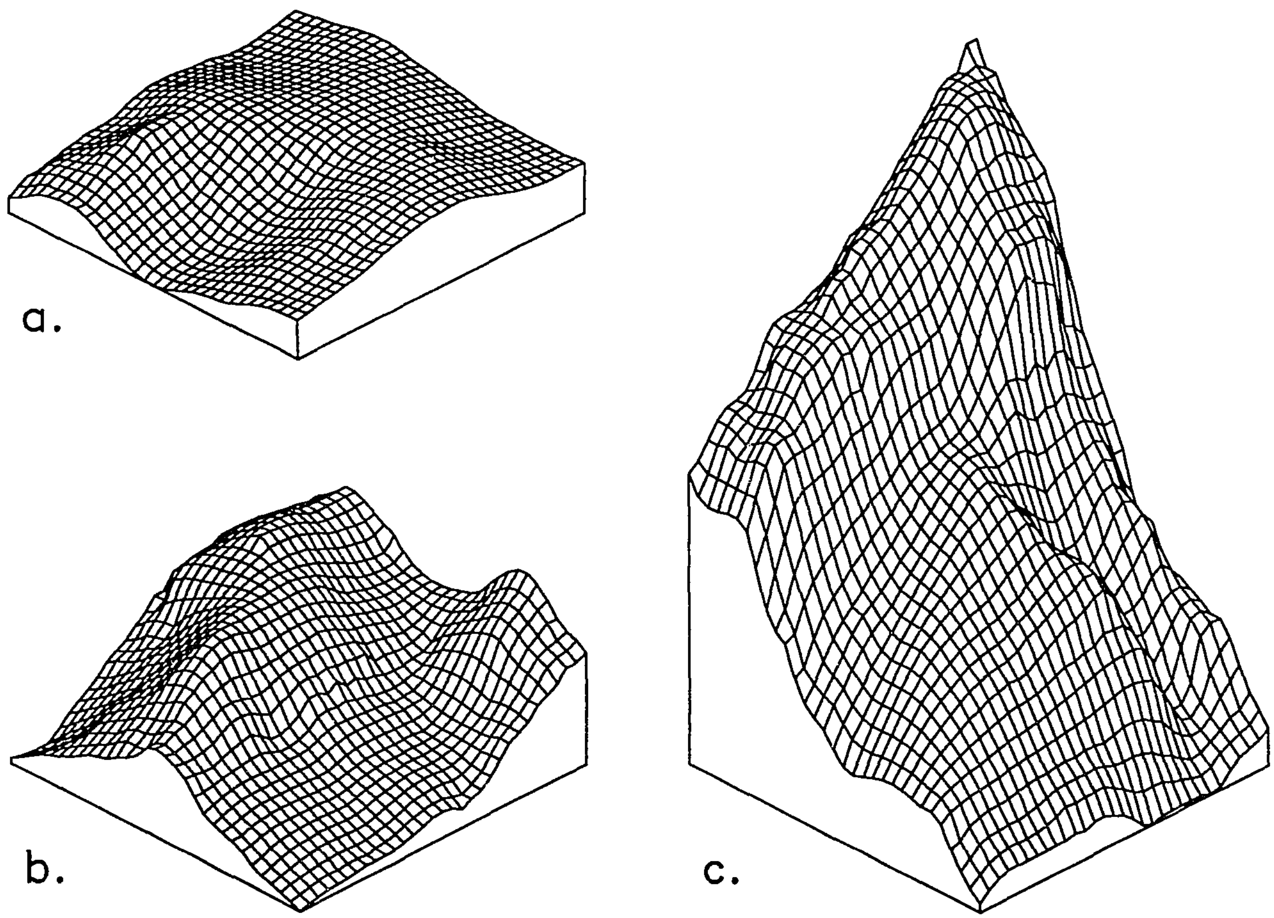

Figure 2. Three dimensional representations of 3 9-hectare areas used in development of GIS based land surface ruggedness index (LSRI). Total contour length for a, b, and c = 32 cm, 64 cm, and 139 cm, respectively. Corresponding values for maximum-slope neighborhood totals = 197, 352, and 894.

Within the GIS package, various derivations of slope, aspect, and relief were computed from the base elevation map and manipulated within each nine ha window. The corresponding values were then output for comparison with total contour length. Relief was determined by subtracting the lowest elevational value in the window from the highest. Individual cell values for *maximum slope, minimum slope, average slope, and fitted slope were computed,* then totaled for each neighborhood. Aspect was determined for each cell by the orientation of its maximum slope. The number of different aspect classes within each window were then counted. Two levels of aspect resolution were used in the evaluation: (1) octants, and (2) 16 points of the compass. Maximum and fitted slopes for the fitted slope and maximum slope maps were also computed. This is similar to computing the second derivative of a surface map and identifies areas where slopes are changing (i.e. surface ruggedness) (SIS 1986). Cell values for these maps were also totaled within the respective windows.

A general linear regression model (Neter et al. 1990) was used to examine the relationship between total contour length (dependent variable) and the different components derived from GIS manipulation (independent variables). Regression through the origin was employed in all tests as areas with no slope, relief, or aspect would be void of contour lines (Neter et al. 1990). All statistical tests were performed using Statgraphics® statistical graphics system.

Results and Discussion

Total contour length for the nine ha windows after standardization ranged from 0 to 139 cm. Ranges for the GIS variables are given in table 1. PMAP's minimum slope operation was excluded from the analysis as all cells were assigned a value of zero.

High coefficients of correlation ($r = 0.79$ to 0.98) were obtained between all remaining GIS components and total contour length (table 1). Maximum slope total (MST) and average slope total (AST) had the best performance with r values of 0.98 and standard errors of 10.62 cm and

Table 1. Linear regressions through the origin with total contour length as the dependent variable for the Colorado River Black Canyon area, Lake Mead National Recreation Area, Clark Co., NV, Mohave Co., AZ. Sample size = 200.

Independent variables	Slope	*r*	adj. r^2	S.E. of estimate	Range
MAXIMUM SLOPE TOTAL	0.168	0.98	0.96	10.62	0 - 894
AVERAGE SLOPE TOTAL	1.513	0.98	0.95	10.66	0 - 99
FITTED SLOPE TOTAL	0.233	0.96	0.92	14.43	0 - 745
RELIEF	0.829	0.95	0.90	15.98	0 - 231
DIVERSITY OF ASPECTS/ OCTANTS	12.22	0.79	0.62	30.75	1 - 6
DIVERSITY OF ASPECTS/ 16 PTS OF COMPASS	9.238	0.79	0.62	30.94	1 - 8
2ND DERIVATIVE/FITTED SLOPE OF FITTED SLOPE	0.579	0.94	0.89	16.89	0 - 229
2ND DERIVATIVE/MAXIMUM SLOPE OF FITTED SLOPE	0.230	0.95	0.91	15.13	0 - 606
2ND DERIVATIVE/FITTED SLOPE OF MAXIMUM SLOPE	0.599	0.91	0.83	20.81	0 - 261
2ND DERIVATIVE/MAXIMUM SLOPE OF MAXIMUM SLOPE	0.297	0.92	0.84	19.92	0 - 531

10.66 cm, respectively. The regression of total contour length on maximum slope total is depicted in figure 3.

Although MST and AST provide a good fit to the data, I felt that a multiple regression model could further reduce the error variance. Spearman's rank correlation was used to identify correlated variables for exclusion from the model. Based on the results, a multiple regression of total contour length on independent variables MST and diversity of aspect (using 16 points of the compass) was performed. The standard error obtained from this regression was only 0.24 cm lower than that reported for MST alone. Application of a multiple regression model in this instance is unwarranted.

Despite the poor performance of the above test, a model with variables reflecting terrain steepness and changes in aspect is intuitively appealing and merits further investigation. By reducing the grid interval to 50 m or less, resolution may improve to the point where changes in aspect can be better assessed. Accuracy of slope determinations would also improve with cell size reduction.

For studies which use one ha resolution, however, use of a maximum-slope three x three neighborhood analysis provides a rapid, fine-grained assessment of LSR analogous to that developed by Beasom et al. (Fig. 4).

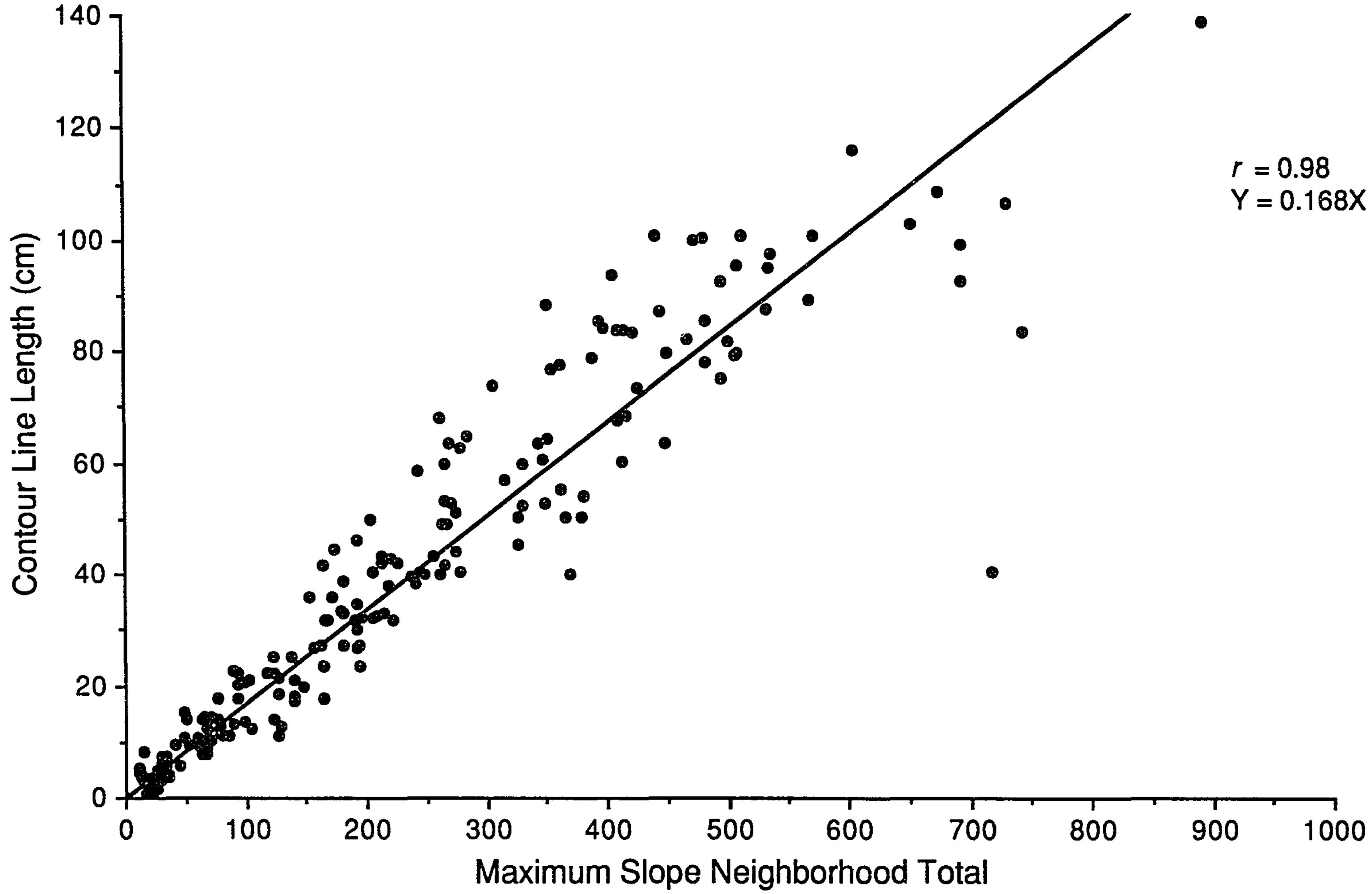

Figure 3. Regression of total contour length on 3 x 3 neighborhood maximum-slope total at the Colorado River Black Canyon area, Lake Mead National Recreation Area, Clark Co., NV, Mohave Co., AZ.

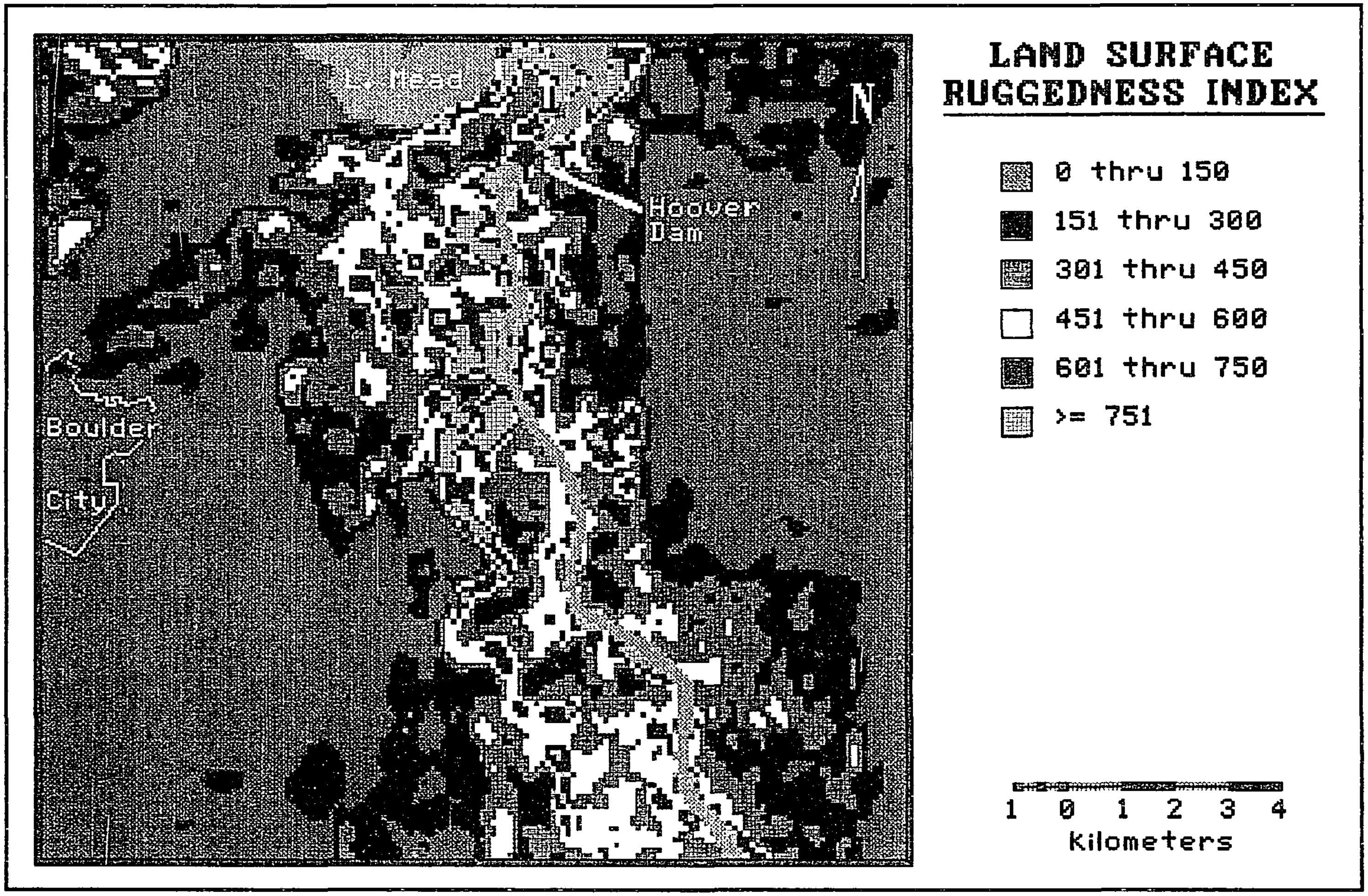

Figure 4. Assessment of land surface ruggedness of the Colorado River Black Canyon area, Clark Co., NV, Mohave Co., AZ, using GIS and a three x three cell neighborhood analysis of maximum slope values.

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