IMPACTS OF CATTLE GRAZING ON BIGHORN SHEEP

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INTRODUCTION

Domestic sheep (Ovis aries) have long been considered undesirable cograzers of bighorn sheep (Ovis canadensis) ranges due to their potential for forage competition and disease transmission (Grinnell 1935, Jones 1950, Buechner 1960, Goodson 1982, Foreyt and Jessup 1982). However, recent attention to possible negative impacts of domestic ruminants on bighorn sheep has been expanding to ask what role cattle (Bos taurus) play (Wilson 1975, Gallizioli 1977, Longhurst et al. 1977, DeForge and Scott 1982, Jessup et al. 1984, King and Workman 1984, Jessup 1985, Wehausen et al. 1985).

Cattle inhabiting mountain ranges containing bighorn sheep have the potential to affect the bighorn population in one of three ways: (1) no influence, (2) a decrease in carrying capacity, or (3) an increase in carrying capacity through facilitation (Sinclair and Norton-Griffiths 1982); facilitation might result from cattle removing mature plant material, thereby exposing or stimulating production of more nutritious young forage.

A decrease in carrying capacity can occur through (1) exploitation competition, where both species utilize a limited food resource (Ricklefs 1979), (2) long term habitat changes as a result of overgrazing, such as a decrease in important forage species, (3) interference competition -- a behavioral interaction whereby bighorn avoid areas of cattle use (Ricklefs 1979), or (4) introduction of diseases to the bighorn population from the cattle. These are not exclusive factors in that more than one can be operating simultaneously.

The ultimate carrying capacity of any bighorn range is set by the availability of nutrients and is attained through the effect of population density on intraspecific competition for these nutrients (Caughley 1979, McCullough 1979). Any change in population density or the availability of nutrients that alters the ratio of sheep to nutrients will result in the establishment of a new equilibrium. Factors causing a decrease in carrying capacity should manifest themselves through a population decline followed by a leveling off at the new carrying capacity. In the case of exploitation competition and long term habitat changes, the new carrying capacity should be a reduced density, with little change in geographic range used by the population. In contrast, interference competition will result in a decrease in total geographic range of use. Initially, this will result in a high bighorn density followed by a population decline until the original density is reached over the reduced range. Diseases will reduce carrying capacity through a higher nutrient requirement of the population to maintain itself. This would occur through (1) additional nutrients used to combat the disease organisms and (2) extra nutrient wastage in higher lamb mortality.

Despite the use of "K" to represent carrying capacity as a constant in such common formulations as the logistic equation (Ricklefs 1979), carrying capacity is in fact a dynamic parameter (Caughley

1979) with a multifactor basis. In the arid ecosystems inhabited by desert bighorn sheep, precipitation is a major dynamic variable influencing nutrient availability, and thus carrying capacity (Monson 1960, Beatley 1974, Wehausen 1980, Wehausen et al. 1985). Consequently, any attempt to study influences of cattle on bighorn population parameters must do so in the context of a multiple factor approach.

The primary focus of the work reported here concerns the question of competition between cattle and bighorn sheep in selected areas of the Mojave Desert of California. This project was carried out over the course of one year -- a time period grossly inadequate to provide rigorous support of competition as a significant factor among the many factors potentially influencing demography of any bighorn population. Consequently, this pilot study has served to determine whether continued research on this question is warranted.

We studied the question of competition through systems of multiple falsifiable hypotheses (Platt 1964). Because of the multivariate nature of ecological systems, these were frequently not exclusive hypotheses (Quinn and Dunham 1984); however, we considered the explanation that incorporated the fewest parameters to be the most desirable one in having a greater empirical content and being more testable (Popper 1968). Interference competition, exploitation competition, and long term habitat changes from cattle grazing were considered separately. Our problem analysis involved sequential levels of investigation. At each level, our null hypothesis was that the bighorn population was significantly influenced by cattle. In order to tentatively accept the null hypothesis, we considered it necessary at each step to fail to completely explain observed patterns on the basis of natural factors rather than cattle. In this regard, these natural factors represented the more parsimonious explanation. Acceptance of the null hypothesis was a necessary prerequisite to move to the next stage of investigation. Consequently, our problem analysis provided a number of opportunities to refute the overall hypothesis that through competition or habitat change, cattle were adversely affecting the bighorn population.

The first stage of investigation concerned the distribution of potential competitors and habitat. Necessary conditions for exploitation competition to be occurring were (1) overlap in ranges of bighorn and cattle and (2) significant total exploitation of important resources used in common. Negative influences of long term habitat alteration by cattle required (1) a similar overlap in ranges, (2) differences in vegetation composition on areas of cattle-bighorn overlap compared with analogous areas lacking cattle, and (3) a similar indication that an important resource was in short supply in the area of cohabitation. Conditions necessary for interference competition were (1) a negative correlation in areas of use by cattle and bighorn, and (2) inability to explain the bighorn distribution pattern on the basis of habitat parameters unrelated to cattle.

It was considered that any results that satisfied the above criteria for competition or habitat degredation would have only indicated the potential for such to be occurring. The significance of such potential impact would be determined by its effect on demographic parameters related to changes in carrying capacity. Hence, the second stage of investigation was proposed to investigate demographic parameters, especially population density and population trend. Since the study reported here concerns itself only with the first stage in this problem analysis, it is unnecessary to detail the criteria of the second stage.

This study began in early July of 1984 with a fixed-wing flight over a number of mountain ranges in the Mojave Desert that contained both bighorn sheep and cattle. Following this flight, two areas were chosen for study.

STUDY AREAS

Old Woman Mountains

The Old Woman Mountains are located in eastern San Bernadino County about 40 miles west of Needles, California. The Old Woman Mountains consist of four subunits totaling about 80 square miles. Their designations were Dripping Spring, Sheep Camp, Wilhelm Spring, (Figure 1) and Surveyer Spring (which lies south of the previous two). Each subunit contains a series of rugged ridges composed mostly of granite boulders and rock outcrops mixed with some metamorphic rocks. Subunits and some ridges are separated by outwash plains 0.25 to 1.0 miles wide. Elevations range from 2000 to 5300 feet.

Annual precipitation ranges from 3 to 5 inches (Freiwald 1984), occurring largely during the winter, but with irregular summer thundershowers. Several springs and seeps in bighorn habitat provide water sources in three of the subunits, whereas only one occurs in the fourth. Additionally, three artificial water catchment and storage systems are present in this study area. Summer high temperatures vary between 90 and 110 F, while winter lows occasionally drop below freezing.

The Old Woman Mountains support a large variety of desert shrubs, as well as several abundant grasses. Compared to our second study area, the Old Woman Mountains have relatively less grass cover and more shrub cover. The latter also supports junipers at higher elevations, as well as pinyon pines on some higher mostly north-facing slopes. Neither deer nor mountain lions are present in the Old Woman Mountains; but two feral goats have been resident for at least 5 years (M. Wood, pers. comm.).

Domestic cattle were grazed on the east side of the Old Woman Mountains until the mid-1950's (R. Weaver, pers comm.). From that time until the recent episode of cattle grazing began in 1979 (BLM files), no cattle were found in the area. In 1979, the allotment was reopened and expanded to include portions of the western side of the range that had not received grazing in the previous episode of cattle use. Apparently 200 cattle were on the allotment in 1984 for year-round grazing (BLM files).

Eastern Lanfair Valley Ranges

Three Mountain ranges on the Nevada border that flank the north and east sides of the Lanfair Valley in eastern San Bernadino County about 30 miles north of the Old Woman Mountains were also investigated: the Castle Peaks, Castle Mountains, and Piute Range. These ranges are essentially contiguous, and may be viewed as an eastern extension of the New York Mountains. In total length, these three ranges extend about 30 miles in a narrow northwest to southeast arc, comprising slightly over 50 square miles. All three are of volcanic origin. Most exposed rock in the Castle Peaks and Castle Mountains consists of isolated rock outcrops that cap volcanic cones. In contrast, the Piute Range is a faulted volcanic table with exposed rocks mostly as horizontal bands. The Castle Peaks and Castle Mountains have about 1000 ft. of verticle relief, cresting at about 5,500 ft. elevation. Bighorn habitat on the eastern face of the Piute Range extends from 3,000 to 5,000 ft. elevation.

These ranges receive an average of 7-9 inches of precipitation annually, ocurring primarily in winter, but including unpredictable summer thunder showers (Freiwald 1984). Each of these mountain ranges contains one or two year-round water sources within bighorn habitat. Additionally, an artificial water catchment and storage system is present in the Piute Range. The temperature regime is typical of the higher Mojave Desert ranges, with summer high temperatures generally below 100 F, and winter low temperatures occasionally below freezing.

Vegetation on these ranges includes abundant arid land grasses, yuccas, various desert shrubs, cacti, and scattered junipers at upper elevations. Sparse populations of mule deer and mountain lions are present in the Castle Peaks and Castle Mountains.

METHODS

Field work for this study occurred during the twelve months beginning November 1, 1984, with the majority of effort allocated to the Old Woman Mountains. A small amount of additional field work during December 1985 - March 1986 was included in the final editing of this report. Data collection followed the needs outlined in the problem analysis. Distribution of bighorn and cattle in all study areas was mapped on the basis of direct observation of animals, presence of tracks, fecal deposits, and beds in open rocky terrain (bighorn only). In order to evaluate the potential for exploitation competition and long term habitat changes, our approach was first to visually assess forage utilization, water availability, and vegetation composition in areas of distribution overlap between bighorn and cattle. Quantification of pertinent parameters was planned to follow where any visual assessment suggested a need. Additionally, we attempted to locate all water sources within the study areas and recorded water availabilty at each as the season progressed. Changes in plant phenology were also recorded and food habits of bighorn sheep were noted during direct observation and from inspections of feeding sites.

To study possible interference competition where bighorn and cattle distribution were exclusive, we attempted to develop a sampling scheme that could elucidate potential habitat factors other than cattle as responsible for bighorn distribution. Circular pellet plots 500 sq. m. in size were located at randomized distances along random compass bearings using water sources as starting points. Number of pellet groups in each plot was recorded, as was distance from water sources and nearest rock outcrop, slope, aspect, and elevation. Pellet groups were classified into four categories on the basis of weathering: (1) fresh - complete surface sheen, (2) recent - complete color but loss of sheen, (3) old - color fading, and (4) bleached - gray or white in color. Additionally, length and diameter of a representative pellet from each group was measured with calipers as an index of animal size. This criterion also was used in mapping ram versus ewe distributions throughout the range. The pellet plot sampling was carried out in the Wilhelm Spring drainage as a control area, since cattle use was not evident there. We intended to use the results from this control area as a comparison with samplings in ecologically similar areas containing cattle. Instead, we terminated this sampling after the completion of 29 plots in the Wilhelm drainage, when it became apparent that no ecologically comparable areas existed within cattle distribution.

Fresh fecal material was collected from observed bighorn groups at all opportunities. When necessary to fulfill a continuity of sampling, fecal samples judged to be very recently deposited on the basis of appearance, odor, and adjacent sign were also collected. A composite of fecal samples was made for each sampling time, and analyzed for crude protein content to measure seasonal patterns of diet quality (Hebert 1973, Wehausen 1980, 1983, Seip and Bunnell 1985). The Lanfair Valley and Old Woman Mountains were each treated as single populations in this analysis, and were compared with similar samplings from the Sierra Nevada, White, and Inyo Mountains made during the same year.

Demography

Population size estimates were made for the Old Woman Mountains using a mark-recapture technique. A total of 11 bighorn were captured in these mountains by the California Dept. of Fish and Game during a state-wide disease survey. The following sheep were caught using a helicopter and net or dart gun: 2 adult ewes on 14 October 1984, 2 adult ewes on 3 March 1985, 2 adult ewes, 1 class III ram on 30 March 1985, and 3 adult ewes, and 1 class II ram on 23 April 1985. These sheep all received both plastic and metal numbered ear tags. Additionally, 2 received rope with medallion collars (October), 3 received 3 inch wide lettered marking collars (March), 1 received a 1 inch wide white plastic collar (March), and 4 received radio collars (April). Only the class III ram received no collar. Additionally, two sheep (1 ewe and 1 ram) received marking collars and ear tags in the Piute Range in October of 1984.

Radio collars were used in two ways for mark-recapture estimates: (1) equivalent to marking collars (radio receiver not used), and (2) to aid in finding bighorn groups (radioed sheep excluded from mark-recapture calculations and added for final estimate). Three mark-recapture estimates were obtained -- May, July, and September. The first and last of these were made as hiking counts, and the July estimate was derived from a waterhole count involving 10 water sources. All sheep observed were classified with binoculars and spotting scopes using the classification of Geist (1971). Lamb:ewe, yearling:ewe, and ram:ewe ratios were calculated from these counts and additional observations for each of three seasons: spring, summer, and fall. Ram:ewe ratios were meaningful only for summer and fall when the rut was in progress.

Super - 8 mm time lapse cameras were set at various water sources during the hot season in an attempt to derive an additional mark-recapture population estimate. While various problems precluded the intended use, some cameras aided in documenting movement of marked animals, and verified the survival of one marked sheep.

During the course of our investigations, we encountered a number of bighorn sheep skulls and carcasses, which were examined for clues as to causes of death. All skulls were collected, and later aged by tooth eruption (Taber 1971) and horn rings (Geist 1966, Turner 1977).

RESULTS

Old Woman Mountains

Distribution

Bighorn Sheep

Evidence of bighorn sheep use was widely distributed in the Dripping Spring, Sheep Camp, and Wilhelm subunits, but less so in the Surveyor Spring subunit. Figure 1 delineates only those areas of significant use; undoubtedly occasional use also occurs in more outlying areas. Bighorn sign in the Surveyor Spring subunit was sparse, and appeared to be of relatively recent origin. Distribution mapping in the Surveyor Spring area was incomplete, since the vast majority of effort was directed toward the other more regularly used areas. Consequently, that subunit is not included in Figure 1.

Bighorn sheep ranged from the bases of slopes to ridge tops, and regularly used several travel routes across washes. Nowhere did we find evidence of bighorn leaving the base of mountain slopes to feed on alluvial fans. However, during vegetation greenup, there was evidence of use on the lowest slopes at the western tips of some ridges.

Observations of lambs and lamb pellets indicated that the lambing period extended from about late December to early May. Ewes with small lambs restricted their activities to limited areas of particularly steep, broken bedrock outlined on Figure 2. During the period when these lambing areas were used, surface water was present in or near them.

Temperatures rose steadily through spring, beginning to break 100 F in late May. By this time, most forage species were rapidly drying up. Concurrent with this change, both marked and unmarked ewes were documented to move betweeen Dripping Spring and Sheep Camp subunits (Table 1). There was evidence in mid-May of at least 2 ewes and one lamb near Surveyor Spring, but no such use in summer, suggesting a similar movement between the Surveyor and Sheep Camp subunits. It is likely that some similar movements occurred between the Wilhelm Spring and Sheep Camp subunits, since a ewe captured in the Wilhelm Spring area appeared on time-lapse film at Upper Sheep Camp Spring in July (Table 1). By June, ewes had shifted the center of their distribution from the proximity of lambing areas to that of the nearest water sources. No movement of marked ewes between subunits was recorded from this time through September.

Thunder showers in 1985 apparently produced no significant summer rainfall in bighorn habitat in the Old Woman Mountains, and all ewes observed were within 1/2 mile of water. Absence of recent sign elsewhere confirmed this restricted distribution. Beginning in mid September, a series of storms wetted soils in this range to a depth of at least 15 inches, and initiated some vegetation greenup. This coincided with cooling temperatures, and was followed by an expansion of ewe distribution beginning in late September. In early October, we tracked at least six sheep, in groups of one and two, that moved from the Sheep Camp subunit across Browns Wash to the Surveyor Spring basin. While some of these may have been tracks of ewes, only a single ram was observed at Surveyor Spring.

Rams apparently used areas outside of ewe ranges for much of the year. Ram distribution overlapped that of ewes during the rut, which was coincident with the hot season. During this period, most ewe groups contained rams. However, unlike ewes, we recorded collared and other distinguishable rams moving between subunits. Furthermore, it is probable that intermountain movement is frequent among rams, as evidenced by our observation of a marked ram from the Whipple Mountains in the Sheep Camp area (Table 1).

Outside of the rutting period, we observed only young rams with ewes, and documented few adult rams within ewe range. Based on sizes of fecal pellets and tracks, we suspect that the center of the mountain range, around Old Woman Statue, may be used only by rams (Figure 2). This is supported by previous observations: (1) Russi (1981), (2) summer waterhole count in 1982 (BLM files), (3) helicopter count in 1982 (BLM files), (4) other observations (M. Wood, G. Sudmeier, pers. comm.), and (5) a ram carcass found during this study. Other parts of the total bighorn range (Figure 1) may also be used only by rams.

Cattle

Our findings suggest general differences in habitat use by cattle and bighorn sheep. Cattle use generally occurred on alluvial fans and washes, and extended higher only on the gentler, less rocky slopes. The result was overlap with bighorn sheep range only in limited areas, such as low saddles, some lower slopes, and bighorn travel routes across washes. The total distribution of cattle during this study included the north and east base of the mountains from Florence Mine to Wilhelm Spring, and the Scanlon Wash systems on the west side (Figure 1). During the hot season, cattle were found to occupy only small areas immediately adjacent to certain major water sources. However, in winter and early spring, we frequently found evidence of them exploring the distribution boundaries recorded in Figure 1, especially side washes as far as they could be negotiated. Thus, for instance, outside of the hot season, we found some use by cattle of the lower sections of the Wilhelm Spring drainage and the drainage immediately north, but no such use in summer. There is ample evidence that a few cattle resided for a while during a recent year in the large wash separating the Wilhelm Spring and Sheep Camp subunits (Figure 1); but none were present during this study. The evidence there suggests that they crossed a low saddle above Ford Well to enter this wash.

Water

We located a total of 65 water sources in or near bighorn range in the Old Woman Mountains. Included were 3 artificial catchment and holding facilities constructed for wildlife (Figure 3). About 50% of water sources had some free-standing water throughout the 1985 hot season, while about 35% were found to go dry. An additional 15% of the total sites recorded were not checked after the beginning of the hot season (Table 2); however many of these are known historically to be perennial sources. Most of the unchecked sources lie in areas not used in summer by ewes. Rutting rams probably use these marginal water sources occasionally. Approximately one-third of the water sources recorded to run through the summer had storage capacity of more than two gallons.

Seventeen water sites were found to be important to bighorn sheep in the summer of 1985. Thirty-one additional sites were used by bighorn to some extent during the year, of which five were used only by rams. Some of the latter 31 sites were in or near lambing terrain and may have been important to ewes during the lambing season. Bighorn ewes preferred certain water sources over others, and in some cases it was possible to determine their priorities by noting how use shifted as preferred sources dried up. Safety factors appeared to be important. Bighorn tended to use water at the highest elevation sources first, and progressively to shift downward as these sources dried up. Similarly, preferred lambing habitat also occured at higher elevations. Secondly, bighorn preferred springs that were located in rugged escape terrain, and rarely used water that was not adjacent to rocky slopes. Additionally, a definite preference was shown for natural sources over artificial facilities. At all three locations of artificial catchment and storage facilities in the Old Woman Mountains, water was also available in nearby natural rock basins in 1985. Sheep sign was concentrated at the natural sites to the near exclusion of artificial drinkers, even though the two were less than 50 feet apart in two cases. This suggests that only in dry years are the artificial water catchment and storage devices important to sheep.

Behavior of bighorn at water sources was variable, depending primarily on group size. Single animals generally drank quickly and remained at water for relatively few minutes, while groups of three or more often remained at the site for up to an hour or more. The greater time spent at water by larger groups probably reflects the greater total water requirement for more animals and slow rates of recharge. When the water available at a site was not sufficient to satiate all group members, some or all of the group would sometimes feed or bed on nearby slopes and return to the spring later when the basin had refilled.

Water sources used by cattle tended to be in less rugged terrain, and at lower elevations than those used by bighorn. In contrast to bighorn, cattle usually remained in or near favored water sources during daylight hours in the hot season. Foraging away from water occurred mostly in the morning, evening, and at night. This behavior potentially reduced the value to bighorn of springs used by cattle through: (1) trampling and overgrazing of nearby forage plants, (2) considerable fouling of the water with mud, feces, and urine, and (3) domination of the water source through nearly continual presence of large animals. Of the 65 water sources considered to be in or near bighorn range in the Old Woman Mountains, 38 were used only by bighorn, 10 were used only by cattle, and 10 were used by both species (Table 2). Of those water sources used by both, 3 were not used by ewes, all were used only occasionally by one or both species, and seasonal overlap may not have occurred at any.

<u>Factors Underlying Bighorn Distribution</u>

Our finding of essentially no overlap in the distribution of bighorn and cattle in the Old Woman Mountains refuted the hypotheses that exploitation competition or long-term habitat degredation by cattle were factors of concern. However, these distributions were in accord with the possibility of interference competition. The establishment of randomized pellet plots in the Wilhelm Spring drainage was an attempt to elucidate what habitat factors influenced distribution of bighorn use in the absence of cattle. Large plots (500 sq. m.) were chosen to minimize zeros, and resulted in a range of 1 to 78 total pellet groups per plot. Three of the 29 plots were eliminated from analysis because they fell on what were intensively-used bedding areas not representative of the rest of the plots. These three plots represented statistical outliers in the very large number of pellet groups recorded for each. This reduced the range to 1 - 36 pellet groups. We further reduced this range to 1 - 29 by excluding our fourth pellet group age category (completely bleached). This exclusion was based on pellets that we set out to weather, which indicated that our first three classes represented pellets deposited over about one year.

Our approach to the analysis of these data was to attempt to build a biologically meaningful multiple regression model. Our prior expectation was that distance to surface water would be a pervasive factor due to its importance to bighorn during a large portion of the year. Additionally, it was expected that bighorn use would decline in a curvilinear pattern as distance from water increased, similar to the inverse-square laws of such physical phenomena as gravity. This sampling and data analysis was fraught with a number of problems. First, the focal point of our sampling was Wilhelm Spring #1 (#46 on Fig. 3 and Table 2), but part way through we discovered two springs higher in that drainage (Fig. 3), as well as an important one in the next drainage north. Since our sampling took place in winter after storms had recharged springs, we could not know whether these other springs contained water the previous summer. Thus the question of distance to water was muddied. Second, a lack of independence (multicollinearity) was found among some of the variables: (1) elevation was significantly correlated ($r=.84$, $P<.001$) with distance to Wilhelm Spring #1 because the further the plot was from that spring, the higher in the drainage it was; (2) slope was also positively correlated ($r=.49$, $P=.01$) with distance from Wilhelm Spring #1, i.e. the further away, the steeper the slope; (3) distance to Wilhelm Springs #2 and #3 was highly correlated ($r=.92$, $P<.001$) because of their close proximity to each other; and (4) distance to each of these springs was significantly negatively correlated ($r=-.59$, $P=.001$ and $r=-.78$, $P<.001$, respectively) with distance to Wilhelm Spring #1, i.e. the further the plot was from Wilhelm #1 the closer it was to the other two and visa versa. In part, this multicollinearity among independent variables resulted because our sampling scheme randomized only relative to one variable, distance from Wilhelm #1.

When independent variables were tested individually, three produced significant correlations with the number of unbleached pellet groups per plot: distance to Wilhelm Spring #1 ($r=-.436$, $P=.026$), elevation ($r=-.612$, $P=.001$), and slope ($r=-.457$, $P=.019$). When a log transformation was used to test for curvilinearity of the relationship with distance to Wilhelm #1, the correlation improved considerably ($r=-.654$, $P=.0003$) and exceeded all others. This latter result fit prior expectations discussed above. When either or both elevation and slope were entered as additional independent variables with log transformed distance to Wilhelm #1, in no case was there an improvement in the regression. This indicates that the significant correlations of elevation and slope alone were due to their correlations with distance to Wilhelm #1 rather than anything meaningful relative to habitat selection by bighorn. The only potentially meaningful multiple regression in this analysis was the addition of distance to Wilhelm Spring #3 as a second independent variable with the log transformed distance to Wilhelm #1. This second independent variable had a negative slope as expected, and increased the coefficient of determination from .43 to .50, but was significant only at the 8.8% level. It appears from this that Wilhelm #1 had a substantially stronger influence on distribution of bighorn in 1984 than did Wilhelm #3.

The above analysis of the distribution of bighorn use relative to water would have served an important function relative to the question of interference competition if ecologically equivalent springs lacking bighorn use could be found within cattle distribution. We terminated this sampling project when it became obvious that such did not exist. The reason concerns topographic features outside but immediately adjacent to the area we sampled that evidently serve as centers of bighorn distribution. This is the previously-described habitat that we found ewes to inhabit during the lambing season. One such patch of this habitat runs from the top of the Wilhelm Spring drainage across the top of the drainage immediately north. Likewise, the western section of the south ridge of the Sheep Camp drainage and the western section of the ridgetop in the Dripping Spring subunit contain such habitat (Figure 2). Water sources used in summer were those in close proximity to the lambing areas. We could find no habitat resembling these lambing areas in or immediately adjacent to springs regularly used by cattle that could be used as a comparison with our sampling of the Wilhelm Spring drainage.

Forage

Utilization

Heavy utilization of forage was one of the visually obvious impacts of cattle in the vicinity of their major water sources. However, since these were not within ranges of overlap with bighorn sheep, this forage utilization had no implications relative to the question of exploitation competition or long term habitat alteration. Consequently, we made no measurements of forage utilization.

High utilization of forage species by bighorn was visually evident only in close proximity to some preferred springs (Missing Spring and Wilhelm #3); but high availability of forage only a short distance away indicated that this level of utilization was not of significance.

Phenology

During our first visit to the Old Woman Mountains in the last couple of days of October, 1984, some green vegetation was evident in both perennial grasses and some shrubs. This presumably reflected the influence of late summer/early fall precipitation. This area received considerable precipitation in the following fall and winter, with the results that small rosettes of annual forbs were very abundant by the beginning of January. At that time, lush growth of _Bromus rubens_ was locally abundant. Regular precipitation occurred through winter and, as temperatures warmed, a proliferation of green forage was evident. However, a particularly cold snow storm in mid-winter killed back new growth on _Encelia farinosa_, and apparently also on many annual forbs. Nevertheless, spring produced a large biomass of rapidly growing plant tissue. Annual species peaked in March, while most perennial species peaked in April and the beginning of May. By the second week of May, little remained in the way of growing annual vegetation, and growth by perennials was clearly waning. At the beginning of July, the spring growing season essentially had passed -- grasses were mostly dry, and few shrubs showed any growth activity. This remained the case until rains in the second half of September triggered new growth in some grasses and shrubs, producing forage conditions similar to late October the previous year.

Food Habits

Information on food habits was limited to casual observations of feeding bighorn and plants where they had fed. These observations indicated that grass was a part of their diet throughout the year, and may have constituted the bulk of the diet during winter and summer. However, during the peak of spring vegetation growth, it was evident that the bulk of the diet was from a variety of other vegetation classes, including new growth of _Ephedra_ sp., and _Eriogonum_ sp., flowers of _Encelia farinosa_ and _Macaeranthera totifolia_, and growing flower stalks of _Nolina bigelovii_. During the hot dry season, green leaves of _Acacia greggii_ and seed of _Nolina bigelovii_ were regularly consumed.

Diet Quality Pattern

The fecal protein curve for the 1985 growing season in the Old Woman Mountains closely paralleled changes in plant phenology discussed above -- a steady rise through winter into spring, a peak during April, and a subsequent decline to a summer low (Figure 4). The variance in the three peak values probably reflects different elevations of sheep in each of three subunits involved in these collections. Chronologically, these collections were from 4,000, 3,600, and 5,000 feet elevation, each in a different subunit of the range. Cooler temperatures at higher elevations cause vegetation phenology to peak and decline later (Wehausen 1980); thus, the observed pattern for these three points can be accounted for by the collection elevations.

Figure 4 includes fecal protein curves from the 1985 growing season for the Mount Baxter herd in the Sierra Nevada and the White Mountain Peak herd in the White Mountains for comparison. The basic patterns of these latter two curves have been discussed previously (Wehausen 1983), and reflect fundamental differences in the ecosystems inhabited by these populations. The most striking difference between fecal protein curves for the Mount Baxter herd and the Old Woman Mountains occurs during summer. The substantial drop in May for the Mount Baxter herd resulted from ewes migrating into the alpine before the vegetation had reached peak growth -- a pattern not elucidated in previous reports on this population (Wehausen 1980, 1983) due to lack of samples from late May and most of June. The subsequent summer pattern reflects the season of plant growth in the alpine. The substantially higher values for the Mount Baxter herd compared with the Old Woman Mountains during summer and fall represent the advantage of altitudinal migration -- an advantage that Hebert (1973) demonstrated by feeding captive bighorn different diets.

The Old Woman Mountains and the winter/spring range of the Mount Baxter herd have considerable overlap in plant species, including a large amount of Stipa speciosa in each. They differ in that the Old Woman Mountains are drier, and the highest elevations are equivalent to the lowest ones for the Mount Baxter herd. On the basis of elevational differences alone, one would predict an earlier rise in diet quality for the Old Woman Mountains. Instead, the timing of the rise is virtually equivalent (Figure 4). Whether this reflects differences in available forage species between the two ecosystems (high desert sagebrush scrub vs. low desert creosote bush scrub) or some other factor is not clear. The higher spring peak for the Mount Baxter herd probably reflects greater precipitation in the Sierra Nevada ecosystem, and associated differences in the vegetation community. Since the 1984-85 growing season in the Old Woman Mountains involved a very favorable precipitation pattern for a Mojave Desert ecosystem, the winter/spring pattern of diet quality in Figure 4 is probably close to the maximum for that population.

The substantial lag in the winter/spring rise in diet quality in the White Mountains compared with the Sierra Nevada probably reflects two factors: (1) colder temperatures due to higher elevations and a generally colder mountain range for the White Mountains, and (2) greater aridity in the White Mountains due to their location in the precipitation shadow of the Sierra Nevada. This latter factor is evident in the less diverse vegetation community of winter/spring ranges in the White Mountains (Wehausen 1983). It is noteworthy that the overall annual nutrient intake in 1985 (as would be measured by integrating the curves in Figure 4) appears higher in the Mojave Desert ecosystem of the Old Woman Mountains, where altitudinal migration is minimal, compared to the Great Basin ecosystem of the White Mountains, which include 8,000 ft. of altitudinal relief used by the bighorn.

Demography

Sex and Age Ratios

While we documented lambing as late as early May, apparently few lambs were born after the beginning of April. Thus our best measure of lamb production was a ratio of 33 lambs per 100 ewes obtained in April and May (Table 3). We documented one lamb to have died at the beginning of this sampling period. Because of the long lambing period and potential that others may have died before April, this ratio is almost certainly an underestimate of lamb production. Our three sampling periods showed a steady decline in lamb:ewe ratios, suggesting continuing lamb mortality through the hot season. We found remains of 4 lambs that died in spring and summer of 1985 (Table 4).

The ratio of yearlings to ewes remained approximately constant through our three sampling periods (Table 3). However, we documented the mortality of one yearling ram during the summer, and one yearling ewe in the spring prior to our first count. It is noteworthy that our fall lamb:ewe ratio was approximately equal to the average yearling:ewe ratio for the three samplings.

The pattern of ram:ewe ratios over our three samplings (Table 3) reflects sexual segregation during part of the year. The only rams observed in the spring sampling were 2-year olds. The summer and fall ratios both were obtained during the rut; thus they represent our best measure of the true adult sex ratio in the population. This provided an average of 43 rams per 100 ewes.

Population Estimates

Because of differing probabilities of sighting rams and ewes, a stratified mark-recapture procedure (Overton 1971) was used such that only the population size of adult ewes was estimated. The simplest Lincoln-Petersen mark-recapture procedure assumes that (1) the population is closed, (2) animals do not lose marks and marks are not missed during the procedure, and (3) each animal has a constant and equal probability of being observed on any count (Otis et al. 1978). Bighorn ewes, as compared with rams, satisfy the first assumption well because they rarely move between mountains. Additionally, recruitment did not violate the closure assumption since, by our system of age classification, ages were advanced three months prior to our first sampling. Our sampling period varied from 10 to 15 days, thus minimizing the probability of any mortality occuring during a count. Our pattern of sampling within the mountain range was designed to avoid any duplicate counting, despite considerable movement between the Dripping Spring and Sheep Camp subunit during our May sampling. Survival of all marked ewes and retention of marks was verified by direct observation and time-lapse photography. In one case a ewe lost a rope collar, but was subsequently recognized as a marked animal on numerous occasions by her ear tag. All sheep were observed at sufficiently close distances during counts such that no marks could have been missed. We tested the assumption of equal observability of ewes with a goodness-of-fit test. Our results indicated that the marked ewes were not equally observable (see Appendix A).

Our mark-recapture estimates are based on an unmodified Lincoln-Petersen equation (Overton 1971). These estimates varied from 30 to 34 adult ewes (Table 3). Because of our small population size and limited number of marked animals, 95% confidence limits, calculated by the Clopper-Pearson graph (Adams 1951), are very large for each estimate (Table 3). However, the high consistency of our three estimates lends mutual support to their collective accuracy, especially considering that different sampling schemes were used. Furthermore, the slight drop in the estimated number of ewes in the September sampling appears to accounted for by mortalities. One ewe in the Sheep Camp subunit was known with certainty to have died between the July and September counts. The carcass of another ewe was found in March 1986 in the Dripping Spring subunit (Table 4). The amount of weathering of this carcass, along with the gross composition and phenology of rumen contents with the carcass suggested that she also died during summer. Additionally, one old ewe with chronic sinusitus (Bunch 1978) and substantial jaw infections that was observed in extremely poor condition in the Sheep Camp subunit during the July count probably died soon thereafter.

Bailey (1951, 1952) noted an imbalance in the standard mark-recapture equation that will lead, on the average, to an overestimate of population size; however the range includes both over- and underestimates. Otis et al. (1978) pointed out that behavioral heterogeneity of individuals that leads to unequal observability of animals will result in an underestimate. Our finding of apparent unequal observability of the marked ewes (Appendix A) might be due to such heterogeneity of individuals, resulting in an underestimate. However, a likely alternative explanation is that this lack of equal observability instead reflects a sampling system in which areas used by certain ewes were not sampled. For instance, Missing Spring (#6 on Table 2) was not discovered until after the July waterhole count; yet it was very heavily used by sheep at that time. Had this site been included in the July count, the total distribution of resightings of marked ewes (Appendix A) might have been quite different. If the apparent lack of equal observability of marked ewes was entirely due to such unsampled areas, our estimates are unbiased, because marked and unmarked ewes should be present in unsampled areas in the same proportion as in sampled areas. Lacking further information, we cannot quantitatively evaluate potential biases; therefore we accept the population estimates as calculated.

It is possible to produce an estimate of the total bighorn population in the Old Woman Mountains using the mark-recapture estimates of the adult ewe population and sex and age ratios. We did this for the fall sampling using the largest sample size for the yearling:ewe and lamb:ewe ratios, and the average ram:ewe ratio of summer and fall counts (Table 3). These average ratios produced estimates of 5 lambs, 5 yearlings, and 13 rams which, when summed with the estimated ewe population, resulted in a total estimated population of 53. Our observed ram:ewe ratio was low compared with what is commonly recorded for unhunted bighorn populations (Wehausen 1980, 1983); consequently this total population estimate may be an underestimate by about 5 rams.

Population Dynamics

In the strictest analysis, population dynamics of bighorn sheep can only be studied adequately over more than one year in order to measure changes in population size. No data from prior years are available for the Old Woman Mountains that would allow such a comparison. However, we can make some crude, short term, inferences based on population parameters. One such parameter is recruitment rate. This measure is difficult to interpret relative to population change, since a number of factors can influence population turnover rate. A recent re-analysis of data of McQuivey (1978) by Witham and Sterne (J. Witham, pers. comm.) indicated that approximately 20 lambs per 100 ewes were necessary for population maintenance for desert bighorn in Nevada. Two empirical analyses of data from bighorn in the Santa Rosa Mountains of California indicated 16-18 lambs per 100 ewes necessary for population maintenance (Wehausen et al. 1985). However, these analyses were for 1977-82 -- a period that immediately followed years of population increase. Consequently, the age structure of ewes during 1977-82 would be expected to be weighted toward young and middle-aged animals with low rates of mortality; and the recruitment rates calculated as necessary for population maintenance probably represent a near minimum for this parameter.

Relative to these values, the yearling and lamb recruitment rates recorded in 1985 for the Old Woman Mountains suggest an approximately stable population if the age structure is skewed toward the younger ages. Our observations of rams suggest a more even age distribution; thus the observed recruitment ratios probably represent a slight population decline.

Another approach to this question involves comparisons of actual losses and additions of animals to the population. During this study, the ewe population incurred the artificial loss of one old radio-collared ewe that apparently died as a result of a capture-related injury prior to our spring count. However, counterbalancing that loss was the unexpected survival of the ewe with collar "V". When captured, she was in exceptionally poor condition, including sinusitis and a scabies-like skin disease (D. Jessup, pers. comm). Her survival (and addition of a lamb to the population) was very likely a function of antibiotics given her at capture. Consequently, her survival is probably as artificial as the mortality of the radio-collared ewe. Additional mortalities of ewes during this study included a 2-year old, a 5-year old (Table 4), and the probable death of an old ewe in summer discussed above. In total, this suggests that under undisturbed circumstances, the ewe population would have lost a minimum of 4 adult ewes. In fall 1985, we could account for a minimum of 3 yearling ewes in this mountain range. This suggests that recruitment did not quite offset adult ewe mortality in 1985, although additional mortality and recruitment of adult ewes may have gone undocumented. While one year's data do not allow an exact assessment of population dynamics, they suggest that the bighorn population in the Old Woman Mountains probably underwent a slight decline in 1985. The number of lambs in the fall of 1985 suggests that recruitment in 1986 may continue this trend. It is also noteworthy that mortality in 1985 included a yearling and a 2-year old ewe (Table 4), both of which had excellent body and horn growth. These are age classes that (1) normally experience low mortality rates, and (2) represent substantial losses to the population due to their high reproductive value (Fisher 1958).

Lanfair Valley Ranges

Distribution

Piute Range

Surface water in the Piute Range was limited to two areas: (1) Piute Spring and its associated stream, which run year-round, and (2) an artificial catchment and storage facility and nearby tinaja and seasonal seep. The distribution of bighorn sheep sign in the Piute Range extended along the eastern face from Piute Spring north about 11 miles to the end of the Old Homestead Road. Vertical distribution of sheep sign extended from the base of the eastern face to the top of the rim. Sheep sign on the plateau was limited to a 30 m band along the eastern rim. Sign was sparse near Piute Spring and at the north end of their range; it was most concentrated around and immediately north of the artificial water catchment, that lies midway in the sheep range. While Piute Spring supplies considerably more water than the other water sources, the sparse use there is probably due to less precipitous terrain and dense riparian vegetation. Water availability at the seep and tinaja in the mid part of the range was not continuous through the hot season in 1985, in contrast with the artificial water system, which was likely the primary source for bighorn in this range.

Cattle were widely distributed in the Piute and Lanfair Valleys on both sides of the Piute Range. Cattle range in the Piute Valley extended into many of the washes along the eastern base of the escarpment. There was essentially no overlap with bighorn range, because cattle water sources were located away from the mountain range on alluvial fans. Water for cattle in Lanfair Valley was also located away from the mountain range, which probably accounts for our finding of little past use by cattle on the mountain top.

Castle Mountains

Year-round surface water was available in the Castle Mountains only at Kidney Spring. We found water during winter in 2 other sites near the Nevada state line. Based on sign, we found bighorn distribution to extend to Hart, at the extreme south end of the range, and to about one mile into Nevada at the north end. Our sightings of bighorn in this range totaled three groups: one at Hart, one at Kidney Spring, and one across the Nevada border. Bighorn sign was very patchy, being confined mostly to areas around rocky knobs and ridges, and travel routes between. Among these patches, we found a few areas of more concentrated use, especially the Kidney Spring basin.

We observed cattle and their sign throughout the Castle Mountains; but use was most concentrated on the northwest side in all but the more rocky terrain preferred by bighorn. Similar to the Piute Range, summer watering sites for cattle were located away from the range. Consequently, cattle were essentially absent from the range during the hot season in 1985; thus, there was no overlap of use by cattle and bighorn at Kidney Spring in that season. The fact that cattle and bighorn were both widely distributed in this mountain range suggests that an overall social intolerance did not exist. However, we had no opportunity to investigate whether at any specific time bighorn might be avoiding localized areas containing cattle.

Castle Peaks

Bleached fecal pellets of bighorn were found from the Ivanpah Road to the easternmost of the Castle Peaks, and on several outlying buttes and ridges. Recent sign consisted of only 3 pellet groups near Dove Spring and the carcass of a ram that died in early summer of 1985 (Table 4). Three unclassified sheep were observed from the air in early July 1984, and two ewes were seen at Dove Spring by John Walters (pers. comm.) in October of 1984. Our interpretation is that bighorn currently use this range on a transient basis only. This represents a substantial change since the mid-1970's. In 1974, Loren Lutz (pers. comm.) observed 27 different bighorn in the Willow Spring drainage west of Dove Spring, which then was a regularly-used lambing area. In 1976, 4 rams, 13 ewes, 3 yearling rams, and 3 lambs , totalling 23 sheep, were observed at Dove Spring during a July waterhole count (Glenn Sudmeier, pers. comm.). The lack of evidence of continued use of this area by bighorn was noted in 1983 by Loren Lutz (pers. comm.)

Cattle are widely distributed through the Castle Peaks, with the exception of steep rocky terrain. However, recent cattle sign was absent in the vicinity of Dove Spring and the area immediately to the west.

<u>Demography</u>

Only four observations of bighorn sheep in the Castle Mountains and Piute Range were made during the course of this work. These were (1) 3 adult ewes seen 23 and 24 December 1984 in the Piute Range, of which one had ear tag #506 (marked in that range 2.5 months prior), (2) 4 adult ewes, 2 (1984) lambs at Hart on 13 January 1985 (none marked), (3) 2 adult ewes, 2 yearling ewes, 2 lambs, and 1 yearling ram on 7 June 1985 at Kidney Spring (none marked), and (4) 2 adult ewes, 1 lamb, 1 3-yr. old ram (none marked) on 11 September 1985 across the Nevada border in the SW corner of Section 4. These sightings are too few to make any statements relative to population sizes and trends, although the figures from the Castle Mountains suggest regular recruitment. Also fecal pellets from summer 1985 in the Piute Range indicated at least one lamb there. One thing that appears clear on the basis of sign and infrequency of sightings is that bighorn are quite sparse in both ranges.

<u>Forage</u>

Utilization

Only in the Castle Mountains was there any possibility of exploitation competition from cattle on shared ranges. However, throughout this mountain range forage utilization was visually light. This probably reflected (1) a large amount of grass in this range, (2) relatively few cattle that fed seasonally on this grass resource, and (3) a sparse bighorn population. Similarly, the Piute Range exhibited very light grazing.

Phenology

The Castle Mountains and Piute Range exhibited winter greenup of grasses similar to the Old Woman Mountains in 1985. However, in March it was evident that growth of forbs and browse in the sheep habitat of these ranges was delayed relative to those at lower elevations available to bighorn in the Old Woman Mountains. Lack of sufficient field time later in spring precluded documentation of similar delays in phenology at that time.

Unlike the Old Woman Mountains, the Piute Range and Castle Mountains apparently received rain in July, as well as in late summer. The result was that some grasses, especially <u>Stipa coronata</u>, showed considerable green growth in mid-August. In the second week of September, this greenery clearly was waning; but a month later, after late September rains, a new flush of growth was evident in grasses and some shrubs.

Food Habits

Observations of bighorn feeding sites in the Piute Range and Castle Mountains in December, January, and September all suggested that grass, including Stipa speciosa, S. coronata, and Sitanion hystrix, was the main component of their diet. The only non-grass documented to be eaten was Erodium cicutarium leaves in mid-January. However, a shift to new growth of shrubs probably also occurred here in spring, as in the Old Woman Mountains, but went unrecorded due to lack of field time.

Diet Quality Pattern

A curve of fecal crude protein based on combined collections from the Piute Range and the Castle Mountains exhibited a pattern somewhat different from that for the Old Woman Mountains (Figure 5). The points from December and January are coincident for the two ranges -- a period when the only greenup available to sheep in either range was some grasses. As the growing season progressed, the sheep from the Lanfair Valley ranges exhibited a lag in diet quality rise as compared to the Old Woman Mountains. This lag correlates well with the noted lag in phenology, and probably is due largely to elevational differences. However, it is noteworthy that the peak value for these Lanfair Valley ranges appears to be considerably lower than for the Old Woman Mountains. This may reflect a lesser diversity of shrub species in the former. It might also indicate lower total vegetative growth among the species present, resultingfrom a reduction in soil moisture by late spring when temperatures were optimal for flowering in some of the shrub species. It also is possible that a somewhat higher spring peak in diet quality was missed by the sampling schedule.

The differences in summer fecal protein values in Figure 6 are quite instructive. Both the Castle and Inyo Mountains had considerable lush grass that sheep were eating in August, while none was present in the Old Woman Mountains. Consequently, it was expected that the fecal protein level from the Old Woman Mountains would be notably lower than from the other two ranges during that month. In fact, it fell in between the two, with little difference overall. Furthermore, in the first half of September, the Old Woman Mountains yielded the highest value. While grasses clearly were in a declining phenology in the Castle and Inyo Mountains at this time, they were considerably greener than in the Old Woman Mountains. It appears that other plants greatly influence summer diet quality in desert ecosystems. A major factor probably bolstering the summer diet quality in the Old Woman Mountains was the inclusion of considerable Acacia greggii in their diet. This species is lacking in the Inyo Mountains, and is found primarily in washes at the lower edge of sheep habitat in the Castle Mountains and Piute Range. More detailed information on diet composition is needed to further understand these differences.

DISCUSSION

Competition

None of the areas we studied passed our first tests for competition or adverse habitat alteration. In the Castle Peaks we found no evidence of a permanent bighorn population. It was not possible to test whether cattle were involved in the disappearance of this population. However, the lack of evidence of recent use of the Dove Springs area by cattle could suggest that competition may not have been a significant factor.

In the remaining mountain ranges studied, we found consistent patterns. There was little, if any, overlap in distribution between bighorn and cattle. While this pattern is consistent with the hypothesis of interference competition, in all cases it was apparent that the pattern resulted from different habitat preferences, rather than avoidance of cattle areas by bighorn. In the few areas of range overlap, we found neither significant utilization of any potentially critical resource, nor any indication of possible detrimental habitat alteration by cattle. In short, our results relative to the question of competition and habitat alteration involving cattle do not warrant moving to the next stage in our problem analysis. The only location where competition may have occurred lies in the upper Gemco area, where a spring (#26 on Table 2) apparently used by both cattle and bighorn was found late in the study after the 1985 hot season; thus it received minimal investigation.

King and Workman (1984) also concluded that observed habitat separation between cattle and bighorn sheep in their study area was due to inherent differences in habitat selection rather than interference competition. However, Horejsi (1975) and Wilson (1975) both related instances of apparent social intolerance of cattle by bighorn sheep; and Dunn and Douglas (1984) presented data suggesting the same involving burros and bighorn ewes. It is the nature of the subject of competition that any conclusion will be limited to the circumstances of the investigation. Probably the greatest potential for competition between bighorn and cattle in desert environments will revolve around common use of water sources and their immediate surroundings. Our study was carried out in a year of abundant surface water in the Old Woman Mountains (Table 2) that provided the bighorn ample sources close to topography preferred by them and avoided by cattle. What happens under drier environmental regimes, such as occurred prior to the wet period that began in 1976? Very few of the water sources that we found bighorn using in the summer of 1985 contained water in that season during the dry years before 1976 (R. Weaver, pers. comm.); and bighorn were known to use some of the lower water sources currently used by cattle. However, during the previous period of cattle grazing in the Old Woman Mountains in the 1950's, these lower springs did not provide enough water for cattle. Cattle were instead watered further out from the range; thus it is unlikely that a situation of competition occurred at that time (R. A. Weaver, pers. comm.). A major question remaining is whether an intermediate situation might occur in which current bighorn water sources would be insufficient, but some cattle would continue to use sources needed by bighorn. This is a question particularly relevant to the Wilhelm Spring subunit that contains no springs as reliable as Dripping Spring, nor an artificial water catchment system to help carry bighorn through such dry periods.

A question at least as important as the results of a changing weather regime concerns the expanding distribution of cattle in the Old Woman Mountains. At the beginning of our study, evidence of cattle use of the Wilhelm Spring drainage and the one immediately north suggested a few wandering cattle in past years. During the winter and spring of 1985, we found regular cattle use in this vicinity. Cattle were absent there in summer, but had already returned by late September. We noted succesively greater penetration of the Wilhelm Spring drainage. As of our last visit in October 1985, cattle had been using Wilhelm Spring #1 and had explored considerably further up the wash. Given the apparent social intolerance of large herbivores by bighorn, especially ewes, it may be but a short time until impacts are present in the Wilhelm area. The same could occur in the Sheep Camp and Dripping Spring subunits. Dripping Spring itself is particularly vulnerable, because it lies in a wash with no impediments to cattle. Yet, it is a spring of particular importance to bighorn sheep in that it has always contained water during dry periods (R. Weaver, M. Wood, pers. comm.). Prior to the construction of the artificial water catchment at Sheep Camp Spring, Dripping Springs may have been the only summer water source in dry years for bighorn ewes on the west side of the Old Woman Mountains. Expansion of the cattle population in the Old Woman Mountains offers considerable potential for significant competition with bighorn to occur.

Diseases

In addition to competition and habitat alteration, cattle have the potential to impact bighorn sheep adversely through the introduction of diseases. Since some of the diseases transferable between these species are vectored by flying insects, this can occur without distributional overlap. Others might be transmitted to the rest of the bighorn population by rams whose ranges overlap cattle distribution.

Blood samples collected from bighorn caught in the Old Woman Mountains in 1984-85 were tested for the presence of, or recent exposure to, a number of diseases, through serum titers and virus isolation. Most of these diseases are associated with domestic livestock and are not among the native pathogens with which bighorn evolved. Particularly noteworthy in this regard are the viruses epizootic hemorrhagic disease (EHD), bluetongue (BT), and parainfluenza-3 (PI-3), all of which have been implicated in the substantial depression of lamb recruitment in the bighorn population in the Santa Rosa Mountains since 1977 (Deforge et al. 1982, Wehausen et al. 1985). Of the 11 bighorn sampled in the Old Woman Mountains, 7 had significant titers to EHD, 4 to BT, 4 to PI-3; and additionally, PI-3 virus was isolated from 2 (Clark et al. 1985). A scabies-like skin condition on one of these sheep, and evidence of chronic sinusitis in the same animal (D. Jessup, pers. comm.) and in others that we have observed, indicate the presence of additional diseases possibly not transmitted by livestock.

A number of factors suggest that diseases may be impacting this population significantly. Demography of bighorn populations in variable, arid ecosystems such as the Old Woman Mountains should be affected strongly by precipitation patterns (Wehausen et al. 1985). Vegetation growth and resulting nutrition under favorable precipitation patterns should result in high reproductive success and population increase, while the opposite should occur when precipitation in critical periods is scant. Thus ecological carrying capacity largely will be an abstraction (MacNab 1985) representing no more than a mean over some time period.

Precipitation patterns in the Mojave Desert of California have been quite favorable overall since 1977, including 1984-85, as documented in the Old Woman Mountains by the phenological response of the vegetation and the resulting fecal protein curve of diet quality. The prediction on that basis is that bighorn populations should have increased and be at high densities. Yet, reproductive success in the Old Woman Mountains was low at 16 lambs recruited per 100 adult ewes -- apparently not quite enough to maintain the population. The hypothesis that this may result from high intraspecific competition for available nutrients due to a high population density after numerous years of population increase can be refuted: (1) the population density is quite low relative to some nearby ranges, and (2) there is no evidence of a shortage of forage; in fact, it is for the most part difficult to find any evidence of forage use by bighorn. This situation is consistent with a population that is artificially depressed, as could result from introduced diseases. Noteworthy disease conditions were documented for two young bighorn in 1985. One was a lamb in spring with a deep cough and running nose in the Wilhelm Spring subunit that survived the pneumonia. The other was a small, yearling ram that we found freshly dead in July in the Sheep Camp subunit which was diagnosed to have fibrinopurulent pleuritis and bronchopneumonia (D. Jessup, lab report). These observations are consistent with the common disease syndrome associated with the presence of PI-3, BT, and EHD in bighorn (Jessup 1985).

It is probable that PI-3, BT, and EHD in the bighorn in the Old Woman Mountains all originated from domestic livestock. Both BT and EHD are vectored by gnats (Hoff and Trainer 1981), and cattle commonly carry BT (and presumably also its close relative EHD) in a chronic form, with little influence on their health (Marsh 1965, Bruner and Gillespie 1966, Hoff and Trainer 1981, Thorne 1982). In contrast, similar to some other North American wild ruminants (Thorne 1982), bighorn sheep appear to contract BT only as an acute disease (Robinson et al. 1967, Hoff and Trainer 1981), and probably carry the virus in an infective state only for a short period until dead or recovered. Thus, it is likely that cattle are the long-term reservoir of infection in the Old Woman Mountains, since they are grazed there year-round. PI-3 differs from BT and EHD in that, once introduced, the bighorn population probably serves as its own reservoir of infection. The presence of PI-3 in some bighorn populations that are otherwise demographically healthy (Clark et al. 1985) suggests that additional stressors may be necessary for it to be manifested as a demographically significant disease. BT and EHD may serve as such stressors, suggesting that the removal of cattle as the probable disease reservoir for BT and EHD in the Old Woman Mountains might produce a significant change in the demography of the bighorn population.

Recommendations

Old Woman Mountains

Bureau of Land Management (BLM) grazing records indicate that recent cattle grazing in the Old Woman Mountains began with 60 cows in 1979 and the following year. The boundaries of this allotment (Lazy Daisy), as outlined in The California Desert Conservation Area Final Environmental Impact Statement and Proposed Plan (BLM 1980), completely skirted the Old Woman Mountains to the east and north. It was ammendment 81-21 to that Plan in 1981 that expanded (1) the boundaries of the allotment to include the Old Woman Mountains and (2) the allotment designation from ephemeral to ephemeral/perennial. The number of cattle grazed there increased immediately. This action occurred despite the following statement in the Plan regarding management for bighorn sheep: "Grazing would be eliminated in the Lazy Daisy allotment in bighorn habitat and the allotment would be reduced in size and changed to an ephemeral class" (p. E-74). The Plan further stated: "When bighorn sheep and livestock conflicts are identified, Allotment Management Plans (AMPs) will be developed with the specifid objective to maintain or improve bighorn numbers" (p. P-55). Consequently, Ammendment 81-21 included the following stipulation: "At the end of five years (1987), there will be a full reanalysis of bighorn populations and range conditions. If grazing is shown to negatively impact bighorn population, elimination or reduction of cattle range will be considered". A BLM Memorandum dated 18 June 1982 to the California Desert district manager from the Needles area manager reaffirmed this commitment. It included at the end a statement of minimum information needs summarized as follows: (1) determine the size of the bighorn sheep population in the Old Woman Mountains and monitor it for a minimum of 5 years; (2) determine important water sources for bighorn sheep in that range, and (3) determine what effect livestock use is having on bighorn sheep.

Our study has dealt with all 3 of these subjects. While our results suggest that diseases of cattle may be more detrimental to the bighorn than competition, competition cannot be dismissed entirely because of its dynamic nature. Relative to competition, we recommend the following: (1) that competition be further investigated in the Gemco drainage, since our work there was incomplete; (2) that expanding range of cattle be monitored relative to potential overlap with bighorn range, especially in the Willhelm Spring area; and (3) that the current allotment boundaries be redrawn on the basis of our maps of bighorn range so as to eliminate possible future overlaps that could lead to competition. Minimally, this would involve the elimination of (1) the Wilhelm

Spring area, (2) the large wash between the Sheep Camp and Wilhelm Spring subunits, (3) the Sheep Camp subunit, and (4) the Dripping Spring subunit from the allotment. Some fencing may be necessary to maintain such boundaries.

The thrust of future study regarding bighorn in the Old Woman Mountains should concern itself with the demographic effects of the diseases currently infecting the population. Introduced diseases can be expected to reduce carrying capacity of a population by increasing the nutrient requirements of individuals for maintenance and reproduction. The degree of such a reduction in carrying capacity is a major unknown. It is possible that the current demographic situation of the population in the Old Woman Mountains is a slow decline that will continue until the population is gone. This can be determined only through continued collection of demographic data sufficiently accurate to detect change over relatively few years.

A second approach to the study of the demography of this disease process should involve comparison with nearby bighorn populations lacking these diseases. The relative sparsity of bighorn in the Old Woman Mountains suggests the hypothesis that they have declined in number since livestock diseases entered the population. Comparison of current population density with nearby non-diseased populations would be a first test of this hypothesis.

The final question relative to livestock diseases concerns the current role of cattle in the process. Given evidence of PI-3, BT, and EHD infection in the bighorn population, it is probably a foregone conclusion that the cattle are infected with these viruses; but documentation of this should be a first step. The real question of importance in this regard is whether cattle are the long-term reservoir of infection for BT and EHD. There is only one certain way to determine this -- to manipulate the system (MacNab 1983) by eliminating them as a reservoir. In the Serengeti Plains of Africa, vaccination of all cattle against rinderpest accomplished such an end, and resulted in the immediate disappearance of this virus in the wildlife (Sinclair 1977, 1979). Since vaccination against BT and EHD is not yet reliable (D. Jessup, pers. comm.), the only way to make this test is to remove all of the cattle. This should be planned as part of a long-term research design and agency commitment, but to be carried out only after the demography of the bighorn population has been accurately quantified for 3 years and compared with nearby non-diseased populations. A good timetable would be collection of baseline demographic data through 1987, followed by removal of cattle in late 1987 for at least 5 years.

Another recommendation concerns control of tamarisk near critical springs for bighorn. Our sampling of the distribution of bighorn pellets in the Wilhelm Spring drainage indicated that, in 1984, Wilhelm Spring #1 was the most important spring in that drainage. However, we found Wilhelm Spring #3 to be much more important in 1985. Despite a wet year, Wilhelm Spring #1 dried up in summer, while the two upper springs in that drainage did not (Figure 2, Table 2). It appears that increasing growth of tamarisk around Wilhelm Spring #1 may be causing it to dry up. This could be easily determined with some removal of tamarisk. It would also be a good practice to monitor and contol tamarisk around other springs that we identified as important to bighorn.

Lanfair Valley Populations

The major question regarding the bighorn inhabiting ranges around Lanfair Valley concerns the definition of populations. While our observations of bighorn in the Castle Mountains would be consistent with a small resident population, they by no means preclude a far ranging population. It is possible that the disappearance of bighorn from the Castle Peaks does not represent extinction, but instead a shift in distribution pattern associated with wetter conditions that have prevailed since 1977. Thus, our recommendation for further research in that area would be to radio collar some bighorn in the Castle Mountains and monitor them regularly.

One concern worth voicing is the large amount of new fencing that divides the Castle Peaks into sections. Only a small amount of this fencing is designed to allow wildlife to pass through easily. We would recommend that all sections of this fencing in areas around Lanfair Valley that are adjacent to bighorn habitat or bisect potential travel routes be converted to this design. This should be an immediate concern, as bighorn appear generally incapable of negotiating standard livestock fencing (Wehausen, unpub. observations), and have been documented to die in such fences due to entanglement (Russi, pers. comm.).

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APPENDIX A

Test for Equal Observability of Marked Ewes

We tested the assumption of equal observability of ewes with a goodness-of-fit test. The first procedure in this process was the calculation of the expected distribution of our 8 marked ewes into the 4 possible categories of resighting frequency: 0, 1, 2, and 3. There are respectively 1, 3, 3, and 1 ways any ewe could be resighted with these frequencies. Probabilities of resighting were not uniform for all surveys. In each of the summer and fall surveys, 4 of the 8 marked ewes were observed, yielding a 0.5 probability of being observed or of not being observed. In the spring survey, the radio receiver was used to locate 2 of the marked ewes, thus these could not be included as random resightings. Since 3 other marked ewes were seen in that survey, the probability of resighting was 3/8, and that of not being observed was 5/8. Applying these probabilities and summing their products for the permutations in each of the 4 resighting categories yields expected proportions of 5/32 for 0 resightings, 13/32 for 1 resighting, 11/32 for 2 resightings, and 3/32 for 3 resightings. Multiplying these proportions times 8 (the number of marked ewes) gives the respective expected resighting frequencies of 5/4, 13/4, 11/4, and 3/4, compared with respective observed frequencies of 3, 2, 0, and 3.

The second step involved comparing the observed and expected frequencies with a statistical test. The low numerical values of the expected frequencies prevented use of a chi-square test. Siegel (1956) instead recommends lumping of adjacent categories and the use of a binomial test. The lumping of resighting categories 0+1 and 2+3 resulted in a test of the symmetry around the midpoint only, both sides of which have nearly equal expected frequencies. More meaningful is to test the sum of the 2 central categories, which have a combined expected frequency of 6, against the sum of the 2 peripheral categories, which have a lower combined expected frequency of 2. The combined observed frequencies were exactly the reverse of these expected values, and a binomial test (Siegel 1956) indicated that the probability of this occurring due to chance under the null hypothesis of equal observability is only .0038. This strongly suggests that marked ewes were not equally observable.

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Table 1 - Resighting history of marked sheep in the Old Woman Mountains by subunit. Sheep identifications are various, including ear tag numbers, collar letters and colors, and radio channels. All sheep are adult ewes except for the following rams: #493, Ch. 5, and #408. Asterisks denote location by radio signal only.

	SUBUNIT	OF	SIGHTING	
Date	Dripping Spr.	Sheep Camp	Wilhelm Spr.	Surveyor Spr.
14 Oct 84			#501 (capture) Medallion (capture)	
3 Mar 85	V (capture) L (capture)			
30 Mar 85	A (capture)	White/O (capture) #493 (capture)		
9 Apr 85			#501	
20 Apr 85	Ch. 14 (capture) Ch. 16 (capture)		Ch. 3 (capture) Ch. 5 (capture) Medallion (helicopter) #493 (helicopter)	
2 May 85		Ch. 16*		
3 May 85	A			
4 May 85	White/O			
5 May 85		Ch. 16*		
6 May 85	A, White/O	Ch. 16*		
10 May 85		Ch. 16		
11 May 85		Ch. 5*		
12 May 85		Ch. 14		
13 May 85	Ch. 14*, Ch. 16*		Ch. 5*	
17 May 85			Ch. 3 (dead)	
18 May 85			#501, Ch. 5	
4 Jun 85	Ch. 16*			
6 Jun 85	Ch. 14			
5 Jul 85	V	A, White/O		
6 Jul 85		White/O		
7 Jul 85	V	White/O		
12 Jul 85		Medallion		
14 Jul 85			#501, Ch. 5	
15 Jul 85			#501	
15 Aug 85	Ch. 16*			
16 Aug 85	Ch. 14			
13 Sep 85	L			
15 Sep 85		A, White/O #408 (from Whipple Mtns.)		
27 Sep 85			#501, Ch. 5	
30 Sep 85	Ch. 16*	White/O, Ch. 5		
5 Oct 85	Ch. 14*, Ch. 16*			
6 Oct 85		White/O, Ch. 5		
7 Oct 85				#493
26 Oct 85			#501, Ch. 5	
4 Dec 85	Ch. 14, A			
20 Jan 86	Ch. 16			

Table 2 - Water sources and their status during 1985 in the Old Woman Mountains. Location numbers are plotted on Figure 2.

I. D. no.	Name	Time it became dry in 1985	Minimum water available (gal.)	Importance to bighorn[1]	Use by Cattle[2]
1	Rattlesnake #1	June	0	2	N
2	Rattlesnake #2	May	0	2	N,A
3	Rattlesnake #3	June	0	2	N
4	Rattlesnake #4	June	0	2	N
5	Florence Spr.	July	0	2	N
6	Missing Spr.	-	3	1	N
7	Lyons Cabin	July	0	3	Y
8	Lower Lyon	-	1	2	Y
9	Upper Lyon	-	<1	2	N
10	Willow Spr.	-	>50	3	Y
11	Goat Spr. #1	-	>50	2	N
12	Goat Spr. #2	-	20	2	N
13	Dripping Seep East	Aug	0	1	N
14	Dripping Seep West	July	0	2	N
15	Lone Spr.	-	15	1	N,A
16	Carbonate Seep	May	0	2	N
17	Dripping Spr. #2	?	?	3	N,A
18	Upper Dripping Spr.	-	2	1	N,A
19	Dripping Spr.	-	>50	1	N,A
20		Aug	0	2	N
21	Sweetwater Spr.	Dry	0	3	Y
22	Paramount Spr.	?	?	?	Y
23	Tunney Spr.	-	>50	3	Y
24	Tunney Well	?	?	?	?
25	Craig Mine Spr.	Dry	0	3	N
26	GemCo 2, 3	-	10	2	Y
27	GemCo Mine Spr.	-	<1	3	Y
28	Upper GemCo Wash Spr.	-	2	?	Y
29	Lower GemCo Wash Spr.	-	2	?	Y
30	Sunflower Spr.	?	?	?	Y
31	Lower Bert Spr.	-	35	3	Y
31	Middle Bert Spr.	-	25	2-R	N
31	Upper Bert Spr.	-	>50	2-R	Y
32	O. W. Statue Drinker	-	3000	2-R	Y
33	O. W. Statue Wash	-	20	2-R	N
34	Ford Well	-	0	3	Y
35	Ford Spr.	?	?	3	Y
36	Painted Rock Spr.	Summer	0	3	Y
37	Upper Painted R. 1,2	?	?	3	Y
38	Craig Spr.	?	?	2	Y
39	Dead Ram Spr.	Aug	0	1	N
40	Lower Dead Ram	Jun	0	2	Y
41	Lower Nursery Spr.	Jun	0	2	Y
42	Middle Nursery Spr.	Jun	0	2	N,A
43	Nursery Spring	-	2	1	N
44	Wilhelm Spring #2	-	1	1	N
45	Wilhelm Spring #3	-	1	1	N
46	Wilhelm Spring #1	Aug	0	1	Y
47	Dead Ewe Spr.	?	?	2	N
48	S. Scanlon #1	-	2	2-R	Y
49	S. Scanlon #2	-	2	3	Y
50	S. Scanlon #3	-	<1	3	Y
51	Lower S. Scanl. Seep	Jul	0	1	N
52	Upper S. Scanl. Seep	-	<1	1	N
53	Upper Sheep Camp #1	-	1	1	N,A
54	Upper Sheep Camp #2	-	15	1	N,A
55	Sheep Camp Drinker	-	3000	1	N
56	Lower Sheep Camp	Jul	0	1	N
57	Coyote Spr.	Aug	0	2	N
58	Black Metal Spr.	Summer	0	2	N
59	Surveyor Drinker	-	3000	2	N
60	Old Woman Seep	Jul	0	2	N
61	Sudmeier Spr.	-	20	2-R	N
62	Lower Marv Wood Spr.	-	>50	2	N
63	Upper Marv Wood Spr.	-	4	2	N
64		Aug	0	2	N
65		-	<1	2	N

[1] 1 = very important; 2 = used; 3 = not used; R = rams only.

[2] Y = yes; N = no; N,A = no but accessible to cattle.

Table 3 - Summary of demography for bighorn sheep in the Old Woman Mountains, 1985.

Parameter	Spring	Summer	Fall
Mark-recapture estimates[1]			
Adult ewes observed	18	17	15
Estimated adult ewes[2]	34(15-152)	34(15-114)	30(15-100)
Sex and age ratios[3]			
Lambs:100 adult ewes	33\39	21\24	16\7
Yearlings:100 adult ewes	17\11	12\12	16\13
Adult rams:100 adult ewes[4]	10\11	33\47	53\40
Sample size (adult ewes)	30\18	24\17	19\15

[1] Spring and fall estimates are from hiking surveys, while the summer estimate is from a waterhole count. Radio collars were not included in the marked population in the spring estimate due to use of the receiver to find sheep.

[2] Parenthetical values are 95% confidence limits. Adult ewes are 2-yr. olds and older.

[3] The double values for each season represent different sampling periods. In each case, the second value is from a single census, while the first incorporates more observations. The time periods are (1) Spring: 4/9-5/19 \ 5/6-5/19, (2) Summer: 6/20-7/15 \ 7/5-15, and (3) Fall: 9/12-30 \ 9/12-27.

[4] Rams recorded in the spring count were all 2-yr. olds. Adult rams are 2-yr. olds and older.

Table 4 - Inventory of bighorn sheep carcasses found during this study.

Date of Collection	Location[1]	Approximate time of death	Age at death	Sex
4/23/85	above Wilhelm Spr. #2, OW	4/10/85	2 mo.	?
9/13/85	w. of Carbonate Seep, OW	spring '85	2 mo.	?
12/84	near Carbonate Seep, OW	1983-84	6 mo.	?
9/16/85	Sheep Camp Wash, OW	summer '85	6 mo.	?
10/27/85	Goat Spr. #1, OW	1983-84	6 mo.	?
7/14/85	Wilhelm Spr. #3, OW	1983-84	7 mo.	?
7/4/85	Lower s. Scanlon Seep, OW	7/1/85	7-8 mo.	M
7/5/85	Dripping Spring, OW	1983-84	8 mo.	?
1/12/85	Kidney Spr., CM	fall '84	9 mo.	M
4/9/85	Dead Ram Spr., OW	4/7/85	12 mo.	F
7/12/85	Sheep Camp Pass, OW	7/11/85	16-18 mo.	M
9/16/85	Sheep Camp Wash, OW	summer '85	2 yrs.	F
9/11/85	w. of Dove Spr., CP	summer '85	3.75 yrs.	M
6/8/85	Piute Guzzler, PR	1983-84	4.5 yrs.	M
6/8/85	Piute Guzzler, PR	1983-84	4+ yrs.	F
4/9/85	Dead Ram Spr., OW	1983-84	4.5 yrs.	M
10/9/85	n. of Piute Guzzler, PR	old	4+ yrs.	M
1/12/84	Kidney Spr., CM	summer '84	5.5 yrs.	M
3/13/86	near Carbonate Seep, OW	summer '85	5.5 yrs.	F
5/13/85	Old Woman Statue, OW	1982-83	6.5 yrs.	M
4/9/85	Dead Ram Spr., OW	1983-84	9.5 yrs.	M
3/1/85	Upper s. Scanlon Seep	1984	11-12 yrs.	F
5/17/85	Dead Ewe Spring	5/10/85	12 yrs.	F (#3)

[1] OW = Old Woman Mountains, CM = Castle Mountains, CP = Castle Peaks, PR = Piute Range

Figure 1 - Distributions of cattle and bighorn sheep in the Old Woman Mountains, California. Left-slanting cross-hatching represents bighorn sheep range, right-slanting cross-hatching represents cattle range, and shaded areas represent zones of overlap.

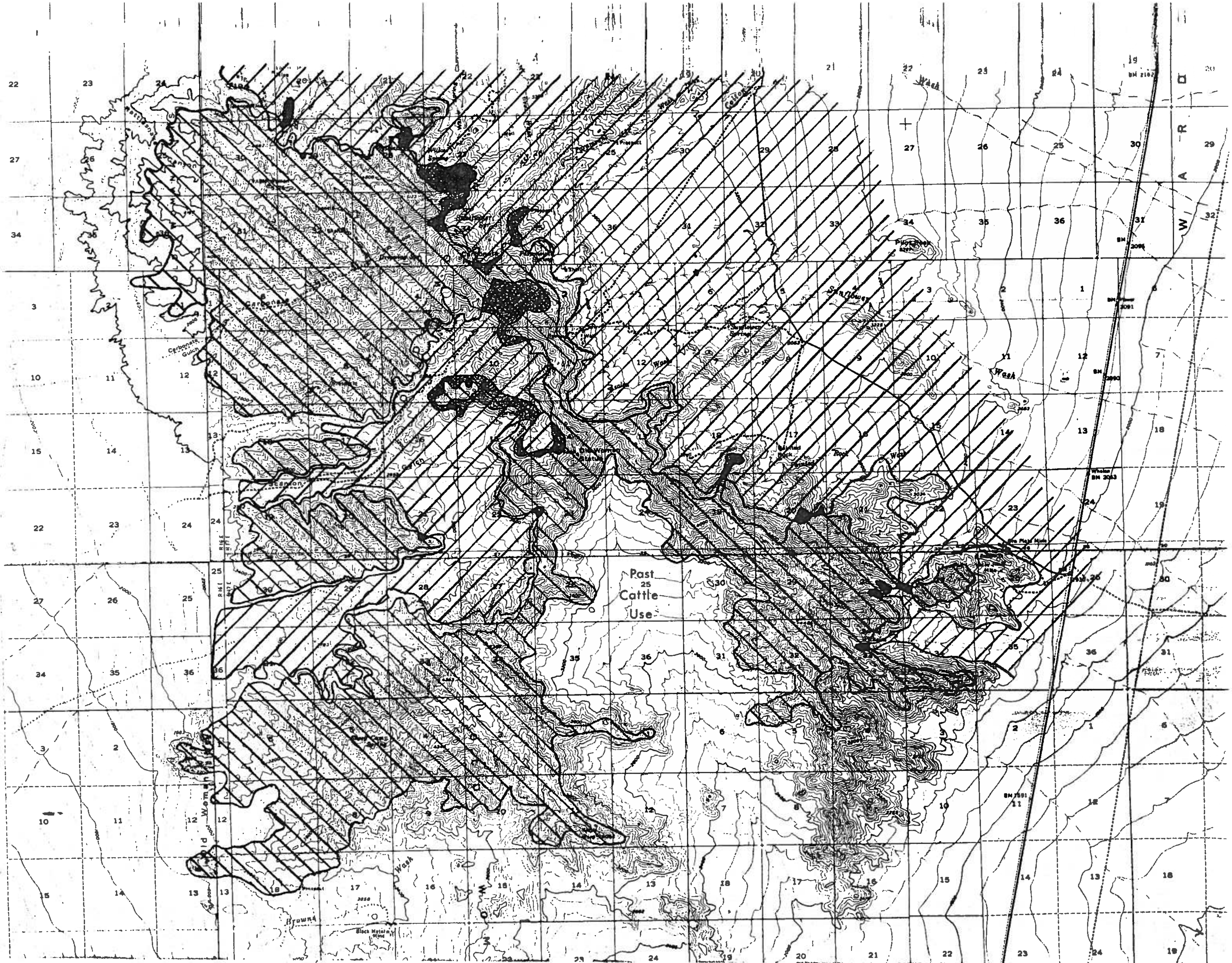

Past
25
Cattle
Use
Wash
Carbonate Gulch
Canyon
Old Woman
Browns
Black Metals Mine

Figure 2 - Sighting locations, lambing area, ram range, and travel routes of bighorn sheep in the Old Woman Mountains, California. Sighting locations are denoted by dots, documented travel routes across washes by arrows, and suspected travel routes by dashed arrows. The cross-hatched area appears to receive only ram use, and the areas outlined without cross-hatching are lambing areas.

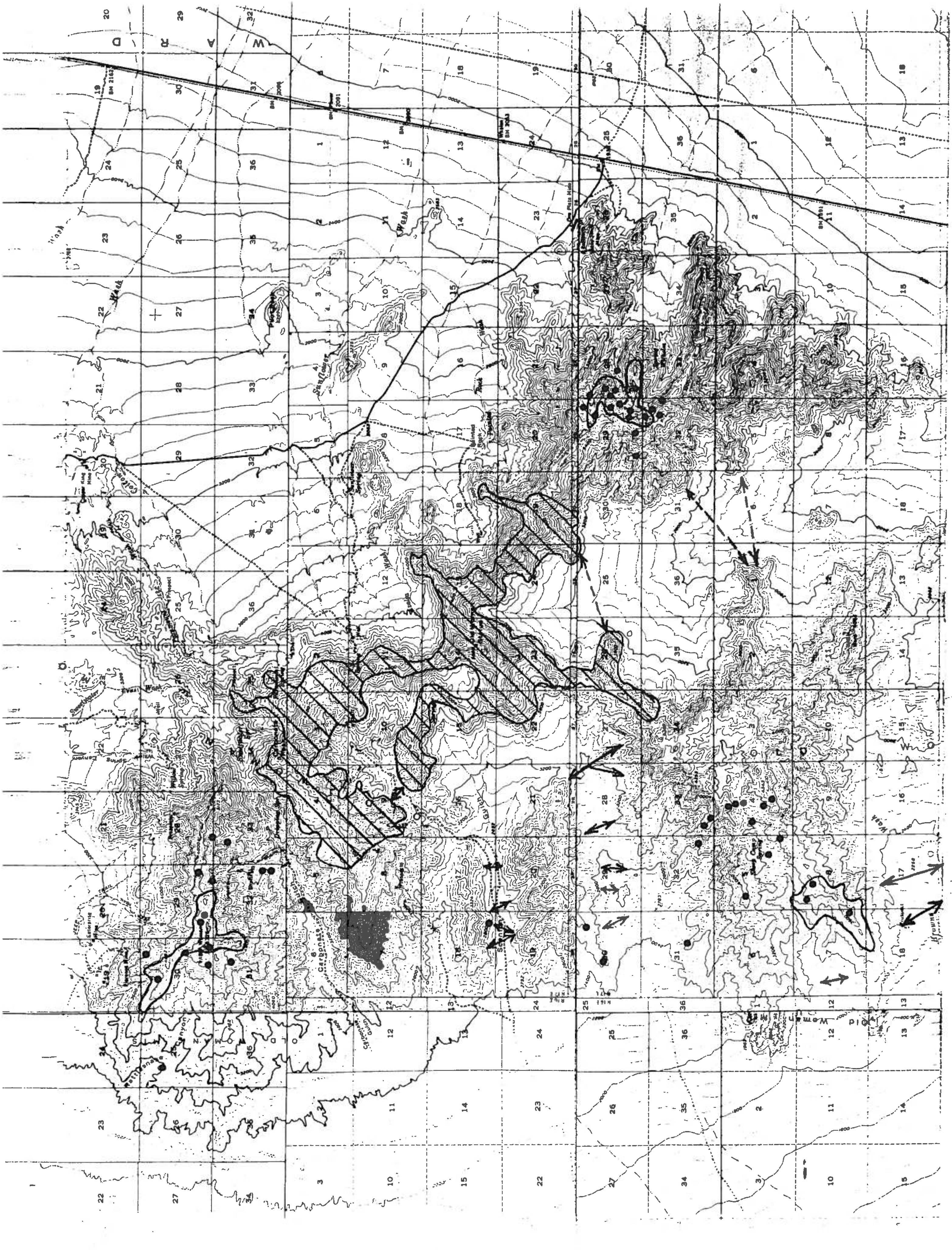
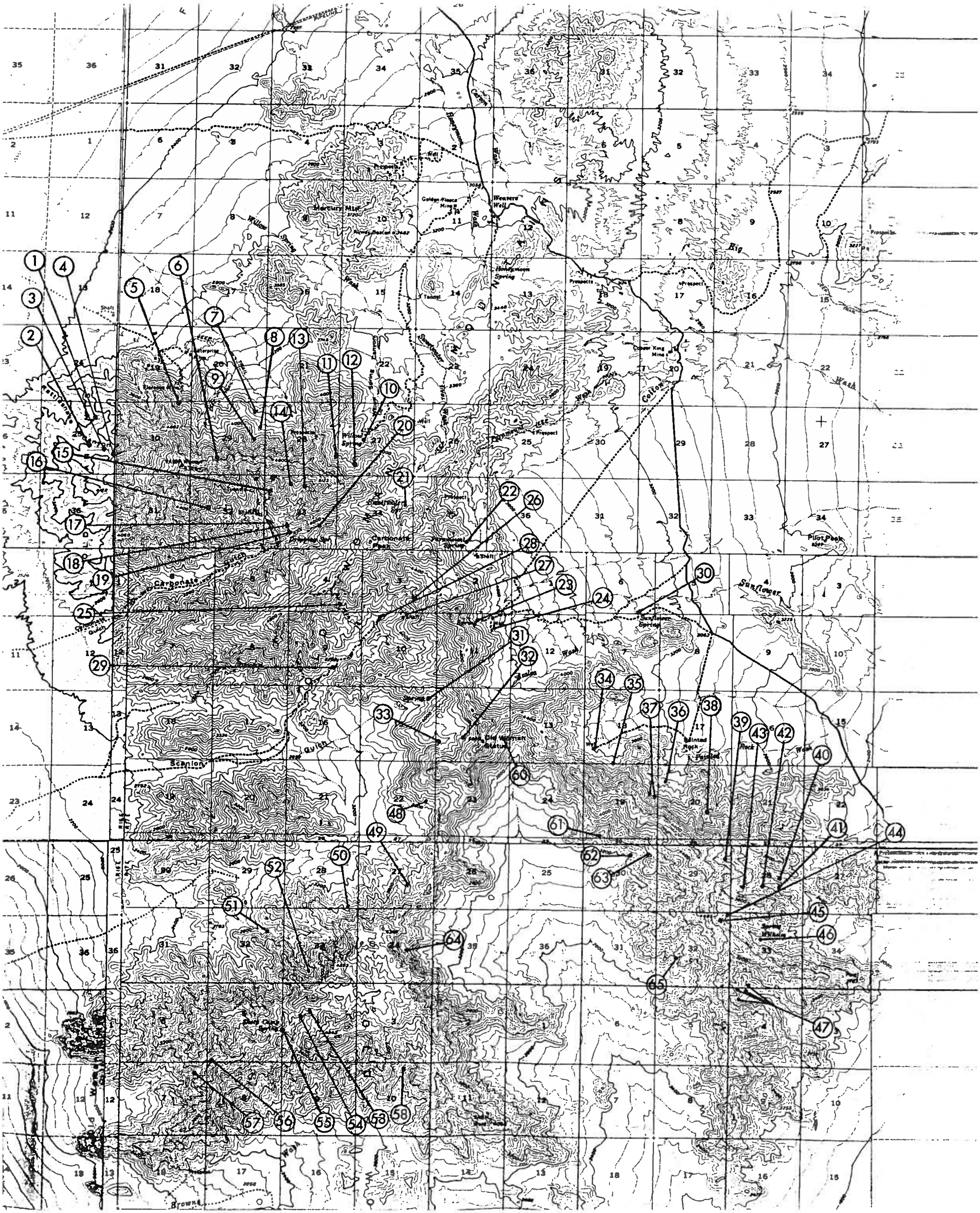


Figure 3 - Locations of surface water sources in the Old Woman Mountains, California. Data on each source are listed in Table 2 by location number.



Mercury Mine
Golden Fleece Mine
Western Well
Honeymoon Spring
Willow Spring
Copper King Mine
Big
Wash
Carbonate
Carbonate Peak
Sunflower Spring
Sunflower
Scanlon
Gulch
Old Woman Statue
Painted Rock
Pilot Peak
Prospects
Prospect
Shaft
Well
Browns

Figure 5 - Curves of percent fecal crude protein for bighorn sheep in the Old Woman Mountains, Castle Mountains / Piute Range, and Inyo Mountains of California from 1984-85.

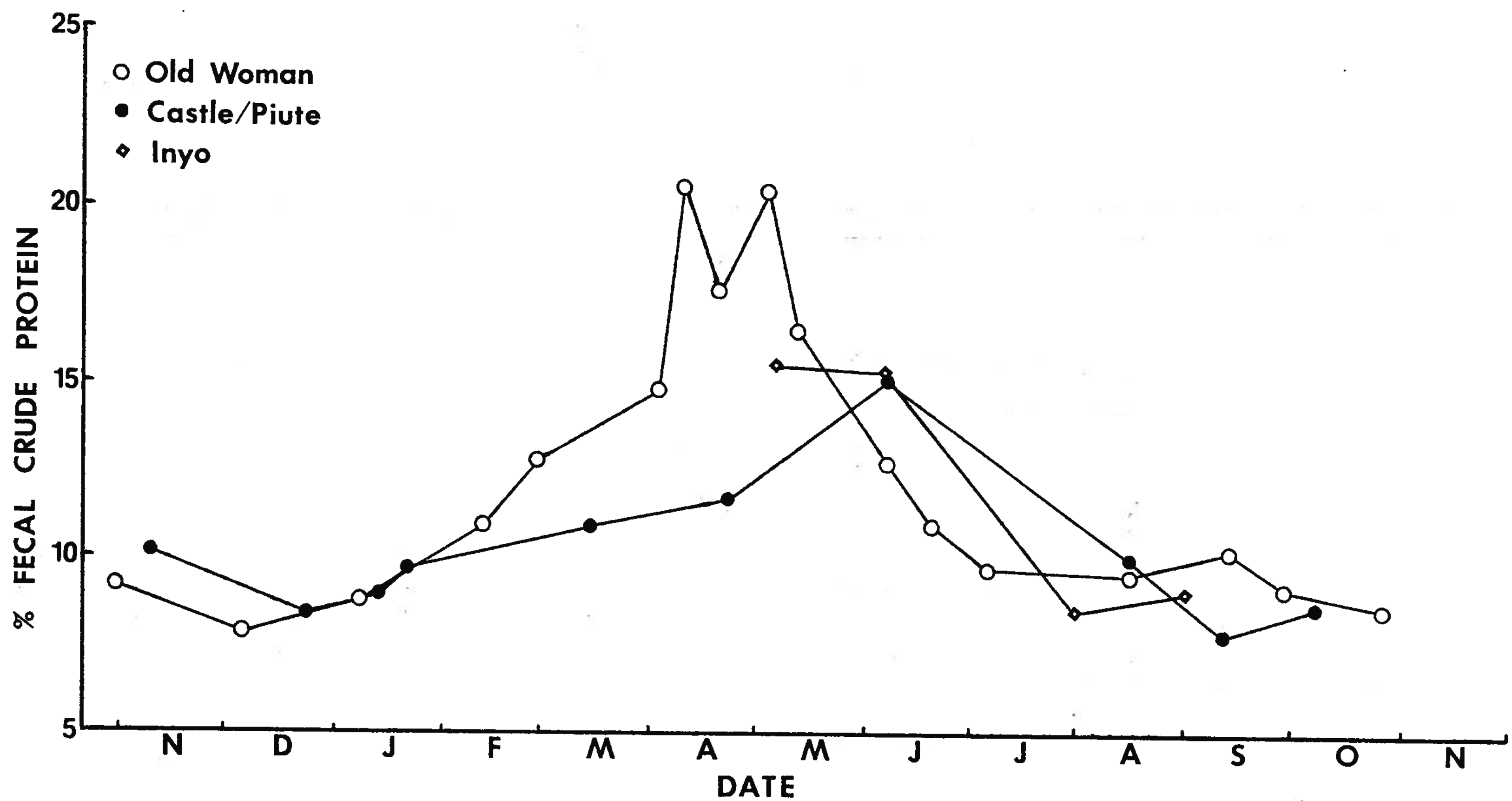


Figure 4 - Curves of percent fecal crude protein for bighorn sheep in the Old Woman Mountains, Mount Baxter herd in the Sierra Nevada, and White Mountain Peak herd in the White Mountains of California from 1984-85.