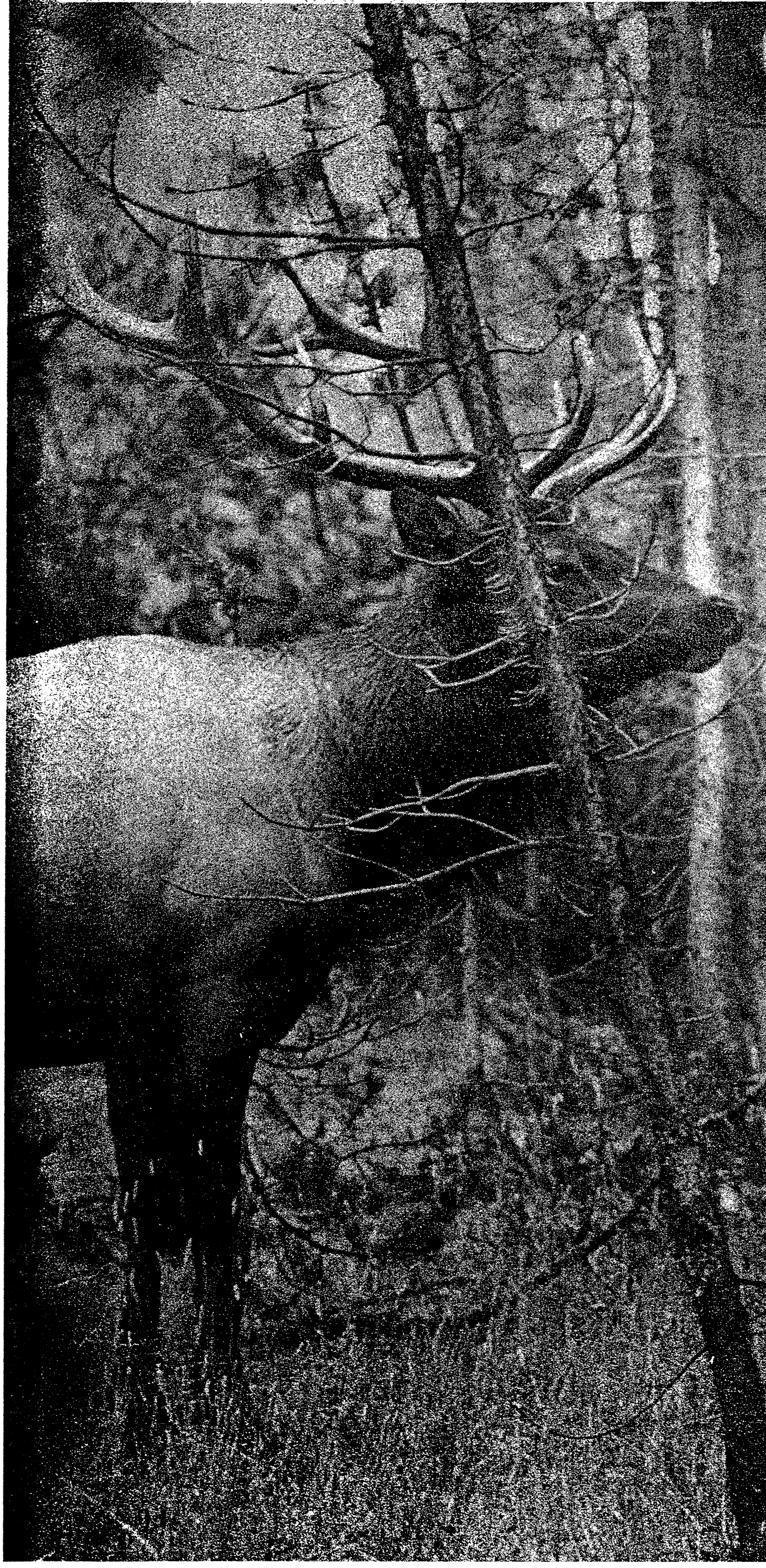

ARIZONA GAME AND FISH DEPARTMENT

RESEARCH BRANCH
TECHNICAL REPORT #10

EFFECTS OF TIMBER MANAGEMENT PRACTICES ON ELK
A Final Report

RICHARD L. BROWN

September 1991
Revised February 1994

FEDERAL AID IN WILDLIFE RESTORATION PROJECT

Arizona Game and Fish Department Mission

To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

Arizona Game and Fish Department
Research Branch

Technical Report Number 10

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Effects of Timber Management Practices on Elk

Richard L. Brown

Abstract: Thirty-seven radio-telemetered elk *(Cervus elaphus nelsoni)* were located at bedsites between 10:30 AM and 3:30 PM during June through August of 1988, 1989, and 1990. Standard silvicultural measurements were recorded at the bedsites and at associated satellite plots. The latter provided a measure of habitat availability in proximity to the bedsites. Two habitat types were examined; ponderosa pine (*Pinus ponderosa*) with a Gambel oak (*Quercus gambelii*) inclusion, and a woodland association of pinyon pine (*Pinus edulis*) and juniper (*Juniperus spp.*). A discriminant function was developed for both habitat types combined that correctly classified about 90% of the bedsites. Elk selected bedsites in areas with higher canopy closure, greater total dbh, few limbs below 6.5 ft, and clear of rocks. Optimum thermal cover habitat was composed of stands between 30 A and 60 A, with a canopy closure exceeding 70%. Average tree heights in these covers equaled or exceeded 17 ft for ponderosa and 11 ft for P/J woodland. Distance to lowest limb requirements were automatically met in the ponderosa type due to normal self pruning. The discriminant analysis selected this requirement only for the P/J woodland where this characteristic was dependent upon the presence of mature trees. These data were then used to generate tables describing moderate and optimal bedsite characteristics in terms of standard silvicultural criteria. There was not a high degree of correlation between either basal area or stand density index values and canopy closure levels. These values are poor predictors of canopy closure in ponderosa forest and are unusable for this purpose in P/J woodland. The U.S. Forest Service R03WILD (WESTWILD) habitat capability model was therefore found to be unreliable in its present form for classifying elk habitat. This unreliability was due in part to the low potential for structural stage data, or their derivatives, to accurately reflect canopy closure levels. Additionally, the model's fractional acre matrix values were in disagreement with our findings.

INTRODUCTION

The accepted definition of high quality elk habitat calls for maintaining 40% of the total land mass in cover and 60% in forage areas (Black et al. 1976, Thomas et al. 1979). The 40/60 cover/forage ratio calls for 1/2 of the 40% to be hiding cover, 1/4 thermal cover, and the remaining 1/4 either hiding or thermal cover, whichever is the more limited. Forage areas are defined as those that do not qualify as cover areas. Cover is divided into two types, hiding and thermal. Hiding cover provides an escape or security function and is defined as vegetation that will hide 90% of a standing adult elk at 200 ft or less (Thomas et al. 1979). Thermal cover protects from solar radiation during warm periods and reduces the animal's radiant heat loss during cold periods.

Elk have a heavy, low-conductive hair coat, which provides efficient insulation. They begin sweating at about 55 F, and 77 F is the approximate upper limit of the thermal neutral zone (Parker 1983). They lack an extensive sweat gland system, are better adapted to cold than heat, and their response to warm weather is to select cool shaded areas (Skovlin 1982).

Because elk historically inhabited extensive, treeless areas, it can be argued that they do not need thermal cover to survive. However, several authors agree that lack of adequate thermal cover reduces performance levels. Mitchell et al. (1981) reported that for red deer *(C. elaphus)* in a coniferous woodland in England, stags were 67% heavier, hinds 34% heavier, many more yearling females were pregnant, and reproductive potential was greater than for those occupying open hill habitat in Scotland.

Leckenby (pers. comm.) discussed an elk herd existing in nearly pure stands of 10-12 ft tall sagebrush *(Artemisia spp.)* near the Idaho border. That herd did little more than maintain its numbers and did not produce a meaningful harvestable surplus. Holechek et al. (1981) report that in the Blue Mountains of Oregon, cattle maintained higher summer weight gains in forested areas than in open grasslands. Wickstrom (1983) found that dry matter intake by elk was greater in forested areas than in grasslands. This difference was due, in part, to the fact that during hot weather, animals in open grassland spent more time bedded and less time feeding than their counterparts in wooded areas. Peek (1984) concluded that, in herds with access to adequate thermal cover, numbers will fluctuate less, there will be more uniform use of available forage, and survival will be higher during weather extremes.

Information from at least one study is not in full agreement with the aforementioned. McCorquodale (1985) studied a small, recently established herd that occupied a shrub-steppe community year-round in south-central Washington. While sagebrush (height not specified) provided some microclimatic advantage, it did not equal that provided by forested communities. That pioneering elk herd was on a nutritionally high plane and produced calf crops equal to those found in other populations. It was also characterized by greater than normal nocturnal activity, reduced diurnal activity, and much larger than normal individual home range sizes. Additionally, that population was not exploited and overall incidence of human disturbance was low. McCorquodale (1985: 97-98) cautioned against applying his findings to elk herds in general, particularly those not on an equally high plane of nutrition, nor relatively free from human disturbance. He viewed use of thermal cover as an "optimization process whereby elk seek to optimize their energy budget by decreasing the energy costs associated with thermoregulation," and stated that "other, more energy limited populations may need cover in order to optimize their growth, survival, and reproductive rates."

The accepted description of adequate summer thermal cover is any stand of coniferous trees 40 ft or more in height with an average canopy closure of 70% or greater (Thomas et al. 1979). That definition was developed in the mixed conifer forests of Washington and Oregon. Leckenby (1984) found vegetation characteristics, at elk-selected diurnal bedsites in Northeastern Oregon mixed conifer forests, to be identical to characteristics described in the Thomas et al. (1979) thermal cover guidelines.

Elk in the western half of Arizona do not have access to a large amount of mixed conifer forest. They summer primarily in ponderosa pine and to a much lesser degree in pinyon pine /juniper woodland (P/J). In the eastern half of the state, elk utilize mixed conifer forest to a much greater degree, but also use ponderosa pine forest and P/J woodlands as summer habitat.

According to Greg Goodwin (USDA Forest Service, Coconino Natl. Forest, pers. comm.) pure ponderosa pine stands, greater than 40 ft in height, rarely achieve 70% canopy closure. He also stated that P/J woodland usually does not reach, and rarely exceeds, the 40 ft minimum height limit defined in the Pacific Northwest studies. These characteristics suggested that a major portion of Arizona's elk were using a different tree stand structure for mid-day bedsites than was used in the Pacific Northwest.

Around 1987, the USDA Forest Service (USFS) Region III, began implementing new multi-resource stand management prescriptions for all national forests within Arizona. In general, forests were to be managed in 10,000 A (10K) blocks (range 8,000-12,000 A) comprised of 10-100 A even-aged stands, except for the old growth component, which was to be managed in 100-300 A stands. Forest plans required each 10K block to meet the 40/60 cover ratio prescription for elk habitat.

More recently, Management Recommendations for the Northern Goshawk *(Accipiter gentilis atricapillus)* in the Southwestern United States (MRNG) (Reynolds et al. 1992), have been adopted by the USFS as an overall management plan for southwestern forest habitats used by the Northern Goshawk. This plan imposes goshawk habitat guidelines on all other species within those habitats. Within each 6000 A parcel, the MRNG calls for 3 nest areas and 3 replacement nest areas of 30 A each (total 180 A in nest areas); 420 A in post-fledgling-family areas (PFA), and 5400 A in foraging areas (FA). In mid-aged ponderosa forests, the MRNG requires nest areas to be characterized by dense canopies (% canopy closure not specified). PFA are characterized by canopy closures of 60% or greater over 1/3 of their area and 50% or greater over the remaining 2/3. FA in mid-aged ponderosa have canopy closures of 40% or greater. In mature ponderosa forests, both nesting areas and PFA are characterized by canopy closures of 50% or greater and FA 40% or greater.

The MRNG further specifies that all of the nest area overstory is to exist in vegetation structural stages (VSS) 5 and 6. VSS 5 is defined in the MRNG as mature forest with diameter at breast height (dbh) limits of 18 to 24 in, and VSS 6 is defined as forest with a high density of large trees. Mean (dbh) would therefore be 18 in or greater. Sixty % of the PFA and FA will be represented by mean dbh values of 12 in or greater (VSS 4, 5, and 6).

The Implementation and Interpretation Guidelines for MRNG further describe a desired future condition on moderate to high (productivity) sites as being characterized by PFA and FA with average Stand Density Index (SDI) values of 150 and 104 respectively. Hiding cover requirements, for species other than goshawks, are to be met by seedlings and saplings, open grown to maintain the full live crown and prevent self pruning of lower limbs. Thermal cover will be provided by groups of VSS 4+ size trees (12+ in dbh) with interlocking crowns.

Furthermore, over time, the average stand size would be greatly reduced. Regeneration cuts of less than 1-4 A will provide the basis for future tree group (stand) management.

Prior to 1987, a series of USFS multivariate habitat models was designed to predict probable outcomes and track results of timber harvesting operations. Among these was the RO3WILD habitat capability model (the most recent version is known as WESTWILD), which was designed to predict probable effects on wildlife. The model's elk matrix values are based on tree structural stages (stem density classes within stem diameter categories) and are assumed to reflect canopy closure levels. However, the ability of structural stages to accurately predict canopy closure levels in ponderosa and P/J vegetation types was not tested. Outside of the RO3WILD modeling system, there had been attempts by forest managers to use the more readily available timber inventory data on basal area within diameter classes to predict canopy closure levels. It was therefore necessary in this study, not only to identify and describe what elk were using for summer day-beds in ponderosa and P/J types, but also to relate this information to basal area and diameter classes, as well as the structural stage matrix values used by the computer models that will facilitate any subsequent USFS intensive management program.

While ponderosa pine is the primary species for commercial timber harvest in Arizona, pinyon pine and juniper are primarily used for fuelwood. Extensive tracts of P/J woodland have also been chained or pushed to improve forage production for livestock. A Gambel oak inclusion occurs within both vegetation types that is also used for fuelwood. Summer thermal cover guidelines that apply to elk are therefore needed for both

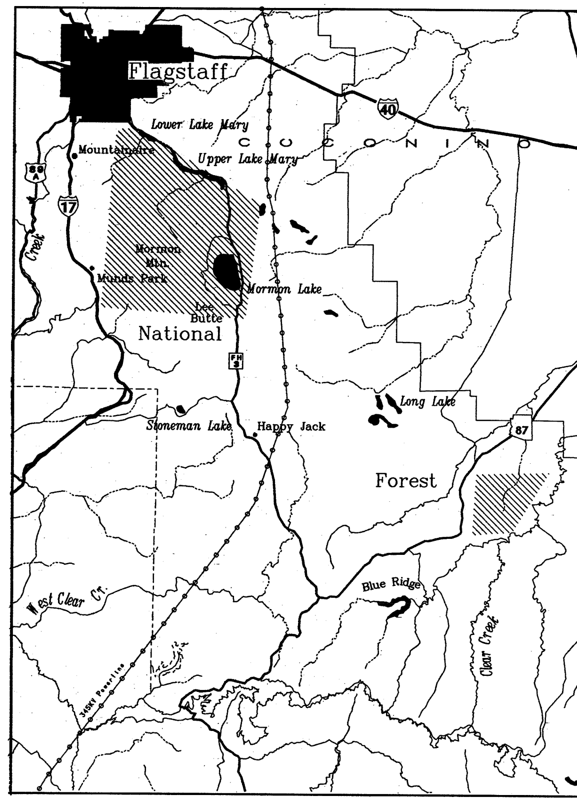


Figure 1.
Location of elk study area, Flagstaff, Arizona, 1988-90.

ponderosa forest and P/J woodland. The objectives of this study are listed below:

- Describe the habitats selected by Arizona elk for summer day-bed cover in ponderosa forest and P/J woodland, and for calving/nursing areas.
- Determine if there is a reliable relationship between tree stem characteristics (density and diameter) and level of canopy closure.
- Evaluate the RO3WILD habitat capability model relative to elk selection of summer day-bed cover.

STUDY AREA

Ponderosa Pine Forest

Over 90% of the observations made during the ponderosa pine portion of the study were obtained within a 13 by 18 mi area southeast of Flagstaff, Arizona (Fig. 1). This area was bounded on the north and northeast by Forest Highway 3 that ran southeast from Flagstaff, along the northeast shores of Upper and Lower Lake Mary, and then turned south toward Happy Jack. The study area extended 14 to 18 mi south from Lake Mary, to Lee Butte (approximately 3 mi north of Stoneman Lake), west as far as Mountainaire and Munds Park, and east as far as the powerline 3.5 mi east of the north-south portion of Forest Highway 3. The few observations obtained outside of this area were made within 30 mi west of Flagstaff in similar topography and vegetation.

Except Mormon Mountain, which supported a mixed conifer type, vegetation of the area was ponderosa pine forest (Brown 1982) with a substantial inclusion of Gambel oak. It ranged between 6600-7700 ft elevation, and the general substrate was volcanic in origin. Surface rock was primarily basalt, with Kaibab Limestone in a few locations. The study area had several heavily vegetated cinder hills covered with a well developed layer of topsoil. Most of the area was relatively flat, with occasional low ridges, hills and shallow drainages, that did not produce major changes in overstory vegetation. Less than 20% of the area was steep slopes.

Annual precipitation in the Flagstaff area averaged 20.45 in for the period 1951-1972, with 38% falling between June and September (Sellers et al. 1985). Summer moisture came from violent, localized thunderstorms that were generated from air masses from the Gulf of California and the Gulf of Mexico. About 75% of the winter precipitation was snow (Sellers et al. 1985) originating from the Pacific, which entered the state from the west and northwest. At Flagstaff, for the 33 years preceding 1984, average maximum and minimum temperatures for July were 81.1 and 50.6 F and were 42.2 and 14.6 F respectively for January (Sellers et al. 1985). Temperatures recorded during this study at mid-day bedsites between June 1-August 31, from 10:30 AM through 3:30 PM, ranged from 64-91 F.

Major consumptive uses of the resources on the study area were logging of ponderosa pine, summer cattle grazing, harvest of dead and down fuel wood, hunting, and fishing.

Pinyon/Juniper Woodland

The pinyon/juniper (P/J) woodland portion of the study area was located about 9 mi northeast of Blue Ridge, Arizona (Fig. 1). It encompassed an area 7 by 7 mi bounded on the east and south by Clear Creek, and on the west by Highway 87. One seed juniper *(Juniperus monosperma)*, Utah juniper *(J. osteosperma)*, alligator juniper *(J. deppeana)*, pinyon pine , Gambel oak, and ponderosa pine inclusion formed the major overstory on the study area, which was between 6400-6800 ft elevation. Lowe and Brown (1973) classified this ecotype as Juniper-Pinyon Woodland due to the statewide preponderance of juniper. Forested areas have a well developed understory of cliffrose (*Cowania mexicana*). Rabbit-brush *(Chrysothamnus sp.)* occurred at some localities in alluvial bottoms. Surface rock was primarily Kaibab Limestone with some Coconino Sandstone (Wheeler and Williams 1974). The study area was flat with low ridges, hills, and shallow drainageways that did not produce major changes in overstory vegetation (although the frequency of alligator juniper and ponderosa pine increased with elevation).

Annual precipitation at Blue Ridge, Arizona averaged 20 in for 1970-1984, with 38% falling from June through September. The lowest portions of the study area, nearly 500 ft lower than Blue Ridge, received less moisture (perhaps 40% less; Ken Vensel USFS Range Conservation Officer, pers. comm.). Seasonal storm patterns had the same origin as those that affected the Flagstaff area. At Blue Ridge, the average maximum and minimum temperatures for July during the 15-year period preceding 1984, were 83.4 and 51.5 F and for January 44.1 and 15.3 F respectively (Sellers et al. 1985). Temperatures recorded during this study at mid-day bedsites between June 1 and August 31, from 10:30 AM until 3:30 PM, ranged from 74-92 F.

Major consumptive resource uses on the P/J study area were spring to fall cattle grazing, harvest of dead and down fuel wood, and hunting.

METHODS

Capture and Telemetry

Thirty-seven elk were captured in modified, portable box traps (Clover 1956), during summer and winter, and instrumented with radio transmitter collars (Telonics Inc., Mesa, Arizona). The primary study populations were comprised of

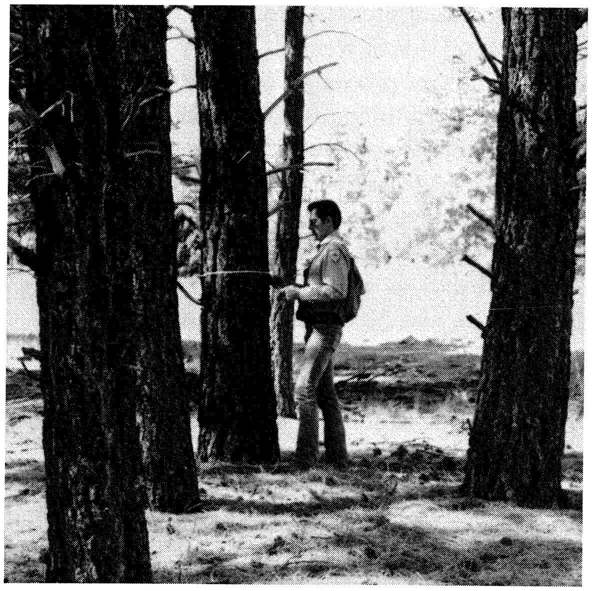


Figure 2.
Measuring ponderosa pine diameters (DBH).

Figure 3.
Measuring Utah juniper diameters (DRC).

22 instrumented animals in the ponderosa type and 15 in P/J woodland. During June-August,radio collared elk were located at mid-day bedsites between the hours of 10:30 AM and 3:30 PM. Additionally, any bedded non-instrumented animals (or groups) encountered incidentally during radio tracking operations were also included.

Bedsite Characteristics

Bedsite locations were identified when an animal was seen, either bedded or just rising to its feet. With the exception of cow/calf associations, in which both sites were noted, only 1 bedsite per group of animals was measured. The bedsite of the radio-collared animal was marked if that elk could be located. If not, the bed of the first animal seen was selected. That approach provided the most independent, systematic sample of adult bedsites that was possible, and enabled us to examine sites used by calves that were old enough to accompany adults. Sampling bias favored obtaining observations of elk (both groups and individuals) occupying more open habitats.

At the bedsites, the following measurements were made: temperature, wind velocity, slope, aspect, distance to water, and level of horizontal visual obstruction, for hiding cover evaluation. The center of the bed impression was used to establish the center of a 16.7 ft radius plot (0.02 A). A standard dbh (bole diameter at breast height, i.e., diameter 4.5 ft above ground) measurement was made on each ponderosa pine and Gambel oak within the plot (Fig. 2). For other species (Fig. 3), drc (diameter at root collar: i.e., diameter just above the root swell) was measured (Stand Specifications, Stage 2 Inventory, USFS, Feb. 1986). Tree height was measured with a hypsometer from a distance of 66 ft, and crown ratio (the % of the tree bole carrying live vegetation) was estimated for each tree. This latter value was obtained through averaging, which compensated for asymmetrical foliage distribution. For instance, if the crown ratio on 1 side of a tree was 60%, but only 40% on the other, the crown ratio for that tree was estimated as 50%. Two additional values, canopy depth, and distance to lowest limb carrying live vegetation, were derived from a combination of tree height and crown ratio. Total stem counts were used to estimate seedling density (trees less than 4.5 ft high) initially. The point-centered-quarter method of estimating stem density (Cottam and Curtis 1956) was later substituted to decrease survey time. All distance measurements were rounded off to the nearest ft.

A 5.27 ft radius plot (0.002 A) was centered within the larger plot. This plot encompassed the

Figure 4.
Spherical densiometer reading in Gambel oak.

bedsite and only a small portion of the surrounding area. Within both plots, ocular estimates were made of percent ground cover of dead and down material and rock. Canopy closure was measured from the center of the bedsite by using the full field of a concave spherical densiometer held at elbow height (Fig.4). All vegetation (limbs and stems as well as foliage) was recorded as canopy. Four readings, toward each cardinal direction, were taken at each bedsite and averaged into a single value.

Habitat selection

A satellite plot was located 900 ft from the bedsite in each of the cardinal directions. Data collection procedures for vegetation and ground cover were identical to those described for bedsite plots, except that hiding cover data were not collected. Satellite plots were used to estimate habitat availability in the immediate bedsite vicinity, and to determine if elk selected certain site characteristics relative to vegetative cover.

Discriminant Function Analysis (DFA) was used to test the hypothesis that mid-day bedsites used by adult female elk did not differ in their multivariate characteristics from immediately available alternative satellite sites. Initially, 1 satellite associated with each bedsite was randomly selected for inclusion in the data set used to build the discriminant model. From this initial data set (n = 280), 231 cases were ultimately accepted by the discriminant procedure (122 bedsites, 109 satellites). Forty-nine cases from the original data were discarded due to at least 1 missing discriminating variable. Eighteen variables (Table 1) were tested for both study areas combined across all vegetation types (ponderosa pine and P/J woodland), as well as for an association of Gambel oak and New Mexico locust *(Robinia neomexicana)*. Continuous data were $\log_{10}$ transformed. Percentage data were analyzed as whole integers (from 0 to 100), that were arcsine transformed. All analyses were performed on coded and transformed data. Mean values presented in tables are non-transformed values.

Of the 18 variables tested, those that were correlated with $r \geq 0.75$ were identified. One variable of each of the correlated variables was retained for further analysis. The discarded variables would have represented measurement redundancy relative to their independent contributions to the discriminant model. This reduction yielded 13 independent variables (Table 1). However, because each discarded variable was correlated with a retained variable, appropriate substitutions could have been made without seriously compromising the integrity of the model.

The stepwise procedure to eliminate additional unnecessary variables used an F-to-enter of $P \leq 0.15$, and a selection rule to minimize Wilks' Lambda values. The 0.15 level of significance was selected to avoid premature termination of the stepwise procedure (Litvaitis 1990: 521) as recommended by Dillon and Goldstein (1984). Four variables were subsequently selected from the set of 13 used to generate the original model. These 4 were placed in a new reduced model and its predictive robustness was compared to that of the original model. Lastly, the 4 variable model was used to classify 414 of the remaining satellite plots, those (3 per bedsite) previously unused in the construction of the model.

A Mann-Whitney U-test was then applied to each of the 4 variables to determine whether bedsite plots differed from the randomly selected satellite plots in that particular characteristic. An alpha error value of $P < 0.05$ was set for establishing a reliable relationship.

Table 1. Non-transformed means and (SD) for variables included in DFA.

Variable	Group Means			
	Bedsite n=122		Satellite n=109	
Dead & Down Height 0.02 Acre plot	8.9	(8.70)	8.7	(10.45)
Dead & Down Height 0.002 Acre plot	3.3	(4.98)	2.7	(4.04)
Rock Height 0.02 Acre plot	2.1	(2.05)	2.2	(1.88)
Rock Height 0.002 Acre plot	1.1	(1.38)	1.8	(1.46)
Dead & Down % 0.02 Acre plot	8.5	(10.60)	7.8	(9.61)
Dead & down % 0.002 Acre plot	4.1	(7.01)	5.3	(10.60)
% Rock Cover 0.02 Acre plot } % Rock Cover 0.002 Acre plot* }	2.7	(6.87)	20.4	(26.35)
Seedling Height	16.2	(8.36)	18.5	(9.41)
Seedlings/Acre	744.9	(4166.71)	130.8	(283.16)
Stand Density Index } Basal Area } Total DBH per acre } Total DBH per plot* }	95.9	(41.95)	39.7	(29.10)
Mean Canopy Depth	6.6	(5.71)	6.3	(6.36)
Mean Tree Height } Distance to lowest limb* }	13.1	(8.62)	10.1	(9.09)
Canopy Closure	78.8	(14.47)	32.6	(28.65)

[1] Bracketed variables were correlated with P > .75
* indicates variable used in analysis from bracketed set

Relationships Between Canopy Closure and Bedsite Characteristics

Log_{10} values for tree height, diameter, and derivatives of tree densities and diameters, were obtained from satellite plots. These data were regressed on canopy closure levels to examine the potential for predicting canopy closure with structural stage parameters. An attempt was made to improve these correlations by removing observations with sums of residuals greater than 3.0 and Mahalanobis distances greater than 2.8.

R03WILD Model Evaluation

The original formula for the RO3WILD calculations is given in Appendix 1. This model is based on a crosswalk table defining structural stages (stems/A within diameter classes) for each particular ecosystem (Appendix 2) from Schubert (1974). Buttery and Gillam (1984) defined the a, b, c classifications as canopy closure levels of less than 40%, 40%-70%, and greater than 70% respectively. Byford et al. (1984) modified these in a Wildlife Coefficients Technical Report (Appendix 3) and constructed modified elk matrices for each ecosystem (Appendix 4). The 1, 2, 5 entries in each matrix represent fractional acre values for either feeding or cover (i.e., 1 = 1/1, a full acre value or optimal condition; 5 = 1/5 the relative value of optimal). These are used as multipliers in the RO3WILD model (Appendix 1).

A more recent version of the model was issued in 1991, which assigns single-story and multi-storied characteristics to the structural stage classifications. It used modified a, b, c canopy closure classes of 10-39%, 40-60% and 61+%.

The most recent version, WESTWILD, used almost identical a,b,c canopy closure classes (0-39, 40-59, 60+%). Slightly different stem diameter classes were used to establish vegetation structural stages (VSS) than those shown in Appendix 2. At the time this report was being prepared, we did not have all of the information that would enable us to address the WESTWILD model directly. Therefore, data processing and subsequent discussion in this report addresses the RO3WILD model only. The 2 models appear to be similar, and users familiar with the intricacies of WESTWILD should be able to make appropriate modifications as needed.

Bedsite and satellite plots were classified by vegetation type according to the most common species on the plot, as determined by the greatest total basal area. Two vegetation types were recognized: ponderosa forest and P/J woodland. Additionally, the Gambel oak/locust (O/L) association within the ponderosa forest was considered a separate vegetation type. Various analyses for ponderosa forest (i.e., those dealing with silvicultural descriptives and habitat capability modeling) were conducted both with and without O/L representation. This dual approach was necessary because Gambel oak was not classified as a "commercial species" by the USFS and therefore, some USFS tree inventory data sets have not included it. Due to the relatively low frequency of O/L in P/J woodland, this dual approach was not used for that habitat type.

Within each vegetation type, ratios derived from bedsite frequency distributions (all ages and sexes of elk) and satellite plot canopy closure levels, were used to evaluate the fractional acre values used in the original RO3WILD model. Canopy closure data from the bedsites were divided into 3 segments according to naturally occurring breaks in the data set, which were assumed to reflect elk habitat selection patterns. An identical set of divisions was imposed on the canopy closure data from the satellite plots (see Table 6 for an example). For each of the 3 divisions, a ratio was created using the percent of the bedsites occurring within that division as the numerator and the percent of the satellite plots as the denominator. The numerator was then divided by the denominator to produce a single number (decimal fraction) for each division. This value from the division with the highest canopy closure then became the numerator in a fractional ratio created for each of the 3 divisions. The originally created decimal fraction value for each division became the denominator for that division. This always resulted in a 1/1 ratio (full acre value) for the division with the highest canopy closures, and something less than that for each of the other 2 divisions (see Table 7 for an example).

Silvicultural Descriptives

Descriptive tables were constructed to demonstrate the relationship between canopy closure levels and standard timber inventory parameters (stem density, diameter class, basal area, stand density index, and tree height), on mid-day bedsites. Data for those parameters were obtained from the 16.7 ft radius plots.

Basal area was calculated as follows.

$$BA = TPA \times (0.005454\ Dq^2) \qquad (1)$$

Stand density index was calculated as follows.

$$SDI = TPA\left(\frac{10}{Dq}\right)^{-1.605} \qquad (2)$$

where TPA represents the number of trees per acre. Dq represents the quadratic mean tree diameter, and is determined as

$$Dq = \frac{\sqrt{\sum_{i=1}^{n} D_i^2}}{n} \qquad (3)$$

where D_i represents the diameter (dbh) of the i'th tree on the plot.

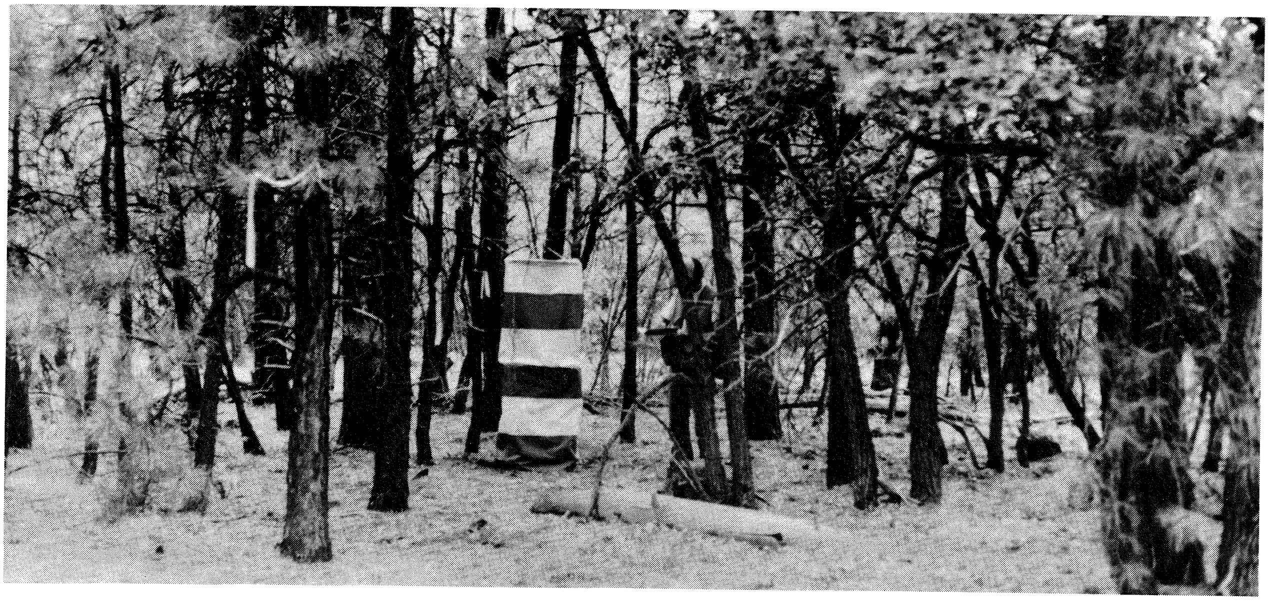


Figure 5.
Sight tube suspended over elk day-bed in pole size ponderosa with a Gambel oak inclusion.

Hiding Cover

Each bedsite was evaluated for hiding cover (90% or greater visual obstruction at 200 ft or less) by means of an alternately red and white colored sight target (tube) 2 ft wide and 6 ft tall (Leckenby 1984). The sight tube was suspended directly over the bedsite (Fig. 5). The distances in ft at which 90% level of obstruction occurred were then measured. These measurements were taken from each of the cardinal directions and averaged into a single value for the site.

A similar set of measurements, referred to as "Forest Wall Distance" (FWD) was taken at each bedsite. The observer stood on the bedsite while an assistant, wearing neutral-colored clothing, walked away in each of the cardinal directions until completely obscured. The assistant then paced the distance back to the plot center. Those distances were averaged for each bedsite. A regression analysis was conducted to determine whether sight tube distance was related to forest wall distance. The frequency of bedsites that qualified as hiding cover was determined.

Cover:Forage Ratio

Sixteen adult female elk were radio located in the ponderosa vegetation type at 2-week intervals during June 15-August 15 of 1988, 1989, and 1990. Least-sided convex seasonal home range polygons were constructed for each animal from these locations. Polygons were superimposed on a 1:24,000 scale map depicting canopy closure classes of 0-49%, 50-69%, and 70-100%. The base map was derived through aerial photo interpretation. Within these classes, contiguous areas containing 10 or more A were mapped. Cover to forage ratios based on canopy closure levels were calculated for each home range polygon, and for the entire study area.

Stand Size and Distance to Edge

Tree stands within which bedsites occurred were outlined on aerial photographs (scale 1:24,000). Stand size and distance of bedsite to the nearest stand edge were calculated manually from the photographs. A stand was considered to be any forest community uniform enough in composition and spatial arrangement to be distinguishable from adjacent communities (Hoover and Wills 1984). Level of canopy closure was the sole criterion used in the definition of stand boundaries. It is the primary determinant for day bed selection by elk, and due to the vegetative composition on the study area, was the most noticeable feature on the aerial photographs.

Topographic Characteristics

Distance to water, % slope, aspect, and slope features were measured at each bedsite. However, similar data were not collected at satellite plots. This design made those variables incompatible for DFA. Intersections of section lines and section centers on 7.5' U.S. Geological Survey topographic maps were used as sampling points to determine the availability of these attributes over the entire study area. The frequency of these sampling points occurring within use categories provided availability estimates for each topographic attribute. Likewise, numbers of bedsites within use categories provided frequency distributions of use. The Chi-square goodness of fit test was used to compare observed (used) versus expected (available) frequency distributions. A significant difference ($P<0.01$) indicated that the animal did not use each habitat category in proportion to its availability. If a particular distribution yielded a significant Chi-square value, Bonferroni confidence intervals were calculated for the difference between the frequency of used and available sites for each topographic category (Marcum and Loftsgaarden 1980).

Calving Habitat

Measurements at calf bedsites were identical to those taken at adult bedsites. Mann-Whitney U-tests were used to determine if calf bedsites differed from adult bedsites in respect to 9 variables that we believed to be most important.

Winter Cover

Winter cover selection by elk was evaluated under a separate study by a graduate student from Northern Arizona University (Abbott 1991). Data were collected from recently used, but vacant bedsites that could have been used by elk during either the day or night. In general, measurement techniques paralleled those used in the summer phase of this study described above. However, because of funding and time limitations, no data on habitat availability were collected from adjacent areas.

Radio-collared cow elk.

RESULTS

Habitat Selection

The full (13 variable) model (Table 1) for both study areas combined (ponderosa and P/J) correctly classified 95.1% of the bedsites and 83.5% of the satellite plots. The lower classification rate for satellite plots was expected. Nearly 20% of the satellite plots were classified as bedsites by the model because they had bedsite characteristics. The model recognized them as sites which elk could have used. Only by having available habitat completely filled with animals could this have been avoided. The overall classification power of the saturated model was 89.6%.

The reduced (4 variable) model (Table 2) classified 92.1% of the bedsites and 81.3% of the satellite plots correctly with an overall classification capability of 86.9%. When this model was applied to 414 satellite plots, that were not used to derive the model, 87.0% of the observations were correctly classified.

Both the full and reduced models significantly discriminated between bedsites and satellite sites (Table 3). Wilks' Lambda values were small (0.405), indicating a much greater between than within group variation. Chi-square values were significant ($P<0.01$).

Mean values of bedsite characteristics (Table 1) show that elk bedsites were characterized by higher canopy closure levels, higher total dbh, greater average distance to lowest limb, and lower percentage of rock cover than was available on the satellite plots. Areas with high levels of canopy closure were used in proportions greater than their availability (Figs. 6 and 7). Likewise, areas with high dbh levels were used in excess of availability (Figs. 8 and 9).

There was a significant difference ($P<0.05$) between bedsite and satellite plot characteristics for all DFA variables in the reduced model, except distance to lowest limb in ponderosa (Table 4). Areas having a distance to lowest limb of less than 6.5 ft were rarely used, if not avoided (Figs. 10 and 11). Strong selection for this characteristic was not necessary in ponderosa, where a substantial amount of "self-pruning" of lower branches occurred (Figs. 12 and 13). Selection was highly noticeable in P/J, where tree limbs frequently extend to within 1 or 2 ft of ground level (Fig. 14). Mean drc for the single largest tree on each small plot (centroid to 5.27 ft radius) across all plots in the P/J type was 14.02 in, (*SD* = 11.41). Mean diameter for the single largest tree on each large plot (centroid to 16.7 ft radius) across all plots in the P/J type was 23.43 in (*SD* = 10.63). Bedsite selection in P/J was therefore associated with the presence of larger trees (Figs. 15, 16 and 17).

In all vegetation types, areas with greater than 8% rock cover (Figs. 18 and 19) were rarely used.

Wind velocity was not included in the DFA. However, air movement greater than 2 mph was documented on 93% of the bedsites at the time the elk were located, and only 2% had no air movement.

Relationships Between Canopy Closure and Bole Characteristics

Regression analyses indicated that mean tree height, total diameter breast height, basal area, and stand density index values explain little of the variation in canopy closure (Table 5). An attempt to improve the relationships by removing outliers failed. This manipulation of the data caused the correlations to deteriorate for 6 of the variables and produced only small increases in coefficients of determination for the other 6.

McTague and Patton (1989) have suggested that, in ponderosa, SDI calculations might be better predictors of canopy closure than basal area. Regression analyses of data from our study failed to demonstrate any advantage in using 1 over the other for predicting canopy cover. The coefficients of determination produced were nearly identical (Table 5).

R03WILD Model Evaluation

Although we did not classify stands as single- or multi-storied, there was no indication during this study that elk prefer day-bedsites with 2 or more canopy layers in the overstory. This particular attribute is probably of little importance when modeling habitat capability for elk in Arizona's ponderosa and P/J forests. Conversely, establishing proper boundaries for the a, b, c canopy closure classes appears to be extremely important and is dealt with in the following sections.

Ponderosa Type. Naturally occurring breakpoints in the data indicated that 3 canopy

Table 2. Discriminant functions for variables included in DFA.

	Fisher's Linear Discriminant Functions (Classification Function Coefficients)	
Variable	Bedsite n=122	Satellite n=109
% Rock Cover 0.002 Acre plot	4.0	6.1
Total DBH per plot	29.8	25.5
Distance to lowest limb	51.3	56.8
Canopy Closure	-10.2	-17.4

Table 3. Statistics indicating the significance of the discrimination function analysis between bedsites and satellite plots.

Model	Eigenvalue	Wilks' Lambda	Chi-Square	DF	Sig.
Adult Female 13 Variable	1.51	0.40	205.18	13	<0.01
Adult Female 4 Variable	1.47	0.41	205.0	4	<0.01

Table 4. Mann-Whitney U-Tests on 4 DFA selected variables: adult female bedsites and 1 associated randomly selected satellite plot.

Variable	Z	*P*	N=No. Bedsites; No. Satellites
Canopy Closure			
All spp.	-11.79	<0.01	140;140
Ponderosa	-6.64	<0.01	68;69
PJ	-8.41	<0.01	56;43
O/L	-3.31	<0.01	16;9
Total dbh			
All spp.	-10.87	<0.01	140;136
Ponderosa	-6.98	<0.01	68;69
PJ	-6.37	<0.01	56;43
O/L	-3.40	<0.01	16;9
Dist. to lowest limb			
All spp.	-4.17	<0.01	140;136
Ponderosa	-1.71	0.087	68;69
PJ	-5.00	<0.01	56;43
O/L	-2.55	0.011	16;9
% Rock			
All spp.	-7.43	<0.01	140;138
Ponderosa	-4.39	<0.01	68;68
PJ	-5.08	<0.01	56;43
O/L	-2.64	0.008	16;9

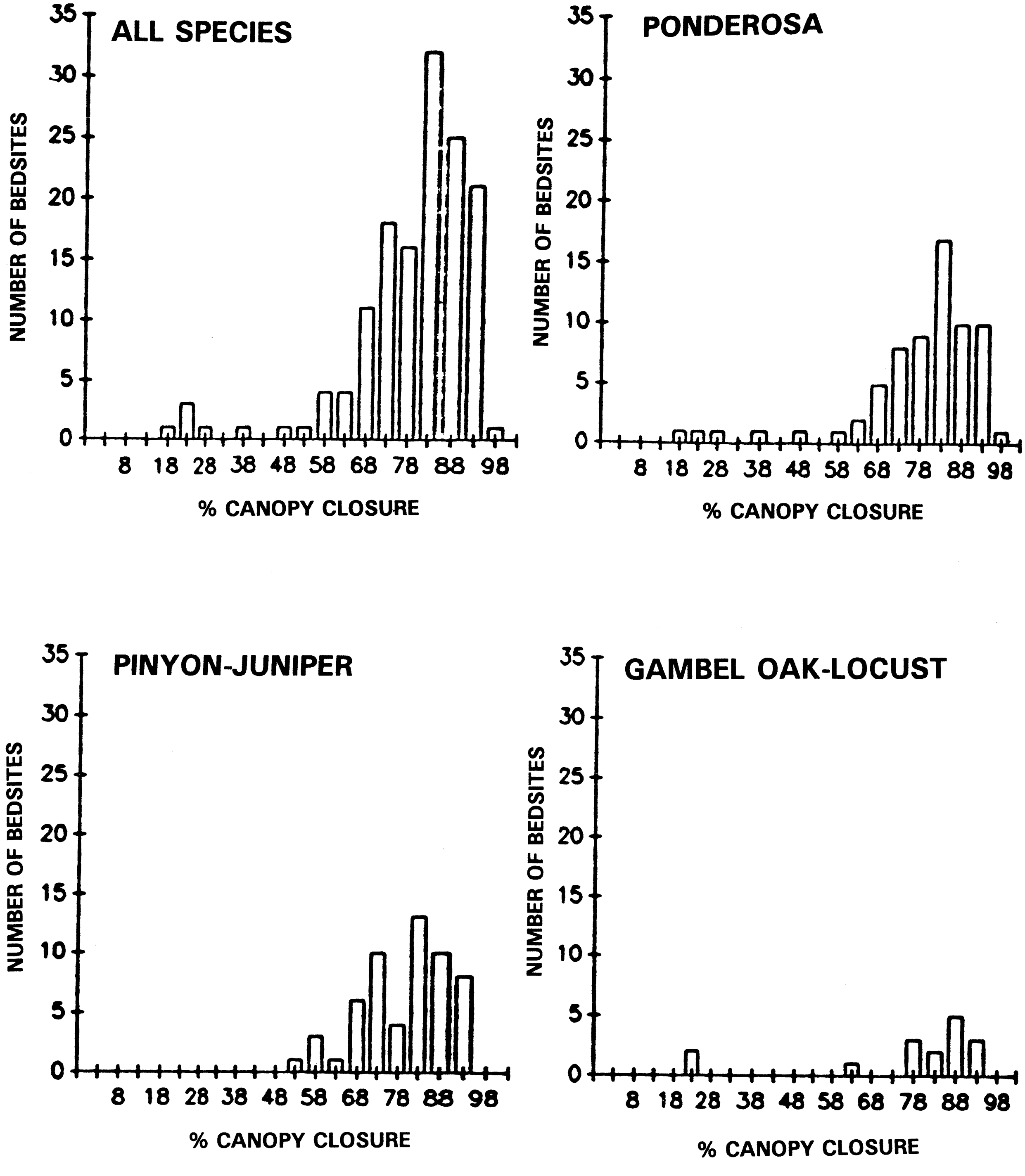


Figure 6.
Frequency distribution of bedsite plots within canopy closure classes.

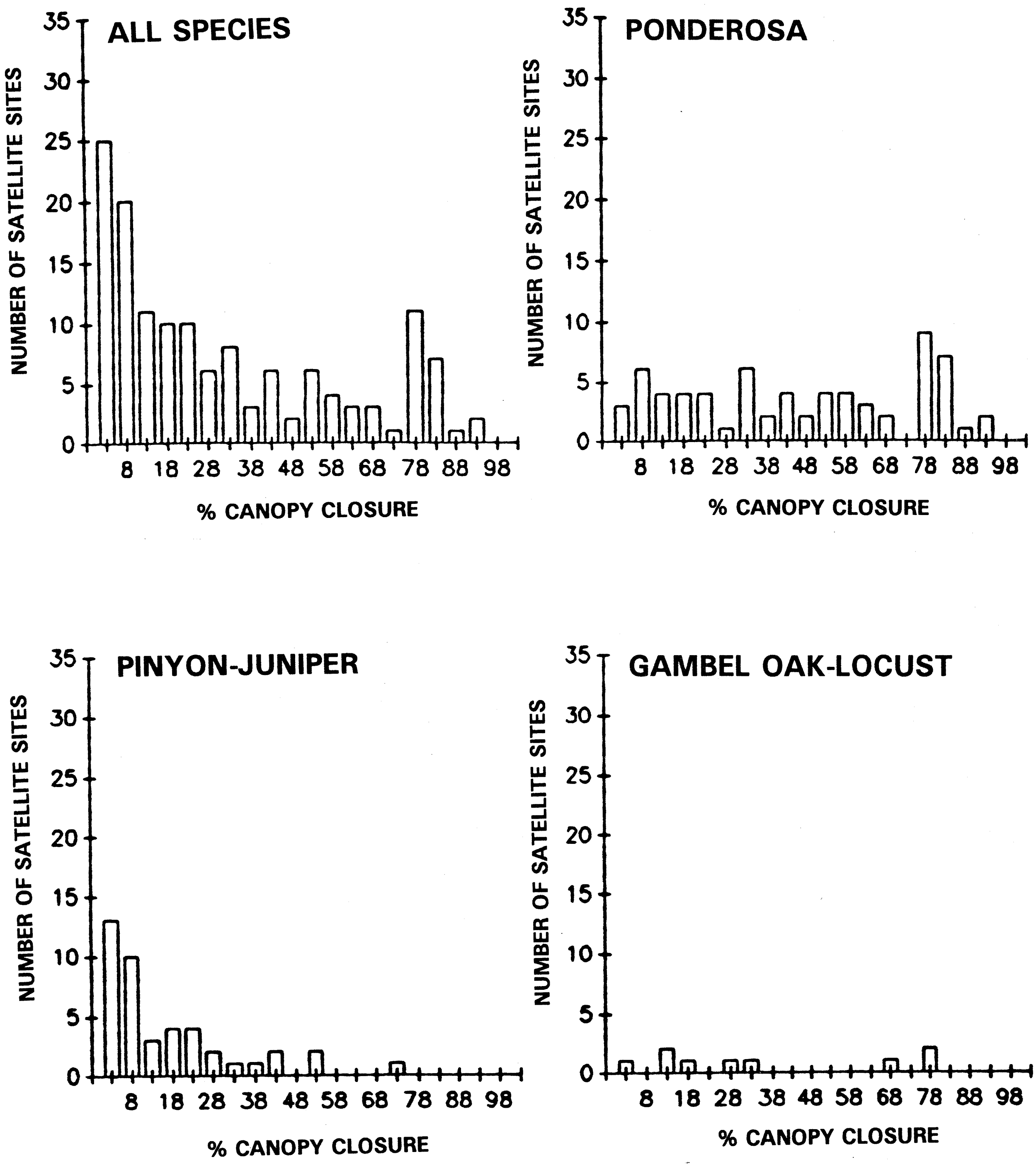


Figure 7.
Frequency distribution of satellite plots within canopy closure classes.

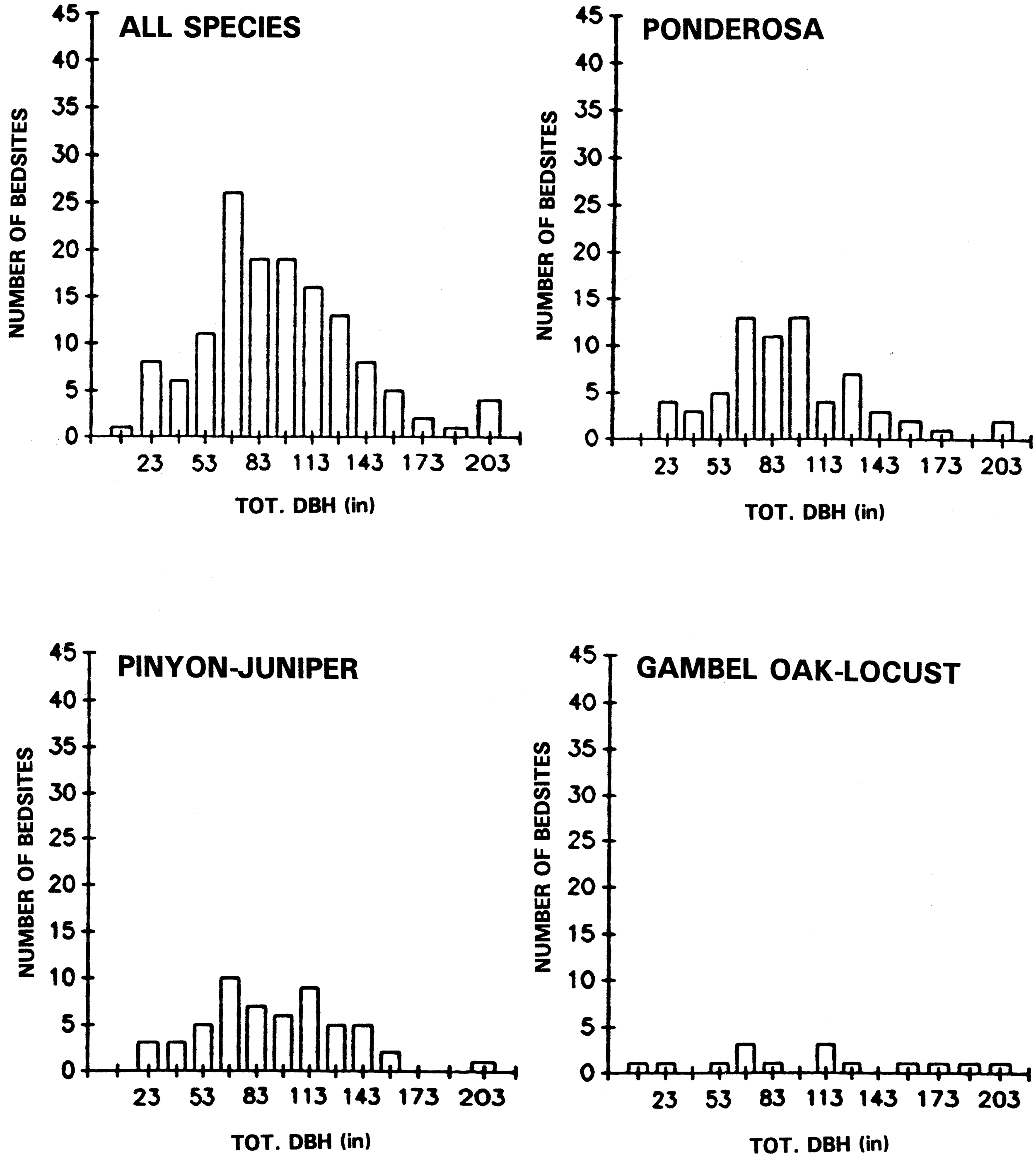


Figure 8.
Frequency distribution of bedsite plots within total dbh classes.

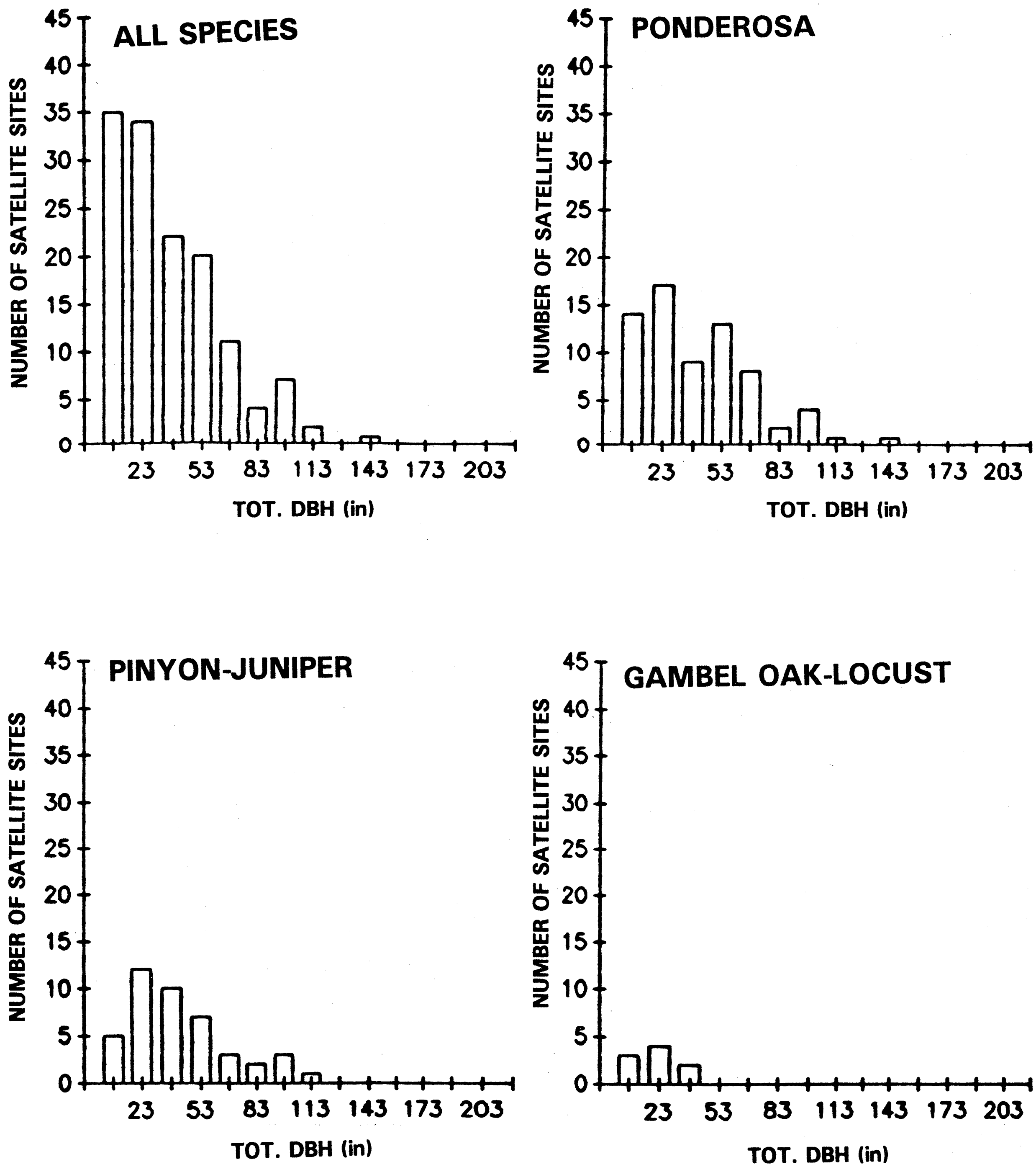


Figure 9.
Frequency distribution of satellite plots within total dbh classes

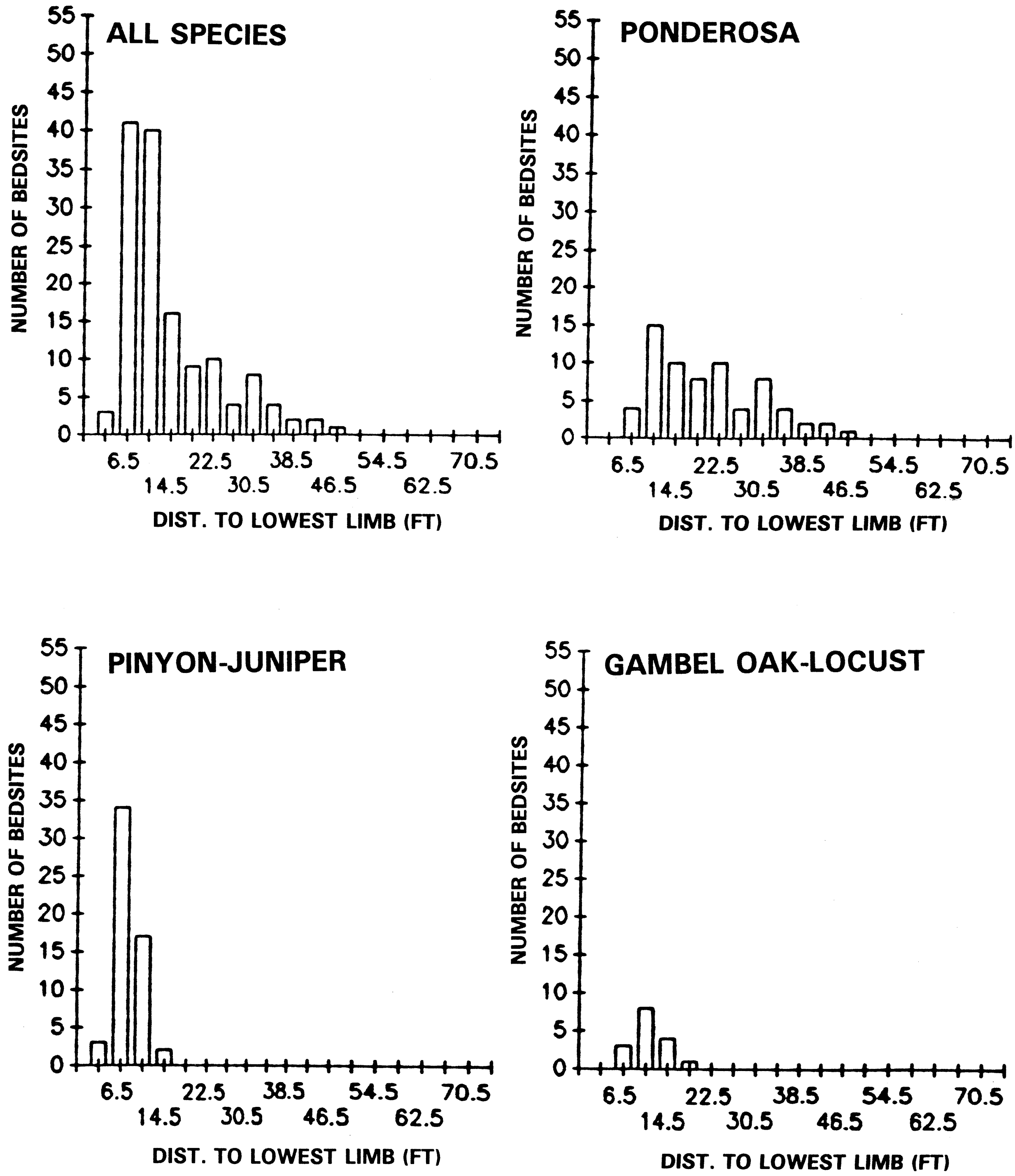


Figure 10.
Frequency distribution of bedsite plots within distance to lowest limb classes.

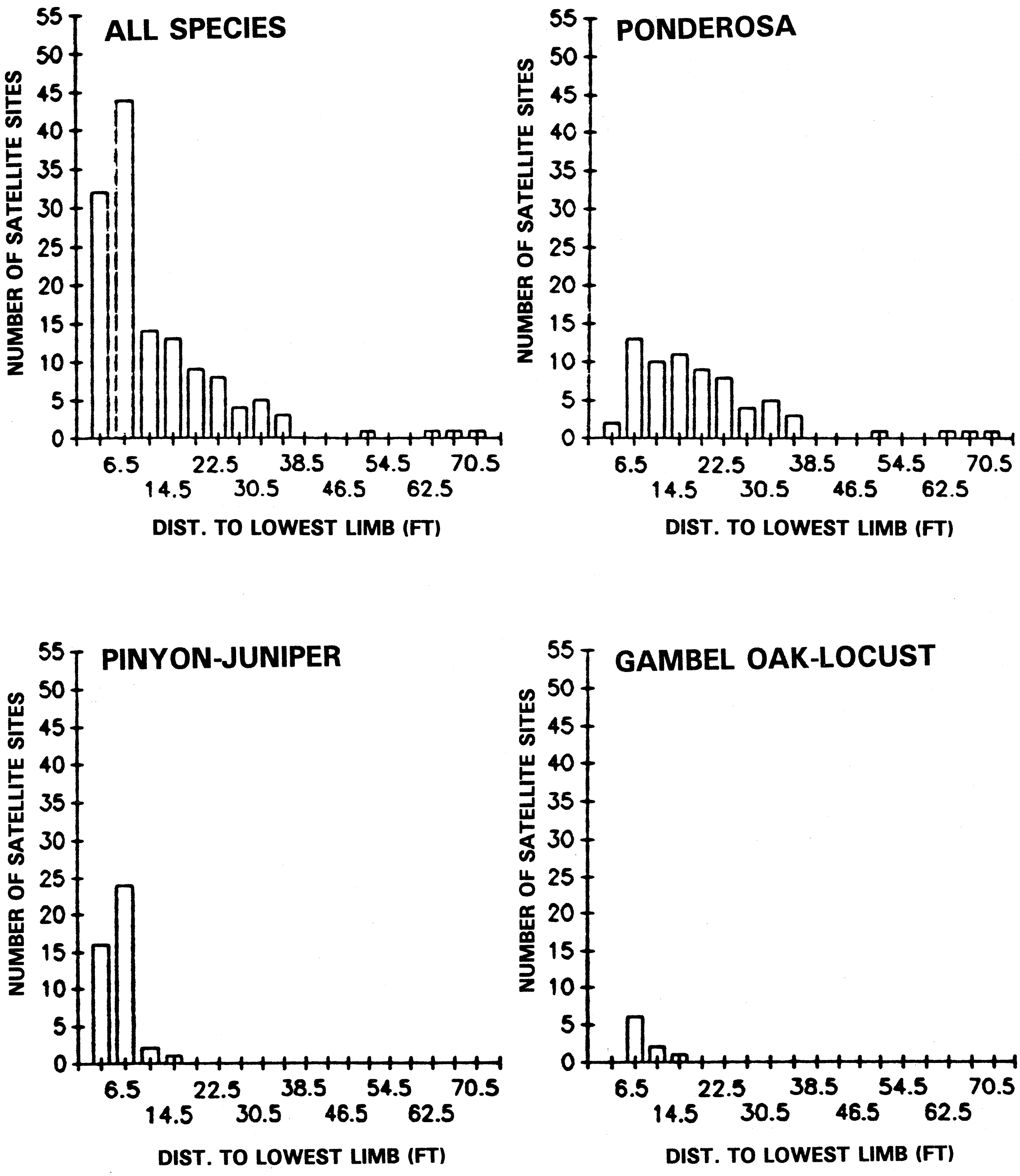


Figure 11.
Frequency distribution of satellite plots within distance to lowest limb classes.

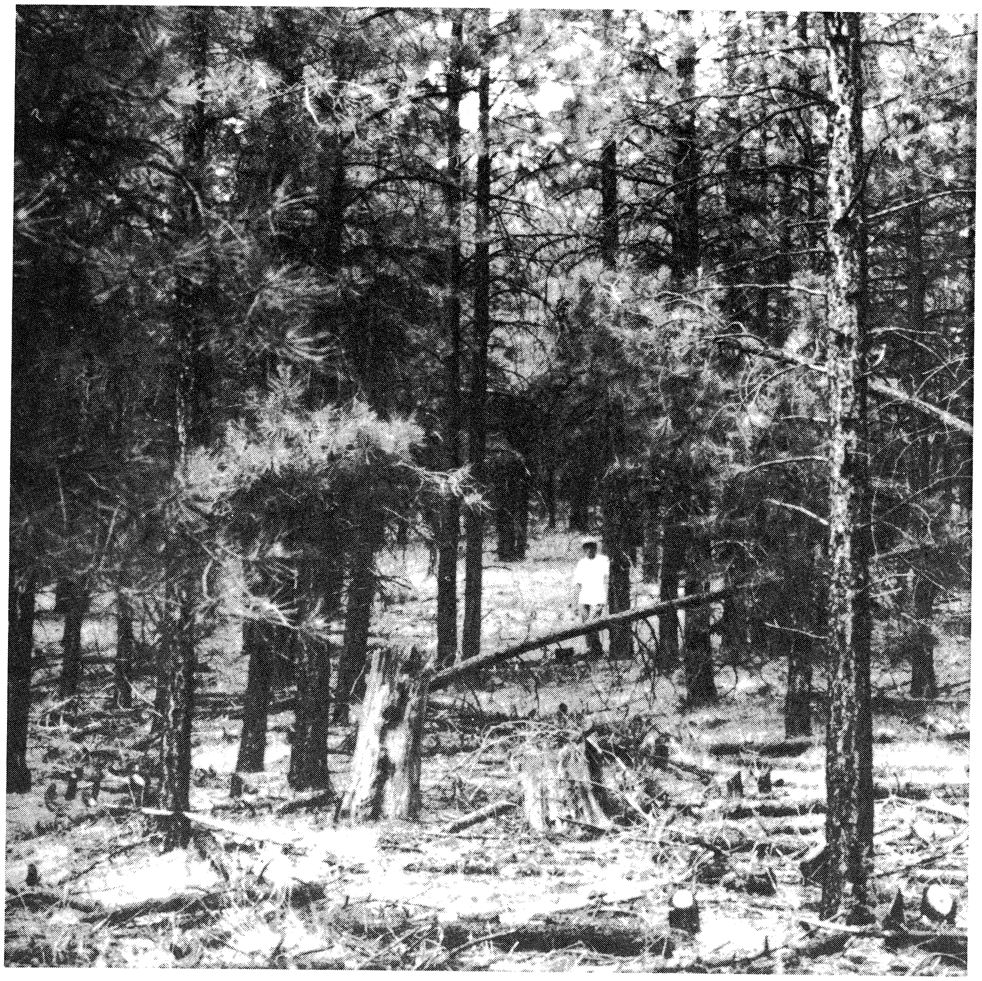


Figure 12.
Elk day-bed in pole-sized ponderosa.

Figure 13.
Elk day-bed in pole-sized ponderosa.

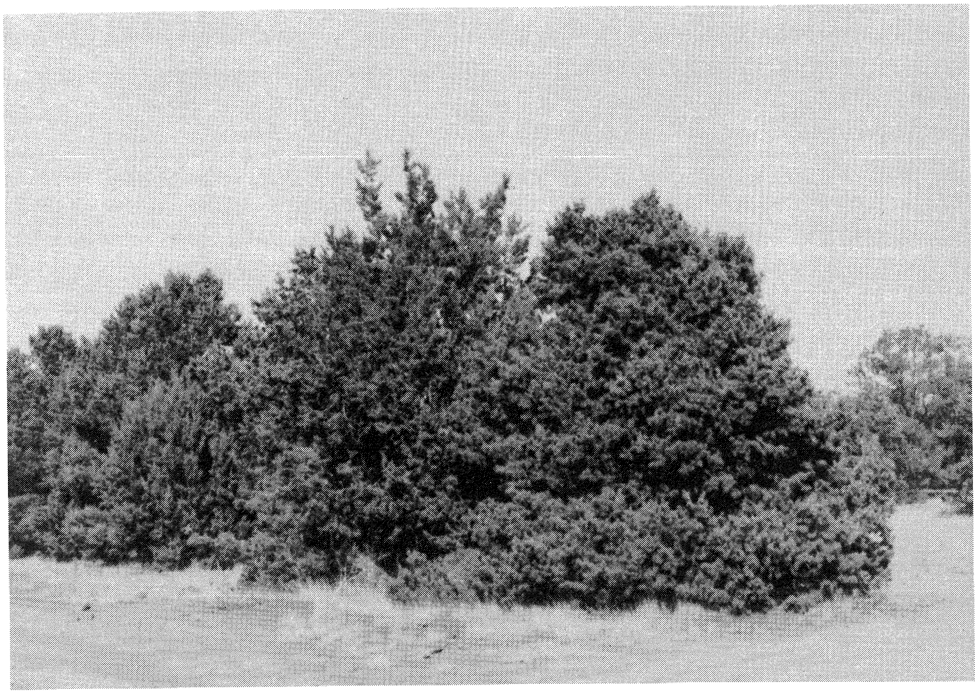


Figure 14.
Pinyon pines with lowest limbs near ground level.

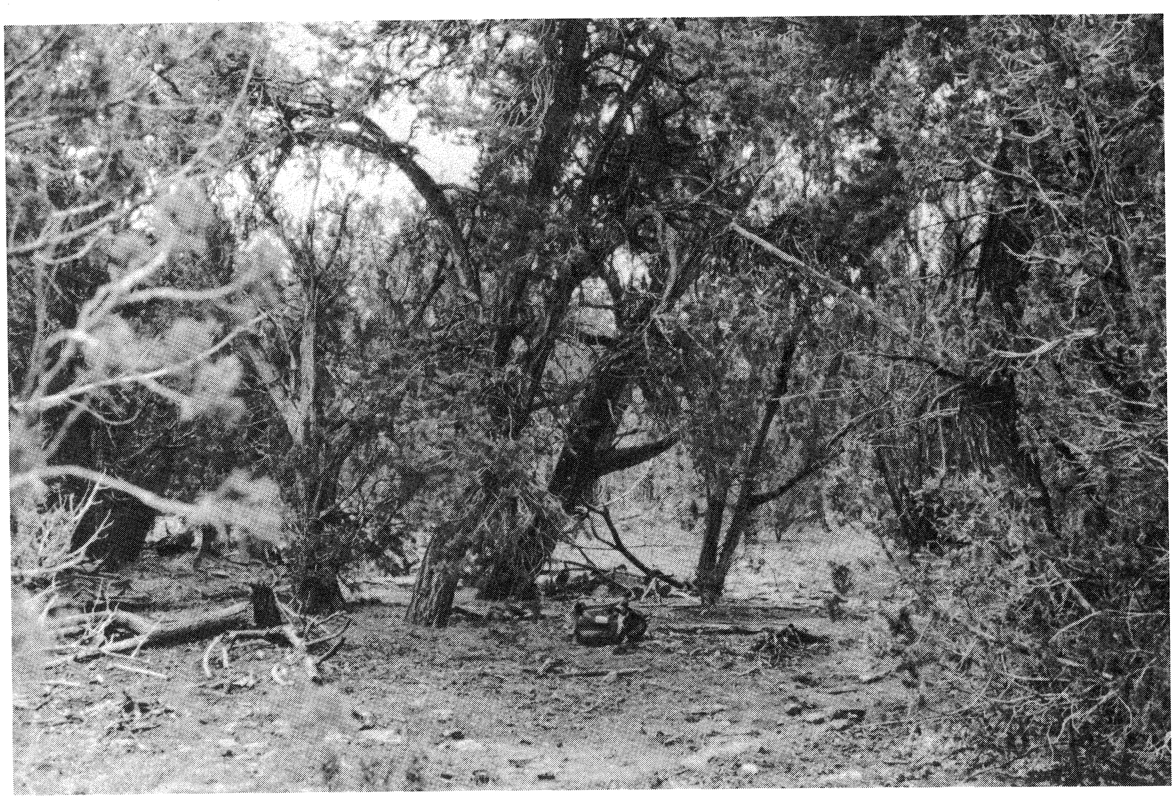


Figure 15.
Elk day-bed beneath mature pinyon pine.

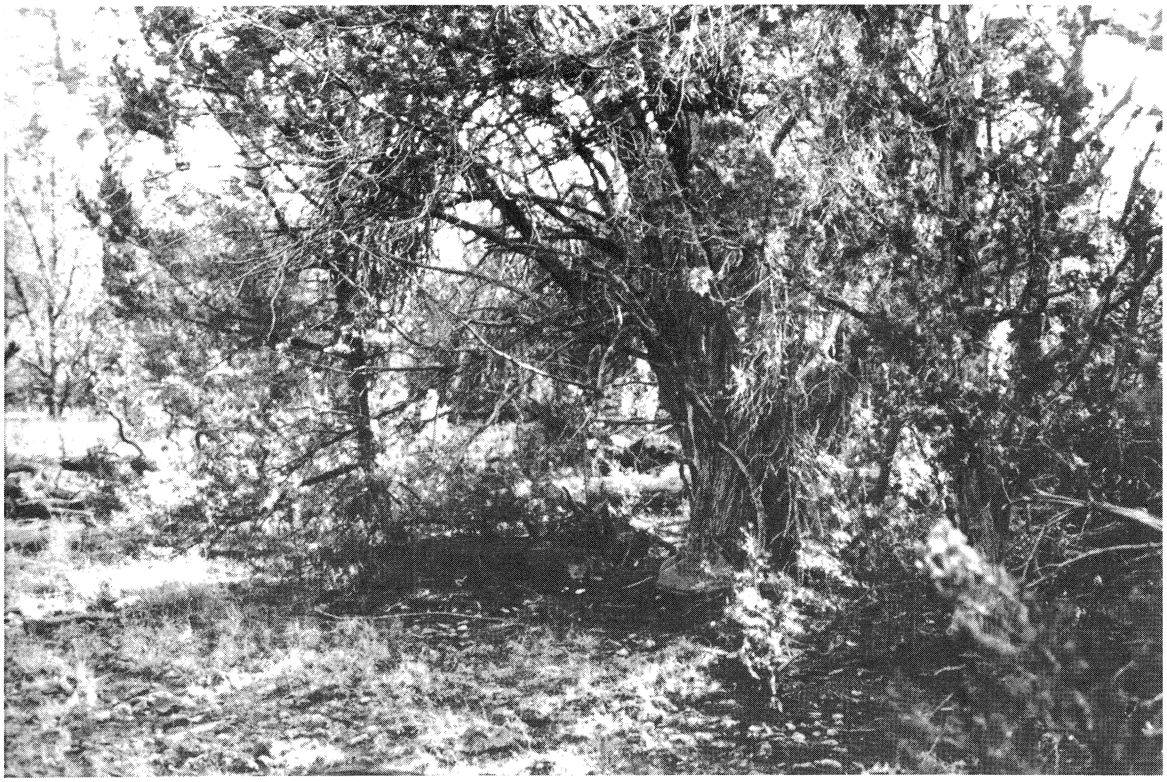


Figure 16.
Elk day-bed at base of mature Utah juniper.

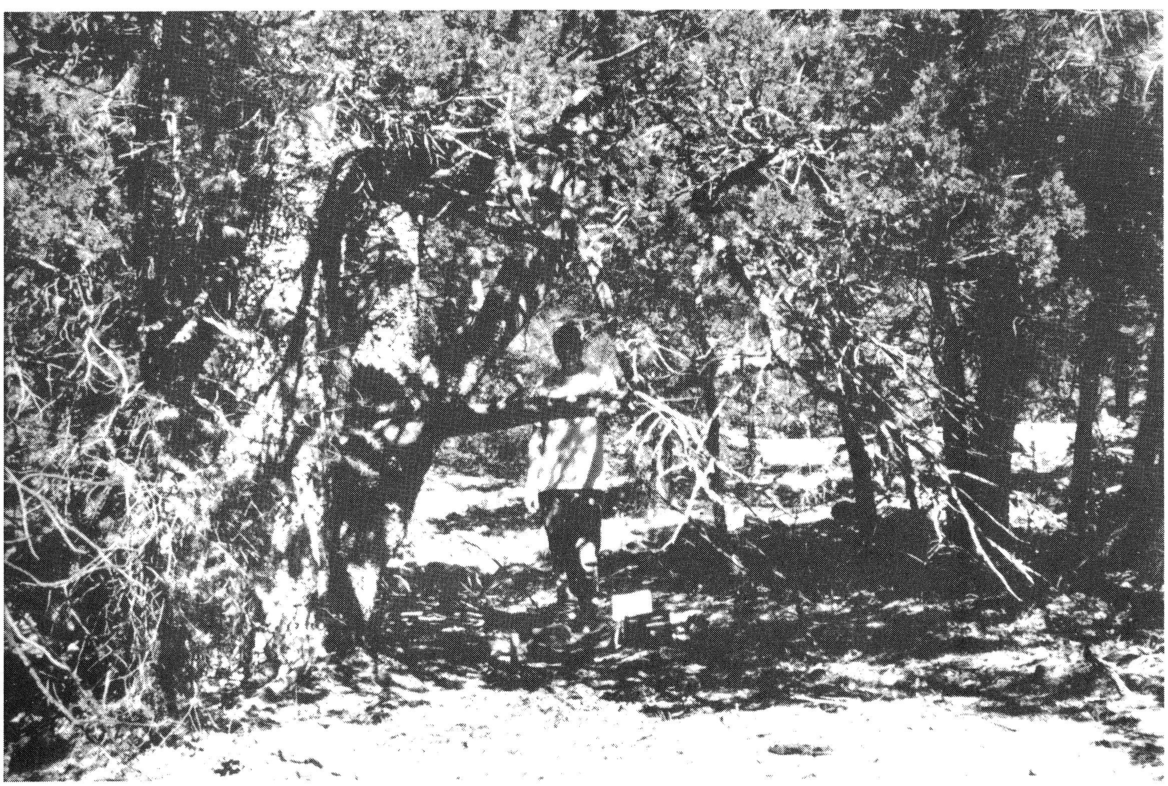


Figure 17.
Elk day-bed beneath mature alligator juniper.

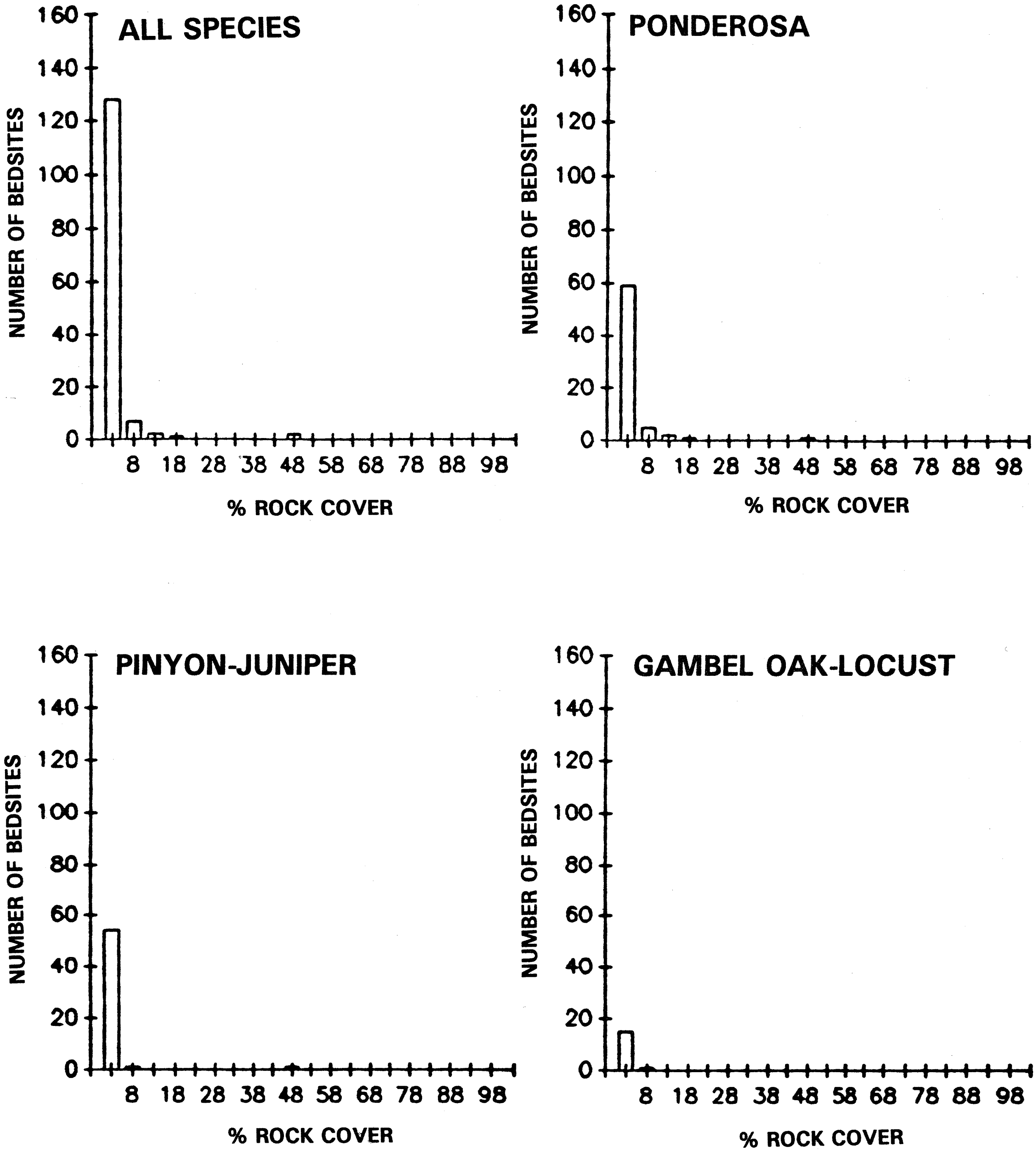


Figure 18.
Frequency distribution of bedsite plots within rock cover classes.

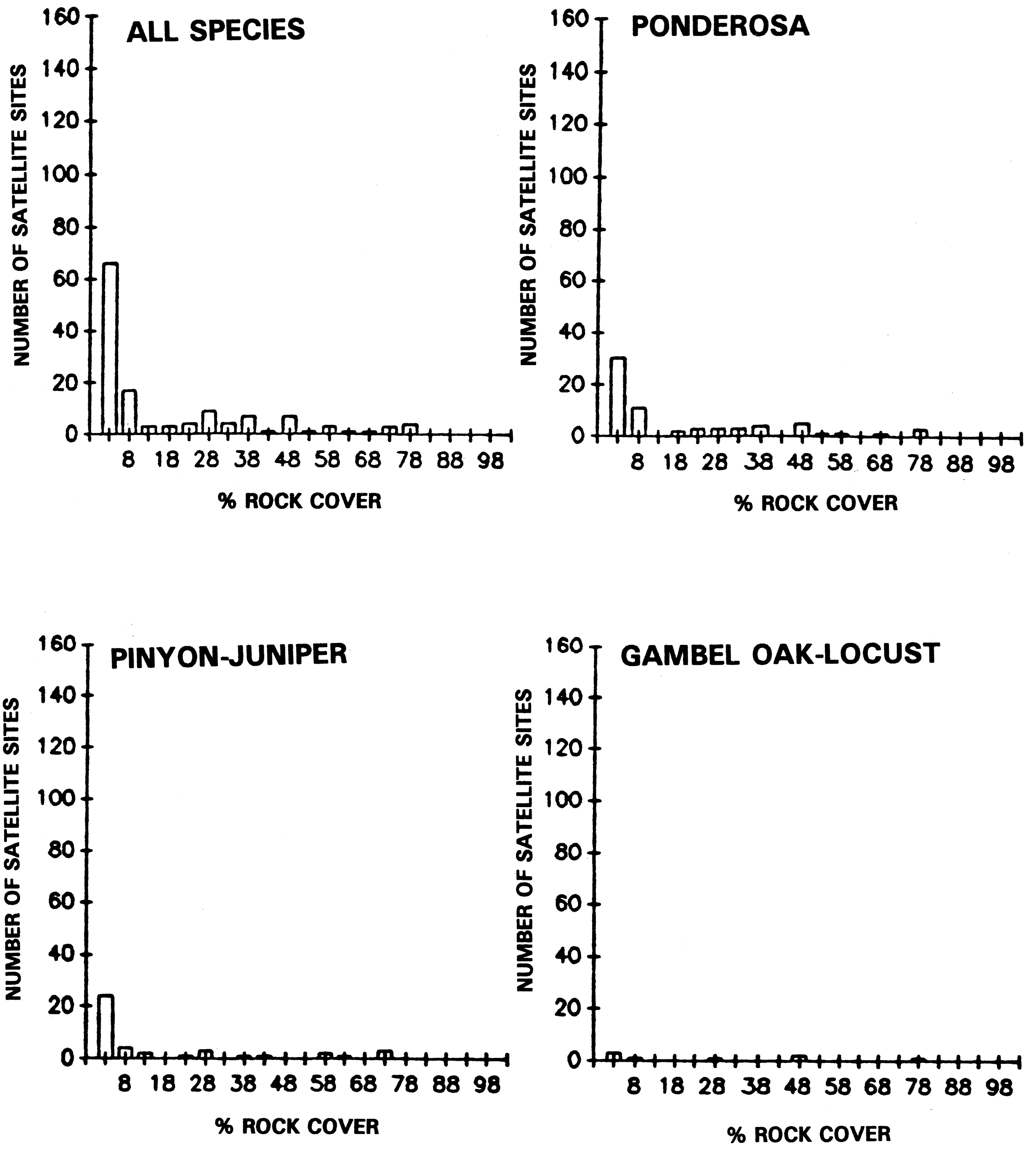


Figure 19.
Frequency distribution of satellite plots within rock cover classes.

Table 5. Coefficient of determination for canopy closure (by forest type) regressed on each of 4 measures of tree structure. This analysis considers satellite plots only. $P \leq 0.01$ in all cases.

		Ponderosa		P/J		Oak/Locust	
Variable		r^2	(n)	r^2	(n)	r^2	(n)
Mean Tree Height	1)	0.26	(368)	0.15	(192)	0.38	(52)
	2)	0.18	(335)	0.08	(177)	0.35	(48)
Total Diameter at Breast Height	1)	0.40	(368)	0.10	(192)	0.39	(52)
	2)	0.29	(344)	0.15	(182)	0.42	(48)
Basal Area	1)	0.43	(368)	0.10	(192)	0.44	(52)
	2)	0.34	(341)	0.17	(182)	0.59	(50)
Stand Density Index	1)	0.43	(368)	0.09	(192)	0.43	(52)
	2)	0.33	(343)	0.17	(179)	0.51	(48)

1) No outliers removed
2) Outliers from first regression removed. Sums of residuals $\geq$ 3; Mahalanobis distances $\geq$ 2.8

Table 6. Frequency of occurrence of bedsites and satellite plots within canopy closure classes: ponderosa ecosystem.

% Canopy closure	Number bedsites		Number satellite plots	
0-5	0		4	
6-10	0		6	
11-15	1		5	
16-20	1		6	
21-25	1		4	
26-30	1		1	
31-35	0	10%	8	59%
36-40	1		3	
41-45	1		4	
46-50	1		2	
51-55	1		5	
56-60	3		5	
61-65	3	13%	3	12%
66-70	5		2	
71-75	8		1	
76-80	13		10	
81-85	18		8	
86-90	12	77%	2	29%
91-95	13		2	
96-100	1		0	
TOTAL	n=84	100%	n=81	100%

closure classes were used by elk to varying degrees. These divisions are believed to reflect elk preferences within the realm of what was available (Table 6). A greater proportion of elk bedsites (77%) than satellite plots (29%) occurred within the high canopy closure class. This difference indicated the elk's preference for high (greater than 70%) canopy closure. In contrast, there were far fewer bedsites (10%) observed in open canopies than were available among the satellite plots (59%).

Relative degree of habitat selection, with the highest use to availability quotient standardized to 1, is analogous to the relative acre value index used by the RO3WILD model. These values, indicate that open canopy closure areas are about 1/16 as important as high canopy closure areas for summer use (Table 7). This value 16 (15.7) is a corrected value for the "a" category in the elk matrix when naturally occurring breaks in canopy closure are used to define the a,b, and c categories.

Pinyon/Juniper Type. In the P/J type as well, areas with high canopy closures were used as bedsites in excess of availability (Table 8). Natural breaks in the bedsite data set were found to be only slightly different from those that occurred in the ponderosa. Relative acre values of canopy closure for the P/J type as bedding habitat decline more rapidly than ponderosa with lower canopy closure (Table 9).

Gambel Oak/Locust Association. This association was not a recognized "ecosystem" for which an RO3WILD matrix had been developed. It exists as an inclusion within the ponderosa type and to a lesser degree within the P/J type. Nevertheless, 17 of the bedsites encountered in this study had basal areas dominated by the oak/locust species combination. Within this association, higher canopy closure levels were again selected (Table 10) and this selection was reflected in the relative acre values (Table 11). When the oak/locust data were incorporated into the ponderosa data and the resultant relative acre values rounded off to whole numbers, only the 0-55% canopy closure class for ponderosa was changed slightly, from 16 to 17 (Tables 12 and 13).

Silvicultural Descriptives

The national forests within Arizona do not rely solely on habitat capability modeling when timber sales are planned. It is therefore necessary to provide managers with a comprehensive set of descriptives that can be used outside of any modeling system. The general characteristics of bedsite overstory, by vegetation type, are given in Tables 14 through 19. Two data sets are presented for each type. The first data set is for moderate to high quality habitat combined (canopy closure > 55%). The second data set is for high quality habitat only (canopy closure > 70%). Little difference exists between the 2 sets within any vegetation type. Frequency distributions of SDI and basal area calculations from bedsites used in the DFA appear in Appendices 11-14.

Deciduous tree species were found to be important elk day bed cover in Arizona (Tables 20, 21). The spherical densiometer, used to take canopy closure measurements, does not allow an observer to accurately measure differences in species composition. Basal area by species (Tables 20, 21) is perhaps the next best indicator of species composition in the canopy.

Hiding Cover

Sight tube readings indicated that 82% of the bedsites dominated by ponderosa (n=86) and 100% of the P/J sites (n=61) qualified as hiding cover. This difference was expected because of the average differences in lower limb height between the species.

Forest wall distance was found to be significantly related to sight tube distance ($r^2 = 0.64$; $P < 0.01$) for ponderosa (Fig. 20). While the relationship in that vegetation type is strong, relatively low coefficients of determination were obtained in P/J and Gambel oak-locust.

Cover:Forage Ratios Within Summer Home Ranges

Habitat available to elk on the ponderosa pine portion of the study area appeared to possess an adequate amount of forest that possessed day-bed canopy closure requirements. Optimum day-bed cover for ponderosa was defined in this study as having canopy closure levels exceeding 70%, and medium quality as having 56% or greater (Table 6). This definition is very close to the 50-69% and 70-100% canopy closure stratification originally selected for the Lake Mary Study Area mapping. Only 11% of the ponderosa pine (Lake Mary) study area was classified as optimum. However,

Table 7. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: Ponderosa Ecosystem.

Canopy closure class	% canopy closure	% bedsite plots/% satellite plots			Relative acre value		
a	0-55	10/59	=	0.169	2.655/0.169	=	15.7
b	56-70	13/12	=	1.083	2.655/1.083	=	2.5
c	71-100	77/29	=	2.655	2.655/2.655	=	1.0

Table 8. Frequency of occurrence of bedsites and satellite plots within canopy closure classes: Pinyon/Juniper habitat type

% Canopy closure	Number bedsites		Number satellite plots	
0-5	0		13	
6-10	1		13	
11-15	0		3	
16-20	0		5	
21-25	0		4	
26-30	0	2%	2	92%
31-35	0		1	
36-40	0		1	
41-45	0		3	
46-50	0		0	
51-55	1		2	
56-60	4	10%	0	4%
61-65	1		0	
66-70	7		0	
71-75	11		1	
76-80	4		1	
81-85	14	88%	0	4%
86-90	10		0	
91-95	10		0	
96-100	0		0	
TOTAL	n=63	100%	n=49	100%

Table 9. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: Pinyon/Juniper habitat type.

Canopy closure class	% Canopy closure	% Bedsite plots/% Satellite plots			Relative acre value		
a	0-50	2/92	=	0.022	22.0/0.022	=	1000.0
b	51-65	10/4	=	2.500	22.0/2.500	=	8.8
c	66-100	88/4	=	22.000	22.0/22.000	=	1.0

Table 10. Frequency of occurrence of bedsites and satellite plots within canopy closure classes: Gambel oak/locust Association.

% Canopy closure	Number bedsites		Number satellite plots	
0-5	0		1	
6-10	0		1	
11-15	0		2	
16-20	0		1	
21-25	2		0	
26-30	0	12%	1	70%
31-35	0		1	
36-40	0		0	
41-45	0		0	
46-50	0		0	
51-55	0		0	
56-60	0		0	
61-65	1	6%	0	10%
66-70	0		1	
71-75	0		0	
76-80	3		2	
81-85	2	82%	0	20%
86-90	5		0	
91-95	4		0	
96-100	0		0	
TOTAL	n=17	100%	n=10	100%

Table 11. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: Gambel oak/locust association.

Canopy closure class	% Canopy closure	% Bedsite plots/% Satellite plots			Relative acre value		
a	0-55	12/70	=	0.171	4.1/0.171	=	23.9
b	56-70	6/10	=	0.600	4.1/0.60	=	6.8
c	71-100	82/20	=	4.100	4.1/4.1	=	1.0

Table 12. Frequency of occurrence of bedsites and satellite plots within canopy closure classes: ponderosa ecosystem with a Gambel oak inclusion.

% Canopy closure	Number bedsites		Number satellite plots	
0-5	0		5	
6-10	0		7	
11-15	1		7	
16-20	1		7	
21-25	3		4	
26-30	1		2	
31-35	0	10%	9	60%
36-40	1		3	
41-45	1		4	
46-50	1		2	
51-55	1		5	
56-60	3		5	
61-65	4	12%	3	12%
66-70	5		3	
71-75	8		1	
76-80	16		12	
81-85	20		8	
86-90	17	78%	2	28%
91-95	17		2	
96-100	1		0	
TOTAL	n=101	100%	n=91	100%

Table 13. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: ponderosa ecosystem with a Gambel oak inclusion.

Canopy closure class	% Canopy closure	% Bedsite plots/% Satellite plots			Relative acre value		
a	0-55	10/60	=	0.167	2.786/0.167	=	16.7
b	56-70	12/12	=	1.000	2.786/1.000	=	2.78
c	71-100	78/28	=	2.786	2.786/2.786	=	1.0

Table 14. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 55% (moderate to high quality habitat) occurring in ponderosa pine.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy closure		No. bedsites
1.0-4.9	1597	(738)	197	(63)	479	(141)	5900	(2131)	12	(3)	17	(3)	82	(10)	30
5.0-6.9	718	(237)	206	(65)	426	(127)	4377	(1340)	23	(7)	29	(7)	81	(9)	20
7.0-8.9	489	(204)	197	(88)	383	(166)	3767	(1540)	25	(9)	32	(9)	80	(10)	28
9.0-10.9	442	(312)	274	(248)	488	(422)	4453	(3461)	27	(9)	33	(9)	82	(13)	6
11.0-12.9	270	(97)	241	(77)	400	(129)	3109	(993)	28	(12)	42	(8)	85	(6)	5
13.0-16.9	313	(170)	580	(397)	828	(530)	4338	(2121)	25	(14)	45	(14)	78	(15)	4
17.0-19.9	100	(0)	159	(0)	236	(0)	1707	(0)	32	(0)	40	(0)	73	(0)	1
20.0-27.9	---		---		---		---		--		---		---		---
>28.0	50	(0)	226	(0)	272	(0)	1440	(0)	47	(0)	78	(0)	73	(0)	1
Entire Population	856	(687)	222	(138)	446	(213)	4555	(2083)	21	(10)	28	(12)	81	(10)	95

Table 15. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 70% (high quality habitat) and occurring in ponderosa pine.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy closure		No. bedsites
1.0-4.9	1637	(772)	203	(62)	493	(139)	6022	(2191)	12	(3)	17	(4)	85	(7)	26
5.0-6.9	738	(228)	199	(51)	418	(105)	4499	(1288)	24	(6)	31	(6)	84	(6)	17
7.0-8.9	486	(218)	192	(90)	375	(173)	3748	(1641)	23	(9)	31	(9)	83	(8)	22
9.0-10.9	450	(348)	291	(273)	515	(466)	4623	(3842)	29	(10)	34	(9)	87	(6)	5
11.0-12.9	270	(97)	241	(77)	400	(129)	3109	(993)	28	(12)	42	(8)	85	(6)	5
13.0-16.9	267	(176)	401	(209)	600	(329)	3817	(2263)	25	(17)	51	(8)	85	(7)	3
17.0-19.9	100	(0)	159	(0)	236	(0)	1707	(0)	31	(0)	39	(0)	73	(0)	1
20.0-27.9	---		--		---		---		--		--		--		0
>28.0	50	(0)	226	(0)	272	(0)	1440	(0)	46	(0)	78	(0)	73	(0)	1
Entire Population	879	(722)	214	(105)	438	(188)	4610	(2182)	21	(10)	29	(12)	84	(7)	80

Table 16. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 50% (moderate to high quality habitat) and occurring in Pinyon/Juniper.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy closure		No. bedsites
1.0-4.9	1152	(426)	290	(181)	611	(331)	4694	(2036)	7	(2)	11	(2)	80	(13)	25
5.0-6.9	762	(296)	316	(158)	604	(268)	4472	(1660)	7	(2)	12	(2)	77	(10)	20
7.0-8.9	635	(175)	376	(134)	674	(219)	5075	(1322)	8	(3)	14	(3)	79	(10)	13
9.0-10.9	625	(347)	665	(496)	1045	(675)	6125	(3229)	8	(3)	16	(5)	82	(10)	6
11.0-12.9	--		--		--		--		--		--		--		0
13.0-16.9	225	(35)	469	(143)	657	(181)	3178	(95)	9	(7)	23	(15)	79	(6)	2
17.0-19.9	--		--		--		--		--		--		--		0
20.0-27.9	--		--		--		--		--		--		--		0
>28.0	--		--		--		--		--		--		--		0
Entire Population	856	(413)	354	(231)	662	(348)	4786	(1938)	7	(2)	13	(4)	79	(11)	66

Table 17. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 65% (high quality habitat) and occurring in Pinyon/Juniper.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy closure		No. bedsites
1.0-4.9	1182	(446)	306	(185)	642	(337)	4947	(2040)	7	(1)	11	(2)	84	(10)	22
5.0-6.9	759	(268)	334	(163)	633	(275)	4453	(1532)	7	(1)	12	(2)	80	(8)	17
7.0-8.9	654	(167)	397	(115)	710	(186)	5266	(1178)	9	(2)	14	(2)	81	(7)	12
9.0-10.9	625	(347)	665	(496)	1045	(675)	6125	(3229)	8	(3)	17	(5)	82	(10)	6
11.0-12.9	--		--		--		--		--		--		--		0
13.0-16.9	225	(35)	468	(143)	657	(181)	3178	(95)	9	(7)	22	(15)	79	(6)	2
17.0-19.9	--		--		--		--		--		--		--		0
20.0-27.9	--		--		--		--		--		--		--		0
>28.0	--		--		--		--		--		--		--		0
Entire Population	864	(422)	375	(235)	695	(351)	4929	(1913)	8	(2)	13	(4)	81	(9)	59

Table 18. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 55% (moderate to high quality habitat) and occurring in Gambel oak/Locust.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy closure		No. bedsites
1.0-4.9	1700	(864)	189	(95)	472	(235)	5913	(2561)	10	(3)	17	(6)	86	(9)	16
5.0-6.9	1583	(644)	327	(96)	727	(226)	8400	(2808)	14	(3)	21	(3)	89	(6)	3
7.0-8.9	375	(106)	176	(6)	332	(28)	2958	(1107)	17	(10)	27	(1)	69	(1)	2
9.0-10.9	--		--		--		--		--		--		--		0
11.0-12.9	--		--		--		--		--		--		--		0
13.0-16.9	--		--		--		--		--		--		--		0
17.0-19.9	100	(0)	214	(0)	298	(0)	1745	(0)	18	(0)	32	(0)	96	(0)	1
20.0-27.9	--		--		--		--		--		--		--		0
>28.0	--		--		--		--		--		--		--		0
Entire Population	1491	(905)	207	(99)	486	(238)	5794	(2832)	12	(4)	19	(7)	85	(9)	22

Table 19. Mean values and (*SD*) of measures taken at mid-day bedsites with canopy closure > 70% (high quality habitat) and occurring in Gambel oak/Locust.

Diameter class (in)	Stems per acre		Basal area		SDI		Total DBH/acre		Distance to lowest limb		Height		% Canopy Closure		No. bedsites
1.0-4.9	1723	(889)	191	(98)	479	(241)	5943	(2648)	11	(3)	17	(6)	88	(6)	15
5.0-6.9	1583	(644)	327	(96)	727	(226)	8400	(2808)	14	(3)	21	(3)	89	(6)	3
7.0-8.9	--		--		--		--		--		--		--		0
9.0-10.9	--		--		--		--		--		--		--		0
11.0-12.9	--		--		--		--		--		--		--		0
13.0-16.9	--		--		--		--		--		--		--		0
17.0-19.9	100	(0)	214	(0)	298	(0)	1745	(0)	17	(0)	32	(0)	96	(0)	1
20.0-27.9	--		--		--		--		--		--		--		0
>28.0	--		--		--		--		--		--		--		0
Entire Population	1616	(894)	214	(105)	509	(249)	6110	(2878)	12	(4)	18	(6)	88	(6)	19

Table 20. Mean basal area and (*SD*) of 95 adult female bedsite plots within the Lake Mary study area. Results are stratified by species and diameter classes.

	Diameter Classes (in.)							
Species	1.0 - 4.9		5.0 - 8.9		9.0 - 12.9		13.0 >	
Pinus ponderosa	133	(76)	160	(72)	173	(98)	392	(358)
Juniperus deppeana	--		53	(0)	--		1398	(0)
Abies concolor	--		--		23	(0)	--	
*Robinia neomexicana**	7	(10)	--		--		--	
*Quercus gambelii**	69	(57)	109	(84)	54	(30)	137	(56)
TOTAL	209		322		250		529	
% Deciduous species*	36		34		22		26	

Table 21. Mean basal area and (*SD*) of 57 adult female bedsite plots within the Blue Ridge study area. Results are stratified by species and diameter classes.

	Diameter Classes (in.)							
Species	1.0 - 4.9		5.0 - 8.9		9.0 - 12.9		13.0 >	
Pinus ponderosa	41	(55)	84	(61)	241	(0)	123	(41)
Juniperus osteosperma	29	(50)	111	(112)	341	(16.4)	279	(151)
Juniperus monosperma	31	(0)	122	(0)	229	(0)	--	
Juniperus scopulorum	5	(0)	16	(0)	--		--	
Juniperus deppeana	46	(67)	149	(170)	401	(213)	295	(184)
Pinus edulis	20	(20)	84	(65)	135	(0)	--	
*Quercus gambelii**	24	(32)	83	(57)	--		--	
Cowania mexicana	4	(4)	13	(0)	--		--	
Cerocarpus montanus	tr	(0)	--		--		--	
TOTAL	200		662		1347		697	
% Deciduous species*	12		13		0		0	

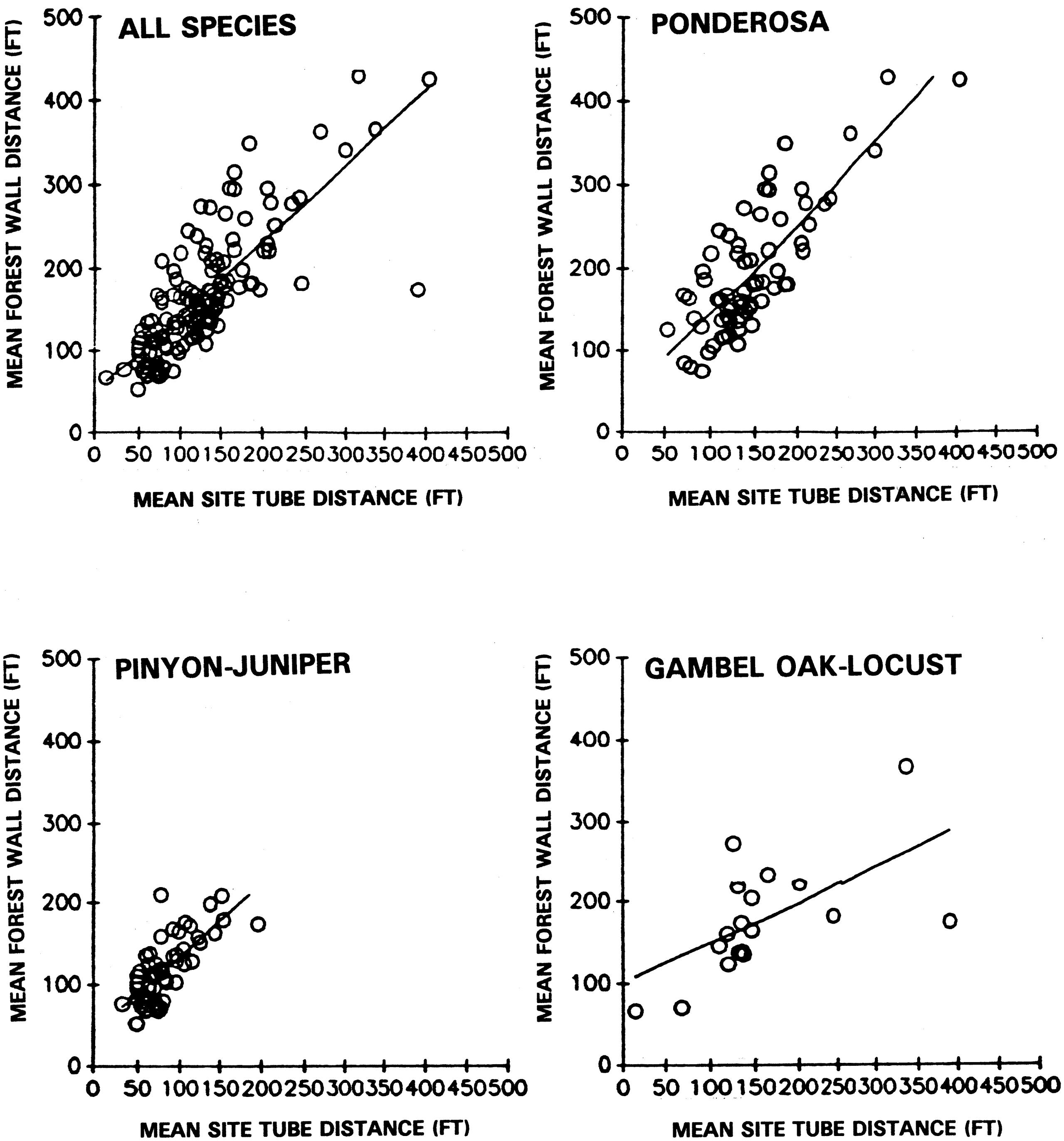


Figure 20.
Hiding cover distance regressed on distance to Forest Wall.

Table 22. Percent of elk home ranges and study area that are comprised of three canopy closure classes. Large bodies of water (lakes) and subdivisions were excluded from the calculations.

Canopy closure	Mean for elk home ranges n=16	Entire study area
70 - 100%	11%	11%
50 - 69%	59%	48%
0 - 49%	29%	41%
	99%	100%

an additional 48% fell into the medium quality range. Combined, nearly 60% of the study area qualified as day-bed cover (Table 22). However, if the RO3WILD relative acre value approach is used, medium quality cover is only 0.4 (1/2.5) as effective as the optimal class (Table 6). This fact reduces the 48% to 19%, so only 30% (11% + 19%) of the area exists in optimal day-bed cover equivalent. Additional hiding cover exists, due to oak undergrowth. Therefore, the requirement that 40% of the area consists of thermal and hiding cover in combination is probably met.

Summer home ranges used by 16 radio instrumented elk on the study area were comprised of 70% high and medium quality day-bed cover combined (Table 22). This value exceeded the combined percentages for available high and medium quality habitat on the entire study area. Therefore, this data set also demonstrates selectivity for higher canopy closures.

Stand Size and Distance to Edge

About 88% of our observations occurred in stands of 2.7 A or greater and about half in stands of 9 A or more. Approximately 20% occurred in stands of more than 30 A (Table 23). On the ponderosa pine study area, 95% of the bedsites occurred within 300 ft of stand edge (Table 24). The nearest adjacent stand was usually an area with less canopy closure, and qualified as a forage area.

Topographic Characteristics

Bedsite positioning relative to free water on the Lake Mary Study Area differed significantly from random (Table 25). Areas 1321-2640 ft from the nearest water were selected, whereas areas 2641-3960 ft were avoided. However, areas greater than 3960 ft were not avoided. The reason(s) for this pattern of selectivity was not apparent.

Some preference for slope feature was indicated (Table 25). The upper 1/3 of slopes was selected while the lower 1/3 was avoided. No significant differences between use and availability were documented for either steepness or direction of slope. Only 10% of the area has slopes of 21% or greater (Table 26), and major changes in overstory do not occur on the study area as a result of slope direction.

Calving Habitat

With the exception of 2 birthing sites, 18 calf bedsites found during this study involved animals in the later phase of the nursery period (i.e., they were in the company of adults and capable of fleeing with the group). Eleven of those sites occurred in the ponderosa type. They differed significantly from adult bedsites only in the height of dead and down material on the small (0.002 A) plot (Table 27). Seven calf sites encountered in this study occurred in P/J, and they did not differ from adult sites (Table 28). An alpha error value of $P<0.05$ was set for establishing a reliable relationship.

Both of the birthing sites located during this study qualified as hiding cover and were on slopes of less than 5%. One was less than 0.75 mi from water and the other 0.25 mi from water. The canopy closure on 1 site was 96%, but only 9% on the other. Tim Rogers (pers. comm.) provided the following description of the events on the latter site. "The cow and calf were first observed at 12:01 p.m., shortly after the cow had given birth in full exposure to sunlight. Between 12:01 and 12:16 p.m., cow licked calf clean and devoured the placenta. At 12:16, calf got up and wobbled around for 14 minutes. At 12:30, it laid down, still at the birthsite. The cow stood over the calf until 1:02 p.m.. At 1:02, the calf got up and was less wobbly. The cow and calf then moved 15 feet to a bedsite with a canopy closure level of 76%." This bedsite also qualified as hiding cover, with a mean distance of 75 ft providing a 90% level of horizontal visual obstruction to the sight tube, and with no individual directional measurement exceeding 96 ft. During this period the ambient temperature 1 ft above ground in the shade was 89 F.

Winter Cover

A copy of the Graduate Study Report Abstract (Abbott 1991), describing winter cover requirements, is attached as Appendix 16.

Table 23. Frequency of bedsites found within stand size classes (acres).

No. acres[1]	No. bedsites	%	Cumulative %	No. acres	No. bedsites	%	Cumulative %
0.9	1	1.1	1.1	18.3	2	2.2	68.9
1.8	2	2.2	3.3	20.1	2	2.2	71.1
2.7	8	8.9	12.2	21.0	1	1.1	72.2
3.7	7	7.8	20.0	21.9	2	2.2	74.4
4.6	7	7.8	27.8	22.9	1	1.1	75.6
5.5	3	3.3	31.1	24.7	1	1.1	76.7
6.4	7	7.8	38.9	27.5	1	1.1	77.8
7.3	3	3.3	42.2	29.3	2	2.2	80.0
8.2	1	1.1	43.3	31.1	4	4.4	84.4
9.2	7	7.8	51.1	32.0	2	2.2	86.7
10.9	1	1.1	52.2	32.9	1	1.1	87.8
11.9	2	2.2	54.4	36.6	3	3.3	91.1
12.8	3	3.3	57.8	38.4	1	1.1	92.2
13.7	3	3.3	61.1	51.3	3	3.3	95.6
14.6	1	1.1	62.2	56.7	1	1.1	96.7
15.6	2	2.2	64.4	64.1	1	1.1	97.8
16.5	2	2.2	66.7	75.0	1	1.1	98.9
				80.5	1	1.1	100.0
TOTAL					90	100	

[1] Class interval midpoints

Table 24. Frequency distribution: Distance from bedsite to nearest stand edge.

Distance (ft)	No. bedsites	Percent	Cumulative percent
12	1	1.0	1.0
14	1	1.0	2.1
18	1	1.0	3.1
20	3	3.1	6.2
40	3	3.1	9.3
60	1	1.0	10.3
70	1	1.1	11.3
84	14	14.4	25.8
100	16	16.5	42.3
120	11	11.3	53.6
140	10	10.3	63.9
150	1	1.0	64.9
158	9	9.3	74.2
160	2	2.1	76.3
180	8	8.2	84.5
200	1	1.0	85.6
220	2	2.1	87.6
240	4	4.1	91.8
300	3	3.1	94.8
360	1	1.0	95.9
420	1	1.0	96.9
440	1	1.0	97.9
540	1	1.0	99.0
900	1	1.0	100.0
TOTAL	97	100.0	

Table 25. Selection of topographic features at elk bedsites.

Item	X^2	% Available	% Used	Bonferonni Confidence Interval $P \leq 0.10$ Range	Use relative to availability[a]
Distance to Water (ft)	0.005	(n=545)	(n=93)	-0.114 to 0 .094	=
0-1320		0.194	0.204	-0.262 to -0.010	+
1321-2640		0.294	0.430	0.053 to 0.223	-
2641-3960		0.246	0.108	-0.128 to 0 .070	=
3961-5280		0.154	0.183	-0.033 to 0 .107	=
5281>		0.112	0.175		
Slope Feature	0.000	(n=545)	(n=95)		
Ridge Top		0.051	0.064	-0.080 to 0.054	=
Upper 1/3		0.167	0.298	-0.252 to -0.005	+
Middle 1/3		0.178	0.181	-0.110 to 0.104	=
Lower 1/3		0.310	0.117	0.093 to 0.293	-
Canyon Bottom		0.020	0.032	-0.059 to 0.035	=
Stream Bed		0.033	0.000		
Bench		0.015	0.053	-.098 to 0.022	=
Flat		0.226	0.255	- 0.149 to 0.091	=
Slope Direction	0.356	(n=545)	N=82)		
Slope Steepness	0.203	(n=545)	(n=89)		

[a] + = use greater than availability (range < 0)
- = use less than availability (range > 0)
= = No significant difference (range crosses 0)

Table 26. Percent slope on Lake Mary study area.

% Slope	% of Area
0-3	32
4-10	40
11-20	18
21-30	7
31-40	2
>41	1
	100

Table 27. Means, standard deviation and Mann-Whitney U tests on selected variables measured at adult female bedsites and calf bedsites in ponderosa pine forest.

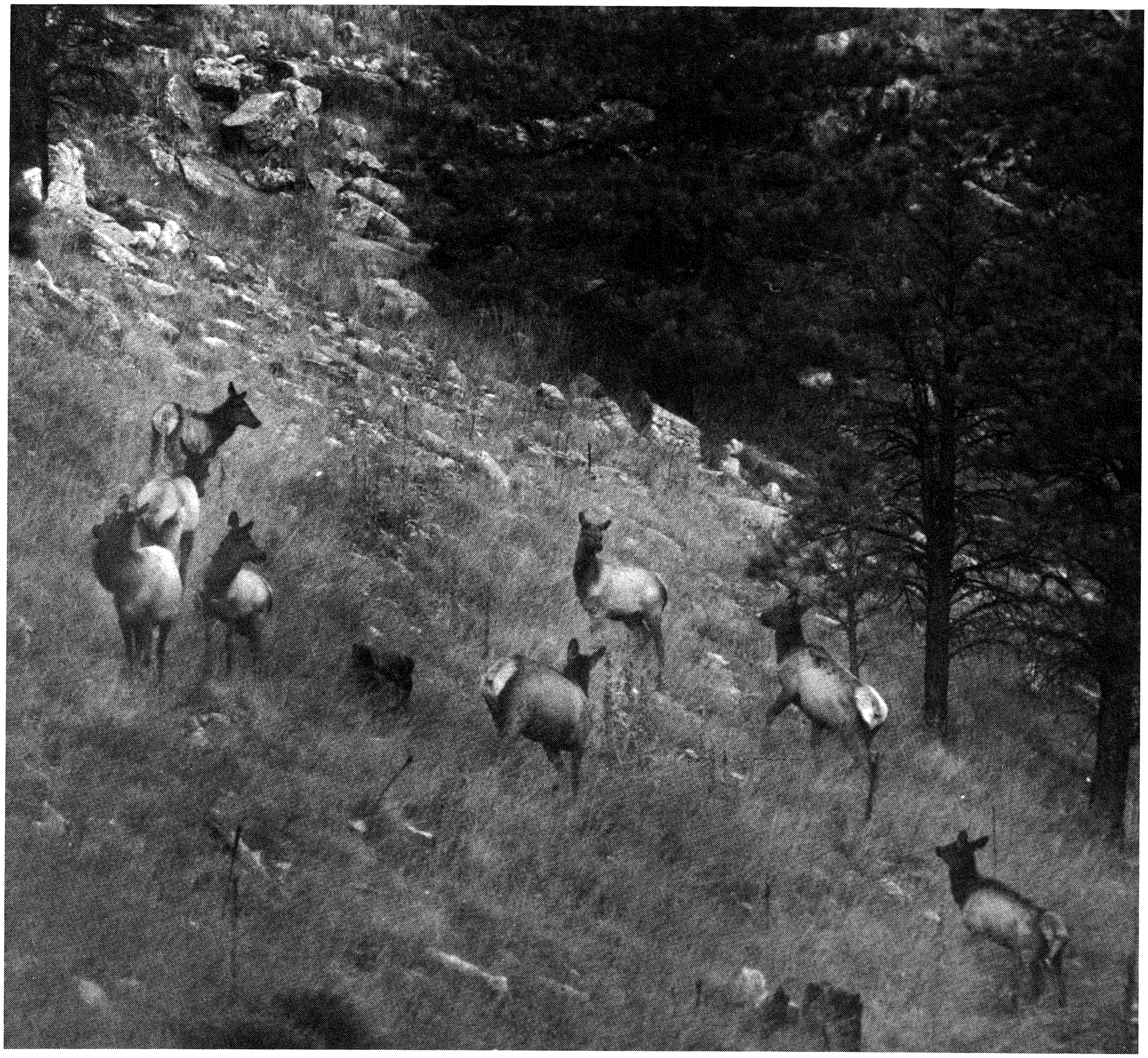
	Mean (SD)						
Variable	Cow		Calf		Z	*P*	N[a]
% Canopy Closure	76	(16.8)	85	(10.0)	-1.94	0.053	86;11
Total DBH on Plot (sq ft)	86.2	(38.4)	111.6	(64.9)	-0.97	0.334	86;11
Sight Tube Distance (ft)	151	(61.5)	170	(57.3)	-1.42	0.157	86;11
% Slope	7	(5.8)	7	(3.3)	-0.81	0.416	81;7
Distance to Water (ft)	4543	(5709.3)	4326	(3851.4)	-0.15	0.879	85;10
Mean Dead Height Small Plot (in)	3.9	(5.6)	9.0	(10.1)	-2.03	<0.05	86;11
Mean Dead Height Large Plot (in)	11.3	(8.8)	7.8	(8.6)	-1.38	0.166	70;8
% Dead Ground Coverage - Small Plot	5	(8.9)	14	(26.9)	-0.94	0.345	86;11
% Dead Ground Coverage - Large Plot	14	(12.7)	9	(10.9)	-1.21	0.225	70;8

[a] no. cow; no. calf

Table 28. Means, standard deviations, and Mann-Whitney U tests on selected variables: adult female bedsites and calf bedsites in pinyon/juniper woodland.

Variable	Mean (SD)				Z	*P*	N[a]
	Cow		Calf				
% Canopy Closure	78	(13.1)	73	(20.1)	-0.503	0.615	60;7
Total DBH on Plot (sq ft)	93.2	(38.3)	107.6	(40.1)	-0.779	0.436	60;7
Sight Tube Distance (ft)	85	(31.9)	91	(27.2)	-0.738	0.461	60;7
% Slope	5	(4.6)	3	(3.7)	-0.703	0.482	58;6
Distance to Water (ft)	8570	(4543.9)	7697	(5389.3)	-0.431	0.667	60;7
Mean Dead Height Small Plot (in)	2.0	(3.2)	1.1	(1.6)	-0.628	0.530	58;7
Mean Dead Height Large Plot (in)	5.8	(5.7)	4.2	(2.9)	-0.370	0.711	56;6
% Dead Ground Coverage - Small Plot	2.0	(3.9)	0.7	(1.1)	-1.145	0.252	58;7
% Dead Ground Coverage - Large Plot	3.4	(3.5)	3.8	(4.3)	-0.230	0.818	56;6

[a] no. cow; no. calf



Elk in ponderosa habitat.

DISCUSSION

Habitat Selection (DFA)

During summer mid-days, elk sought areas with higher canopy closures that were characterized by higher total dbh values. Canopy closure estimates are a direct measure of the degree of obstruction to incoming solar radiation.

High dbh levels in ponderosa roughly coincide with high canopy closure levels, and to a degree the tree boles themselves block the sun's rays. In this vegetation type, both high canopy closure levels and high total dbh levels appear in greatest frequency in the sapling and pole class timber.

Distance to lowest limb did not appear to be a limiting factor in ponderosa, where enough self-pruning occurs that elk can easily walk underneath the limbs of most trees. In P/J, this self-pruning is not exhibited by younger trees, and it is the larger, more mature trees that provide a mean distance to lowest limb that allows elk to move underneath the tree canopy. Having several trees in proximity promotes this characteristic, because branch development is inhibited on the inside of the clump. The exact reason for elk selecting bedsites with a mean distance to lowest limb of 6.5 ft or greater is not fully understood. Obviously, shading potential is greatest if elk can move directly underneath the object providing the shade. Additionally, elk may not want to crouch to either enter or exit a bedsite. On the other hand, air movement or ventilation may be involved. It was beyond the scope and capabilities of this study to make this determination. However, measurable air movement was documented at 98% of the bedsites (n=122). Elk avoided rocky areas when selecting bedsites, which may be caused by a dislike for bedding on irregular surfaces. They will occasionally scrape or clear a bedsite of debris before lying down. Sapling and pole size trees in ponderosa, and mature P/J, provide mid-day bedsite habitat for elk in Arizona. Consequently, intermediate tree thinning operations in ponderosa and fuelwood harvest of mature trees in P/J reduce elk day-bed habitat. Cutting operations should be planned so that a proper balance between cover and forage areas is maintained.

Relationships Between Canopy Closure and Bedsite Characteristics

The use of modified relative acre values within the RO3WILD elk matrices, would not necessarily remedy all problems inherent to this habitat capability model. Canopy closure is the primary component of thermal cover. The structural stage crosswalk table upon which the model is based, assigns canopy closure values to stem density ranges within stem diameter classes. Therefore, an estimate of the accuracy with which these structural stage characteristics can explain variation in canopy closure levels is essential. Stem density and diameter data are the components of basal area and SDI calculations. Neither of these calculations, nor total dbh, explained more than 43% of the variation in canopy closure levels in ponderosa, nor more than 17% in P/J. Additionally, without the removal of outliers, only 10% of the variation was explained in the P/J type. Therefore, stem density and diameter data are not good predictors of canopy closure.

During this study, we recorded densiometer "hits" on all vegetation (foliage, stems, and limbs) as canopy. The premise was that all of those items can block solar radiation and therefore can contribute to the level of shade sought by elk. Recently there has been discussion within the USFS on which of these items should be included in canopy closure readings, and also how spherical densiometer readings compare with so called "vertical projection" measurements. There is evidence that the technique we used tends to produce readings approximately 8% higher than vertical projection methods (Appendix 15). Appropriate adjustments of our canopy closure data may be necessary for them to be compatible with some data sets.

Optimum day-bed cover for elk in Arizona appears to be any stand of trees (coniferous or deciduous), that meets average distance to lowest limb requirements and has a canopy closure of 70% or greater. One cannot effectively evaluate the availability of elk cover without monitoring the canopy closure of each stand. Direct measures, by means of a spherical densiometer, vertical projection tube, or remote sensing, appear to be the only methods of obtaining accurate information on canopy closure.

RO3WILD Model Evaluation

The RO3WILD model was intended to provide a means of predicting probable impacts of commercial timber operations on wildlife habitat. Data collected during this study have provided meaningful canopy closure classes for summer day-beds (which are assumed to reflect thermal cover selection) and modified relative acre values for 2 of the elk matrices (ponderosa and P/J). Even so, the potential for the RO3WILD model to predict probable impact of silvicultural operations is very limited for ponderosa forest, and almost nonexistent for the P/J type, because structural stage characteristics (stem densities within diameter classes) are used by the model to reflect canopy closure levels. Conversely, the DFA model was capable of classifying bedsites with an accuracy level of 92%. This is primarily because direct measures of canopy closure were used.

The revised RO3WILD model utilized canopy closure classes of 10-40, 41-60, and 61-100%. When the Lake Mary and Blue Ridge study area data are forced into those canopy closure classes (Appendices 5-10), the lower limit for optimum habitat is reduced from 70 to 60% canopy closure. This stretches the full acre value beyond its correct lower limit. Superficially this might appear to have the potential to increase the habitat capability rating for certain areas. Simultaneously, however, the relative acre value for medium quality habitat is being degraded. This conclusion is evidenced by a comparison of Tables 6 & 7 with Appendices 5 & 6. Whether this results in an increase or decrease in the overall score for any particular area will depend upon the habitat composition of that area. An area with small amounts of high quality habitat and large amounts of medium quality habitat could actually receive a lower rating than it would have received if our recommended canopy closure classes had been used. Additionally, early versions of the RO3WILD model did not use matrix values in excess of 5 (i.e., 1/5 acre value). Our derived matrix values for medium and low quality habitat (Appendix 6) both exceed 5 and therefore cannot be utilized under that system. Within the mechanics of the model, there is nothing particularly important about the number 5. The only prerequisite for matrix values is that they all be greater than 0, because they are used as multipliers in the final equation. There is probably no overall scoring advantage to be gained by using skewed matrix values or canopy closure ranges.

The RO3WILD model was designed to simultaneously model habitat capability for several animal species from a common database. This analysis requires a common expression of the habitat requirements used in the modeling process. However, canopy closures preferred by other species may not be the same as those preferred by elk. Therefore, it is probably not possible to model habitat capability for all species simultaneously, without seriously compromising the description of habitat requirements for some of the species involved.

Silvicultural Descriptives

One approach that has been used to establish and maintain proper cover to forage ratios is based on the assumption that certain basal area levels within certain diameter classes reflect canopy closure levels. Plans to thin individual stands to predetermined basal areas were worked into an overall pattern that approximated a 40/60 cover to forage ratio for a larger piece of habitat. Currently, mean SDI values are being used to characterize the PFA and FA under the USFS MRNG guidelines. However, because of the poor correlations with canopy closure, these calculations (basal area and SDI) have only a limited potential to define thermal cover in ponderosa or ponderosa/Gambel oak mix and no potential for that purpose in P/J woodland. If 67% confidence intervals are created from data in tables 14-19 (mean $\pm$ 1 *SD*), rather wide ranges of mean values are generated from the basal area and SDI columns. If one wishes to use either basal area or SDI calculations to reflect canopy closure levels when dealing with a timber sale in ponderosa or ponderosa/Gambel oak mix, target values should be held to the right of the means to provide the best chance of ensuring adequate canopy closure levels (Appendices 11-14). Neither of these calculations should be used to predict canopy closure in P/J woodland due to their poor correlation (r^2 = approximately 0.10; Table 13).

Although this study failed to demonstrate any advantage in using SDI instead of basal area calculations to reflect canopy closure, it should be noted that SDI values are best suited to use in even-aged stands. While a substantial percentage of the plots used in this study contained trees that could be considered even-aged, not all plots fell into this category. Therefore, the use of SDI on data from those sites may not have been appropriate, and some improvement in correlation might be expected when only even-aged stands are involved.

There is little overlap between data from this study and forest characteristics described in the MRNG. Mean SDI values of 150 and 104, used to characterize the PFA and FA, are substantially lower than those in Tables 14 and 15. Additionally, mean diameter classes of ponderosa at mid-day bedsites used by elk are smaller than those specified for goshawk habitat. The MRNG calls for 60% of the PFA and FA to exist in trees with a mean dbh of 12 in or greater and 100% of the nest area in trees 18 in or greater. Approximately 88% of bedsites listed in Tables 14 and 15 occurred on microsites with mean stem diameters of less than 11 in. The use of smaller trees was due to their greater stem density and canopy closure compared to stands composed of larger trees.

The existing definition of thermal cover (Thomas et al. 1979), restricts vegetation comprising these covers to coniferous species. Deciduous species, primarily Gambel oak, made significant contributions to canopy closure levels in the ponderosa forest (Lake Mary study area).

The DFA selected 6.5 ft as a critical level for distance to lowest limb in P/J woodland. When the same bedsite data were stratified into diameter classes for descriptive purposes, the smallest mean distance to lowest limb calculation for any diameter class in optimum habitat was 7 ft (*SD* = 1; Table 17). Average values as low as 5 ft (mean - 2 *SD*) or greater are probably acceptable.

In this study, elk day-beds were characterized by trees shorter than the 40 ft minimum specified in the Pacific Northwest guidelines (Thomas et al. 1979). Stands with mean tree heights of 17 ft in ponderosa, and 11 ft in P/J, were used (Tables 14 -17).

Hiding Cover

Moderate to dense stands of ponderosa induce a substantial amount of self pruning of the lower branches. Pruning produces trees characterized by single straight boles and canopies whose lower extremities begin several feet above the ground. In the absence of understory, shading requirements may be more easily met than hiding cover requirements.

Smith and Long (1987), using computer simulations of lodgepole pine *(Pinus contorta)* stands, determined that the standard definition of hiding cover would be met by tree boles alone when total dbh exceeded 4979 in/A. This conclusion was reached from what is basically a trigonometric procedure. Diameter classes of ponderosa involved in thermal cover bedsites are small, and approximate lodgepole diameters. A value similar to this approximate 5000 in dbh figure probably applies to ponderosa in the absence of any undergrowth. Even distribution of trees achieved through selective thinning, is often an objective of stand management programs. An absence of undergrowth is not uncommon in some areas. Only 25% of the 105 bedsites qualified as hiding cover when this 5000 in dbh criterion was applied to the ponderosa data. This observation suggests that in ponderosa stands having clean forest floors, it may be easier to satisfy 70% canopy closure requirements than hiding cover requirements. In areas with negligible undergrowth, the major emphasis should be to maintain stands with high enough stem densities to hide elk. Canopy closure requirements most likely will automatically be met on those acreages. In P/J, hiding cover requirements are more easily satisfied than are thermal cover requirements, because the latter demand stands with mature trees.

Hiding cover is probably best evaluated by means of a sight target that provides a direct measure of horizontal visual obstruction. Such direct measures automatically include the influence of undergrowth and low limbs as well as tree boles.

Transporting sight targets in the field is usually difficult. The distance to forest wall measurements were made with the intent of determining whether the disappearance of a human walking away from the bedsite would provide a comparable set of data, thus removing the necessity of transporting a sight target in the field. In general, the average distance of disappearance for a human wearing neutral colored clothing could be used for hiding cover evaluation. However, the use of this technique in the P/J type is only marginally acceptable.

The MRNG proposes to satisfy cover requirements in ponderosa with open grown seedlings and saplings that exhibit no self pruning of lower branches. This management option will require that hiding cover and thermal cover occur in totally separate areas. Therefore, an animal that is hidden will not have the benefit of high quality thermal cover. And, an animal that is using thermal cover may be displaced as soon as a foot traveler or vehicle comes into sight.

Cover:Forage Ratios

The Lake Mary study area seems to have met the requirement that 40% of the land mass exist in hiding and thermal cover combined. Calf to cow ratios during the study and for several years prior have been satisfactory (50 calves or greater/100 cows). That level of calf production in itself suggests that there is adequate thermal cover on the area.

However, it is unlikely that the 40/60 cover/forage ratio recommended for elk habitat management will be satisfied in the future under the current forest management guidelines (MRNG). The 2 habitats with the highest ponderosa density, Nest Area and PFA, when combined, will comprise only 10% of each 6000 A management parcel. Allowable canopy closure on the nest areas and PFA could be as low as 50%. Allowable canopy closure on the remaining 90% of the 6000 A (the FA) could be as low as 40%.

Stand Size and Distance to Edge

Optimum stand size and distance to edge are important and closely related components of any forest management plan. Thomas et al. (1979) recommended that thermal covers be 30 to 60 A. They felt that smaller stands would not accommodate herd behavior, while larger ones would not be fully utilized. However, they stated that too large is better than too small. Our data imply that stands smaller than 30 A are adequate during the summer months. Because stands as small as 0.9 A were used, and 88% of our bedsites (n=90) occurred in stands of 2.7 A or greater, one could conclude that 3 A represents an approximate minimum threshold for stand size selection by elk for day-beds. However, many of our observations involved small groups of 1-5 animals. Large groups, which require more area, could not be accurately counted as they fled from the bedsites. Consequently, our data may not reveal the acre requirements for herds of 20-30 elk. Therefore, no value below the mid-point of the data distribution (9 A) should be accepted as a minimum value.

Data from this study on distance to edge supports recommendations by other researchers. Thomas et al. (1979) cite Reynolds (1966) and Harper (1969) as having shown that most elk use of either forage or cover areas occurs within 600 ft of the forest edge. Leckenby (1984) found that on both summer and winter ranges, about 80% of the elk use of day-beds occurred within 100 yd of the forest edge adjacent to forage areas, and nearly 100% occurred within 400 yd of the edge. He stated that the models presented by Thomas et al. (1979) are supported by his results.

Distance to edge is probably the better criterion to use when designing timber cutting patterns, than stand size or acreage alone. For the sake of discussion, a square block of ground which contains 25 A is 1043.6 ft on a side. This means an opening of this size does not exceed the distance to edge requirement since the distance from the center of the clearing to the nearest edge is less than 600 ft. Likewise, a 25 A cover block does not exceed distance to edge recommendations.

Since about 1987, most Land and Resource Management Plans (USDA Forest Service, Region 3, Albuquerque) required stands to be 10-100 A in size. Either a 100 A clear cut or cover patch could satisfy distance to edge requirements if it were comprised of 4, 25 A blocks set end to end. However, recent forest management in Arizona rarely considered distance to edge recommendations.

While stand size was supposed to be kept below 100 A, violations of this constraint were not uncommon. Additionally, many stands which did comply with the 100 A constraint had major and minor axes of about equal length. The tendency was therefore to use block or patch layouts rather than strips. Distance to edge requirements can be met by either reducing stand acreages, or by using stand shapes that are compatible with the requirements. Thomas et al. (1979) imply that until this requirement is met, the most effective use of available acreages for elk will not be realized.

The data on which those recommendations were based, and the data from this study as well, were obtained at times of the year other than hunting seasons. One aspect of hiding cover that is not dealt with in the literature concerns the acreage needed for elk to elude an intruder that has entered the cover stand. If acreages are small, the herd would have to leave the cover. For this purpose, the 100 A stand would be superior to smaller ones, and the 100 A block may be superior to the 100 A strip. This applies to cover patches only and not to forage areas. Within this context, stand size and distance to edge regimes that afford the most efficient use of any area during most of the year may have some disadvantages during hunting seasons.

The MRNG guidelines call for eventual replacement of the current stand size range. Gradually, through the use of small regeneration cuts, tree groups of less than 1 A to 4 A will become the stands. One 4 A patch could provide thermal cover for a group of elk if the density of vegetation is adequate. However, hiding cover usually requires a greater area. One A, if square in shape, is 208.7 ft on a side. Hiding cover must obscure 90% of a standing adult elk at 200 ft. Very dense vegetation can hide an elk at shorter distances, however, dense vegetation at thermal cover sites is not called for in the MRNG. An equal sided 4 A expanse of habitat with marginally adequate vegetation density could hide 2 or 3 elk positioned exactly at its center. However, a 4 A patch with marginally dense vegetation will not hide a large group. Using the stem densities and SDI values called for in the MRNG, it is unlikely that a single animal would be hidden at sites that provide thermal cover.

Topographic Characteristics

Nelson and Burnell (1975) and Mackie (1970), in Thomas and Toweill (1982: 390), found a significant decrease in elk use of summer habitat beyond 805 m (0.5 mi) from water. DelGiudice and Rodiek (1984) found that elk on the Sitgreaves National Forest in Arizona preferred to stay within 0.5 mi of free water during the mid-May through September period. Our data from the Lake Mary area are not in agreement, possibly because our locations were at mid-day bedsites where elk were not seeking water. Alternatively, temporary waters greater than 3960 ft from bedsites and whose presence were not known to us could also have been responsible for the lack of a consistent pattern.

Selectivity for steepness and direction of slope are apparently area-specific phenomena. In a Washington study, Nelson and Burnell (1975) documented that elk selected north and east facing slopes during hot dry weather, and tended to use gentle rather than steep slopes. Slopes on the Lake Mary study area are for the most part gentle and do not produce major changes in vegetation. In general, the area provides little opportunity or reason for topographic selectivity.

Calving Habitat

Habitats used by calves will be considered under 4 separate categories: birthing sites and 3 categories of nursery sites, those used during early, middle, and late phases of the nursery period. During the early phase of the nursery period, except for visits by its mother, the calf is not in the company of other elk. During the middle phase, both cow and calf are part of a nursery herd, but the calf has not attained full mobility. In the late phase, the calf is capable of traveling with a herd.

Within 24 hours after giving birth, the cow may join others in the vicinity of the birth site (Harper et al. 1967). For a short time the calf remains secluded. The cow visits the calf several times each day. Darling (1937) states that this hiding phase lasts 3 to 4 days for red deer calves. Calves may join other calves and their dams within the first week and are secluded together with the cows nearby. This period of seclusion lasts from 10 days to 3 weeks (Altmann 1956, 1963; Knight 1970). After 3 weeks, the "hider" strategy gives way to the normal anti-predator strategy which is to flee from disturbance with a group and relocate (Geist 1982). Large nursery herds form within 6 weeks after calves are born (Franklin and Lieb 1979). Adequate concealment is very important during the early and middle phases of the nursery period when the calf is either unable or has a very limited ability to flee from predators. However, it is probably most important during the early phase when only 1 adult may be in the vicinity and in a position to protect the calf. During the late phase of the nursery period, habitat requirements probably more closely approximate those for adults.

Selection for dead and down material by older calves may be residual concealment behavior used during the earlier phases of the nursery period when large objects are used for hiding. Waldrip and Shaw (1979) found a relationship between daytime calf bedsites and ground concealments in the form of woody cover and boulders. Mark Wallace (pers. comm.) reported that calf bedsites encountered on the White Mountain Apache Reservation in Arizona were frequently associated with downed woody material, usually logging slash piles. Bedsites used by calves in the ponderosa type, during our study, had significantly higher accumulations of dead and down material than adult bedsites. However, this was not the case in the P/J type. In general, because those calves were capable of traveling and fleeing with adults, similarities in habitat selection were expected. Nevertheless, regarding this variable (height of dead and down material), there does seem to be a difference between habitat use by calves in ponderosa and those in P/J. One possible explanation is that the high frequency of close-to-the-ground tree branches, characteristic of P/J forests, provides the necessary concealment for calves, thus minimizing the importance of dead and down material for this purpose.

The latter of the 2 birthing site observations obtained during this study suggests that cover components on the actual spot where the calf is born are of less importance than those available in the immediate vicinity, because the calf is capable of moving short distances approximately 2 hours following birth.

The single observation during this study of a calf moving shortly after birth seems to be consistent with descriptions of behavior of red deer calves. Calves in that subspecies are able to stand 1/2 hour after being born and are suckled for the first time 40 minutes after birth. One to 1-1/2 hours after birth the placenta is expelled and eaten and the ground cleaned of fluids by the mother. The calf is then cleaned, suckled again, and encouraged to move, usually less than 300 m (180 ft) (Clutton-Brock et al. 1978).

Substantial variation is present among the descriptions of calving habitat used by Rocky Mountain elk. However, some similarities exist. Skovlin (1982) generalized from several studies conducted in western states.

> "After pregnant cows have departed the herd, forest hiding cover will be within easy reach of each cow if she does not actually calve within that cover type. Ground cover concealments, often in the form of shrubs, down logs, or broken terrain, seem to be important. Sagebrush is preferred when available. Most calving will occur in the ecotone between rather open foraging areas and the adjacent forest escape cover. Free water normally is within easy access for the cow - usually within 400 meters (1,312 ft). Slopes usually are gentle relative to surrounding terrain but can exceed 40 percent; average slope conditions probably range from 20-30 percent."

The foregoing is fairly consistent among sources. Inconsistencies occur when more specific parameters such as slope, aspect, and canopy closure levels are considered.

There is little quantitative information on overstory canopy closure levels on calving grounds. Rodiek and DelGiudice (1982 and pers. comm.) report that most calving near McNary, Arizona occurred in dense stands of timber with a high percentage of overstory canopy closure, a high level of horizontal visual obstruction, and within 1 km (3100 ft) of water. However, at least 1 study documented the use of areas with rather sparse canopy closure. Phillips (1974) reported that on calving grounds in the Sawtooth Mountains of Idaho, timber canopy closure averaged 37% (range 20-60%). Skovlin (1982) stated that most migratory Rocky Mountain elk calve along their migrational routes (i.e., on transitional spring range). This may be the source of some of the variation in habitat description. Skovlin (1982) stated that migration times can vary from year to year, but calving times do not. Most calving occurs between mid-May and mid-June.

DelGiudice (1982) reported that most calving in the McNary, Arizona area occurred between late May and the end of July. Most Arizona elk are on summer range by mid-May (Brown 1990). Therefore, most calving activity in Arizona is associated with summer range vegetation selected by the cow, and this involves high canopy closure levels.

We were not able to obtain direct information on calf habitat requirements during the early phases of the nursery period. To do that would have required capturing and radio tracking calves. It is unclear from the literature whether calves less than 3 weeks old require the same level of overstory canopy closure used by adults. However, it may not be necessary to determine that for elk in Arizona because calving occurs on summer range, where adult summer range requirements have to be met as well. Background information indicates that calving habitats provide hiding cover for the calf; plus forage, hiding cover, and free water, all in proximity for the cow. However, where calving occurs primarily on summer range, adequate day-bed habitat for the cow must also be available.

Except for the short periods when the calf is suckled and stimulated to void, cows stay away from their newborn (Clutton-Brock and Guinness 1975). However, travel to the calf does not involve great distances. Murie (1951) reported that the cow may wander 1/4 mi from the concealed newborn. Anti-predation strategies include vocalization by the calf (Geist 1982), the cow directly attacking the predator, or the cow acting as a decoy to lure larger predators away (Altmann 1963; McCullough 1969; in Elk of North America, p 238). An inadequate combination of habitat characteristics in the vicinity of the calf requires the cow to travel excessive distances to feed, water or shade thus reducing the amount of time she is nearby to protect her calf. Inadequate hiding cover for the calf increases its chances of being located by a predator.

Elk calving habitat in Arizona is best described as habitat that is adequate for the cow in terms of forage to cover ratio (including both thermal and hiding cover), on slopes less than 30% and within 1/4 or perhaps 1/2 mi of free water. Additionally, ground concealment with a mean height of 28 in or greater should be present to provide hiding cover for calves. Roberts (1974) reported that sagebrush with a mean height of 28 in is used in Idaho for hiding calves. Ground concealments can be boulders, down timber, slash piles, shrubbery, stumps, and lopped tree tops. During this study, the latter 2 were used by calves in the late phase of the nursery period.

Winter Cover

Abbott (1991), reported that winter bedsites were associated with high basal area, 203 and 250 ft^2/A for ponderosa pine and P/J, respectively. The mean drc of individual trees nearest each bedsite was 28 in, ranging from 5 in to 86 in. Areas surrounding elk bedsites contained a large proportion of large trees. Canopy closures at bedsites averaged 80% and clusters of trees were used either as hiding or thermal cover. All bedsites qualified as hiding cover due to the presence of Juniper spp. Abbott recommended attempting to satisfy the overall cover requirement by maintaining 40% of the forest's area in dense clusters rather than attempting to satisfy 40% at the administrative stand level.

Management Options

This study clearly demonstrated that summer habitat selection patterns and requirements of elk vary with forest type. Based on these findings, the following recommendations will improve the effects of timber management on elk populations in ponderosa pine and pinyon pine/juniper forest types in Arizona.

The reader is cautioned that the following management options pertain only to elk. They may not be suitable for other species or affect them in the same way they do elk.

1. Adopt the following definition for high quality summer thermal cover in Arizona's ponderosa and P/J forests: "single or multi-storied stands of coniferous or deciduous species with a canopy closure of 65% or greater in P/J, and 70% or greater in ponderosa, and a distance to lowest limb of 5 ft or greater." (The distance to lowest limb requirement was determined from the P/J community (mean - 1 *SD*) for diameter classes up to 11 in (Tables 16 and 17).

Contrary to definitions of thermal cover developed in mixed conifer forests of the Pacific Northwest, stands with mean tree heights of 17 ft in ponderosa and 11 ft in P/J (Tables 15, 17) appear to be adequate. Additionally, thermal cover is not restricted to coniferous species.

2. Maintain 40% of the total land mass in hiding and thermal cover combined, and 60% in forage areas. This is consistent with the Pacific Northwest study results (Black et al. 1976, Thomas et al. 1979). Smaller trees (sapling and pole class timber) provide most of the thermal cover in ponderosa, while more mature trees provide this requirement in P/J forests. Therefore, it is the thinning operations in ponderosa and harvest of mature trees in P/J that pose the greatest threats to these habitats. Failure to maintain the 40/60 ratio will result in deterioration of elk habitat.

3. Canopy closure, the primary component of thermal cover, should be measured directly, either through the use of a spherical densiometer, vertical projection tube, or through aerial photo interpretation. Spherical densiometer data may require adjustment to be compatible with data from aerial photos (Appendix 15).

4. If direct measurements of canopy closure are lacking, and basal area or SDI values must be used to evaluate the suitability of ponderosa stands for thermal cover, it should be done with caution. Descriptives such as basal area or SDI, which are based on stem densities and diameters, are not reliable predictors of canopy closure. When a basal area of 200 ft/A or greater is used to reflect canopy closure of 70% or greater, 1 *SD* for the value 200 is in the range of 50 to 90 (Table 15).

5. The RO3WILD model, using the revised matrix values, could be used to model habitat capability for elk in ponderosa. However, its a,b,c, classifications, which are used to reflect canopy closure levels, will inherently have the same level of inaccuracy as basal area or SDI values when used to predict canopy closure. Model outputs will therefore lack a high level of precision. If more direct measures of canopy closure (estimates derived either from the use of a spherical densiometer, vertical projection tube, or from aerial photographs, as opposed to canopy closure values assigned to a structural stage crosswalk table) are used in conjunction with the corrected matrix values provided in this report, the model should provide reliable estimates of habitat capability for elk.

6. In P/J, use of the RO3WILD or WESTWILD model will require data obtained through the direct measure of canopy closure. Basal area and SDI calculations should not be used to reflect canopy closure. In this vegetation type, the relationship of stem density and diameter derivatives to canopy closure is so poor that it is almost nonexistent.

7. In both ponderosa and P/J, cutting patterns should gradually be modified so that 600 ft distance to edge requirements are met. When those requirements are satisfied, holding maximum stand size to 100 A becomes unimportant from the standpoint of optimizing elk habitat use (i.e. 5 or more 25 A blocks placed end to end still satisfy the distance to edge requirements).

8. Gambel oak was a significant contributor to overall canopy closure levels on the Lake Mary study area. It also made substantial contributions to hiding cover. There are some very strong suggestions that pure stands of ponderosa are more efficient at providing thermal cover than hiding cover, if the latter is entirely dependent upon ponderosa boles to provide an acceptable level of horizontal visual obstruction. Gambel oak has the potential to augment both thermal

and hiding cover levels in ponderosa forest. All age classes should be maintained for this joint purpose whenever possible.

9. The general literature on calving habitat, in conjunction with the limited amount of information from this study, has enabled us to formulate the following recommendations. Calving habitat in Arizona should provide a 40/60 cover to forage ratio for the cow (including both thermal and hiding cover) within 1/2 mi of a water source. It must also provide hiding cover for the calf in the form of large ground concealments at least 28" in height within 1/2 mi of water. This can be satisfied by shrubbery or downed woody material in the form of stumps, logs, or slash. Slash should probably be piled or wind-rowed. Lop and scatter seems to be the least desirable method of distribution. Lyon (1976) has stated that slash depths of 18 in discourage elk use of areas. This may be due to impaired mobility and reduced ability to flee. A variety of concealments should probably be available in any particular area to discourage selective hunting by predators.

10. Attempt to satisfy the overall cover requirement by maintaining 40% of land mass in dense tree clusters scattered throughout the forest, rather than attempting to satisfy this requirement at the administrative stand level. This recommendation was originally made by Abbott (1991) for elk winter range. However, it might be the most realistic approach on both summer and winter ranges (i.e. ponderosa as well as P/J forest).

11. The current forest management plan (MRNG) satisfies few of the accepted standards for managing elk habitat. Provisions for tree stands large enough (30 A or larger) and dense enough to hide large herds of elk should be incorporated into the plan. On summer range, thermal covers should not be totally separated from hiding cover. Within the guidelines for elk habitat management there appears to be no justification for recommending that less than 40% of the landscape exist in hiding and thermal cover combined.

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Appendix 1.

General formula for the RO3WILD habitat capability model with specific inclusions for elk:

$$\textit{Feeding capability} = \left(\frac{1}{\textit{Total Acres}}\right)\left(\begin{array}{c}\textit{No. acres per habitat type}\\ \textit{and structural stage}\end{array}\right) \div \textit{Matrix factor for that stage}$$

Cover Capability = Calculated same as F.C.
Habitat Capability Index = {(FC x CC) .5} x RD
For roads (RD):

if $\leq$ 1 mi/section, RD = 1 - 0.40 x (road class factor)
if > 1 mi/section, RD = 0.75 - 0.10 x (road class factor)

Road class factors:

2 lane + surfaced = 1/1
Secondary (< 2 lane, surfaced) = 0.7/1
Primitive unsurfaced = 0.07/1

Roads will not be allowed to reduce habitat capability below 90%.

Forage/cover ratios can be built in by multiplying FC or CC by appropriate factor:

Factor for 60% = 1.67
Factor for 40% = 2.50

HCI values will range from 0 to 1 with 1 being optimum.

HCP Habitat Capability Population can also be calculated:

HCP = HCI x 0.02 x Total Acres = No. of animals
(0.02 elk/acre is considered Optimum Population density)

Appendix 2. Structural stage ratings within stem density and diameter classes (Byford et al. 1984) for both Ponderosa pine and pinyon/juniper habitats.

Ponderosa Pine - Diameter Classes

Stems/A	0- 1.0	1.1- 5.0	5.1- 7.0	7.1- 9.0	9.1- 11.0	11.1- 13.0	13.1- 17.0	17.1- 20.0	20.1- 28.0	28.1+
1 - 10	1	1	1	1	1	1	1	1	5	5
11 - 20	1	1	1	1	1	1	4a	4a	5	5
21 - 40	1	1	1	1	3a	4a	4a	4b	5	5
41 - 80	1	1	3a	3a	3a	4a	4b	4c	5	5
81 - 120	1	2	3a	3a	3b	4b	4b	4c	4c	
121 - 200	1	2	3a	3b	3b	4b	4c	4c		
201 - 350	2	2	3b	3b	3c	4c	4c			
351 - 500	2	2	3b	3b	3c	4c				
501 - 700	2	2	3b	3c						
701 - 1000	2	2	3c	3c						
1001 - 2000	2	2	3c							
2000+	2	2								

Pinyon/Juniper - Diameter Classes

Stems/AC	0- 1.0	1.1- 5.0	5.1- 7.0	7.1- 9.0	9.1- 11.0	11.1- 13.0	13.1- 17.0	17.1- 20.0	20.1- 28.0	28.1+
1 - 10	1	1	1	3a	4a	4a	5	5	5	5
11 - 20	1	1	3a	3a	4a	4a	5	5	5	5
21 - 40	1	1	3a	3b	4b	4b	5	5	5	5
41 - 80	2	3a	3b	3b	4b	4c	5	5	5	
81 - 120	2	3b	3b	3c	4c	4c	5	5		
121 - 200	2	3c	3c	3c	4c	4c	5			
201 - 350	2	3c	3c	3c						
351 - 500	2	2	3c							
501 - 700	2	2								
701 - 1000	2									
1001 - 2000	2									
2000+	2									

Appendix 3. Structural stages (Byford et al. 1984).

Structural Stage	Description
1	Grass/Forb
2	Seedling/Sapling
	Immature
3a	10-40% canopy closure
3b	41-70% canopy closure
3c	>71% canopy closure
	Mature
4a	10-40% canopy closure
4b	41-70% canopy closure
4c	>71% canopy closure
5	Old Growth

Appendix 4. Fractional acre values to elk of various structural stages and vegetation (Byford et al. 1984).

Ecosystem: ponderosa pine

Season of use: year-round

Type of use	Structural stages								
	1	2	3A	3B	3C	4A	4B	4C	5
Feeding	1	1	1	2		2	5		2
Cover			5	2	1	5	2	1	2

Ecosystem: ponderosa pine

Season of use: winter

Type of use	Structural stages								
	1	2	3A	3B	3C	4A	4B	4C	5
Feeding	2	2	2	5		5			5
Cover				5	2		5	2	5

Ecosystem: Pinyon-Juniper

Season of use: summer

Type of use	Structural stages								
	1	2	3A	3B	3C	4A	4B	4C	5
Feeding	2	2	2	5		2	5		
Cover		5	5	2	2	5	2	2	2

Ecosystem: Pinyon-Juniper

Season of use: winter

Type of use	Structural stages								
	1	2	3A	3B	3C	4A	4B	4C	5
Feeding	1	1	1	5		2	5		
Cover		5	5	2	1	2	2	1	1

Appendix 5. Frequency of occurrence of bedsites and satellite plots within U.S. Forest Service canopy closure classes: Ponderosa ecosystem (R03WILD Model).

% Canopy Closure	No. Bedsites		No. Satellite Plots	
0-5	0		4	
6-10	0		6	
11-15	1		5	
16-20	1		6	
21-25	1	6%	4	38 %
26-30	1		1	
31-35	0		8	
36-40	1		3	
41-45	1		4	
46-50	1		2	
51-55	1	7%	5	23%
56-60	3		5	
61-65	3		3	
66-70	5		2	
71-75	8		1	
76-80	13		10	
81-85	18	87%	8	39%
86-90	12		2	
91-95	13		2	
96-100	1		0	
Total	n = 84	100%	n = 71	100%

Appendix 6. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: U.S. Forest Service canopy closure classes Ponderosa ecosystem (R03WILD Model).

Canopy closure class	% Canopy closure	% bedsite plots/% satellite plots			Relative acre value		
a	10 - 40	6/38	=	0.157	2.231/.158	=	14.1
b	41 - 60	7/23	=	0.304	2.231/.318	=	7.3
c	61 - 100	87/39	=	2.231	2.231/2.231	=	1

Appendix 7. Frequency of occurrences of bedsites and satellite plots within U.S. Forest Service canopy closure classes: Ponderosa ecosystem with a Gambel oak inclusion.

% Canopy Closure	No. Bedsites		No. Satellite Plots	
0-5	0		5	
6-10	0		7	
11-15	1		7	
16-20	1		7	
21-25	3	7%	4	38 %
26-30	1		2	
31-35	0		9	
36-40	1		3	
41-45	1		4	
46-50	1		2	
51-55	1	6%	5	23%
56-60	3		5	
61-65	4		3	
66-70	5		3	
71-75	8		1	
76-80	16		12	
81-85	20	87%	8	39%
86-90	17		2	
91-95	17		2	
96-100	1		0	
Total	n = 101	100%	n = 79	100%

Appendix 8. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: U.S. Forest Service canopy closure classes Ponderosa ecosystem with a Gambel oak inclusion.

Canopy closure class	% canopy closure	% bedsite plots/% satellite plots			Relative acre value		
a	10 - 40	7/41	=	0.171	2.231/.171	=	13.0
b	41 - 60	6/20	=	0.300	2.231/.300	=	7.4
c	61 - 100	87/39	=	2.231	2.231/2.231	=	1

Appendix 9. Frequency of occurrence of bedsites and satellite plots within U.S. Forest Service canopy closure classes: P/J ecosystem.

% Canopy Closure	No. Bedsites		No. Satellite Plots	
0-5	0		13	
6-10	1	2%	13	81 %
11-15	0		3	
16-20	0		5	
21-25	0		4	
26-30	0		2	
31-35	0		1	
36-40	0		1	
41-45	0	8%	3	14%
46-50	0		0	
51-55	1		2	
56-60	4		0	
61-65	1	90%	0	5%
66-70	7		0	
71-75	11		1	
76-80	4		1	
81-85	14		0	
86-90	10		0	
91-95	10		0	
96-100	0		0	
Total	n = 63	100%	n = 36	100%

Appendix 10. Ratios of percent use of canopy closure levels (bedsite plots) to habitat availability: U.S. Forest Service canopy closure classes P/J ecosystem.

Canopy closure class	% canopy closure	% bedsite plots/%satellite plots	Relative acre value
a	10 - 40	2/81 = 0.025	18.0/.025 = 720.0
b	41 - 60	8/14 = 0.571	18.0/0.571 = 31.5
c	61 - 100	90/5 = 18.000	18.0/18.0 = 1

Appendix 11. Frequency distribution of SDI values from 86 mid-day bedsites in ponderosa pine. Mean = 423.3, SD = 200.1. (Data collected on 16.7 ft. radius plots)

SDI value	%	Cum. %	SDI value	%	Cum.%
76.8	1.2	1.2	406.4	1.2	51.2
79.6	1.2	2.3	410.8	1.2	52.3
118.4	1.2	3.5	412.7	1.2	53.5
149.0	1.2	4.7	414.5	1.2	54.7
189.7	1.2	5.8	422.6	1.2	55.8
205.5	1.2	7.0	427.6	1.2	57.0
206.6	1.2	8.1	429.7	1.2	58.1
208.0	1.2	9.3	438.2	1.2	59.3
210.9	1.2	10.5	438.3	1.2	60.5
223.1	1.2	11.6	438.4	1.2	61.6
226.9	1.2	12.8	444.2	1.2	62.8
235.5	1.2	14.0	444.6	1.2	64.0
236.5	1.2	15.1	451.5	1.2	65.1
248.2	1.2	16.3	452.3	1.2	66.3
263.9	1.2	17.4	465.8	1.2	67.4
271.6	1.2	18.6	466.5	1.2	68.6
279.9	1.2	19.8	476.6	1.2	69.8
281.5	1.2	20.9	479.3	1.2	70.9
290.9	1.2	22.1	482.8	1.2	72.1
293.2	1.2	23.3	483.3	1.2	73.3
293.6	1.2	24.4	501.9	1.2	74.4
295.7	1.2	25.6	508.2	1.2	75.6
297.4	1.2	26.7	514.9	1.2	76.7
303.2	1.2	27.9	517.7	1.2	77.9
315.7	1.2	29.1	523.0	1.2	79.1
322.7	1.2	30.2	539.3	1.2	80.2
323.0	1.2	31.4	575.9	1.2	81.4
325.5	1.2	32.6	582.9	1.2	82.6
328.5	1.2	33.7	588.7	1.2	83.7
329.5	1.2	34.9	588.2	1.2	84.9
353.9	1.2	36.0	597.4	1.2	86.0
357.0	1.2	37.2	599.7	1.2	87.2
363.5	1.2	38.4	604.3	1.2	88.4
366.4	1.2	39.5	607.2	1.2	89.5
369.0	1.2	40.7	607.6	1.2	90.7
369.5	1.2	41.9	617.6	1.2	91.9
385.6	1.2	43.0	656.9	1.2	93.0
385.9	1.2	44.2	709.8	1.2	94.2
389.1	1.2	45.3	727.2	1.2	95.3
394.1	1.2	46.5	751.8	1.2	96.5
396.3	1.2	47.7	787.9	1.2	97.7
403.3	1.2	48.8	939.0	1.2	98.8
404.7	1.2	50.0	1513.2	1.2	100.0

Appendix 12. Frequency distribution of basal area values from 86 mid-day bedsites in ponderosa pine. Mean = 210.2, SD = 131.2 (Data collected on 16.7 ft. radius plots)

Basal area value	%	Cum. %	Basal area value	%	Cum %
26.4	1.2	1.2	190.5	1.2	51.2
41.0	1.2	2.3	191.8	1.2	52.3
45.0	1.2	3.5	192.7	1.2	53.5
81.1	1.2	4.7	195.6	1.2	54.7
81.1	1.2	5.8	196.0	1.2	55.8
83.1	1.2	7.0	196.4	1.2	57.0
86.9	1.2	8.1	196.5	1.2	58.1
96.6	1.2	9.3	197.8	1.2	59.3
103.5	1.2	10.5	198.9	1.2	60.5
105.3	1.2	11.6	200.0	1.2	61.6
105.9	1.2	12.8	208.0	1.2	62.8
11.0	1.2	14.0	210.4	1.2	64.0
116.7	1.2	15.1	211.1	1.2	65.0
118.3	1.2	16.3	216.9	1.2	66.3
140.2	1.2	17.4	222.1	1.2	67.4
142.2	1.2	18.6	224.7	1.2	68.6
147.7	1.2	19.8	226.2	1.2	69.8
148.6	1.2	20.9	229.9	1.2	70.9
149.9	1.2	22.1	231.7	1.2	72.1
150.6	1.2	23.3	234.5	1.2	73.3
151.9	1.2	24.4	235.8	1.2	74.4
153.0	1.2	25.6	239.9	1.2	75.6
154.7	1.2	26.7	244.2	1.2	76.7
157.5	1.2	27.9	258.7	1.2	77.9
158.9	1.2	29.1	266.4	1.2	79.1
159.2	1.2	30.2	267.5	1.2	80.2
159.5	1.2	31.4	269.0	1.2	81.4
161.3	1.2	32.6	280.7	1.2	82.6
167.0	1.2	33.7	287.0	1.2	83.7
169.2	1.2	34.9	288.4	1.2	84.9
171.4	1.2	36.0	293.9	1.2	86.0
173.7	1.2	37.2	297.1	1.2	87.2
174.4	1.2	38.4	301.1	1.2	88.4
175.2	1.2	39.5	302.7	1.2	89.5
175.7	1.2	40.7	302.9	1.2	90.7
176.7	1.2	41.9	304.2	1.2	91.9
177.8	1.2	43.0	304.4	1.2	93.0
180.4	1.2	44.2	316.2	1.2	94.2
182.3	1.2	45.3	322.6	1.2	95.3
183.9	1.2	46.5	366.3	1.2	96.5
185.2	1.2	47.7	415.7	1.2	97.7
187.2	1.2	48.8	615.5	1.2	98.8
187.8	1.2	50.0	1117.6	1.2	100.0

Appendix 13. Frequency distribution of SDI values from 23 mid-day bedsites in Gambel oak/Locust association. Mean = 422.8, SD = 233.2 (Data collected on 16.7 ft. radius plots)

SDI value	%	Cum. %
13.2	4.3	4.3
53.6	4.3	8.7
163.0	4.3	13.0
246.3	4.3	17.4
277.1	4.3	21.7
286.8	4.3	26.1
297.7	4.3	30.4
298.2	4.3	34.8
312.7	4.3	39.1
351.6	4.3	43.5
372.8	4.3	47.8
383.9	4.3	52.2
398.9	4.3	56.5
414.1	4.3	60.9
457.2	4.3	65.2
494.8	4.3	69.6
498.1	4.3	73.9
562.2	4.3	78.8
588.3	4.3	82.6
724.5	4.3	87.0
738.5	4.3	91.3
843.8	4.3	95.7
946.4	4.3	100.0

Appendix 14. Frequency distribution of basal area values from 23 mid-day bedsites in Gambel oak/Locust association. Mean = 181.3, SD = 100.3 (Data collected on 16.7 ft. radius plots)

Basal area value	%	Cum. %
2.5	4.3	4.3
21.0	4.3	8.7
52.9	4.3	13.0
94.7	4.3	17.4
115.9	4.3	21.7
117.5	4.3	26.1
128.9	4.3	30.4
147.4	4.3	34.8
147.7	4.3	39.1
165.1	4.3	43.5
165.2	4.3	47.8
172.3	4.3	52.2
180.3	4.3	56.5
183.8	4.3	60.9
197.8	4.3	65.2
209.8	4.3	69.6
213.8	4.3	73.9
223.6	4.3	78.3
236.3	4.3	82.6
294.5	4.3	87.0
342.5	4.3	91.3
343.3	4.3	95.7
413.4	4.3	100.0

Appendix 15. Letter to Carl Edminster, Rocky Mountain Forest and Range Experiment Station.

United States Department of Agriculture | *Forest Service* | *Rocky Mountain Forest and Range Experiment Station* | *222 South 22nd St. Laramie, WY 82070-5299*

Reply to: 4200

Date: 9 September 1992

Carl Edminster
Rocky Mountain Forest and Range Experiment Station
240 West Prospect Road
Fort Collins, CO 80526-2098

Dear Carl,

I have spent two days sampling habitat characteristics at goshawk nest sites. Using the procedures we agreed on, it takes approximately 4 hr for two people to sample a site. I do have one question concerning the measurement of canopy closure.

For the first couple of sites, I measured canopy closure using a modified densiometer mounted on a tripod (see attached) and by using line intercept sampling, as you suggested, I used a clinometer to delineate the vertical projection for line-intercept sampling. I wasn't sure if I should count densiometer "hits" on tree trunks as canopy closure. So for four sites, I took three canopy cover measurements- densiometer readings of all vegetation (foliage and tree trunks), densiometer readings of foliage only (tree trunks excluded), and line intercept sampling (all vegetation, but tree trunks have minimal affect since the projection is so vertical). These techniques yielded the following data (sample plots averaged per site):

Site	*Densiometer (all veg)*	*Densiometer (foliage only)*	*Line-intercept Sampling*
Nest 3	*76.3%*	*63.4%*	*59.1%*
Nest 14	*81.1*	*69.2*	*69.7*
Random pt. 14	*75.4*	*66.9*	*68.9*
Random pt. 9	*77.0*	*71.8*	*79.8*
Average	*77.5*	*67.8*	*69.4*

I also tested for differences among the techniques using t-tests (I realize I am violating some assumptions of this test by testing percentages) and Mann-Whitney tests. I considered the sample plot the sampling unit (n=35). Statistical tests indicated that densiometer readings using all vegetation hits were significantly different from foliage-only densiometer readings (see attached). Foliage-only densiometer readings and line-intercept sampling estimates were statistically similar.

(continued)

Appendix 15. (continued)

When most foresters use densiometers to estimate canopy closure, do they consider hits on tree trunks as canopy cover? If they do, it appears they may overestimate canopy closure if we assume line-intercept sampling is the accurate comparison. I am not well versed in the forestry literature. Would comparisons between densiometer and line-intercept sampling be of interest to foresters in the form of a published, short note? If not, I will only measure canopy coverage using line-intercept sampling.

If you would like to come out into the field, feel free to contact me. We will be measuring sites all this month.

Best Regards,

(Signed) *John Squires*

Appendix 16. Abstract from winter cover report prepared by Margaret L. Abbott, Northern Arizona University, August 1991.

ABSTRACT
STRUCTURAL CHARACTERISTICS OF COVER ON ELK WINTER RANGE IN NORTH CENTRAL ARIZONA

Demand for forest products from pinyon juniper woodlands that occur on elk winter range in north central Arizona has caused concern among wildlife managers. Research on elk thermal and hiding cover on winter range was needed to provide information for managers to assess the effects of timber and fuelwood harvests on elk habitat capability. In this study, structural characteristics of cover were measured on microsites centered on elk bedding sites in two vegetation types on a 20 mi^2 study area approximately 35 mi south of Flagstaff, Arizona. No significant difference was found in tree density between the two vegetation types. Mean basal area was high for both types: 203 ft^2/ac for the ponderosa pine and 250 ft^2/ac for Utah juniper, but did not differ significantly. Canopy cover averaged 80% on microsites. Two species of juniper had the major influence on microsite structure. The majority of elk beds (78%) were associated with either Utah or alligator juniper. The mean drc of bed trees was 28 inches. Large trees were commonly found on microsites. Mean diameter for the largest tree/microsite was 38 inches. Several patterns in elk bedsite selection suggest that cover may not be selected with thermal regulation as a key factor on winter range. The distance from the bed tree (6 ft) was not related to tree size. Elk did not select interlocking crowns of trees out of proportion to abundance on microsites. Elk showed no association with aspect in bedsite or microsite selection. Microsites typically contained clusters of trees which could provide either hiding and thermal cover. Cluster cover could account for most of the cover selected by elk on this study site and is recommended as an easily developed, useful guideline for elks' winter range in north central Arizona. In compliance with USFS guidelines, 40% cover delineated to include tree clusters would benefit elk more than 40% of a forested area at a uniformly specified density.

NOTES

Brown, R.L. 1994. **Effects of Timber Management Practices on Elk**, Arizona Game and Fish Dept., Tech. Rpt. No. 10. 70pp.

Abstract: Thirty-seven radio-telemetered elk *(Cervus elaphus nelsoni)* were located at bedsites between 10:30 AM and 3:30 PM during June through August of 1988, 1989, and 1990. Standard silvicultural measurements were recorded at the bedsites and at associated satellite plots. The latter provided a measure of habitat availability in proximity to the bedsites. Two habitat types were examined; ponderosa pine (*Pinus ponderosa*) with a Gambel oak (*Quercus gambelii*) inclusion, and a woodland association of pinyon pine (*Pinus edulis*) and juniper (*Juniperus spp.*). A discriminant function was developed for both habitat types combined that correctly classified about 90% of the bedsites. Elk selected bedsites in areas with higher canopy closure, greater total dbh, few limbs below 6.5 ft, and clear of rocks. Optimum thermal cover habitat was composed of stands between 30 A and 60 A, with a canopy closure exceeding 70%. Average tree heights in these covers equaled or exceeded 17 ft for ponderosa and 11 ft for P/J woodland. Distance to lowest limb requirements were automatically met in the ponderosa type due to normal self pruning. The discriminant analysis selected this requirement only for the P/J woodland where this characteristic was dependent upon the presence of mature trees. These data were then used to generate tables describing moderate and optimal bedsite characteristics in terms of standard silvicultural criteria. There was not a high degree of correlation between either basal area or stand density index values and canopy closure levels. These values are poor predictors of canopy closure in ponderosa forest and are unusable for this purpose in P/J woodland. The U.S. Forest Service R03WILD (WESTWILD) habitat capability model was therefore found to be unreliable in its present form for classifying elk habitat. This unreliability was due in part to the low potential for structural stage data, or their derivatives, to accurately reflect canopy closure levels. Additionally, the model's fractional acre matrix values were in disagreement with our findings.

Key Words: Arizona, bedsites, calving habitat, *Cervus elaphus*, elk, habitat use, *Pinus Ponderosa*, ponderosa pine

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