Population Attributes of Black Bear in Relation with Douglas-fir Damage on the Hoopa Valley Reservation, California

by

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ABSTRACT

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Black bear (*Ursus americanus*) ecology contributes to the presence and intensity of bear damage in managed timber stands. Black bear densities, sex ratios, age estimates, and use of available vegetation were quantified and compared between an area of high and an area low intensity of observed bear damage on Douglas-fir (*Pseudotsuga menziesii*) trees on the Hoopa Valley Reservation, Humboldt County, California. The effects of diameter at breast height (dbh), crown class, crown ratio, thinning, and timber harvest on the presence or absence of bear damage were also quantified.

Forty black bear (19 males, 17 females, and 4 not sexed) were captured on the two study sites. Black bear density was significantly greater on the study site with more damage (1.77 bears/km^2 with a 95% confidence interval of 1.05-1.85 bears/km^2) compared to bear density on the study site with less damage (0.43 bears/km^2 with a 95% confidence interval of 0.17-0.50 bears/km^2). Sex ratios were not significantly different between the two sites or from the expected 50:50 ratio ($p > 0.05$). Age estimates were not significantly different between the two study sites for either males or females ($p > 0.05$). Bear use of available vegetation was similar between the two study sites. One female on each site used managed areas significantly more than their availability and unmanaged areas significantly less than their availability. All other radio-collared bears used managed and unmanaged areas equal to their availability. No significant differences in bear condition were found to suggest food stress in either sex between the two study sites using bear weight, body length, physical condition, and home range size ($p > 0.05$).

Douglas-fir trees with large diameters, high crown classes, and large crown ratios were significantly more likely to be damaged by bears than other trees ($p < 0.001$). The two study sites had significantly different intensities of damage ($p = 0.004$). Bear-related tree damage was significantly greater in thinned compared to unthinned areas on the study site with more damage ($p = 0.019$). Tree damage was not significantly different between thinned and unthinned areas on the study site with less damage ($p = 0.144$). Tree damage was significantly greater in managed compared to unmanaged areas on both study sites ($p < 0.026$).

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INTRODUCTION

Damage by black bear (*Ursus americanus*) to timber managed for harvest is a significant concern in managed forests of western North America (Glover 1955, Maser 1967, Poelker and Hartwell 1973, Mason and Adams 1989). Bears peel bark from trees in order to make the sapwood layer available for consumption and may affect the tree's growth and timber-market value (Glover 1955, Maser 1967, Poelker and Hartwell 1973, Mason 1985). Presence and intensity of damage has been found to vary with individual trees and timber-stand characteristics, and less conclusively by factors associated with bears (Moore 1940, Lauckhart 1956, Pierson 1966, Maser 1967, Hartwell 1973, Poelker and Hartwell 1973, Furubayshi et al. 1977, Mason 1985, Mason and Adams 1989, Hosack 1990).

The presence and intensity of bear-related tree damage is related to tree species. Bears commonly damage a number of tree species within a given geographic area, but demonstrate a preference for at least one of the available species (Mason 1985). Pierson (1966) and Poelker and Hartwell (1973) found 14 conifer and 5 hardwood species were damaged in Washington. Douglas-fir (*Pseudotsuga menziessii*), even when not the dominant species in a stand, was used more than available, particularly west of the Cascades in Oregon and Washington (Mason 1985, Stewart 1999). However, Glover (1955) reported bears used redwood (*Sequoia sempervirens*) more than Douglas-fir in coastal Humboldt County, California.

Density of trees in the stand was also a factor in the presence and intensity of damage. Faster growing trees with greater crown ratios in stands with comparatively fewer trees per hectare were damaged more frequently (Mason 1985). Brown (1950) found 54 and 73% of Douglas-fir trees to be damaged in stands with 148 stems/ha and 56 stems/ha, respectively. The silvicultural treatment of thinning, or the removal of competing shrubs, hardwoods, and subdominant conifers has been used to stimulate the growth of the dominant conifers; this reduces stand density and increases the intensity of bear damage. Ray (1941) calculated that 90% of balsam fir (*Abies balsamea*) were damaged in a stand following the thinning of competing hardwoods. Conversely, he found no damage on an adjacent, unthinned stand. Schmidt (1987) identified a similar pattern in western Montana, where 70% of western larch (*Larix occidentalis*) in thinned stands were damaged, but no damage was observed in unthinned stands. Mason and Adams (1989) reported damage to be up to three times greater in thinned than in otherwise similar but unthinned stands of mixed conifer in Montana. Douglas-fir and redwood trees with full crowns were reported to have more vigorous growth rates and were more likely to be damaged (Fritz 1951, Glover 1955, Maser 1967, Hartwell 1973, Abbott 1994). Maser (1967) found that bear damage did not occur in stands where tree density was sufficient to reduce the crown to approximately one-half the length of the trunk.

Damage by bears occurs over a wide range of tree ages and diameters (Mason 1985). However, use of certain age and diameter classes have been related to species, geographic location, stand density, and tree vigor conditions (Mason 1985). Glover (1955), Molnar and McMinn (1960), and Schmidt (1987) found 10 to 30 year-old redwood, 21 to 45 year-old western white pine (*Pinus monticola*), and the largest 25 to

35 year-old western larch to be the most often damaged age classes by black bear, respectively. Poelker and Hartwell (1973) found the 20 to 40 year-old Douglas-fir to be damaged at least 10 times more frequently than any other age class and the 15 to 38 cm diameter size class to include the majority of observed damage. Mason and Adams (1989) reported 85% of observed damage occurred in 10 to 20 cm diameter stands of lodgepole pine (*Pinus contorta*) and Engelmann spruce (*Picea engelmannii*). In second-growth conifer stands, the mean diameter of damaged trees ranged from 29.2 ± 0.9 cm to 74.6 ± 1.7 cm; the extreme measures were redwood trees (Hosack 1990).

Variation in bear behavior may also contribute to the presence and intensity of damage. However, the evidence for this relationship is limited and, in some cases, contradictory. Lauckhart (1956), Maser (1967), and Furubayshi et al. (1977) argued that the principle reason for the presence of damage was a decrease in the availability of natural food sources. Poelker and Hartwell (1973) found both males and females ranged greater distances in areas with damage compared to bears in areas without damage. They suggested that this behavior was reflective of a shortage of food items and more intensive searching for food in the areas with damage. They examined evidence of food stress in the areas with damage by comparing bear weight, body length, and physical condition to areas where damage was not observed; however no differences in bear conditions were found. Conversely, Pierson (1966) found bears in areas with damage were generally smaller in skeletal size and weight, in poorer physical condition, and had lower reproductive rates. He also reported that as the intensity of damage decreased, bear physical condition improved. Poelker and Hartwell (1973) calculated density at or slightly greater than 0.53 black bear per km^2 of available bear habitat. However, densities were not compared between their damaged and non-damaged areas. Moore (1940) suggested that the propensity to cause damage is a learned behavior. He questioned whether damage was the result of poor food sources, and used the logic that the bears were present throughout second growth stands, but damage was localized. Maser (1967) presented a similar argument based on the logic that not every bear in a given area would damage trees.

My objective was to describe and compare bear populations between areas with differing levels of bear-related tree damage. I first needed to quantify the amount of bear-related tree damage to demonstrate different levels of damage in the two areas. Next, I needed to measure attributes of the bear populations (density, sex ratios, and age structure) and how these bears used the available vegetation. Although methods of calculating population abundance have been presented for large carnivores (Otis et al. 1978, Seber 1982, Pollock et al. 1990), the calculation of density is problematic because of the difficulty of bounding the population estimate. Abundance alone is inadequate as a measure to compare between localized areas. I developed a methodology to estimate population size for wide ranging carnivores in order to compare bear densities between the areas. Like Poelker and Hartwell (1973), I also measured bear weight, body length, physical condition, and home range size to suggest nutritional condition. The attributes of the bear populations were considered potential factors related to the presence and intensity of bear damage in managed timber stands in conjunction with individual tree and timber stand characteristics. I compared differences existing in these bear populations between the area of high and the area low intensities of bear-related tree damage on the Hoopa Valley Reservation in northern California.

STUDY AREA

The Hoopa Valley Reservation (hereafter Reservation), Humboldt County, California (Figure 1), is located in the Klamath mountains. The area of the Reservation is approximately 356 km^2. Elevation within the reservation ranges between 98 and 1170 m.

Annual maximum and minimum temperatures averaged 20.8 and 6.7° C between 1963 and 1983 (National Oceanic & Atmospheric Administration – Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center 1983). Annual total precipitation and snowfall averaged 148.4 and 4.3 cm between 1963 and 1983 (National Oceanic & Atmospheric Administration – Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center 1983).

Approximately 339 km^2 of the Reservation were forested, generally with Douglas fir, tanoak (*Lithocarpus densiflorus*) and madrone (*Arbutus menziesii*). Other forested areas included Oregon white oak (*Quercus garryana*) and California black oak (*Quercus kelloggii*) stands which generally lined the east side of the valley. White fir (*Abies concolor*) dominated mixed conifer at higher elevations along the eastern boundary of the Reservation. Big leaf maple (*Acer macrophyllum*), incense-cedar (*Calocedrus decurrens*), Port Orford-cedar (*Chamaecyparis lawsoniana*), chinquapin (*Chrysolepis chrysophylla*), Jeffrey pine (*Pinus jeffreyii*), sugar pine (*P. lambertiana*), western white pine (*P. monticolia*), knobcone pine (*P. attenuata*) ponderosa pine (*P. ponderosa*), Pacific yew (*Taxus brevifolia*), mountain dogwood (*Cornus nuttallii*), willow (*Salix* sp.), and

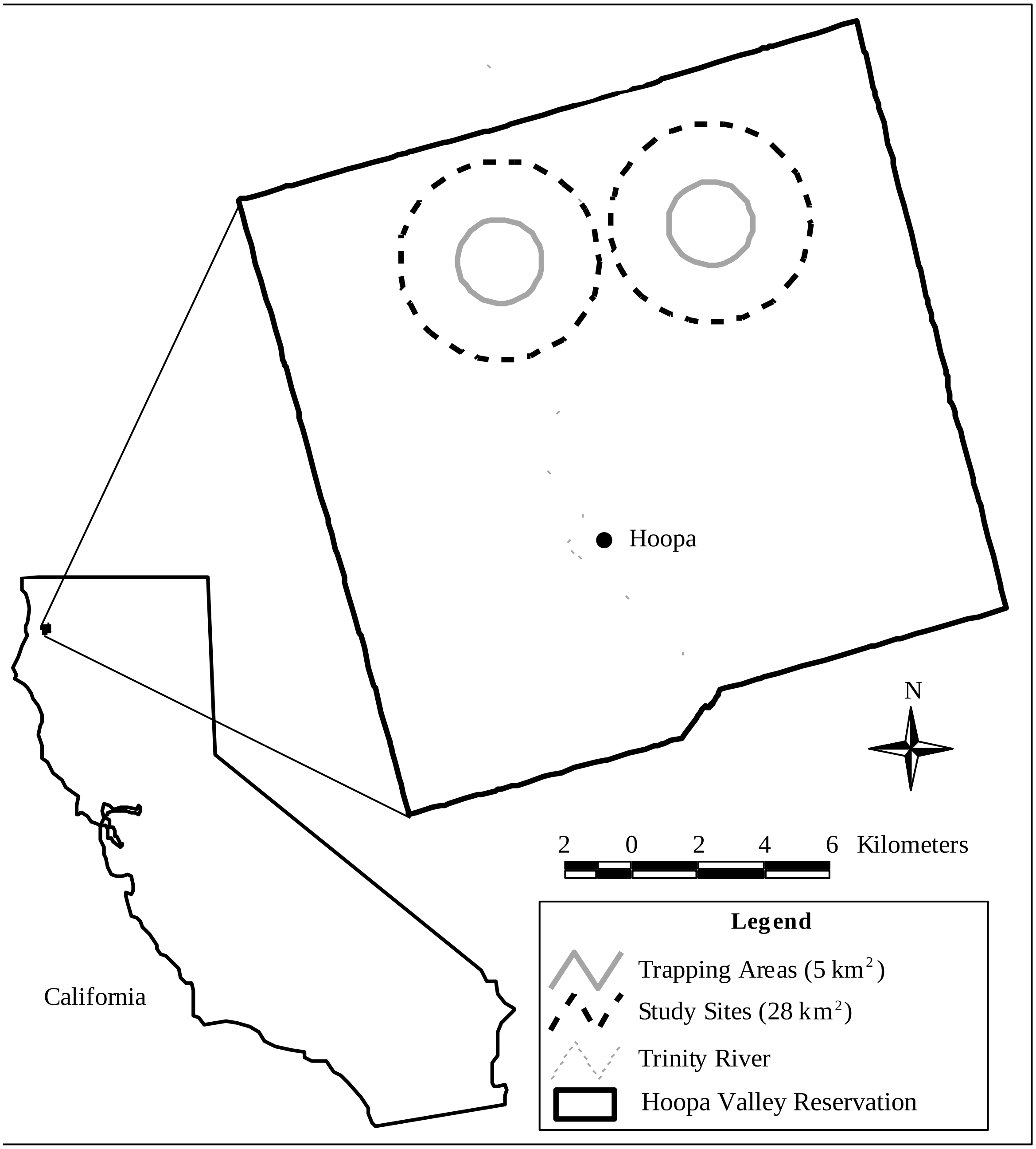

Figure 1. Map of the two study sites and trapping areas used to compare attributes of black bear-related damage on Douglas-fir trees and black bear population variables on the Hoopa Valley Reservation, Humboldt county, California.

canyon live oak (*Quercus chrysolepis*) occurred within riparian zones and were sporadically scattered throughout the Reservation. The shrub layer was generally dominated by evergreen huckleberry (*Vaccinium ovatum*), tobacco brush (*Ceanothus velutinus*), or salal (*Gaultheria shallon*). The non-forested areas on the Reservation were made up of urban areas, natural prairies, large rock outcrops, and brush fields which are sporadically distributed through the otherwise forested landscape.

Timber harvest on the Reservation began in the mid 1940's and became intensive in the late 1950's. Of the 339 km^2 of forested land, the Reservation contained approximately 305 km^2 of commercial timberland with about 1.2 billion board feet of commercially important timber species. By 1994, intensive timber harvest reduced the extent of mature and old growth forest by approximately 49% of historic levels. Timber harvest practices on the Reservation included cable yarding (about 60% of operation) and ground logging systems (about 40% of operation). Prior to 1990, the primary timber harvest method was clear cutting with an average unit size of 18.2 hectares and a range of <1 – 276 hectares. These historic practices of the 1970's and 1980's varied substantially in the number of residual trees left from the original vegetation. Since 1990, the size of clear cuts has been limited to 4 hectares. This modified form of clear cutting left residual trees from the original vegetation, including culls, snags, hardwoods and fast growing conifers.

Tree damage by bears was first observed in the northwest corner of the Reservation in 1977 and a survey for bear-damaged trees was conducted in July 1990 (Abbott 1994). Abbott (1994) categorized damage intensities on the Reservation based on the percent of the tree circumference damaged. He reported 41.7% of measured trees to have some damage. The northeast corner of the Reservation had no observed damage until the spring of 1998, and had been categorized as low (Higley 1998, personal communication). Additionally, the Hoopa Valley black bear population was not hunted because of its cultural significance to the Hupa people (Higley 1998, personal communication). Thus, the Hoopa Valley provided an unmanaged and unstudied black bear population occupying an area of historic and high intensity of damage and an area of low intensity of damage in a managed Douglas-fir forest.

Two study sites were selected, one in the northwest corner of the reservation, an area with historic damage, and the other in the northeast corner of the reservation, an area without historic damage (Figure 1). Selection of these sites was based on selecting two areas with varying intensities of bear-related tree damage but approximately equal elevation ranges, elevation of center points, total meters of roads, total meters of creeks, and areas of similar managed timber stand types and ages.

MATERIALS AND METHODS

I quantified the differences in damage on the two study sites before I compared the bear population-attributes of density, sex ratios, age structure, the use of available vegetation, bear weight, body length, physical condition, and home range size between areas of high and low intensity of bear-related tree damage. A random selection of areas with similar timber harvest and management histories were selected using a geographic information system (GIS, ArcView 3.2, Environmental Systems Research Institute, Inc., Redlands, CA). Damage was surveyed using 0.04 ha circular plots. The species, diameter at breast height (hereafter dbh), crown class, and crown ratio (to determine the influence of tree vigor) of all trees within the circular plots were measured.

I developed a methodology for estimating bear density and confidence intervals in order to compare density estimates between the two study sites. This density estimator was based on a mark-sight design based on the Petersen mark-recapture methodology to estimate abundance (Otis et al. 1978, Seber 1982, Pollock et al. 1990). The developed mark-sight design required that bears first be captured in order to be marked and radio collared. The marking of individual bears was required for future individual identification during the sighting period which followed the capture and marking period. Radio collaring individual bears on each study site was required to estimate the time a bear was on each study site during the sighting period. This methodology provided an estimation of the proportional number of bears within the bounded area of sampling in order to convert the abundance estimate into a density estimate. I also used radio telemetry relocations of collared bears to generate and compare estimates of home range size and frequency of use of available vegetation between the two study sites. Capturing bears also allowed for the collection of sex, age, weight, length, and physical condition for comparison between the two sites.

Tree Damage

Tree damage surveys were conducted during the summer of 1999 within areas that were available for use by the bear populations at the two study sites (centered on the two areas where bear trapping was conducted). These areas were buffered by the average home range size of the bears on each study site. Home range sizes were calculated using the minimum convex polygon estimator (Worton 1987, Harris et al. 1990). This resulted in 23 km^2 of available habitat on the site without historic damage and 18 km^2 of available habitat on the site with historic damage. The 23 and 18 km^2 areas were stratified into vegetation polygons of similar timber harvesting and thinning histories. Vegetation classification, ground truthing, and GIS development of vegetation polygons was done by Hoopa Tribal Forestry personnel (Hoopa Valley Tribal Council, Natural Resources Department, Forestry Division 1998). The GIS development of the vegetation polygons used 1:12,000 color air photo stereographic vegetation interpretation, which was transferred to 1:24,000 mylars, and then the vegetation polygons and their attributes were digitized into a GIS (ArcInfo, Environmental Systems Research Institute, Inc., Redlands, CA). The vegetation polygons used in the bear-related tree damage analysis were classified as naturally occurring young growth; thinned or unthinned harvested areas less than 15 years old;

thinned and unthinned harvested areas between 15 and 29 years old; thinned and unthinned harvested areas greater than or equal to 30 years old; old growth; and non forested areas. Naturally occurring young growth, old growth, and non forested vegetation polygons were not managed for timber production. Based on the finding of Ray (1941) and Schmidt (1987), they were assumed to have no bear damage and were not surveyed.

Each vegetation polygon that was surveyed for bear-related tree damage on the two study sites was randomly selected, with approximately equal areas of each vegetation class surveyed. A random point was placed within each vegetation polygon that was surveyed using a GIS. Then the longest possible transect was drawn through the random point within the vegetation polygon (Figure 2). The number of 0.04 ha circular plots required to generate a two percent sample of the area were positioned equidistantly along the transect. The total number of conifer and hardwood trees were tallied in each of 0.04 ha plots. In the first, every fifth, and each plot where bear-related tree damage was observed along the transect, the species, dbh, crown class, crown ratio, and the presence or absence of bear-related tree damage for each tree greater than 7.62 cm dbh were recorded. Crown class was defined as the relative position of the tree crown within the canopy compared to neighboring trees and was categorized as dominant, co-dominant, intermediate, or suppressed (Appendix A) (Abbott 1994). Crown ratio was defined as the percentage of the tree trunk that had branches with green needles and was recorded to the nearest 5 percent. The influence of diameter, crown class, and crown ratio on whether or not Douglas-fir was damaged by black bears

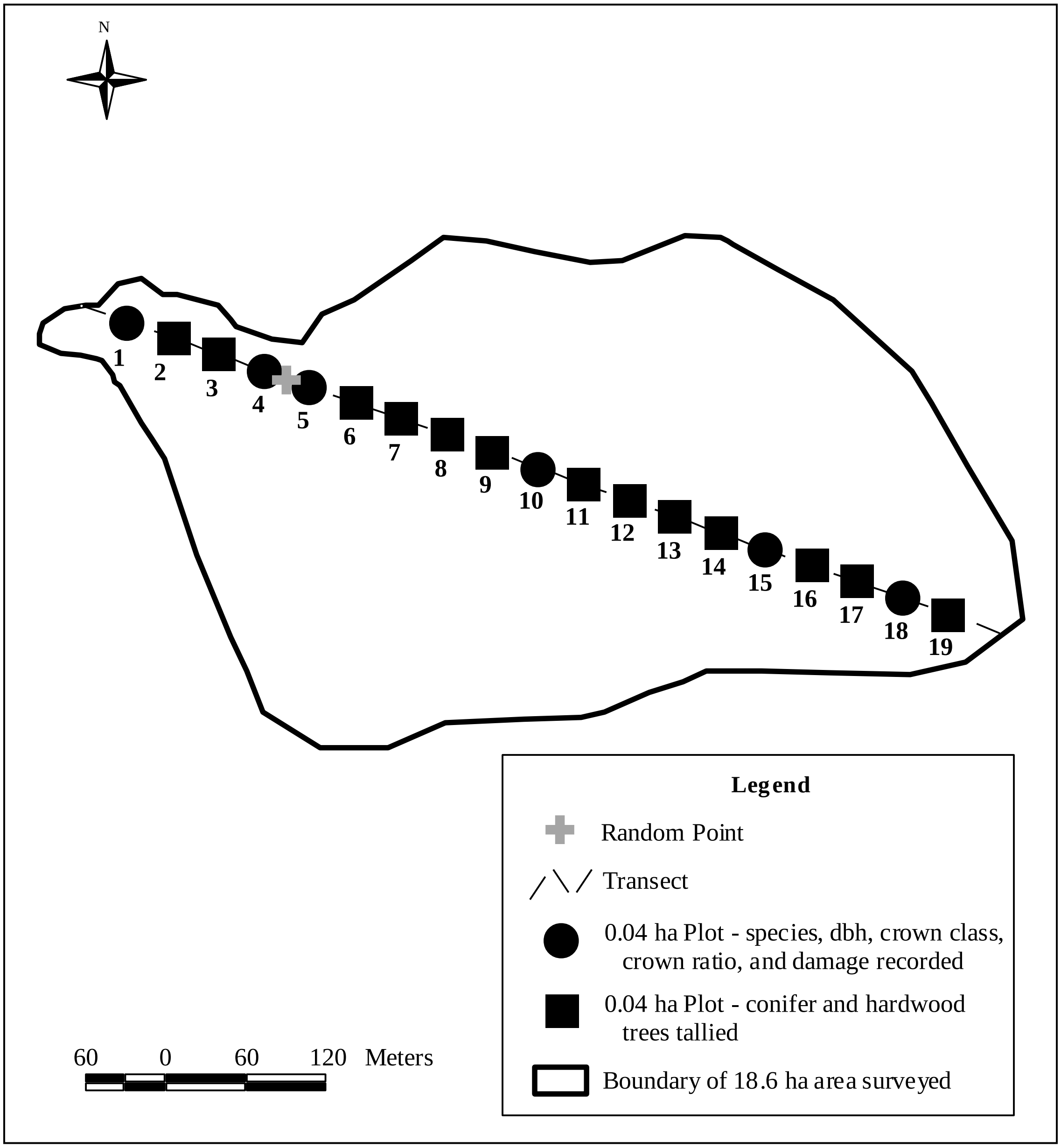

Figure 2. An example of the placement of 0.04 ha plots used to survey vegetation types for bear-related tree damage on the Hoopa Valley Reservation, California during the summer of 1999. In using 19 of the 0.04 ha plots, 4% of the 18.6 ha vegetation type was surveyed. Plots 1, 5, 10, and 15 were predetermined to be used to measure species, dbh, crown class, crown ratio, and damage presence of each tree greater than 7.62 cm dbh. Because damage was observed in plots 4 and 18, species, dbh, crown class, crown ratio, and damage presence of each tree greater than 7.62 cm dbh were recorded. Only tallies of conifer and hardwood trees were recorded in the remaining plots in which damaged was not observed.

was analyzed with a forward and backward stepwise logistic regression procedure (NCSS 2000; NCSS, Kaysville, Utah). Differences in recorded intensities of bear-related tree damage between vegetation classes within and between the 23 and 18 km^2 areas were analyzed with an analysis of variance (ANOVA) procedure (NCSS 2000). The percentages of damaged trees in the vegetation classes were not normally distributed. The percentages of damaged trees were pooled across vegetation polygons within each site. Mann-Whitney U test (NCSS 2000) was used to determine if a significant difference in the intensities of damage existed between the two sites and to determine the influence of thinning on the two sites. A Wilcoxon Signed-Rank test (NCSS 2000) was used to determine if the recorded intensities of damage in the managed vegetation polygons on the two sites were significantly greater than the assumed damage level of zero for the young growth, old growth, and non-forested vegetation polygons.

Bear Capture and Marking

In the center of each study site, a 5-km^2 trapping area was established (Figure 1). Ten trap locations were selected in each trapping area based on road availability and access, potential of the trap being noticed by the general public, terrain suitable for bear immobilization, and effective coverage of the trapping area. Four culvert traps were used, two dedicated to each area. Traps were baited with fish meat. Traps remained at each trap location for 8-10 nights, and were examined at approximately 0800 and 1600 h each day between 6 July and 24 September 1998.

Bears were immobilized using Telazol (300 mg/ml) with a jab stick delivery system, administered 2.95 to 6.8 mg/kg depending on the individual bear and capture conditions (Burton and Schmalenberger 1995). On some bears I used a 2:1 mix of Ketamine:Xylazine administered 2.0 mg/kg (Schroeder 1986, Golightly 1998, personal communication).

The first eight bears captured on the site without historic damage and the first seven bears captured on the site with historic damage that provided approximately equal sex ratios between the study sites were radio collared (Model 500, Telonics, Mesa, AZ). All captured animals were also tagged in each ear with colored and uniquely numbered Fearing Small Round Hog Litter Tags (Fearing Corporation, South St. Paul, Minnesota). Bears that were radio collared and ear tagged are hereafter referred to as collared bears. All subsequently captured bears received only ear tags. Bears that were only ear tagged and not radio collared are hereafter referred to as tagged bears. Each captured bear was photographed to aid in sighting effort identification.

Sighting Period

Arnason et al. (1991) defined marking and sighting experiments as population size estimation using an initial marking effort and subsequent sighting period to determine marked status. Camera stations were used to collect sightings of marked and unmarked bears during the sighting period. Sixteen camera stations were placed within the two trapping areas to provide photographic sighting records. Camera stations were examined every other day between 28 September and 5 November 1998.

The camera stations were made of 119 cm long and 38.7 cm diameter PVC culvert pipe with an infrared triggered camera at one end. This design was used to maximize the likelihood of obtaining a head on photograph of a bear. This led to more reliably determining the marked status and identifying individual bears by their ear tags. Eight locations were selected using a GIS. I established eight lines, each originating in the center of each trapping area and terminating at the outer edge, at 45 degree intervals starting at 0 degrees (Figure 3). The lines were rotated at a random rotation angle between 1 and 360 degrees. A camera station was placed at the location where each line crossed a road within the trapping area. If a line did not cross a road, the station was placed on the road nearest to the line within the trapping area. Locations selected for the camera stations were moved from the GIS assignment as much as 100 m so as to place each station on level ground and out of view of the public.

Density Estimator

In the simple Petersen method of population estimation a sample of the population is captured and marked, then a second sample is sighted and examined for marks (Seber 1982). The total number of animals sighted in the second sample divided by the proportion of marked animals sighted in the second sample gives the Petersen estimate of population size (Seber 1982, Bowden and Kufeld 1995). Bowden (1993) and Bowden and Kufeld (1995) presented a general statistical model for mark-sight experiments and analytical methods of constructing confidence intervals related to the generalized Petersen estimator for mark-sight data (White 1996). The Bowden model is an approximately unbiased estimator, with confidence intervals computed from the variance of the sighting frequencies of the marked animals (Bowden 1993, White 1996).

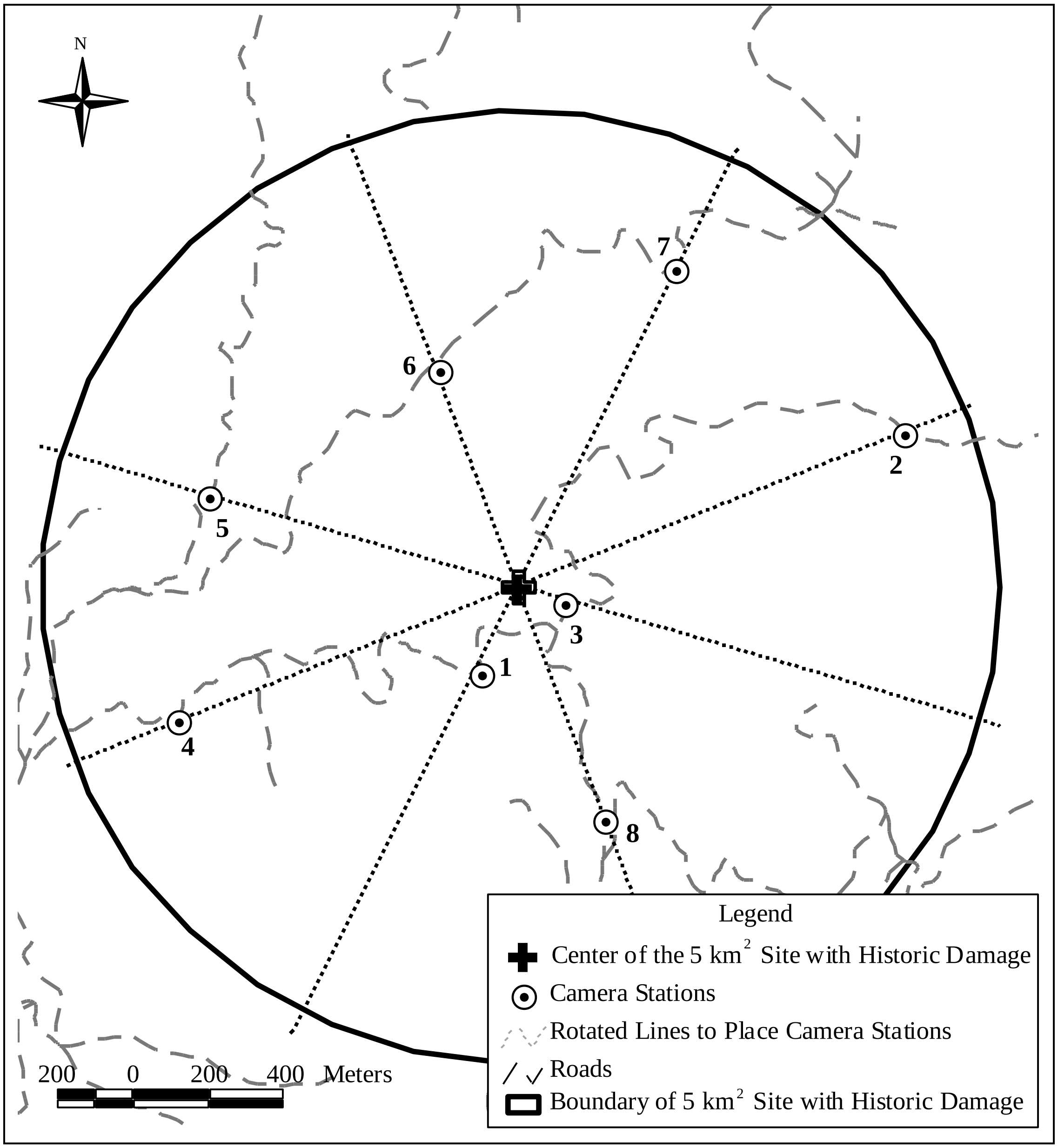

Figure 3. The initial 8 camera station locations on the west study site of the Hoopa Valley Reservation, California between 28 September and 5 November 1998. The eight lines originated in the center of the 5 km^2 area and terminated at the outer edge, at 45^o intervals starting at 0 degrees. The lines were rotated at a random rotation angle between 1 and 360^o. In this case, the rotation angle was 22^o clockwise. A camera station was placed at the location where each line crossed a road within the 5 km^2 area.

The resulting estimate from the Bowden model is the total population of individuals using the study area (abundance) and not an estimate of average density. Density requires a unit of area and defining an estimation of the bounded area of sampling is a problem for wide-ranging mammalian carnivores. In order to convert an abundance to a density estimator, Garshelis (1992) developed a technique to convert the Petersen abundance estimates to density. I applied this logic to the Bowden model. The basis of the Garshelis (1992) technique was to represent each individual as a proportion in the model based on the proportion of time spent in the study area rather than representing each individual as a full-time occupant. Thus, the bias of animals with large home ranges routinely crossing study area boundaries during the course of a mark-sight study was controlled (White et al. 1982, Garshelis 1992). Treating these individuals as full-time occupants during the sighting period would have overestimated density. The presence or absence of each collared animal relative to the trapping area during the sighting period was determined using a telemetry receiver (TR-4, Telonics, Mesa, AZ) and a hand-held yagi antenna (RAH-14, Telonics, Mesa, AZ) every other day during the sighting period. Each collared bear was then weighted by the proportion of time it spent on the trapping area during the sighting period (referred to as an animal-equivalent; Garshelis 1992). This weighting accounted for differing probabilities of sighting related to differing nights of trap exposure and a lack of geographic closure caused by movements across the study area boundaries (Garshelis 1992).

Individual animal-equivalents could not be calculated for all marked bears because some were only ear tagged and not radio collared. To determine animal-equivalents for the tagged bears, it was assumed that the proportion of time spent on the study area was similar for tagged and collared bears. The number of tagged bears minus the number of known mortalities was multiplied by the proportion of collared bears with animal-equivalents (AE) greater than 0 to determine the number of tagged bears available during the sighting period:

$$\#\, of\ tagged\ bears\, available \;=\; \frac{\#\, of\ collared\ bears\ with\ AE > 0}{\#\, of\ collared\ bears} \times \#\, of\ tagged\ bears \quad (1)$$

The calculated number of available tagged bears were assigned the mean animal-equivalent of the collared bears. If the calculations resulted in a fractional number of tagged bears available, the remaining fractional amount of tagged bear was multiplied to the average animal-equivalent and assigned to an additional tagged bear as its animal-equivalent. The remaining tagged bears that were not assigned an animal-equivalent were considered unavailable and assigned animal-equivalents of 0.

The two trapping areas were used to calculate the density estimates. A finite population of *N*, consisting of the *M* marked and the remaining *N*-*M* unmarked animals alive in the study sites at the beginning of the sighting period were defined in the density estimation model. The population was assumed to be demographically closed (i.e. no births or deaths of animals in the population) over the 5-week sighting effort. The model allowed each animal’s sighting probability to differ from the others. This sighting heterogeneity allowed the study area to be geographically open, in that some animals could have been off the study area on occasion(s), and hence have a zero sighting probability (White 1996).

Bowden and Kufeld (1995) further identified the following assumptions: (1) each *N* animal had an equal and independent chance of being marked; (2) marked animals were sighted without error; (3) the sighting effort resulted in at least one and preferably many and equal numbers of sightings of marked animals; (4) sighting of unmarked animals were determined without error and included only unmarked animals from the population of interest; and (5) capture and marking did not affect the sightability of marked animals during the sighting effort.

The Bowden model (with parameters expressed in notation presented by White 1996) and in terms of Garshelis starred (*) animal-equivalents to calculate density was (Bowden 1993, Bowden and Kufeld 1995, White 1996):

$$\hat{N}* = \frac{\left(\frac{u. + m.}{\overline{f}*}\right) + \hat{C}V_f^2*}{1 + \left(\frac{\hat{C}V_f^2*}{M*}\right)} \qquad (2)$$

where *u.* and *m.* were the total number of unmarked and marked animal sightings, respectively; $\overline{f}*$ was the mean number of times marked animals were sighted, which was the result of $\frac{m.}{M*}$ where *M** was the sum of marked animal-equivalents in the population at the time of the sighting period; and $\hat{C}V_f^2*$ was the variance of the sighting frequencies given that unidentified marked animals were sighted. $\hat{C}V_f^2*$ was calculated by:

$$\hat{C}V^{2}_{f}* = \frac{s^{2}_{f'}*}{(\bar{f}'*)^{2}} - \frac{u}{m.\cdot \bar{f}*} \tag{3}$$

The terms *u* and *m.* represented the sum of the identification trials that resulted in an unknown and known animal identification, respectively. An identification trial was defined as the process of determining the individual identity of a sighted, marked animal (Bowden and Kufeld 1995). The term f'_i was defined as the number of times that the *i*th marked animal was individually identified. The terms $s^2_{f'}*$ and $\bar{f}'*$ were defined as the sample variance and sample mean of the f'_i values where:

$$s^{2}_{f'}* = \frac{\sum_{i=1}^{M}(f_i - \bar{f}*)^2}{M*} \tag{4}$$

where *M* was the number of marked, available animals during the sighting period and f_i was the number of times the *i*th marked animal was observed during the sighting period.

The cube root transformation of the estimators presented by Arnason et al. (1991) was used to generate 95% confidence intervals of the density estimate by substituting the number of animals marked (M) with *M**. Arnason et al. (1991) found the cube root transformation effective at improving the approximation to normality for very small samples and small numbers of marked animals. The confidence intervals were used to determine if densities differed significantly between the two sites.

Sex Ratios and Age Structures

Gender of each bear was determined at capture. A χ^2 goodness of fit test was used

(NCSS 2000) to determine if significant differences existed between the sex ratios at the two sites.

Age classification followed the Arizona Game and Fish Department's key based on tooth wear (LeCount 1986). Age classes were old adult, middle age adult, young adult, subadult, yearling, and cub. The first upper or lower premolar was extracted following the protocol established by Arizona Game and Fish Department to estimate year classes using cementum annuli annalysis (LeCount 1986, Matson's Laboratory, Milltown, Montana). Age estimates generated by tooth wear (LeCount 1986) (n=35) and the cementum annuli analysis (Matson's Laboratory, Milltown, MT) (n=23) were compared to determine the reliability of tooth wear aging. A Wilcoxon rank-sum test was used (NCSS 2000) to determine if age estimates differed significantly between the two sites for male and female bears.

Bear Use of Available Vegetation

Bear use of available vegetation was assessed for collared bears between 30 July 1998 and 17 November 2000. The area and percentages of available managed and unmanaged habitat on each site were calculated using a GIS (Appendix B). Use of available vegetation was calculated using a χ^2 goodness-of-fit test and associated confidence intervals for each study site to determine if particular vegetation classes were used more or less than their availability and if use differed between the two study sites (Neu et al. 1974, White and Garrott 1990). The vegetation classes used for the bear damage surveys were also used to analyze bear use of available vegetation. However, due to few bear locations and the low availability of some of the proposed vegetation classes, vegetation polygons were reclassified as either managed or unmanaged for comparison.

Bear locations used in the analysis were obtained using radio telemetry and incidental visual observations A hand held global positioning system (MC5, Corvallis Microtechnology, Inc., Corvallis, OR) was used to identify precise locations. Attempts to relocate a collared bear using a telemetry receiver that resulted in the observer seeing or hearing the bear were included in the use-analysis. Radio telemetry error was assessed using the location error method with a 95% confidence interval (Zimmerman and Powell 1995, Feamster, unpublished data). Feamster (unpublished data) calculated an error circle with a 95% confidence interval of 0.475 ha (radius of 39 m). Attempts to relocate a collared bear that did not result in the observer seeing or hearing the bear but resulted in a location greater than 39 m from the edge of a vegetation polygon were also included in the use-analysis. These relocations were imported into a GIS and categorized based on the vegetation polygon the collared bear was relocated in.

Available habitat was determined by calculating the average home range size with the minimum convex polygon estimator for the radio-collared bears on each study site. Each of the trapping areas were then buffered by the radius of mean home range of the collared bears. The trapping areas and the buffers based on the mean home range radius were defined as available habitat. The area (km^2) of managed and unmanaged habiatat within the available habitat was calculated.

Bear Condition

I also measured bear weight, body length, and physical condition during capture. Total length was measured from the tip of the nose along the contour of the back to the tip of the tail. A Wilcoxon rank-sum test was used (NCSS 2000) to determine if bear weight and body contour measurements differed significantly between the two sites. Physical condition classes were based on the ability to feel specific skeletal structures and included fair and good (based on LeCount 1986). The physical condition analysis could not be stratified by male and female and still meet Cochran's (1954) recommendation for expected values for the chi-square goodness-of-fit test (Ott 1993). Based on Schroeder's (1986) findings, an objective analysis of physical condition could not be done because of problems related to gender bias when data were not stratified.

Home Range

Locations for home range calculations were collected on both sites from 8 July 1998 to 17 November 2000. Location points used to generate home range estimates included capture, recapture, remote camera station photographs, radio telemetry locations, and incidental observations. Radio telemetry relocations were collected using the loudest-signal method (Springer 1979). Home range estimates were generated using the minimum convex polygon estimator in a GIS [ArcView 3.2 and the Animal Movement Extension 2.04 beta (USGS Alaska Biological Science Center, Anchorage, Alaska)]. A Wilcoxon rank-sum test was used (NCSS 2000) to determine if home range sizes differed significantly between the two sites for male and female bears.

RESULTS

A total of 5.84 ha of the site without historic damage and 6.12 ha of the site with historic damage were surveyed using 0.04 ha circular plots (Table 1). Douglas-fir density was 195 trees/ha and was the only conifer species found damaged. Other conifer species found within the plots included Pacific Yew (*Taxus brevifolia*) (3 trees/ha) and western hemlock (*Tsuga heterophylla*) (8 trees/ha). The final logistic regression model correctly classified 83% of the analyzed Douglas-fir trees as damaged or not damaged based on their diameter, crown ratio, and crown class ($\chi^2_{0.05,5} = 256$, $p < 0.001$, Table 2). Trees with dbh measurements near the minimum of 7.6 cm were not damaged. Trees with dbh measurements near the average of 19.1 cm were predicted to be damaged if crown class was dominant or co-dominant and crown ratio was near 100%. Trees with dbh measurements near the maximum of 84.1 cm were predicted to be damaged if crown class was dominant or co-dominant, irrespective of crown ratio.

The vegetation polygons on the site without historic damage had significantly less bear damage than the vegetation polygons on the site with historic damage ($Z_{0.05} = 2.916$, $p = 0.004$) (Table 3). The thinned and unthinned vegetation polygons on the site without historic damage did not have significantly different levels of damage ($Z_{0.05} = 1.463$, $p = 0.144$). The thinned vegetation polygons had significantly greater damage than unthinned vegetation polygons on the site with historic damage ($Z_{0.05} = 2.346$, $p = 0.019$). The recorded intensities of damage in the managed vegetation polygons on the site without historic damage ($Z_{0.05} = 1.952$, $p = 0.026$) and on the site with historic

Table 1. Numbers of 0.04 ha circular plots used to survey for bear-related tree damage on the Hoopa Valley Reservation, California during the summer of 1999. The species, dbh, crown class, crown ratio and the presence or absence of bear-related tree damage for each tree greater than 7.62 cm dbh were the tree attributes that were recorded. Only the total number of conifer and hardwood trees were recorded in the remaining plots.

Study Site	Plots In Which Tree Attributes Were Measured	Plots In Which Hardwood and Conifer Trees Were Only Totaled	Total Plots
No Historic Damage	33	113	146
Historic Damage	77	76	153

Table 2. Summary statistics on the data used for the final logistic regression model which correctly classified 83.66% of the analyzed Douglas-fir trees as damaged or not damaged based on their diameter (dbh), crown ratio, and crown class.

Tree Damaged	DBH (cm)		Crown Ratio (%)		Number of Trees per Crown Class			
	$\bar{x}$ ± 1 SE	Range	$\bar{x}$ ± 1 SE	Range	Dominant	Co-dominant	Intermediate	Suppressed
Yes	24.7 ± 0.5	9.9 – 52.0	72.5 ± 1.3	10 – 99	216	32	0	0
No	16.8 ± 0.4	7.6 – 84.0	48.4 ± 1.0	5 – 100	232	203	135	35

Table 3. Estimates of the percentages of Douglas-fir trees damaged by black bear in each of the vegetation classes on the Hoopa Valley Reservation, California during the summer of 1999. Estimates for managed polygons and managed polygons stratified into thinned and unthinned classes. Unmanaged polygons were assumed to have no bear damage present.

Vegetation Class		Vegetation Polygons Surveyed (n)	Percent of Trees Damaged		p
			$\bar{x}$ ± 1 SE	Range	
Site without Historic Damage	Managed	14	3.4 ± 2.6	0 – 35.6	0.004[1]
	Thinned	3	3.5 ± 2.3	0 – 7.8	0.144[2]
	Unthinned	11	3.4 ± 3.2	0 – 35.6	
Site with Historic Damage	Managed	16	26.1 ± 6.0	0 – 55.2	0.004[1]
	Thinned	7	44.0 ± 6.1	10 – 54.9	0.019[3]
	Unthinned	9	12.2 ± 6.5	0 – 55.2	

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[1] Comparison of damage intensities in managed vegetation polygons between the two sites.

[2] Comparison of damage intensities in thinned and unthinned vegetation polygons on the site without historic damage.

[3] Comparison of damage intensities in thinned and unthinned vegetation polygons on the site with historic damage.

damage ($Z_{0.05} = 3.265$, $p < 0.001$) were significantly greater than the assumed intensity of damage of zero for the unmanaged vegetation polygons (Table 3).

Bear Capture, Marking, and Sighting Period

A total of 40 bears were captured at the two study sites (Table 4). Fifteen were ear tagged and radio collared and 21 were only ear tagged. A total of 1562 photographs were taken during the sighting period. A total of 109 photographs of bears, comprising 24 independent sightings, were taken on the site without historic damage. A total of 255 photographs of bears, comprising 62 independent sightings, were taken on the site with historic damage. The sighting effort yielded 3 and 9 sightings on the site without and the site with historic damage, respectively, of bears whose status as marked or unmarked could not be determined. These were excluded from the analyses (Table 5).

Three of the 8 collared bears on the site without historic damage and 6 of the 7 collared bears on the site with historic damage were relocated in the study site at least once during the 15+ relocation attempts using radio telemetry on each collared bear during the sighting effort and were categorized as available for the population estimation (Table 6). The average animal equivalent of the two sites was 0.286. Of the 7 tagged bears on the site without historic damage, 2.62 were available and assigned the average animal equivalent of 0.286. Of the 14 tagged bears on the site with historic damage, 11.14 were available and assigned the average animal equivalent of 0.286.

Density Estimator

Using the Bowden model with Garshelis animal-equivalents (Garshelis 1992) and a cube root transformed 95% confidence interval (Arnason et al. 1991), I found

Table 4. Black bear capture effort results for the purposes of radio collaring and ear tag marking bears on the Hoopa Valley Reservation, California from 6 July to 24 September 1998.

	Bears Captured				Collared and Ear Tagged		Only Ear Tagged					
Study Site	Males	Females	Not Immobilized	Total	Males	Females	Males	Females	Individual Bears Recaptured	Total Recapture Events	Trap Nights	% Trap Success
No Historic Damage	10	5	4	19	4	4	6	1	2	3	84	26
Historic Damage	9	12	0	21	3	4	6	8	3	5	83	31

Table 5. Black bear sighting effort results for the purposes of a sighting event for population estimation on the Hoopa Valley Reservation, California from 28 September to 5 November 1998.

	Site without Historic Damage	Site with Historic Damage
Camera Stations	16	16
Camera Nights	304	304
Sighting Success (%)	6.6	14.8
Number of Bears Marked	15	21
Marked Bears Photographed At Least Once	5	7
Total number of photographs of marked bears	6	32
Average number of times marked bears were photographed	0.4	1.5
Range of Times Marked Bears Were Photographed	0 – 2	0 - 11
Total number of photographs of unmarked bears	13	12
Photographs of marked bears that could not be individually identified	1	1

Table 6. Black bear animal equivalent results on the Hoopa Valley Reservation, California from 28 September to 5 November 1998.

Study Site	Range of Animal Equivalents	Mean Animal Equivalent
No Historic Damage	0 – 0.313	0.078
Historic Damage	0 – 1.0	0.524

significantly different ($p<0.05$) densities and 95% confidence intervals between the two sites. The site without historic damage had significantly fewer bears (0.43 (0.17-0.50) / km^2) than the site with historic damage (1.77 (1.05-1.85) / km^2).

Sex Ratios and Age Structures

The bear sex ratios on the site without and the site with historic damage were 5:10 and 12:9 males to females, respectively. The sex ratios were not significantly different between the two sites ($\chi^2_{0.05,1} = 1.99$, $p = 0.158$). Neither the sex ratio at the site without historic damage ($\chi^2_{0.05,1} = 1.666$, $p = 0.197$) nor at the site with historic damage ($\chi^2_{0.05,1} = 0.418$, $p = 0.518$) differed from the expected 50:50 ratio.

The age estimates generated using the tooth wear protocol were in agreement with the cementum annuli analysis for only 5 of the 22 bears (22.7% agreement, Table 7). Harshyne et al. (1998) determined Matson’s Laboratory to be 91.9% accurate with 671 known age, Pennsylvania black bear teeth. Thus, the cementum annuli data were used in the age analysis despite a reduced sample size. There was no significant difference in age between the site without and the site with historic damage for either male ($Z_{0.05} = 0.6604$, $p = 0.509$) or female ($Z_{0.05} = 0.1701$, $p = 0.865$) bears (Table 8).

Bear Use of Available Vegetation

A total of 155 and 103 bear locations on the site without and the site with historic damage, respectively, were assigned a vegetation class (Figures 4 and 5). Only two female bears, one on each study site, used managed habitat significantly more than it was available and unmanaged habitat significantly less than it was available. The remaining 11 bears, 7 on the site without historic damage and 4 on the site with historic

Table 7. The age estimates generated using tooth wear and cementum annuli analysis for black bears captured between 6 July and 24 September 1998 on the Hoopa Valley Reservation, California. The estimates were in agreement for 5 of the 22 bears (22.7% agreement). Study sites are abbreviated, site without historic damage (WoHD) and site with historic damage (WHD).

Bear ID	Site	Sex	Tooth Wear Age Class	Cementum Annuli Year Cl	Estimates in Agreement
O7W60	WoHD	Female	16.5 +	14.5	No
P109R84	WoHD	Female	8.5 - 15.5	9.5	Yes
Y26P101	WoHD	Female	8.5 - 15.5	3.5	No
R95W57	WoHD	Male	8.5 - 15.5	7.5	No
R96P115	WoHD	Male	16.5 +	5.5	No
W63O11	WoHD	Male	8.5 - 15.5	2.5	No
W70R97	WoHD	Male	16.5 +	12.5	No
Y35R87	WoHD	Male	8.5 - 15.5	4.5	No
P102R81	WHD	Female	8.5 - 15.5	4.5	No
P103W59	WHD	Female	16.5 +	30.5	Yes
P118Y36	WHD	Female	4.5 - 7.5	9.5	No
R79Y40	WHD	Female	16.5 +	19.5	Yes
W53P107	WHD	Female	4.5 - 7.5	2.5	No
W58Y33	WHD	Female	8.5 - 15.5	5.5	No
Y34P104	WHD	Female	8.5 - 15.5	6.5	No
Y41R83	WHD	Female	16.5 +	7.5	No
O15P117	WHD	Male	8.5 - 15.5	3.5	No
O9R77	WHD	Male	4.5 - 7.5	3.5	No
P114O16	WHD	Male	3.5 - 4.5	3.5	Yes
R86O1	WHD	Male	4.5 - 7.5	7.5	Yes
W61O8	WHD	Male	4.5 - 7.5	3.5	No
Y42W62	WHD	Male	8.5 - 15.5	7.5	No

Table 8. Black bear related variables which were compared between the two study sites on the Hoopa Valley Reservation, California from 6 July 1998 to 17 November 2000. Study sites are abbreviated, site without historic damage (WoHD) and site with historic damage (WHD).

Variable	Sex	Site	n	Mean ± SE	Range
Weight (kg)	Male	WoHD	10	70.1 ± 11.55	24.3 - 115.7
		WHD	9	66.4 ± 8.3	35.5 - 112.0
	Female	WoHD	5	47.3 ± 2.7	42.9 - 57.9
		WHD	12	40.5 ± 3.5	16.8 - 61.6
Length (cm)	Male	WoHD	10	157.7 ± 6.4	124.0 - 183.0
		WHD	9	157.0 ± 5.3	131.0 - 180.0
	Female	WoHD	5	149.5 ± 1.9	144.3 - 155.0
		WHD	12	139.0 ± 4.0	109.4 - 156.0
Home Range Size (km^2)	Male	WoHD	3	33.0 ± 15.0	13.0 - 62.3
		WHD	2	17.5 ± 3.0	14.6 - 20.5
	Female	WoHD	4	6.8 ± 1.4	5.1 - 10.8
		WHD	3	9.4 ± 4.0	4.7 - 17.3
Cementum Annuli Age Estimate (years)	Male	WoHD	5	6.0 ± 1.7	2 - 12
		WHD	6	4.3 ± 0.8	3 - 7
	Female	WoHD	4	8.5 ± 2.3	3 - 14
		WHD	8	10.3 ± 3.4	2 - 30

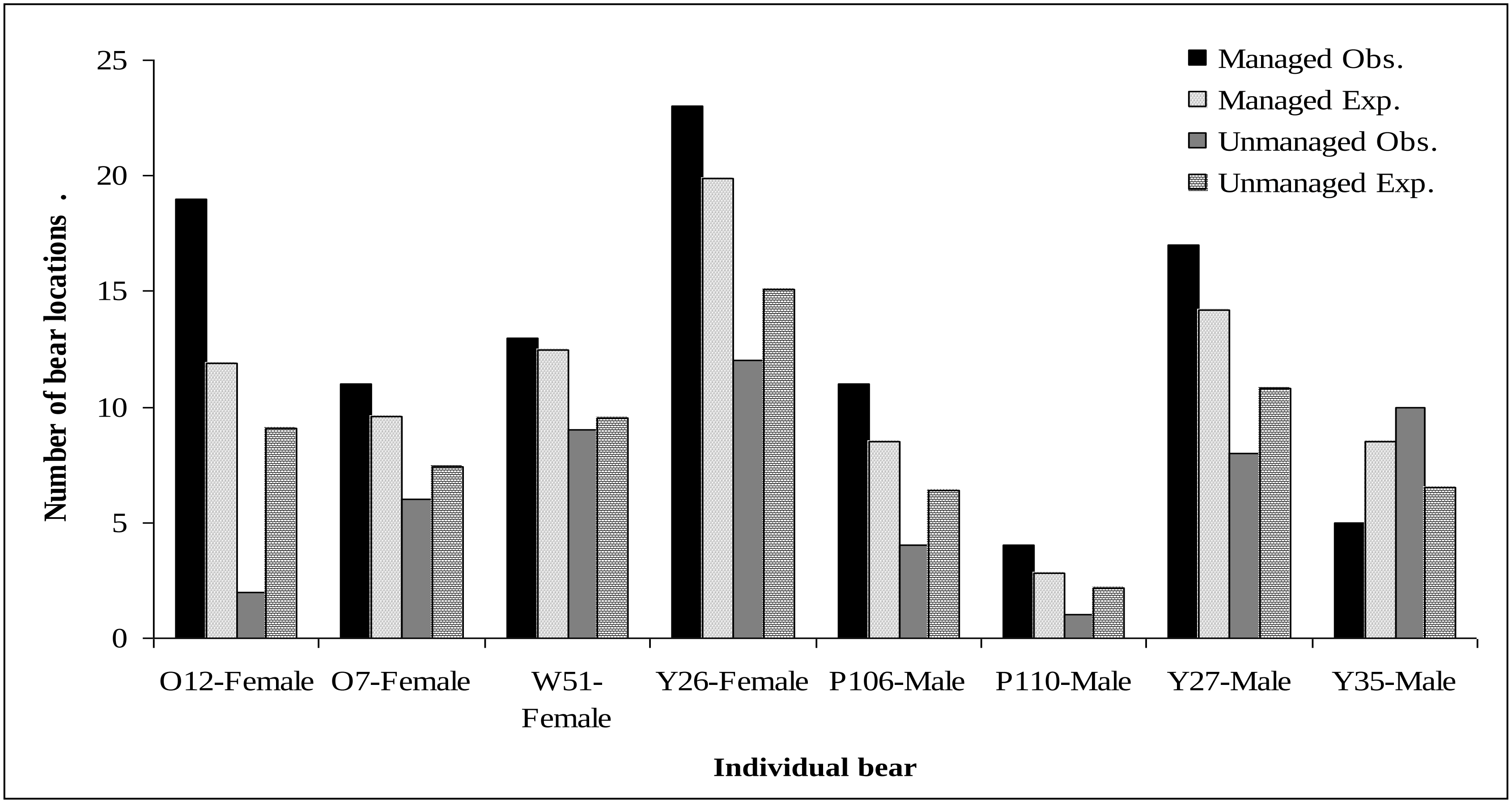

Figure 4. The observed (Obs.) and expected (Exp.) bear locations in managed and unmanaged habitat on the site without historic damage on the Hoopa Valley Reservation, California between July 1998 and November 2000. Only O12 used managed habitat significantly more than it was available and unmanaged habitat significantly less than it was available. The remaining bears used managed and unmanaged habitat in proportion to their availability.

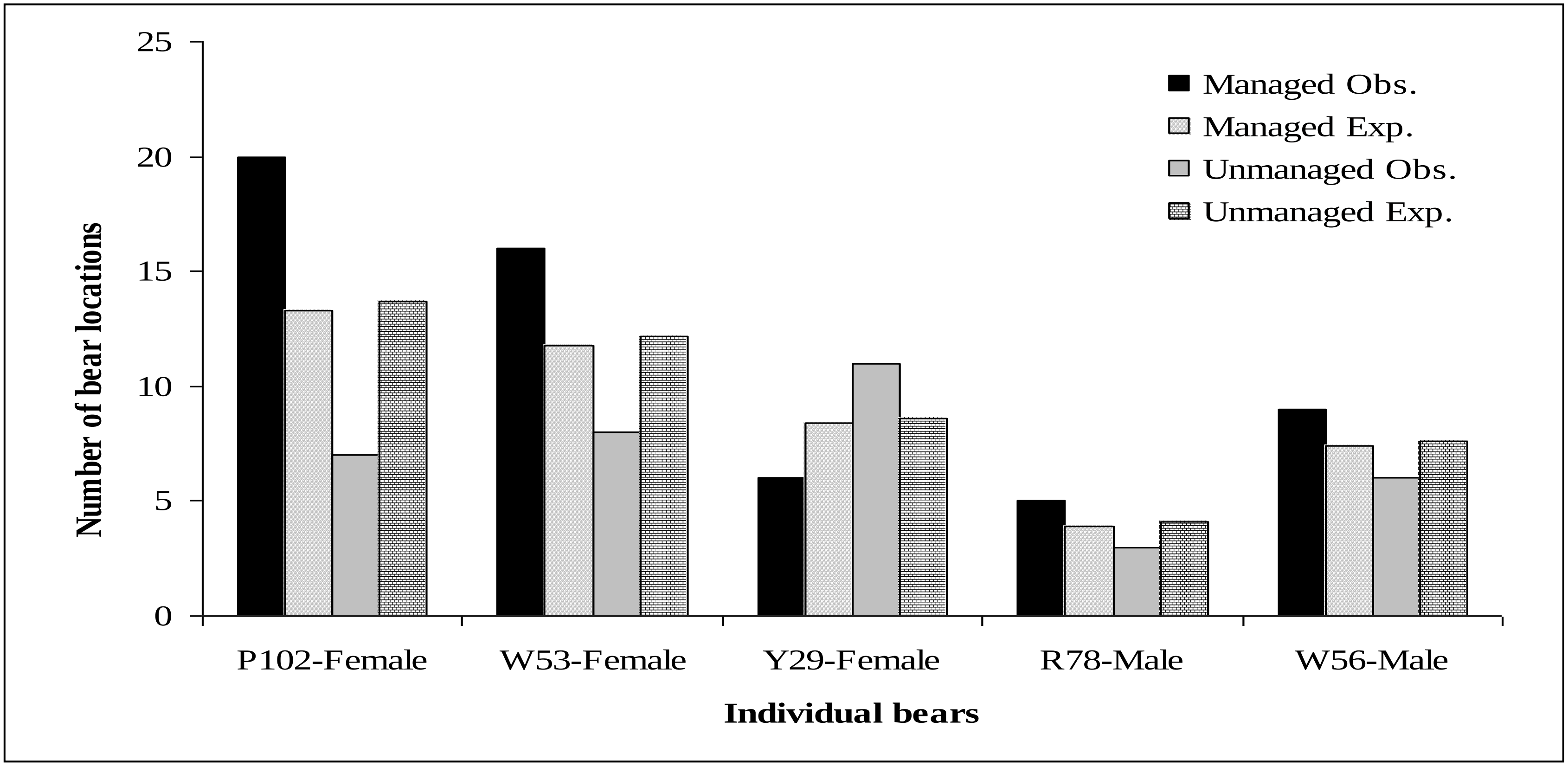

Figure 5. The observed (Obs.) and expected (Exp.) bear locations in managed and unmanaged habitat on the site with historic damage on the Hoopa Valley Reservation, California between July 1998 and November 2000. Only P102 used managed habitat significantly more than it was available and unmanaged habitat significantly less than it was available. The remaining bears used managed and unmanaged habitat in proportion to their availability. One male and one female were removed from the analysis in order to meet Cochran's (1954) recommendation for expected values for the χ^2 goodness-of-fit test.

damage, with a sufficient number of locations, used managed and unmanaged habitat in proportion to their availability. Two bears on the site with historic damage were removed from the analysis in order to meet Cochran's (1954) recommendation for expected values for the χ^2 goodness-of-fit test (Ott 1993).

Bear Condition

There was no significant difference in bear weights between the two sites for either male ($Z_{0.05} = 0.0000$, $p = 1.000$) or female bears ($Z_{0.05} = 1.0051$, $p = 0.315$) (Table 8). There was also no significant difference in bear body length measurements between the two sites for either male ($Z_{0.05} = 0.2453$, $p = 0.806$) or female bears ($Z_{0.05} = 1.5303$, $p = 0.126$). Eight bears on the site without historic damage were in good physical condition and 7 in fair condition. On the site with historic damage, 7 were good and 15 were fair.

Home Range Analysis

One collared male on the site without historic damage and one collared male and one collared female on the site with historic damage were removed from the home range analyses due to low numbers of home range relocation points (less than 20). The average number of locations collected on each bear to generate a minimum convex polygon home range was 34. There were no significant differences in home range sizes between the two sites for either male ($Z_{0.05} = 0.2887$, $p = 0.773$) or female ($Z_{0.05} = 0.1768$, $p = 0.860$) bears (Table 8).

DISCUSSION

The patterns of damage to Douglas-fir trees by black bear on the Hoopa Valley Reservation were consistent with those found in other areas (Fritz 1951, Glover 1955, Maser 1967, and Hartwell 1973, Mason 1985, Stewart 1999). Mason (1985) reported that faster growing trees with larger crown ratios in low density stands were damaged more frequently. Douglas-fir trees on the Hoopa Valley Reservation with larger diameters, higher crown classes, and larger crown ratios in managed timber stands were damaged significantly more often than smaller, less vigorous Douglas-fir trees. Mason (1985) and Stewart (1999) reported Douglas-fir to be preferred, even when not the dominant species in a stand. Of the three conifer species detected in my vegetation plots, (Pacific Yew, western hemlock, and Douglas-fir) only Douglas-fir was damaged. Previous research also demonstrated the effects of low tree density and thinning on bear damage. Brown (1950) calculated 73% of Douglas-fir to be damaged in a low density (56 stems/ha) stand. Ray (1941), Schmidt (1987), and Mason and Adams (1989) calculated bear damage as high as 90% in thinned stands and no damage observed in unthinned stands. Bear damage on the Hoopa Valley Reservation was found to be greater in thinned stands than in unthinned stands on the site with historic damage and greater in managed stands than in unmanaged stands on both sites.

The lack of a significant difference in the levels of damage between thinned and unthinned stands on the site without historic damage may have resulted from several factors. First, the amount of time that damage had been occurring on the site may have influenced the estimate of damage. Because damaged trees persist after being damaged, observable damage will accumulate over time, and a greater difference in the levels of damage between thinned and unthinned stands becomes apparent. Thus, if damage continues on the site without historic damage, differences may eventually become evident in forthcoming years. Alternatively, the absence of a history of bear damage on the site without historic damage may have been attributable to a difference(s) in the bear populations at the two sites.

Estimates of black bear density in North America have ranged from 0.06 bears/km^2 in Arizona (LeCount 1987) to 0.59 bears/km^2 in Virginia (Hellgren and Vaughan 1989) bears per km^2. Poelker and Hartwell (1973) were one of a few studies to address bear density and bear damage. They calculated a bear density of approximately 0.53 bears/km^2, but did not compare densities between their damaged and undamaged study sites. In my study, the density of black bears was greater on the site with historic damage than on the site without historic damage. The significantly greater levels of damage observed on the site with historic damage could have been related to the greater density (1.77 bears /km^2) on that site. With a significantly larger bear population on the site with historic damage, the significantly different levels of damage between the two sites could be a function of more individual bears learning and exhibiting the damage behavior, resulting in significantly greater levels of damage on the site with historic damage.

The density estimator I developed provides a method of defining a bounded area of sampling to construct a density estimate (plus 95% confidence interval) for wide-ranging mammalian carnivores using mark-sight data. Mark-sight experiments have the advantages of reduced cost, reduced disturbance to the studied population, and greater likelihood of robustness of population size estimates compared to traditional mark-recapture experiments (Minta and Mangel 1989). Additionally, any technique that calculates the number of sightings of a marked individual and the total number of unmarked sightings during the sighting period can be used as a sighting process for the density estimator. Sighting probabilities can vary among individuals and can depend on such factors as group size and vegetation cover (Bowden and Kufeld 1995). The technique I developed had no additional radio telemetry effort required beyond that used for a traditional home-range study utilizing radio telemetry.

Both the Bowden model and the density estimator I developed were sensitive to serious violations of each animal having an equal chance of being marked (Bowden and Kufeld 1995). However, the capture effort at both study sites density estimates were applied was well distributed and uniform. Using the PVC culvert-pipe camera station maximized the likelihood of sighting marked and unmarked animals without error by increasing the probability of photographing a bears' ears and identifying the presence or absence of ear tags. Additionally, the mark-sight design which incorporated more than one capture method (culvert traps baited with fish and camera stations baited with chicken) contributed to meeting the assumption of equal sightability of marked and unmarked animals during the sighting effort (Minta and Mangel 1989).

The significant difference in density between the two sites could have been influenced by elements of the study design. Although several habitat related variables were taken into account when selecting site locations, availability of spring food (i.e.

blackberry (*Rubus* sp.)) may have been greater on the site with historic damage. Miller et al. (1997) recommended conducting the sighting effort in areas representative of different habitats as they occur in the larger area to which the density estimate may be extrapolated. Larger trapping and sighting areas in my study would have incorporated a more representative sample of habitat types and areas of differing seasonal food availability. This would have minimized concern about habitat bias in the sampling. Conversely, larger trapping and sighting efforts would have significantly added to the project costs. Budgetary limitations almost always restrict the proportion of the population that can be radio collared due to the very expensive costs of capture, equipment, and following radioed animals. Radio collaring a larger proportion of the population could have resulted in more precise estimates of the animal equivalents used in the estimator.

The greater densities of bears on the Hoopa Valley Reservation compared to estimates from other studies also could be related to the effects of timber management on habitat and food availability. Bears have been found to use managed habitats more than expected and non-managed habitats less than expected (Young and Beecham 1986, Costello 1992). Costello (1992) reported a greater availability of several seasonal food sources in managed compared to unmanaged habitats. With 305 km^2 of the Reservation’s 339 km^2 land base in timber production, habitat and food availability changes could be responsible for the comparatively higher bear densities I estimated on the Reservation.

No significant difference in the sex ratios were detected between the two sites. A female biased sex ratio would have supported Moore's (1940) learned behavior hypothesis. However, the sex ratios on the two sites did not differ significantly from each other or from the expected 50:50 sex ratio. Piekielek and Burton (1975) reported trapped samples were usually male biased. Kemp (1972) and LeCount (1990) suggested this was the result of higher mobility of and hunting pressure on males, resulting in several sub-dominant males occupying an area formally occupied by a single dominant male. In my study, all of the collared males were resident except one subadult male. Additionally, the Hoopa Valley black bear population is not hunted, with the exception of occasional depredation kills. In order to adequately approach the learned behavior hypothesis, genetic relatedness of known damage-causing bears needs to be assessed.

Bear age did not appear to be related to the differences in bear damage on the Hoopa Valley Reservation. LeCount (1990) in Arizona and Kolenosky (1986) in Ontario, calculated mean bear ages (excluding cubs) in hunted black bear populations to be 4.4 and 3.5 years for males and 5.6 and 4.5 for females, respectively. Mean ages for the Hoopa Valley Reservation were 6 and 4.3 years for males and 8.5 and 10 years for females on the site without and the site with historic damage, respectively. The slightly greater average age estimates for bears on the Hoopa Valley Reservation may be because of the absence of hunting.

Bear use of available vegetation did not differ significantly between the two sites on the Hoopa Valley Reservation. Only two collared females, one on each site, used managed habitat significantly more than it was available and unmanaged habitat significantly less than it was available. All other collared individuals used managed and unmanaged habitat equal to their availability.

Based on the lack of significant differences in bear weight, body length, physical condition, and home range size between the two study sites, bear condition as an indicator of food stress did not appear to be related to the differences in bear damage on the Hoopa Valley Reservation. Pierson (1966) found bears in damaged areas to be generally smaller in skeletal size and weight and in poorer physical condition than bears in areas with no observed tree damage. However, Poelker and Hartwell (1973) concluded there were no significant differences in bear weight, contour, or physical condition between damaged and undamaged study sites in Washington. Poelker and Hartwell (1973) also found both males and females in damaged areas to be wider ranging than those in undamaged areas, suggesting food shortages and more intensive searching for food in damaged areas. No significant difference in bear home range sizes were found between the two sites on the Hoopa Valley Reservation. The food stress hypothesis could be examined further by using more direct measures of habitat quality during the damage period between the two sites. Poelker and Hartwell (1973) found a negative correlation between the incidences of sapwood and food species used greater than their availability, such as salmonberry (*Rubus spectabilis*). However, availability of these food species between the damaged and non-damaged study sites on the Hoopa Valley Reservation was not calculated. More direct inferences could be drawn by utilizing a habitat use versus availability analysis considering these food species and the presence or absence of damage.

LITERATURE CITED

Abbott, P.A. 1994. Bald Hill 1995 timber sale environmental assessment – appendix j: bear damage. Hoopa Valley Tribal Forestry, Hoopa, California. Pages 127-142.

Arnason, A.N., C.J. Schwarz, and J.M. Gerrard. 1991. Estimating closed population size and number of marked animals from sighting data. Journal of Wildlife Management 55:716-730.

Bowden, D.C. 1993. A simple technique for estimating population size. Department of Statistics, Colorado State University, Technical Report 93/12, Fort Collins, Colorado. Pages 1-17.

Bowden, D.C. and R.C. Kufeld. 1995. Generalized mark-sight population size estimation applied to Colorado moose. Journal of Wildlife Management 59:840-851.

Brown, E.R. 1950. Bear damage survey. Washington State Department of Game, Olympia, Washington.

Burton, S.F. and F. Schmalenberger. 1995. The use of Telazol for chemical restraint of black bears (Ursus americanus) in northern California. California Fish and Game 81:29-32.

Cochran, W.G. 1954. Some methods for strengthening the common χ^2 test. Biometrics 10:417-451.

Costello, C.M. 1992. Black bear habitat ecology in the central Adirondacks as related to food abundance and forest management. Master's Thesis. Department of Environmental and Forest Biology. State of New York College of Environmental Science and Forestry, Syracuse, New York.

Fritz, E. 1951. Bear and squirrel damage to young redwood. Journal of Forestry 49:651-652.

Furubayshi, K., K. Hirai, K. Ikeda, and T. Mizvquchi. 1977. Relationships between occurrence of bear damage and clearcutting in Central Honshu, Japan. Pages 81-84 in C.J. Martinka and K.L. McArthur, editors. Bears – their biology and management. The Bear Biology Association, Tonto Basin, Arizona.

Garshelis, D.L. 1992. Mark-recapture density estimation for animals with large home ranges. Pages 1098-1111 in D.R. McCullough and R.H. Barrett, editors. Wildlife 2001:Populations. Elsevier Applied Science, New York, New York.

Glover, F. 1955. Black bear damage to redwood reproduction. Journal of Wildlife Management 49:651-652.

Harris, S., W.J. Cresswell, P.G. Forde, W.J. Trewhella, T. Woollard, and S. Wray. 1990. Home-range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. Mammal Review 20:97-123.

Harshyne, W., D.R. Diefenbach, G.L. Alt, and G.M. Matson. 1998. Analysis of error from cementum-annuli age estimates of known-age Pennsylvania black bears. Journal of Wildlife Management 62:1281-1291.

Hartwell, H. 1973. A survey of debarking by black bear in Capitol Forest. State of Washington Department of Natural Resources Note Number 7, Olympia, Washington.

Hellgren, E.C. and M.R. Vaughn. 1989. Demographic analysis of a black bear population in the Great Dismal Swamp. Journal of Wildlife Management 53:969-977.

Hoopa Valley Tribal Council, Natural Resources Department, Forestry Division. 1998 GIS Database. Hoopa, California.

Hosack, D.A. 1990. Black bear damage to regenerating conifers in northwestern California. Master's Thesis. Department of Natural Resources Planning and Interpretation. Humboldt State University, Arcata, California.

Kemp, G.A. 1972. Black bear population dynamics at Cold Lake Alberta, 1968-1970. International Conference on Bear Research and Management 2:26-31.

Kolensky, G.B. 1986. The effects of hunting on an Ontario black bear population. International Conference on Bear Research and Management 6:45-55.

Lauckhart, J.B. 1956. The effect of logging old-growth timber on bear. Pages 128-130 in Society of American Foresters Proceedings, 1954. Society of American Foresters, Corvallis, Oregon.

LeCount, A.L. 1986. Black bear field guide: a manager's manual. Arizona Game and Fish Department, Phoenix, Arizona.

LeCount, A.L. 1990. Characteristics of an east-central Arizona black bear population: a final report. Arizona Game and Fish Department Wildlife Bulletin. Phoenix, Arizona.

Maser, C. 1967. Black bear damage to Douglas-fir in Oregon. Murrelet 48:34-38.

Mason, A.C. 1985. Black bear damage compared in thinned and natural 1931 wildfire origin stands in northwest Montana. Master's thesis. University of Idaho, Moscow, Idaho.

Mason, A.C. and D.L. Adams. 1989. Black bear damage to managed timber stands in northwest Montana. Western Journal of Applied Forestry 4:10-13.

Miller, S.D., G.C. White, R.A. Sellers, H.V. Reynolds, J.W. Schoen, K. Titus, V.G. Barnes, Jr., R.B. Smith, R.R. Nelson, W.B. Ballard, and C.C. Schwartz. 1997. Brown and black bear density estimation in Alaska using radiotelemtry and replicated mark-resight techniques. Wildlife Monographs no. 133. 55pp.

Minta, S. and M. Mangel. 1989. A simple population estimate based on simulation for capture-recapture and capture-resight data. Ecology 70:1738-1751.

Molnar, A.C. and R.G. McMinn. 1960. The origin of basal scars in interior British Columbia white pine type. Forestry Chronicle 36:49-60.

Moore, A.W. 1940. Wild animal damage to seed and seedlings on cutover Douglas-fir lands of Oregon and Washington. United States Department of Agriculture Technical Bulletin 706.

National Oceanic & Atmospheric Administration – Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center (NOAA-CIRES CDC). 1983. Climate Diagnostics Data Base. Boulder, Colorado. From their Web site at http://www.cdc.noaa.gov.

NCSS 2000. User's Manual IV. NCSS Statistical Analysis and Data Analysis Software. Kaysville, Utah.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:1-135.

Ott, R.L. 1993. An introduction to statistical methods and data analysis. Fourth edition. Wadsworth Publishing Company, Belmont, California.

Piekielek, W. and T.S. Burton. 1975. A black bear population study in northern California. California Fish and Game 61:4-25.

Pierson, D. 1966. Washington's black bear problem. Pages 96-100 in Proceedings 46th Annual Conference of the Washington Association of State Game Fish Commission.

Poelker, R.J. and H.D. Hartwell. 1973. Black bear of Washington. Biological Bulletin Number 14, Washington State Game Department.

Pollock, K.H., J.D. Nichols, C. Brownie, J.E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107:1-97.

Ray, R.G. 1941. Site types and rates of growth, Lake Edwards, Champlain Country, P.Q., 1915-1936. Canada Department of Mines and Resources; Lands, Parks, and Forests Branch; Dominican Forest Service Silvicultural Note 65.

Schmidt, W.C. 1987. Bear damage-a function of stand density in young larch forests? Pages 145-146 <u>in</u> D.M. Baumgartner, R.L. Mahoney, J. Evans, J. Caslick, and D.W. Brewer, co-chairmen. Animal Damage Management in Pacific Northwest Forests.

Schroeder, M.T. 1986. Blood chemistry, hematology, and condition evaluation of black bears in northcoastal California. Master's Thesis. Department of Wildlife. Humboldt State University, Arcata, California.

Seber, G.A. 1982. The estimation of animal abundance. Second edition. Charles Griffin and Co., London, U.K.

Springer, J.T. 1979. Some sources of bias and sampling error in radio triangulation. Journal of Wildlife Management 43:926-935.

Stewart, W.B. 1999. Black bear damage to forest stands in western Washington. Western Journal of Applied Forestry 14:128-131.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory Report LA-8787-NERP, Los Alamos National Laboratory, Los Alamos, New Mexico.

White, G.C. and R.A. Garrott. 1990. Analysis of radio-tracking data. Academic Press, New York, New York.

White, G.C. 1996. Program NOREMARK software reference manual. Department of Fisheries and Wildlife, Colorado State University, Fort Collins, Colorado.

Worton, B.J. 1987. A review of models of home range for animal movement. Biological Modelling 38:277-298.

Young, D.D. and J.J. Beecham. 1986. Black bear habitat use at Priest Lake, Idaho. International Conference on Bear Research and Management 6:73-80.

Zimmerman, J.W. and R.A. Powell. 1995. Radiotelemetry error: location error method compared with error polygons and confidence ellipses. Canadian Journal of Zoology 73:1123-1133.

PERSONAL COMMUNICATIONS

Feamster, R.B. 1999. Personal Communicatin. Simpson Timber Company. P.O. Box 1089, Arcata, CA 95521

Golightly, R.T. 1998. Personal Communication. Department of Wildlife, Humboldt State University, Arcata, CA 95521

Higley, J.M. 1998. Personal Communication. Hoopa Valley Tribal Forestry. P.O. Box 365, Hoopa, CA 95546

Appendix A. Crown class classification explanations from Abbott (1994). Crown classes were expressions of the relative position of the tree crown within the canopy compared to neighboring trees, quantified by the amount of photosynthetic surface exposed to direct sunlight.

Crown Class	Description
Dominant	The tallest trees in a stand, with a canopy exposed to direct sunlight throughout the day.
Co-dominant	The second tallest tress in a stand, with a canopy exposed to direct sunlight for at least half of the day.
Intermediate	The third tallest trees in a stand, with a canopy exposed to direct sunlight for less than half of the day.
Suppressed	The shortest trees in a stand, with a canopy that is never exposed to direct sunlight throughout the day.

Appendix B. The area and percentages of available managed and unmanaged habitat on the east and west sites on the Hoopa Valley Reservation, California between July 1998 and November 2000.

Site	Habitat Type	Area (km^2)	Percent of Available on Each Site
Without Historic Damage	Managed	23.5	56.8
	Unmanaged	17.9	43.2
With Historic Damage	Managed	15.8	49.3
	Unmanaged	16.3	50.7