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Location Analysis and Strontium-90 Concentrations in Deer Antlers on the Hanford Site

B. L. Tiller
L. E. Eberhardt
T. M. Poston

May 1995

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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Richland, Washington 99352

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Summary

This study was initiated to evaluate the use of deer antlers as indicators of animal exposure to ^{90}Sr on the Hanford Site in southcentral Washington. Levels of strontium-90 (^{90}Sr) were examined in antlers of Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) residing near previously active reactor sites and from locations at approximately 10 to 30 kilometers away from the reactor sites. In addition, samples were also collected from a remote area in central Oregon unassociated with plutonium production and were used as a reference standard.

From 1991 to 1994, 38 deer antler samples were collected and analyzed for ^{90}Sr contamination. Antlers were collected from 18 bucks that were tagged with radio transmitters to monitor their movements. A significant difference ($P<0.001$) in ^{90}Sr concentrations in antlers was observed between the two Hanford Site areas (reactor areas and the area unassociated with reactors). Examining subsequent movements of 18 bucks and several does confirmed that little to no intermixing existed between the two study sites. Reference antlers collected in central Oregon had nearly five times the ^{90}Sr concentration found in Hanford Site mule deer antlers and is attributed to world wide fallout levels found there. Soil samples were also collected from these three areas and analyzed for ^{90}Sr. Analysis of Variance demonstrated a significant difference between Hanford and Oregon soils but no soil differences were found between the two Hanford Site study areas. Natural vegetation samples were collected within the two Hanford Site study areas and analysis demonstrated no significant difference in ^{90}Sr between them. Regression analysis of the Hanford and Oregon data demonstrated a significant correlation between soil and antler ^{90}Sr concentrations.

Movement analysis suggest that the Columbia River does not restrict deer movement from on and off the Hanford Site. Average home range estimates for several deer ranged from 15.4 km^2 by the 95% minimum convex polygon method to 33.6 km^2 by the 95% bivariate ellipse method, which supports previous home range estimates for mule deer residing in a shrub-steppe ecosystem. Based on data gathered from 1991 to 1994, an average of 11% (range 0% to 37% at the 95% confidence interval) of the male deer residing along the Columbia River may be harvested in any one year. A lower average harvest rate (legal or illegal) of female deer was determined to be 5% (range 0% to 21% at the 95% confidence level) and is consistent with Eberhardt et al. 1982 findings. A population estimate is needed to determine the actual number of deer harvested in any one year.

Antlers of mule deer can be useful for detecting localized contamination of bone-seeking contaminants like ^{90}Sr or other heavy metals. Thus, collecting shed antlers can be used as a nondestructive tool for contaminant monitoring.

Acknowledgments

The authors wish to thank W. H. Rickard, L. L. Cadwell, and R. G. Schreckhise for their insight and assistance in the study design development. The authors further appreciate all of the many SERS, SRAP, and AWU-NW students for their invaluable assistance in field data collections and deer captures. R. K. Zufelt provided GPS/GIS interface and graphical illustrations of this study. Editing and report production were provided by G. P. O'Connor and the Sigma V Communications Support Team. The authors would also like to thank the PNL Flight Aviation Safety Committee for assisting in aircraft operations setup and ensuring that this work could be performed under current DOE aviation safety guidelines.

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Introduction

The Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) is an important component of the ecosystem and a highly valued species for both aesthetics and hunting. Also, because mule deer are often hunted and eaten, they potentially can contribute to the annual radiation dose received by members of the public (Soldat et al. 1990; McClelland et al. 1993). On the Hanford Site in southcentral Washington, the species is also of interest to contaminant monitoring programs because deer can provide useful information that can be used in environmental clean up efforts (Eberhardt and Cadwell 1983). The mule deer study described here was conducted as part of the Hanford Site's Wildlife Resources Monitoring Project (WRMP) and analytical support was provided by the Surface Environmental Surveillance Project. Pacific Northwest Laboratory (PNL) manages the project for the U.S. Department of Energy (DOE). The purposes of the WRMP are to monitor and report trends in wildlife populations, conduct surveys to identify, record, and map populations of threatened, endangered, and sensitive plant and animal species, and cooperate with Washington State and federal and private agencies to help ensure the protection afforded by law to native species and their habitats.

The primary objective of this study was to examine the levels of strontium-90 (^{90}Sr) in deer antlers collected from near previously active reactor sites and distant from the reactor sites along that portion of the Columbia River which borders the Hanford Site. A second objective was to analyze the movements and home-ranges of mule deer residing within these areas and determine to what extent this information contributes to the observed ^{90}Sr concentrations. ^{90}Sr is a long-lived radionuclide (29.1 year half life) produced by fission in irradiated fuel in plutonium production reactors on the Hanford Site. It is also a major component of atmospheric fallout from weapons testing. Concentrations of radionuclides found in the developed environment onsite do not pose a health concern to humans or various wildlife routinely monitored (Woodruff and Hanf 1992). However, elevated levels of radionuclides in found biota may indicate routes of exposure requiring attention.

The utility of a nondestructive approach for collecting a relatively large number of deer tissue samples for radiological analysis was examined. The approach utilizes shed antlers which occurs annually for most all male deer. In this way antlers can be collected and analyzed for contamination without sacrificing the animal and with minimal sample preparation efforts. Although not yet substantiated, it has been postulated that the concentration of ^{90}Sr in antlers is a reflection of environmental contamination within the animals area of use (Zaleha and Kovach 1985). Consequently, information about animal movements and home-range sizes would contribute significantly to the evaluation of using deer antler tissue for environmental monitoring. Previous mule deer studies conducted on the Hanford Site indicate that concentrations of radionuclides in deer tissue are similar to concentrations expected from worldwide fallout (Woodruff and Hanf 1992). However, small sample sizes coupled with the relatively low concentrations found in animals today makes it difficult to interpret the radionuclide results.

Study Area

The study was conducted along that portion of the Hanford Site that borders the Columbia River. The Columbia River Plain, a broad, low-elevation valley located in southcentral Washington, has been

occupied by settlers and used extensively for livestock grazing since the 1850s, and later, for cultivation agriculture and urbanization (Chatters 1989). The Hanford Site was established in 1943 as a national security area and has been closed to public access since that date. The area, in general, is characterized by steppe vegetation, sagebrush (*Artemisia tridentata*)/Sandberg's bluegrass (*Poa sandbergii*) (Downs et al. 1993; Daubenmire 1970), with approximately 16 cm of annual precipitation (Hoitink and Burk 1994). The climate consists of hot dry summers and relatively cool winters when the bulk of annual precipitation occurs.

Deer were studied throughout approximately 80 km^2 of land bordering the Columbia River in Benton and Grant counties (Figure 1). The study region can be divided into north and south areas. The southern area generally has been unaltered by Hanford-related activities and is characterized by sand dunes, old abandoned farm fields, and shrub-steppe habitat that was burned in 1985. Rabbitbrush (*Chrynsothamnus spp.*) and bitterbrush (*Purshia tridentata*) are dominant shrubs occupying the dune habitat (Downs et al. 1993). The northern area contains six inactive production reactor sites, old abandoned agriculture fields, and scattered patches of shrub-steppe habitat.

The Columbia River supports riparian habitat and riverine islands commonly used by resident mule deer. The shoreline vegetation along the Hanford Reach consists of a narrow zone of broad-leafed deciduous trees and shrubs intermingled with a variety of perennial grasses and forbs (Downs et al. 1993; Sackschewsky et al. 1992). The riparian zone tends to remain green throughout the hot dry summer months because its rooting zones are wetted by river water or shallow groundwater.

Background deer antler and soil samples were also obtained form the Silver Lake region of central Oregon for comparison to deer antler samples collected from the Hanford Site. The Silver Lake region was selected because it is relatively arid, consisting of shrub-steppe vegetation. The mean annual average precipitation of the area is about 25 cm (WIC 1974), and it has been used in previous studies on ^{129}I in wildlife (Price et al. 1981).

Background

Strontium found in deer antler tissue comes from two distinct sources: A relatively small portion of ^{90}Sr comes from deposits already present in bone that are remobilized and laid down in antler tissue as it is growing. The primary source comes from uptake of ^{90}Sr found in forage, soil, and drinking water. A substantial portion of ingested ^{90}Sr is absorbed from the gastrointestinal tract, and the remainder is excreted in the feces. The absorbed portion is either deposited in the bone, distributed in an exchangeable pool comprised of the plasma, extracellular fluid, soft tissues, and bone surfaces, or removed from the body by urinary and fecal excretion (Schreckhise 1974; NCRP 1991). Consequently, the concentrations of ^{90}Sr found in antler tissue are not entirely representative of uptake occurring when the antlers are growing; however, the majority of ^{90}Sr and Ca laid down during antler growth is most likely dietary, thus reflective of its surrounding environment. Research has demonstrated that strontium is retained less effectively than calcium in living organisms, however, it is generally accepted that ^{90}Sr is biologically analogous to calcium and is therefore concentrated in calcium rich tissue (NCRP 1991). The biological half life of ^{90}Sr in mammals ranges from 100 to 700 days (DiGregorio et al. 1977). Strontium and calcium plasma/bone turnover is reduced in older aged animals (Farris et al. 1967).

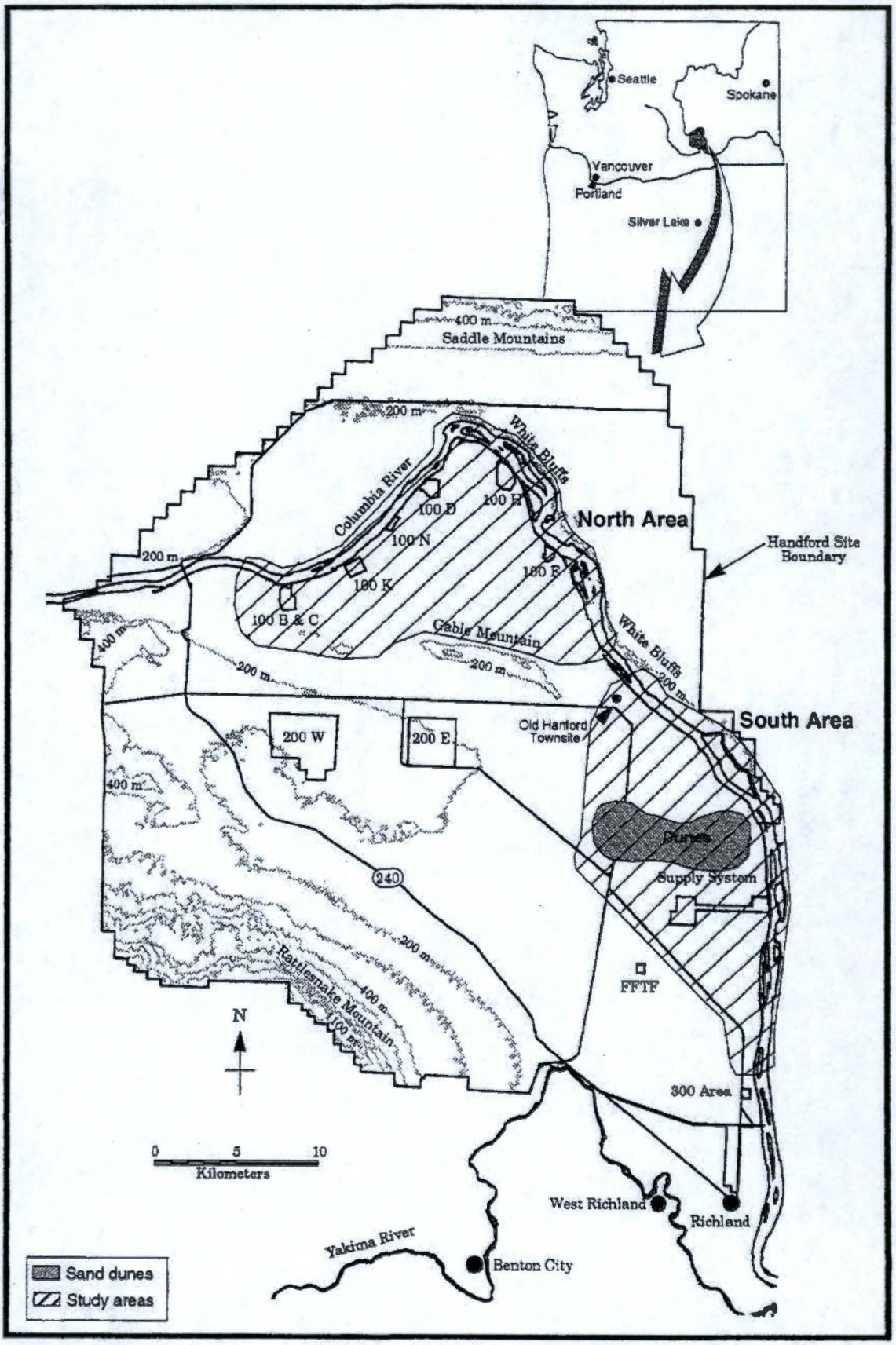


Figure 1. Study Areas

Antlers are "true bone" (Wallmo 1981), and therefore, may be a useful tissue for estimating ^{90}Sr burdens in animals. The usefulness of monitoring antlers taken from a wild mule deer population to determine the potential exposure of ^{90}Sr in the deers' foraging environment has not been previously investigated on the Hanford Site. However, Zaleha and Kovach (1985) found ^{90}Sr contents in white-tailed deer to be principally a function of ^{90}Sr contents in soil and water existing throughout the animals' home range. In this way, examining the ^{90}Sr concentrations in antlers may be a useful tool for identifying areas of localized contamination.

On the Hanford Site, muscle and liver samples are routinely taken from road-killed deer for radionuclide analysis. If road-killed deer are not sampled from near certain reactor sites during the calendar year, up to four deer are sacrificed and sampled (Woodruff and Hanf 1992). Usually, eight or nine deer per year are collected onsite and analyzed for selected radionuclides, including ^{137}Cs, ^{60}Co, and ^{90}Sr. The results indicate very low amounts of radionuclides are taken up by animals; however, the variability of these results and relatively low sample sizes make it difficult to examine for differences in contaminant uptake by deer residing in different locations throughout Hanford. Eberhardt et al. (1982) conducted studies on radio transmitted deer in the central portion of Hanford that resided at different distances from a known contamination site. After examining the animals' movement patterns, the researchers sacrificed the animals' and determined that radionuclide concentrations in the muscle, liver, and bone tissue were significantly correlated with distance from the contamination site and time the animal spent near the contamination site. Movements to offsite areas by the study animals were minimal, however, very few animals were studied near the Columbia River where offsite movements would be more likely.

Preview of Report

This report describes methods used to capture mule deer, fit them with tags and radio transmitters, and collect antler tissue for ^{90}Sr analysis. It reports results and discusses ^{90}Sr concentrations in soil, vegetation, and deer antlers samples, and describes animal movements and harvest potential. Study conclusions are also provided. Appendix A includes raw data, relative frequency distributions of antler results, and statistical tests for ^{90}Sr differences within and between sites described in this study. Appendix B includes goodness-of-fit tests for underlying movement distribution assumptions and a comparison of results for home range estimate techniques.

Methods

This research involved capturing mule deer, fitting them with tags and radio transmitters, and collecting antler tissue, soil, and vegetation for ^{90}Sr analysis, and systematically monitoring subsequent movements of animals tagged with radio transmitters. Data analysis involved determining home-range size and applying statistical tests to determine if differences were present in ^{90}Sr concentration of soil, vegetation, and antler tissue based on location and extent of animal movements.

Deer were mass captured in drive nets (Beasom et al. 1980) at several locations along the Hanford Reach of the Columbia River during February and March of 1991, 1992, and 1993. Deer were visually located from a helicopter and then driven into the nearby net line, which typically took the shape of an "L." In 1994, several deer were captured with a CODA net gun fired from a hovering helicopter and then slung in a cargo net for transport to a nearby staging area. For all deer captured, incisor 1 lengths were measured, age was estimated, general health was noted, an Advanced Telemetry Systems (ATS) solar-powered radio transmitter was fastened to the ear of the adult males, and when available antler samples were collected. An ATS radio collar was fastened around the neck of all adult females. An incisiform canine was removed from several males for age determination by cementum annuli analysis (Erickson and Seliger 1969; Low and Cowan 1963; Robinette et al. 1957).

Animals tracked by radiotelemetry were systematically located by aircraft and/or by ground observers weekly (weather conditions permitting) during daylight hours. A Telonics XA receiver and two H-element antennas were used to locate each animal. Location points were determined with a Garmin GPS-100. Accuracy of aerial relocations was found to be between 0 and 100 m from equipment sources and estimated between 0 and 300 m from observer sources. Location coordinates were plotted on the GRASS Geographical Information System (GIS) to examine the extent of intermixing among animals tagged with radio transmitters and groups of animals not tagged, and to graphically illustrate animal home range estimates.

Antler Sampling and Analysis

During each capture event, antler samples were collected from bucks by clipping a 3- to 5-cm portion from the tips of each point. This sampling design was used because Schultz (1964) and Zelah and Kovach (1985) found the highest ^{90}Sr concentrations to exist in the dense peripheral zone of the antlers, but found no significant difference among particular antler points. A stainless-steel cutting shear was used to snip the antlers. Antler samples were surveyed in the field with a beta-gamma hand-held instrument but no detectable levels of beta or gamma emitting radionuclides were found.

Analysis of antler samples was performed under contract by International Technology Company (IT). Samples were ashed in a muffle furnace and then dissolved in nitric acid. The dissolved ash was scavenged with barium nitrate, and the strontium was precipitated as a carbonate. The strontium carbonate precipitate was transferred to a stainless-steel planchet and counted on a gas flow proportional counter. At least 10 g of tissue was needed to attain a detection limit of 0.01 pCi/g dry weight.

Data Analysis

Home range size estimates of animals tracked by radio transmitter were computed using a P.C. computer program developed at the University of Idaho (Ackerman et al. 1990). Home ranges were obtained using three techniques: 100% and 95% minimum convex polygons (Michener 1979; Bowen 1982; Bekoff and Mech 1984), 95% bivariate normal and 95% bivariate weighted ellipse (Samuel and Garton 1985), and 95% harmonic mean utilization (Dixon and Chapman 1980). Minimum convex polygons are concentric convex polygons whose boundaries encompass a specified innermost percentage of all the observations. This technique is useful for examining areas used by an individual throughout the study period, but may not necessarily provide information on the area that could be potentially used. In addition, this method is limited to comparing animal home ranges when there are equal number of locations for each animal. The bivariate ellipse (non-circular) estimators are parametric and relatively robust to low sample sizes, however, these are only useful for animals with a bivariate movement distribution. The Harmonic Mean technique is a nonparametric method but generally, a large number of observations ($n > 60$) is needed for an accurate home range estimation. Animal locations were tested for fit of underlying distribution assumptions for the ellipse techniques (bivariate uniform, bivariate normality, and weighted bivariate normality) using the Cramer-von Mises goodness-of-fit test (Samuel and Garton 1985, White and Garrott 1990) (Appendix B).

All results were plotted on a relative frequency to examine the contaminant concentration distributions (Appendix A). The non-parametric statistical program, Multi-Response Permutation Procedure (MRPP) was chosen to test for significant differences in ^{90}Sr concentrations between locations onsite and offsite (Mielke 1991) (Appendix A).

Evaluation of Onsite Soil and Vegetation Strontium-90 Concentration

The Hanford Site Surface Surveillance data base was searched for measurements of ^{90}Sr in soil and vegetation samples for 1983 through 1993. Data bases were constructed from soil and vegetation samples based on sampling locations that fell within the areas used by deer in this study. These sample locations were grouped into two areas, north and south, for statistical analysis. The distribution of the data was evaluated, and it was determined that a log transformation best approximated a normal distribution. Analysis of Variance (ANOVA) was conducted on the log-transformed soil and vegetation data based on area. Additionally, the ^{90}Sr database collected during a surveillance of shoreline vegetation from 1990 through 1992 was evaluated to determine the potential significance of shoreline vegetation as a possible source of ^{90}Sr for mule deer. Shoreline vegetation that contained elevated concentrations of ^{90}Sr close to the 100-N Area were removed in 1992.

Results and Discussion

Strontium-90 Concentrations

A total of 38 deer antler samples were analyzed for ^{90}Sr concentrations. Mule deer on the Site were partitioned into two major groups associated with the northern and southern study areas. These herds may represent combinations of smaller but distinct subgroups whose home ranges overlap; however, additional and more extensive monitoring of individual movements would be necessary to make this determination. Fourteen (37%) samples came from animals captured near the 100 area reactor sites, fourteen (37%) were collected from animals captured near or south of the old Hanford Townsite, and ten (26%) were collected from the reference site near Silver Lake, Oregon.

Strontium-90 concentrations found in antler samples collected from 17 animals that were tracked by radio transmitter and 10 other untagged animals residing within the two (north and south) areas were tested for differences using the non-parametric Exact Multi-Response Permutation Procedure (EMRPP) and Multi-Response Permutation Procedure (MRPP). A non-parametric statistical program was chosen because the northern area data were not normally distributed (Appendix A). Initially, samples collected from near 100-BC, 100-K, and 100-N were grouped as one area, as were those samples collected near 100-D, 100-H, and 100-F. Results were subjectively grouped this way because this represented a minimum sample size for area comparisons. No statistical difference in ^{90}Sr concentrations from samples collected throughout the 100 areas was observed. However, when all 100 Area samples were considered as one group, a significant ($p < 0.001$) difference between the north (100 areas) and the south (old Hanford Townsite Area) was determined. Average dry-weight antler concentrations near and far from the reactor sites were 0.41 ($\pm$ 0.06) 1SE pCi/g and 0.19 ($\pm$ 0.02) 1SE pCi/g, respectively (Figure 2). Statistical results are shown in Appendix A.

Concentrations found in antlers collected from the reference site (Silver Lake, Oregon) were approximately five times higher than those found in antlers from near the reactor sites (Figure 2 and raw data in Appendix A). Price et al. (1981) considered central Oregon to be an adequate reference for levels of ^{129}I in deer because this area is similar to the Hanford climate and habitat. Animals residing near Silver Lake, Oregon, migrate from the high mountains in the summer to the shrub-steppe basins in the winter where their shed antlers are found. Six soil samples were collected from near Silver Lake, three in the valley and three in the nearby mountains. Results from soil samples collected in the lower elevation area do not compliment the relatively high values observed in antlers collected in that region. However, results from samples collected at an area higher in elevation compliment the relatively high values observed in antlers collected from that region. The median concentration of ^{90}Sr in the Silver Lake basin and mountain soil samples was 0.180 pCi/g (range 0.136 to 0.233 pCi/g) and 0.653 (range 0.537 to 0.669), respectively.

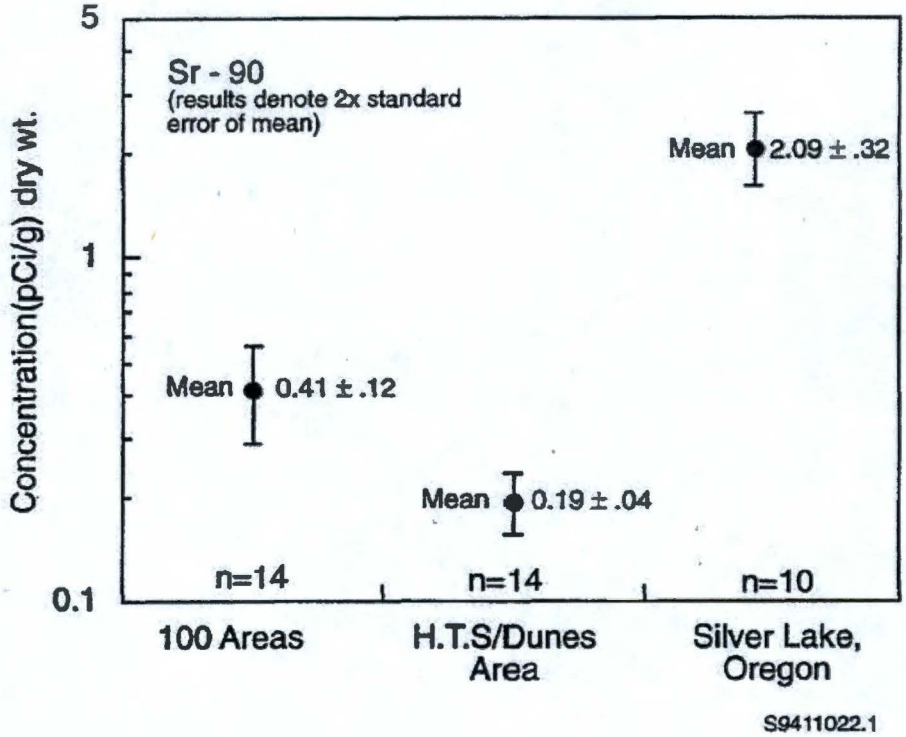


Figure 2. Mean ± 1 Standard Error Strontium-90 Concentrations in Antlers

Soil data collected as part of the Hanford sitewide monitoring project was segregated into two groups, reflecting the north and south grouping of deer populations, and evaluated (Figure 3). The distribution of the soil data clearly indicated a log-normal distribution, and the north and south area soil data were log-transformed and subjected to ANOVA (Table 1). This analysis indicated no significant difference in groups ($P = 0.551$). The median concentration of ^{90}Sr in the combined study areas was 0.0206 pCi/g soil. The basin samples from Silver Lake are generally higher than the Hanford soil data summarized for this study, however, higher soil concentrations of ^{90}Sr were expected in the mountain soil samples due to higher amounts of precipitation there (Whicker 1965, Osburn 1967, Whicker 1983). Consequently, the elevated concentrations of ^{90}Sr in the Silver Lake deer antlers is not unexpected as there is an apparent higher background exposure level because of historic atmospheric fallout from weapons testing. A regression analysis between the soil and antler data from all three locations (Silver Lake, 100 North Areas, and the South Area) was significant ($p < 0.001$; $R^2 = 0.700$) to 0.699 (Figure 4).

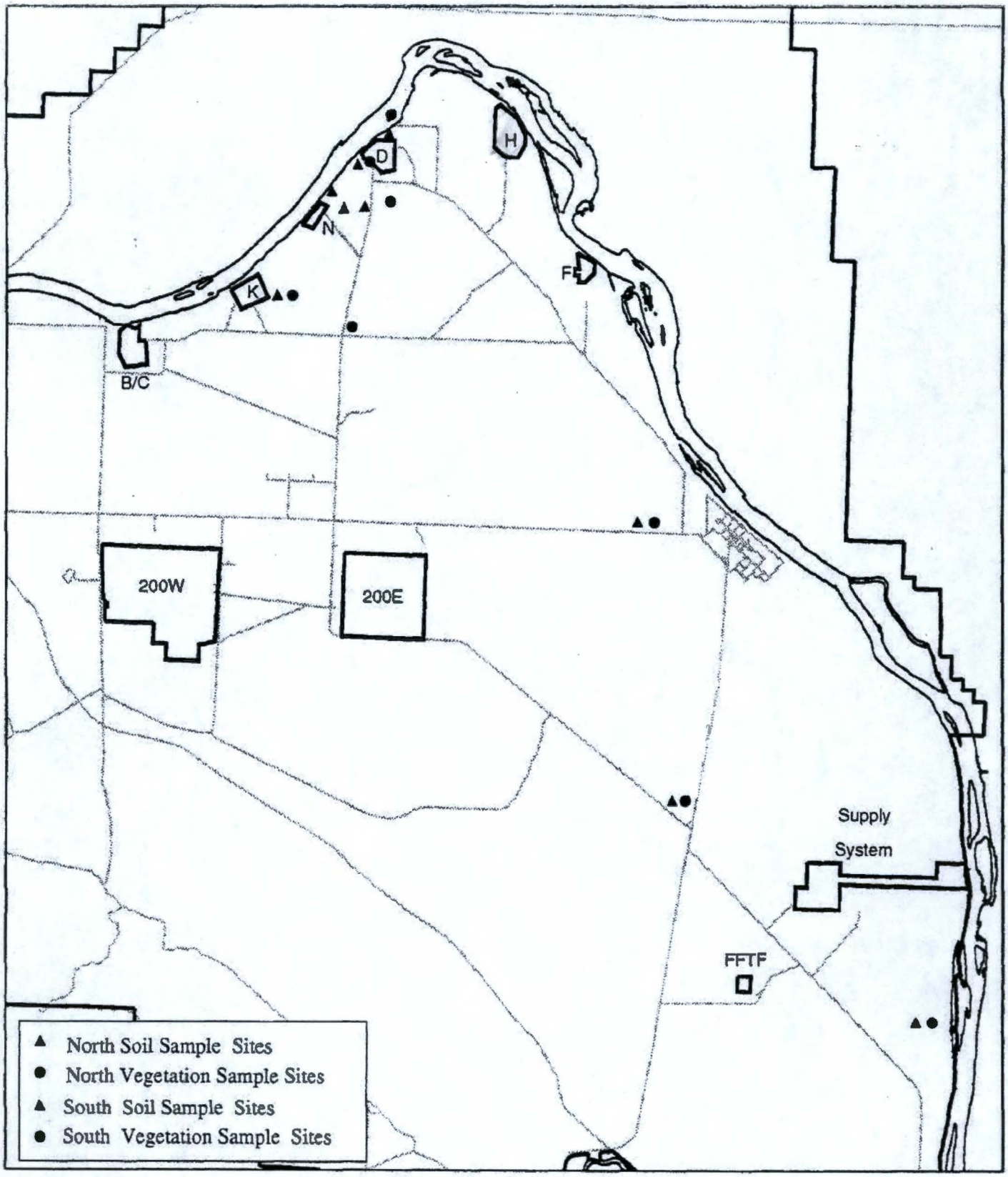


Figure 3. Soil and Vegetation Sampling Locations included in Hanford Analysis

Table 1. ANOVA of Log-Transformed Strontium-90 in Selected Soil Samples Corresponding to North and South Deer Home Ranges

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Area	1	0.04614	0.04614	0.36112	0.5507
Residential	48	6.13349	0.12778		

Vegetation Analysis

The sitewide monitoring database for vegetation samples (annual growth of rabbitbrush and sagebrush) was also evaluated for ^{90}Sr based on the same grouping of north and south areas developed for the deer populations. The data were log normally distributed and, following log-transformation, were analyzed by ANOVA for differences between groups. The ANOVA was insignificant (P = 0.636, Table 2) corroborating conclusions of the site soil data analysis that no difference existed in ambient level of ^{90}Sr in the deers' general habitat at Hanford. Vegetation samples were not collected at Silver Lake.

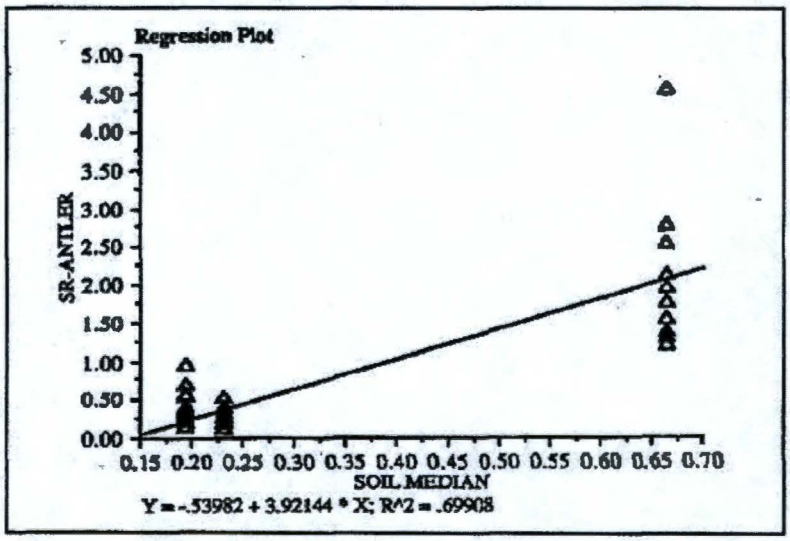


Figure 4. Regression Analysis of Antler Versus Soil Data

Table 2. ANOVA of Log-Transformed Strontium-90 in Selected Vegetation Samples Corresponding to North and South Deer Home Ranges

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	1	0.062	0.062	0.22639	0.6364
Residential	48	14.63384	0.30487		

Shoreline vegetation found along the 100-N Area from 1990 through 1992 had an elevated concentration of ^{90}Sr compared to other shoreline areas in the Hanford Reach (Antonio et al. 1993). Mulberry (*Morus alba*) leaves were found to contain the highest concentrations [440 (± 80) pCi/g], compared to yarrow (*Achillea millefolium*), chickory (*Cichorium intybus*), and willow (*Salix spp.*). Very little foraging data are currently available for deer residing along the Columbia River; however, field observations of deer eating mulberry and willow are common during the summer months. Shoreline vegetation from the 100-N Area represents one potential source of contamination that may explain the apparent elevated concentration of ^{90}Sr found in antlers from the north population. If this were the major ^{90}Sr source for deer uptake, continued monitoring of deer antlers should show a decrease in antler ^{90}Sr concentrations now that the contaminated vegetation from the 100-N shoreline has been removed.

Animal Movements

Home range areas and subpopulation intermixing were examined to further evaluate the observed differences in ^{90}Sr concentrations between the 100 areas and old Hanford Townsite/dunes areas. A potential source of error was introduced when grouping the antler data by location since areas of use were not determined for all animals included in this study. This error could have occurred by capturing an animal that resides in one location but, because of capture activity, had moved a considerable distance from its usual home range. To examine this possibility, animal capture sites and relocations of all deer tagged with radio transmitters in 1991 and 1992 were plotted on the GRASS Geographical Information System (GIS) and color coded by capture site (Figure 5).

Animals caught at or below the Hanford Townsite ranged down river extensively but were rarely present at any distance up river from this location (Figure 5). Animals captured upriver from the Hanford Townsite were never found downstream of this site. It appears that animals captured near 100-F do not readily move upstream to the other reactor sites; however, those animals residing around 100-BC, 100-K, 100-N, 100-D, and 100-H readily intermix and use that entire portion of land. Figure 6 identifies location data for 17 bucks on the Hanford Site that were captured, sampled, and equipped with radio transmitters in 1992, 1993, and 1994. One animal captured near 100-F in 1992 was recaptured in 1994 near 100-H and sampled again (see raw data Appendix A).

Fourteen animals (eight bucks from which antlers were collected and six does) were used to examine deer home-range areas. Six does were also included for area-use indicators of each group because extensive monitoring data for them was available. From 1992 to 1994, 566 relocations of

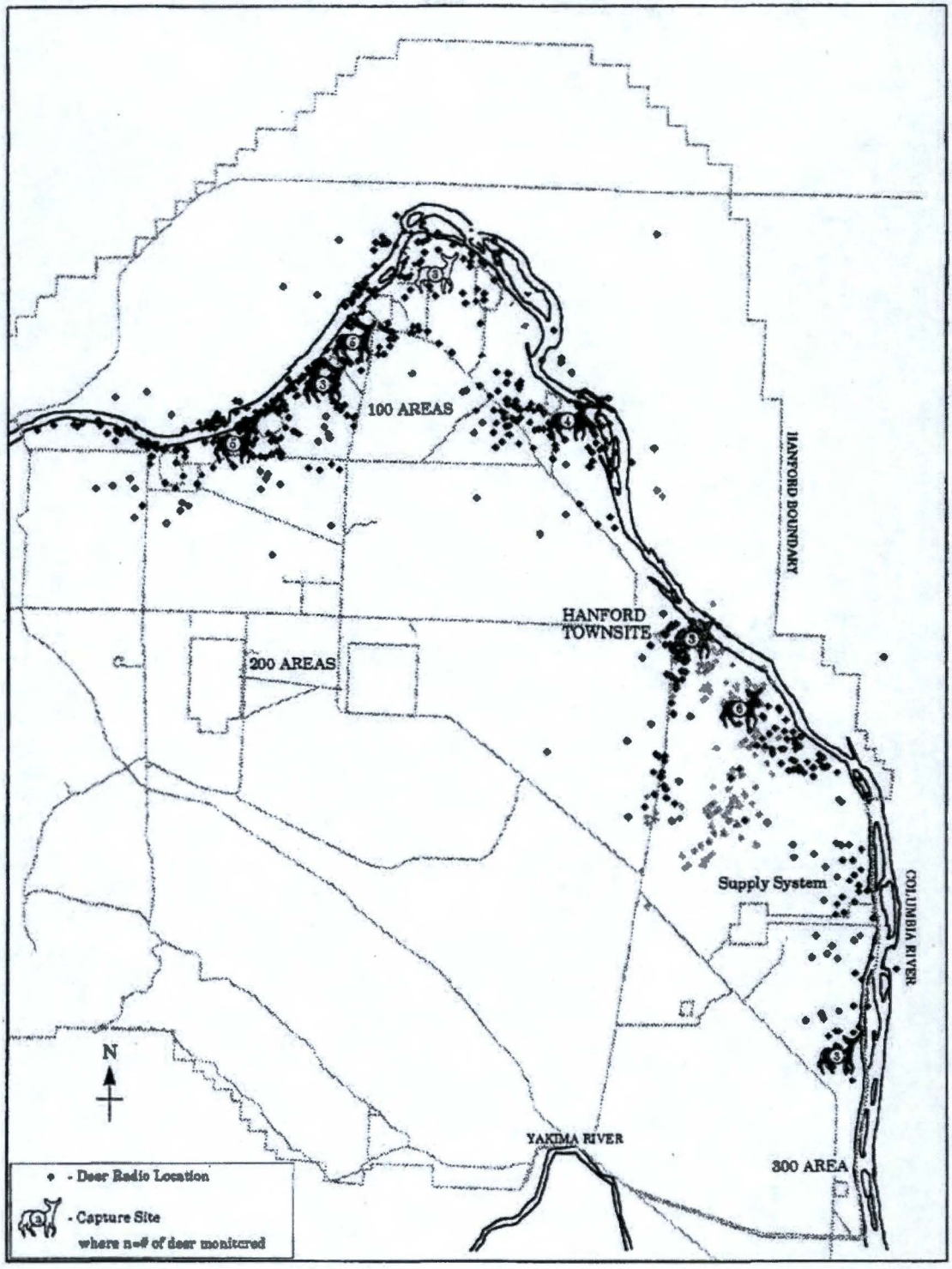


Figure 5. Deer Locations Relative to Capture Sites 1991 - 1992. Illustrates intermixing of deer captured at several sites along river. Color of deer symbol corresponds to color of location points.

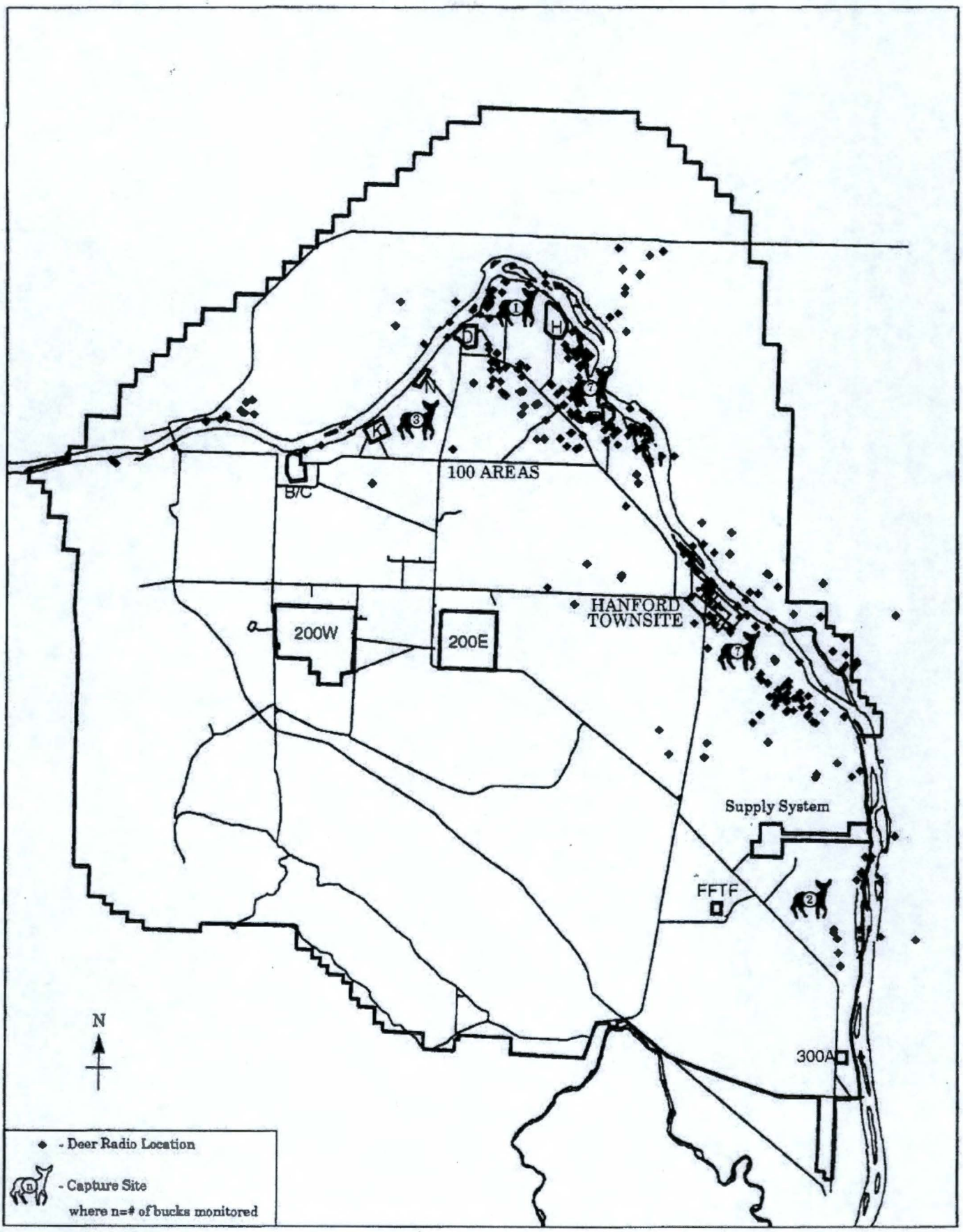


Figure 6. Plotted Re-locations of Bucks Sampled for Strontium-90. Examines potential error of collecting antlers from one capture region where animals may not normally occur.

these deer were made with an average of 40 ± 16 (1 standard deviation) relocations per animal and were tracked an average of 17 ± 6 (1 standard deviation) months. Total monitoring time represents 20 deer years with tracking time slightly emphasized through the summer months when antlers are developing.

Depending on the biological question being asked, various home range estimate techniques are more suitable than others. In this study, the size of the home range was not as important as the extent of area used by individual deer within the two sub-populations. Most radio equipped animals did not use their home range in a uniform pattern. The distribution of movements for animals with an adequate number of relocations was examined to help choose a suitable home-range estimator. Animal location distributions were tested for bivariate normality, weighted bivariate normality, and bivariate uniformity using Cramer von-Miss goodness of fit (Appendix B). Although bivariate normality appeared to fit the movement distribution of more animals than did the other two distributions, the majority of animals (eight out of 14) did not fit any underlying distribution. For this reason coupled with a relatively variable number of relocations for the study animals, the nonparametric 95% harmonic mean technique was chosen for estimating the extent and size of home ranges. Furthermore, home range area estimates for the 95% harmonic mean technique were larger than 100% and 95% minimum convex polygon technique (Appendix B). The 95% harmonic mean estimate is therefore a more conservative evaluation of animal group intermixing potential.

Based on the 95% harmonic mean home-range estimate technique (Appendix B), average home range size was 24.7 ± 12.5 Km^2 (1 standard deviation) and ranged from 12.3 km^2 to 52.1 km^2. Figure 7 illustrates the estimated home ranges of these 14 deer. There appeared to be no significant ($P > 0.1$) difference in home-range size between does and bucks. These results are consistent with findings by Eberhardt et al. (1982) who reported an average home-range size of 37 deer to be 39 ± 27 km^2 (1 standard deviation) using the elliptical technique. To further illustrate animal movements observed within the north and south areas, this figure includes over 1300 relocation points from 32 does residing within the two sub-populations monitored from 1991 to 1993.

Although the mean home range estimates reported in our study are smaller than those reported by Eberhardt et al. (1982), the associated variation is such that they are not significantly different. Differences might be expected because our study focused on populations residing along the river, and 20 of the 37 deer tracked by Eberhardt et al. 1982 occupied the 200 areas. Factors that influence home range include availability of water and trees. At the time of the Eberhardt study, the 200 Area had two major sources of water for deer in B Pond and Gable Mountain pond (West Lake is too saline for a viable drinking water source for wildlife [Poston et al. 1991; Poston and Cooper 1994]). Essentially, no tree grew around the 200 Area except a few willows, poplars, or cottonwoods around the aquatic waste sites (Emery and McShane 1978) and some small fruit or ornamental trees planted by military personnel in areas once used as military camps. In contrast, the riparian zone along the Columbia River contains numerous trees, and the abandoned agricultural areas associated with White Bluffs and the Hanford Townsite have numerous shade or orchard trees. Therefore, because water and shade trees along the Columbia River were not as limiting as the 200 Areas, home ranges may be reduced.

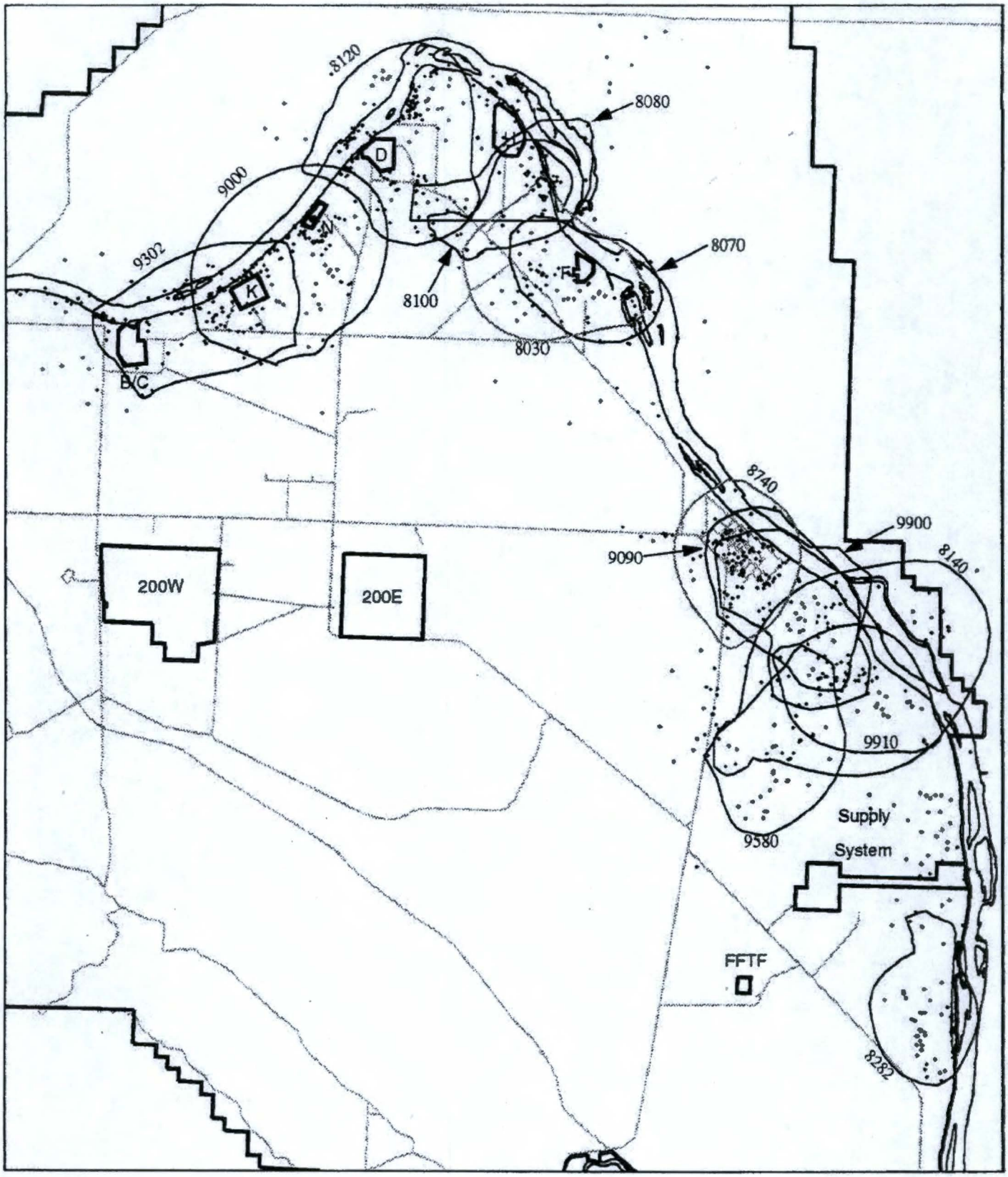


Figure 7. Home Ranges of Selected Bucks and Does on Hanford

Offsite Movements and Harvest Potential

Although lands within the Hanford Site boundaries are closed to public hunting, animals residing on Hanford have the potential to move offsite and be harvested, especially those animals residing near the Hanford boundaries. By tagging several deer with radio transmitters and routinely relocating these animals, the extent and frequency of deer movements to islands on the Columbia River and areas across the river could be determined, including movements to the Wahluke Slope Wildlife Recreation Area and private property where the animals are available to legal hunting.

Based on a previous tagging study of fawn deer along the Columbia River and tagging adult deer with radio transmitters in the 200 Areas, it is known that some Hanford Site resident deer move offsite and are harvested by hunters (Eberhardt et al. 1979, 1982). Fawn movements of up to 113 km have been documented. Until this study, however, it has not been possible to quantify potential of offsite movements. An objective of this study was to collect data necessary to evaluate the frequency and extent of offsite movements by adult deer residing on Hanford near the Columbia River.

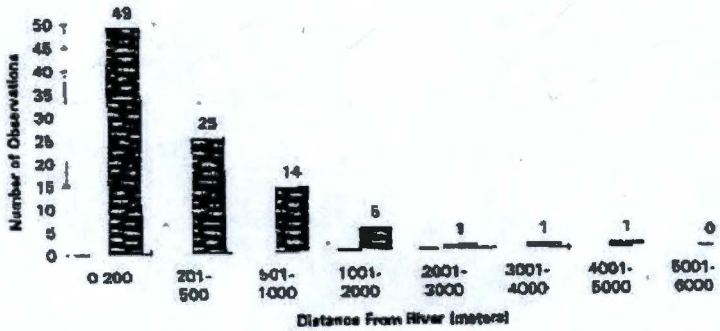
A total of 1,423 animal locations from 53 deer (15 bucks and 38 does) tagged with radio transmitters were used to evaluate the potential and extent of offsite movements by adult deer residing along the Hanford Reach. Frequent movements across the river or onto riverine islands were made by several radio monitored deer, particularly during the breeding and fawning seasons (October-December and May-July).

Twenty-four (45%) of the 53 animals tagged with radio transmitters were located at least once either across the river or on the islands during this study. For those animals that were known to have crossed the river during our study, 125 of 954 (13%) of the relocations occurred either on the islands or across the Columbia River from Hanford proper. This suggests that adult deer are not bound by the river shores and they will readily swim the river in search of food, cover, and breeding mates. Of the 125 relocations that occurred either on the islands or across the Columbia River from the Hanford Site, only 23 of them (18%) were found to be on legally huntable lands.

The extent of offsite movement by deer tagged with radio transmitters, in general, has been small as the most frequently visited locations occur immediately adjacent to Hanford along the riparian edge of the Columbia River. About 75% of deer relocations where found within 500 m of the Columbia River shoreline (Table 3). The reader should note, however, that land below the river high water mark was not considered offsite (the accuracy of location data does not make it possible to consider). This land is owned and controlled by the Corps of Engineers and is potentially huntable.

Deer hunting is common on lands adjacent to the Hanford Site, and in particular, on the back side of Rattlesnake Mountain. Until now, however, little information has been available regarding the hunting pressure on riverine islands and along the shorelines of the Hanford Reach. In 1994, 20 male deer residing near the Columbia River were captured, radio tagged, and released for future monitoring purposes. One animal lost its radio transmitter within the first month after the capture but the remaining deer were systematically tracked by air and observed on the ground through the 1994 hunting season. A total of four (21%) of the males were harvested during the 1994 hunting season, three (16%) of those animals were legally harvested and one (5%) was illegally harvested on the Saddle Mountain Wildlife Refuge near state highway 24. Based on data gathered from 1991 to 1994, an

Table 3. Distribution of Locations from the Columbia River



average of 11% (range 0% to 37% at the 95% confidence interval) of the male deer residing along the Columbia River may be harvested in any one year. A lower average harvest rate (legal or illegal) of female deer was determined to be 5% (range 0% to 21% at the 95% confidence level). The female deer harvest results in this study are consistent with Eberhardt et al. 1982 as they estimated the probability of a female deer being legally or illegally harvested during any given year at 8% (range 0 to 21% at the 95% confidence interval). A population estimate is needed to determine the actual number of deer harvested in any one year.

Conclusions

Monitoring contaminants in mobile animals can often display high variability of results and make data interpretations difficult. In this study, variability was reduced when data were grouped by general locations, i.e., North Area (old reactor sites) versus South Area (old Hanford Townsite/Dunes Area). Monitoring subsequent movements of several sampled animals residing within these two regions strongly supported observed differences in levels of ^{90}Sr found in antlers. Considering the approximate 20 deer-years worth of movement data that was attained in this study, it can be concluded with relative confidence that the concentration of ^{90}Sr found in antlers is indicative of elevated environmental exposure in areas defined by the home ranges of these study animals.

Concentrations of ^{90}Sr measured in deer antlers are low and do not indicate excessive exposure to the radionuclide in the environment. On the Hanford Site, antlers collected from the northern population had significantly higher levels of ^{90}Sr than antlers collected from the southern population. However, levels of ^{90}Sr in Hanford deer were much lower than deer antlers collected from a reference location near Silver Lake, Oregon.

Analysis of the soil samples from the mountainous home-range region of Silver Lake deer indicated higher environmental concentrations of ^{90}Sr than what was found in the shrub-steppe area at Hanford. Monitoring data of soil and terrestrial vegetation (sagebrush and rabbitbrush) indicated no differences

in environmental concentrations of ^{90}Sr between the north and south area data. Studies of riparian vegetation from 1990 through 1992 did indicate that vegetation growing in the N-springs area had elevated concentrations of ^{90}Sr. Other unknown sources of exposure could exist.

Monitoring resident deer movement suggest that the river is not a real boundary for them. Although offsite movements were minimal compared to all movements observed, a relatively high proportion of male deer were harvested in 1994 (21%). Female deer were harvested at a much lower rate than the male deer. While ^{90}Sr in antler may not be directly consumed by hunters, it does provide an indication that animals may have been exposed to contamination and perhaps other radionuclides like ^{60}Co or ^{137}Cs may be present in tissues that could be consumed.

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Appendix A

Sr-90 CONCENTRATIONS IN ANTLERS

Group	Location	Concentration	Date	Animal ID	Age
100Area	100-F	0.574	2/18/94	8.470	2
100Area	100-F	0.505	2/18/94	8.310	2
100Area	100-F	0.125	2/18/94	8.080	8
100Area	100-F	0.309	2/5/92	8.070	
100Area	100-F	0.348	2/5/92	8.710	
100Area	100-F	0.541	2/5/92	8.030	
100Area	100-H	0.277	2/18/94	8.710	5
100Area	100-D	0.348	2/5/92	8.120	
100Area	100-K	0.932	2/19/94	8.490	1
100Area	100-K	0.151	2/19/94	8.980	12
100Area	100-K	0.208	2/19/94	8.250	10
100Area	100-K	0.334	2/5/92		
100Area	100-K	0.387	2/15/91		
100Area	100-K	0.677	2/15/91		
HTS/DUNE	H.T.S./Dune	0.118	2/14/91		
HTS/DUNE	H.T.S./Dune	0.190	2/14/91		
HTS/DUNE	H.T.S./Dune	0.243	2/14/91		
HTS/DUNE	H.T.S./Dune	0.0989	2/14/91		
HTS/DUNE	H.T.S./Dune	0.160	2/14/91		
HTS/DUNE	H.T.S./Dune	0.132	2/18/94	8.430	3
HTS/DUNE	H.T.S./Dune	0.255	3/21/93	9.932	8
HTS/DUNE	H.T.S./Dune	0.383	2/17/94	8.580	2
HTS/DUNE	H.T.S./Dune	0.168	2/17/94	8.820	2
HTS/DUNE	H.T.S./Dune	0.233	2/17/94	8.910	2
HTS/DUNE	H.T.S./Dune	0.239	2/17/94	9.920	2
HTS/DUNE	H.T.S./Dune	0.234	2/17/94	8.970	3
HTS/DUNE	H.T.S/Dune	0.159	2/18/94	8.130	2
HTS/DUNE	H.T.S./Dune	0.103	2/17/94	8.990	2
SL, OR	Silver Lake, OR	2.09	4/1/91		
SL, OR	Silver Lake, OR	1.35	4/1/92		
SL, OR	Silver Lake, OR	1.51	4/1/92		
SL, OR	Silver Lake, OR	1.74	4/1/93		
SL, OR	Silver Lake, OR	1.28	4/1/93		
SL, OR	Silver Lake, OR	1.19	4/1/93		
SL, OR	Silver Lake, OR	1.94	4/1/94		
SL, OR	Silver Lake, OR	2.51	4/1/94		
SL, OR	Silver Lake, OR	4.51	4/1/94		
SL, OR	Silver Lake, OR	2.75	4/1/94		

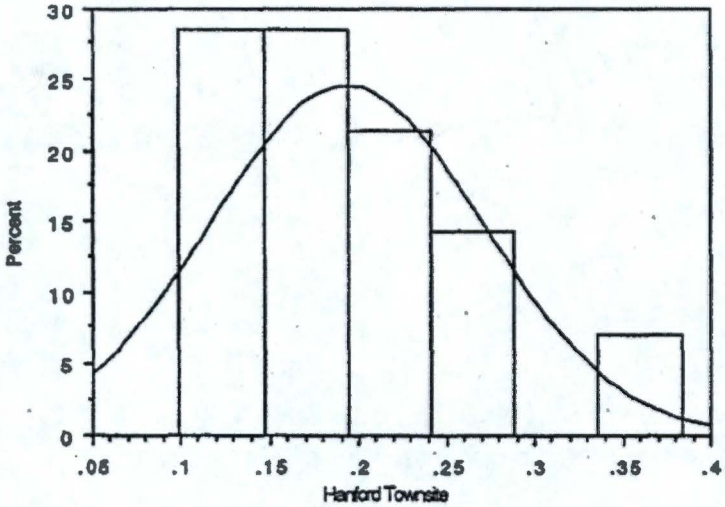
Descriptive Statistics of Sr-90 Results by Location

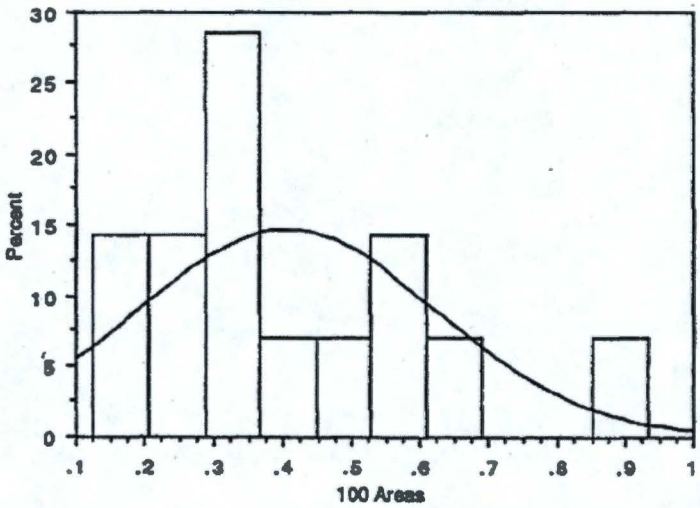
100-Areas	
Mean	0.408285714
Standard Error	0.058732344
Median	0.348
Mode	0.348
Standard Deviation	0.219756309
Variance	0.048292835
Kurtosis	1.116538047
Skewness	1.00578801
Range	0.807
Minimum	0.125
Maximum	0.932
Sum	5.716
Count	14

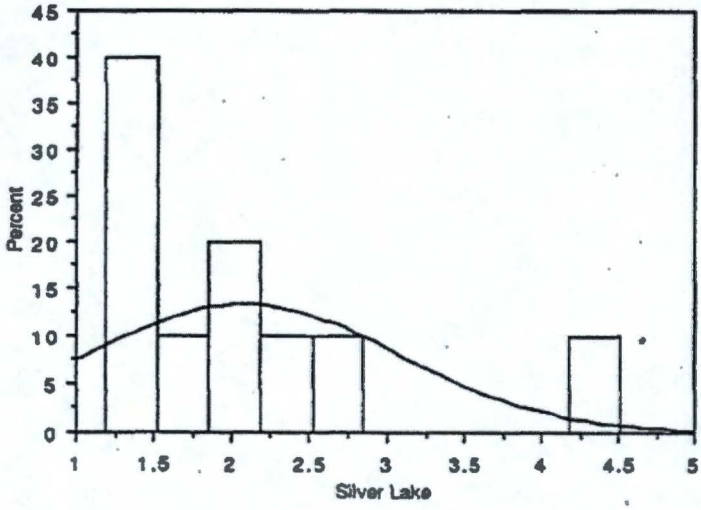
H.T.S./ DUNES AREA	
Mean	0.193993
Standard Error	0.02057
Median	0.179
Mode	#N/A
Standard Deviation	0.076965
Variance	0.005924
Kurtosis	1.413238
Skewness	0.968713
Range	0.2841
Minimum	0.0989
Maximum	0.383
Sum	2.7159
Count	14

Silver Lake, Oregon	
Mean	2.087
Standard Error	0.315584
Median	1.84
Mode	#N/A
Standard Deviation	0.997965
Variance	0.995934
Kurtosis	3.622932
Skewness	1.775779
Range	3.32
Minimum	1.19
Maximum	4.51
Sum	20.87
Count	10

Frequency Distribution of Antler Data







100BC to 100N v.s. 100D to 100F Sr-90 in Antlers

EXACT MULTI-RESPONSE PERMUTATION PROCEDURE RESULTS

NUMBER OF OBJECTS = 14
NUMBER OF RESPONSES = 1
DISTANCE EXPONENT = 1.0000000
NUMBER OF GROUPS = 2
UPPER DISTANCE BOUND = 100000.00
C(I) = n(I)/sum(n(I))

SIZE OF GROUP 1 = 6

SIZE OF GROUP 2 = 8

SIZE OF EXCESS GROUP = 0

1 (0) IMPLIES (NO) C(N,H) RANKS TEST: 0
1 (0) IMPLIES (NO) AVE. DIST. COMMENSURATION: 0
OBSERVED MRPP STATISTIC = .25496327
EXACT MRPP P-VALUE = .63469863

100BC to 100N V.S. 100D to 100F Sr-90 in Antlers

MULTI-RESPONSE PERMUTATION PROCEDURES

INPUT HAS 14 OBSERVATIONS
THERE WERE 1 DIMENSION(S)
IN: 2 GROUPS OF SIZES 8 6
C(I) = n(I)/sum(n(I))

GROUP NUMBER 1 OF SIZE 8 HAS AN AVERAGE DISTANCE = .18039286

GROUP NUMBER 2 OF SIZE 6 HAS AN AVERAGE DISTANCE = .35766667

1 (0) IMPLIES (NO) C(N,H) RANKS TEST: 0
1 (0) IMPLIES (NO) AVE.DIST. COMMENSURATION: 0
THE TEST STATISTIC IS = .60132090
THE DISTANCE EXPONENT = 1.0000000
THE UPPER BOUND VALUE = 100000.00
THE OBSERVED DELTA IS = .25636735
THE EXPECTED DELTA IS = .24789011
THE VARIANCE OF DELTA = .19874493E-03
THE SKEWNESS OF DELTA = -1.9022626
THE AGREEMENT MEASURE = -.34197561E-01

P-VALUE OF A SMALLER OR EQUAL DELTA = .67189934

*** MRPP END ***

100 Areas V.S. Hanford Townsite Area Sr-90 in Antlers

MULTI-RESPONSE PERMUTATION PROCEDURES

INPUT HAS 28 OBSERVATIONS
THERE WERE 1 DIMENSION(S)
IN: 2 GROUPS OF SIZES 14 14
C(I) = n(I)/sum(n(I))

GROUP NUMBER 1 OF SIZE 14 HAS AN AVERAGE DISTANCE = .24789011

GROUP NUMBER 2 OF SIZE 14 HAS AN AVERAGE DISTANCE = .86321978E-01

1 (0) IMPLIES (NO) C(N,H) RANKS TEST: 0
1 (0) IMPLIES (NO) AVE.DIST. COMMENSURATION: 0
THE TEST STATISTIC IS = -6.4050689
THE DISTANCE EXPONENT = 1.0000000
THE UPPER BOUND VALUE = 100000.00
THE OBSERVED DELTA IS = .16710604
THE EXPECTED DELTA IS = .20434048
THE VARIANCE OF DELTA = .33794176E-04
THE SKEWNESS OF DELTA = -2.1114973
THE AGREEMENT MEASURE = .18221761

P-VALUE OF A SMALLER OR EQUAL DELTA = .71352658E-03

*** M R P P E N D ***

Hanford Site V.S. SilverLake, Oregon Sr-90 in Antlers

MULTI-RESPONSE PERMUTATION PROCEDURES

INPUT HAS 38 OBSERVATIONS
THERE WERE 1 DIMENSION(S)
IN: 2 GROUPS OF SIZES 28 10
C(I) = n(I)/sum(n(I))

GROUP NUMBER 1 OF SIZE 28 HAS AN AVERAGE DISTANCE = .20434048

GROUP NUMBER 2 OF SIZE 10 HAS AN AVERAGE DISTANCE = 1.0646667

1 (0) IMPLIES (NO) C(N,H) RANKS TEST: 0
1 (0) IMPLIES (NO) AVE.DIST. COMMENSURATION: 0
THE TEST STATISTIC IS = -22.369215
THE DISTANCE EXPONENT = 1.0000000
THE UPPER BOUND VALUE = 100000.00
THE OBSERVED DELTA IS = .43074211
THE EXPECTED DELTA IS = .88931963
THE VARIANCE OF DELTA = .42026580E-03
THE SKEWNESS OF DELTA = -2.3056067
THE AGREEMENT MEASURE = .51564984

P-VALUE OF A SMALLER OR EQUAL DELTA = .67739477E-09

*** MRPP END ***

Appendix B

Table B.1. Cramer-von Mises Goodness of Fit Distribution

Goodness of Fit Results		Distribution		
		Bivariate Uniform	Bivariate Normal	Weighted Bivariate Normal
P > 0.10 (Fit)		4	6	4
P < 0.10 (Does Not Fit)		10	8	10
Animal ID				
8030	Male	P<.01	P<.05	P<.025
8080	Male	P>.15	.1<P<.15	.05<P<.1
8100	Male	.025<P<.05	P<.01	.025<P<.05
8120	Male	P>.15	.1<P<.15	.1<P<.15
8070	Male	P>.15	.05<P<.1	P<.01
8282	Female	P>.15	P>.15	.1<P<.15
9900	Male	.05<P<.1	P<.01	P<.01
8140	Male	P<.01	P>.15	.05<P<.1
9910	Male	P<.01	.1<P<.15	.05<P<.1
9000	Female	p<.01	P<.01	P<.01
9090	Female	P<.01	.025<P<.05	.025<P<.01
9580	Female	P<.01	01<P<.025	.05<P<.1
9302	Female	P<.01	.05<P<.1	01<P<.025
8740	Female	.025<P<.05	.1<P<.15	.1<P<.15

Table B.2. Comparison of Home Range Estimates

General Location	Deer #	# Relocations	# Months	Minimum Convex Polygon 100% MCP	Minimum Convex Polygon 95% MCP	Bivariate Ellipse Weighted 95%	Bivariate Ellipse Normal 95%	Harmonic Mean 95%
100-F Area	8030	35	15	16.7	14.6	21.4	29.7	23.3
100-D Area	8080	46	8	49.8	42.1	50.6	70.7	14.1
100-D Area	8100	39	16	15.7	7.3	43.1	26.2	12.3
100-D Area	8120	26	12	20.9	15.3	32.4	49.6	29.5
100-F Area	8070	21	8	9.9	5.7	15.3	21.8	16.2
100-N Area	9000	65	26	23.8	18.1	21.7	29.0	38.4
100-D Area	9302	67	26	21.0	15.2	23.0	28.1	26.7
Old Hanford Townsite	8282	32	15	10.2	9.4	14.2	18.3	15.7
Old Hanford Townsite	9900	26	11	21.8	19.3	43.6	50.5	23.6
Old Hanford Townsite	8140	34	18	25.0	19.4	30.3	39.6	52.1
Old Hanford Townsite	9910	21	10	7.8	5.3	12.7	16.8	19.4
Old Hanford Townsite	9090	64	24	29.7	16.9	21.1	34.6	22.6
Old Hanford Townsite	9580	50	22	26.6	20.6	31.9	42.5	32.9
Old Hanford Townsite	8740	37	17	7.7	5.9	8.4	12.3	18.3
Average Values		**40**	**16**	**20.5**	**15.4**	**26.4**	**33.6**	**24.7**

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