MULE DEER MOVEMENTS, SURVIVAL, AND USE OF CONTAMINATED AREAS AT ROCKY FLATS, COLORADO

THESIS

MULE DEER MOVEMENTS, SURVIVAL, AND USE OF CONTAMINATED AREAS AT ROCKY FLATS, COLORADO

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY **KATE K. SYMONDS** ENTITLED **MULE DEER MOVEMENTS, SURVIVAL, AND USE OF CONTAMINATED AREAS AT ROCKY FLATS, COLORADO** BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Abstract of Thesis

MULE DEER MOVEMENTS, SURVIVAL, AND USE OF CONTAMINATED AREAS AT ROCKY FLATS, COLORADO

Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) reside on plutonium contaminated land that surrounds the Rocky Flats Nuclear Weapons Facility, Colorado. Concern exists over the potential for deer to transport radionuclides away from Rocky Flats. Deer may potentially transport radionuclides through excretion of contaminated forage and soil away from the ingestion site, or by retention of radionuclides in tissues or the hide.

To assess their potential to transport radionulcides and to determine annual movement patterns, deer were radio-located throughout the year. Rocky Flats deer were year-round residents, seldom moved farther than 0.05 km from the buffer zone boundaries. At least 9 male yearlings left Rocky Flats, and yearlings are, therefore, the most likely age class for radionuclide transport. Based on annual movement patterns I observed, the potential for does and fawns to transport radionuclides off-site appears to be very low, although more data are needed to better assess movement patterns of yearlings.

Two areas in the buffer zone contain detectable levels of radionuclides and are accessible to deer. I compared deer use to availability in these areas during winter and summer 1991. During winter, 45.3% and 52.0% of radio-collared does and fawns showed preference ($P \leq 0.027$) for these 2 areas over non-contaminated areas. During summer, 39.0% and 36.7% of deer preferred ($P \leq 0.027$) each area to non-contaminated areas.

I also collected tissue samples from 7 vehicle-killed deer that were known to inhabit the buffer zone and submitted them for radionuclide analysis. All tissues had plutonium activities below detection limits. Again, transport of radionuclides appears to be very low, but because of small sample size, any conclusion regarding plutonium transport is premature.

The deer population size was estimated from a helicopter survey during summer 1990, and from a ground survey during winter 1991. Population estimates were 161 (95% confidence interval 136-220) during summer, and 199 (95% confidence interval 198-207) during winter. Winter 1991 buck:doe ratio was 35:100, and fawn:doe ratio was 90:100. Annual adult doe survival rates were 0.792 ± 0.083 (SE) in 1990 ($n = 24$), and 0.857 ± 0.059 (SE) in 1991 ($n = 35$), and were not statistically different ($P = 0.19$). Winter survival rate for female fawns was 0.895 ± 0.043 (SE) ($n=19$), and male fawn survival rate for the same time period was 0.950 ± 0.046 (SE) ($n=21$), and did not differ statistically ($P = 0.51$). The major cause of mortality among radio-collared deer was collisions with vehicles (47.8%), and predation (21.8%). Accidents and unknown causes comprised the remainder of mortalities (30.4%).

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INTRODUCTION

The Rocky Flats Plant is located 12 km northwest of Denver, Colorado on the eastern edge of the foothills of the Rocky Mountains (Figure 1). The plant was constructed in the early 1950's by the Atomic Energy Commission (AEC), early predecessor of the Department of Energy (DOE), and is currently operated by E. G. & G. which replaced Rockwell International in January 1990, after 15 years of management. Rocky Flats is responsible for the manufacture of nuclear weapons components, plutonium recovery, and waste management. Its main mission is to fabricate a product called a pit or a trigger. The pit contains plutonium fuel for nuclear weapons and is not capable of explosion without components from other production facilities. In addition to plutonium, depleted uranium, beryllium, and stainless steel are also used in the manufacturing of components. These components are assembled into weapons elsewhere (Rockwell International 1989).

In the late 1950's and 1960's, improper storage of waste cutting oil, contaminated in the plutonium milling process, resulted in detectable levels of contamination in the southeast portion of the plant site. Beginning in 1958, approximately 3570 barrels of waste oil were stored in this area behind a security fence until their removal in 1968 after the discovery of leaks in the barrels (Little 1976). Following this event and a plutonium-related fire in 1969, 5 curies (Ci) of plutonium, primarily isotope 239, had dispersed from the immediate area,

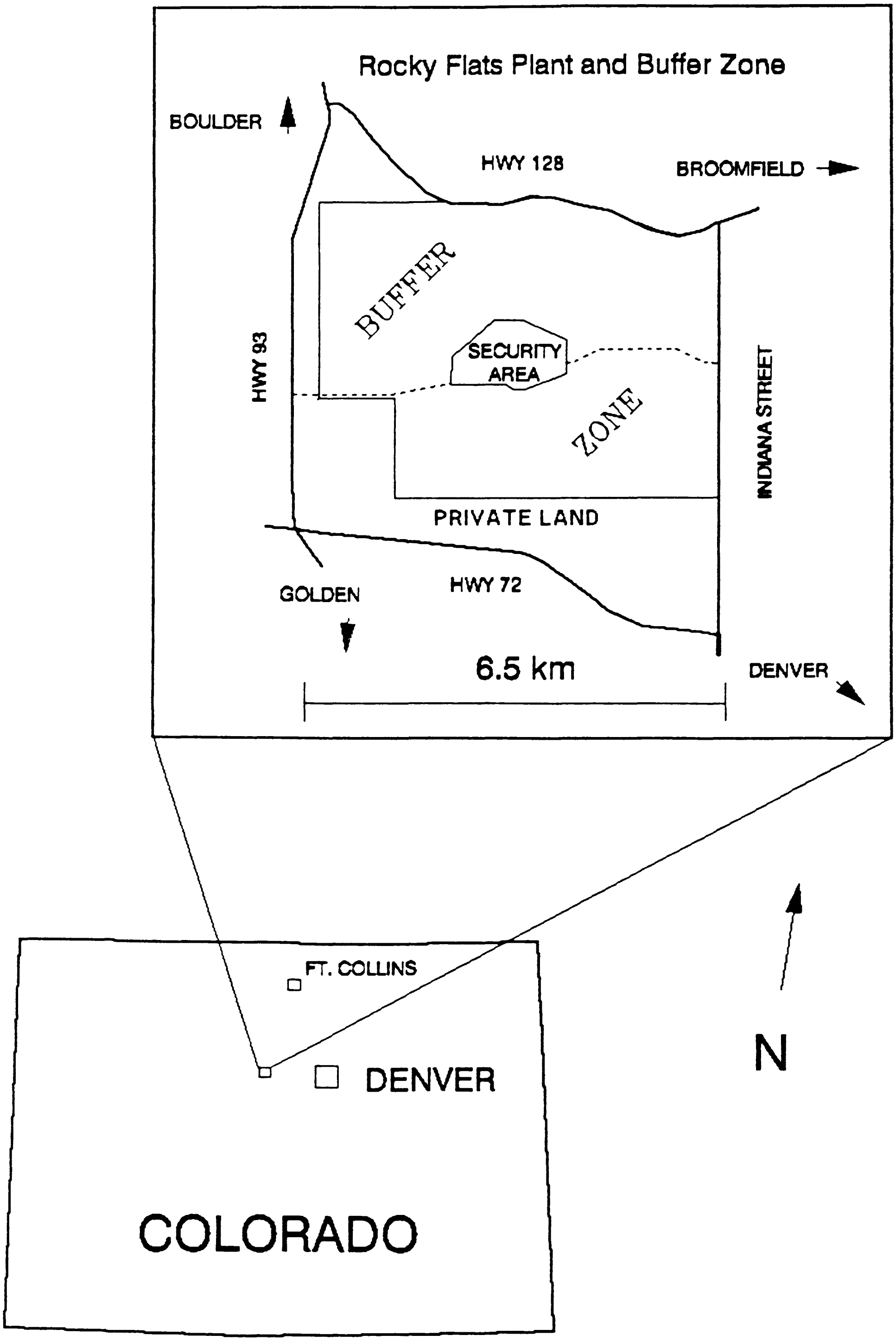

Figure 1. Location of Rocky Flats, Colorado.

probably by wind. The highest levels of contamination were found in the soil adjacent to the barrel storage site and diminished farther from the source in the "buffer zone" which is accessible to deer and other wildlife (Little 1976). The A and B retention ponds, located in the northeast buffer zone, are accessible to deer, and are another source of contamination. These ponds received radioactive leakage from solar evaporative waste ponds that are located within the security area (E.G.& G. Rocky Flats, Inc. 1991).

The buffer zone that surrounds the Rocky Flats manufacturing facility encompasses 2600 ha of open rolling grasslands, and was my primary study site. Concern over effects of plutonium in the buffer zone and surrounding environment prompted several studies at Rocky Flats in the 1970's. Components of the buffer zone that have been studied for presence of plutonium include soil (Little 1976), vegetation (Weber et al. 1974, Clark and Webber 1975, and Little 1976), snakes (Geiger and Windsor 1977), mourning dove (*Zenaida macroura*) (Alexander 1976), and small mammals (Little 1976). In addition, three mule deer (*Odocoileus hemionus hemionus*) studies were conducted which examined the role of mule deer in reference to plutonium. Alexander (1980) studied forage selection, Arthur (1977) studied plutonium uptake by deer, and Hiatt (1977) evaluated transport of plutonium by mule deer from 1975 to 1977.

My study expands and updates these data on mule deer at Rocky Flats. With the use of telemetry, I tracked deer throughout the year and documented their use of contaminated areas. Tissue samples of vehicle-killed resident deer were collected to assess radionuclide body burdens. These combined data on deer movements and body burdens provide insight into the potential movement of radionuclides from deer to humans. In addition, preliminary investigations into deer survival, population size and characteristics, and dispersal were conducted to provide baseline data on population dynamics of this herd.

My specific objectives were:

1. to document seasonal movements of radio-collared deer;
2. to quantify deer use in two contaminated areas;
3. to estimate potential movement of radionuclides by deer.
4. to estimate seasonal population size and composition and;
5. to estimate winter fawn survival and annual doe survival.

This study was part of a larger study conducted by Colorado State University faculty and graduate students that re-evaluated the presence of radionuclides in the environment surrounding Rocky Flats. The Department of Radiological Health Sciences at CSU has sampled soil, vegetation, and rodent tissues for ^{239}Plutonium, ^{241}Americium, and ^{137}Cesium. In addition, they analyzed tissues of Rocky Flats vehicle-killed deer for plutonium.

In addition to providing data that aid in assessing the pathway of radionuclides from deer to humans, this study also contributes information on deer herd characteristics that could guide decisions regarding land and deer management at Rocky Flats. In the interest of maintaining the deer population, which could be important as a public relations tool, Rocky Flats managers would benefit from knowledge of important habitats and home range site fidelity for assessing impacts from any future projects that affect the buffer zone. Data on off-site movements and radionuclides in deer will be useful in decisions regarding any buffer zone clean-up strategies, and in evaluating potential food chain pathways.

Rocky mountain mule deer, white-tailed deer *(O. virginianus)* and hybrids of the two species reside at Rocky Flats. White-tailed deer and hybrids comprise 5% or less of the total deer population (pers. obs.); thus, mule deer were the primary species studied.

STUDY AREA

Rocky Flats is located between Boulder and Golden, Colorado, 39°53'N 105°12'W, and includes an area of approximately 2600 ha in northern Jefferson County. The main plant site is located centrally within a 155 ha fenced security area that is accessible to deer only through security gates (Figure 1). The buffer zone surrounds the main plant facility and comprises 94% of the total area. A barbed wire fence surrounds the buffer zone and is easily negotiated by deer. An additional 1300 ha of private, undeveloped land lie between Rocky Flats property and the bounds of 4 highways. Public open space and pastures border the highways, and 2-8 km away are the communities of Broomfield, Louisville, Boulder, and Arvada.

Rocky Flats lies on a rocky alluvial plain dissected by several drainages that run east to northeast. Elevations range from 1705 m at the eastern end of the site to 1905 m at the western end (Clark et al. 1980). Perennial water sources include Woman Creek south of the plant, Rock Creek to the northwest, Walnut Creek to the northeast, and several springs and man-made water impoundment structures in various locations.

Vegetation in the buffer zone can be described broadly as disturbed grassland with some remnant portions of short-grass and tall-grass prairie, ponderosa pine (*Pinus ponderosa*) woodland, and foothill ravine flora (Clark et al. 1980). Riparian areas made up of cottonwood trees (*Populus sargentii*) and willow (*Salix ssp.*) occur along Woman Creek and in patches along some of the other drainages. A complete description of the vegetation and vegetation types at Rocky Flats can be found in Weber et al. (1974).

Climate is characterized as low in precipitation, low in humidity, with wide variations in daily temperature, and a high incidence of sunny days (Paddock 1959). During my study, temperatures ranged from - 31.5° to 34.7° C, with a mean annual temperature of 10.2° C. Long term mean annual precipitation is 40.0 cm, but only 25.9 cm fell during 1990, and 33.3 cm fell between October 1990 and September 1991. More than 85% of the precipitation occurred between April and August each year. Mean annual wind speed for 1990 and 1991 was 4.0 m/s, but gusts greater than 18.1 m/s were recorded every month during my study. Maximum wind speed was 50.4 m/s (Rocky Flats personnel, unpublished data)

Two areas in the buffer zone contain detectable levels of radionuclides (Figure 2), and part of my study focused on the use of these areas by deer. Boundaries, based on information from E. G. & G. personnel, enclosed areas in which deer are more likely to be exposed to radionuclides than in other parts of the buffer zone. Contamination does not end abruptly at the boundaries as implied by Figure 2, but rather gradually diminishes farther from the source, or is spotty within each area. These areas are called Solid Waste Management Units (SWMU) by E.G. &G. Several smaller SWMU's exist in the buffer zone, but these 2 areas are considered priority sites by E.G. & G. because of extent of contamination.

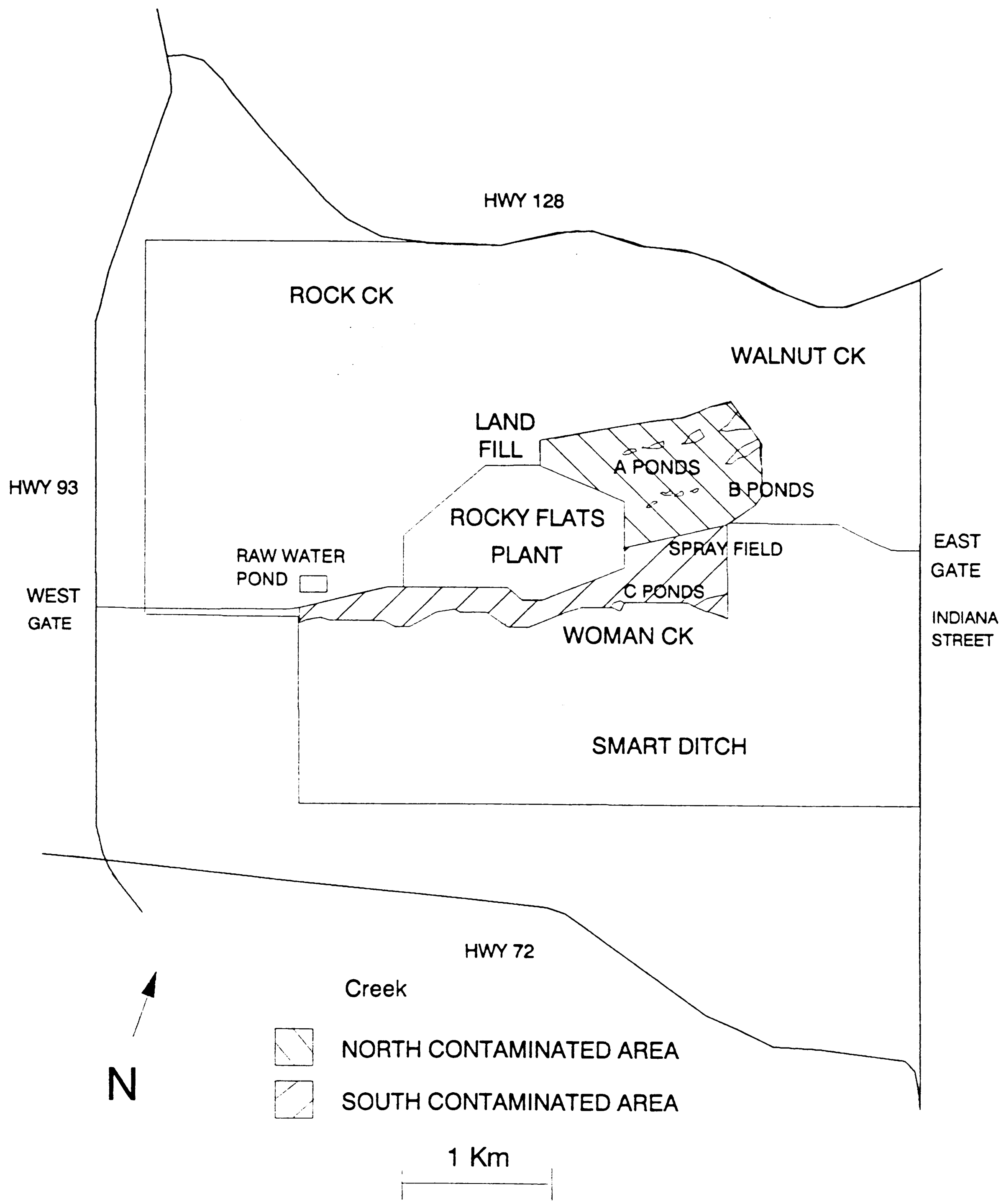

Figure 2. Map of Rocky Flats, CO featuring major creeks, and the north and south contaminated areas in the buffer zone.

One area, the "north contaminated area", lies in the northeast quarter of the buffer zone and includes the A and B waste management ponds and the small drainages in which they are found. These ponds have received radioactive water from 2 sources; leakage from evaporative solar waste ponds located within the security area, and from groundwater contaminated from radioactive material buried south of the B Ponds (E.G. & G. Rocky Flats, Inc. 1991). Although the slopes surrounding the ponds are, apparently, not contaminated, I included them as part of the north contaminated area, under the assumption that deer located in those drainages use the ponds as drinking water.

The second area, the "south contaminated area" is located in Woman Creek between the southern plant security fence and the creek bed of Woman Creek. This area extends east to pond C-2. The soil from this area is contaminated with volatile organic compounds, and the area near the C Ponds contain detectable levels of plutonium and americium.

TRAPPING AND RADIO-TRACKING DEER

Trapping Methods

Deer were trapped with drop-nets (Ramsay 1968) at Rocky Flats during January and February 1990 and December 1990 with the help of many volunteers. The nets were set up in 10 locations (Appendix 1) and pre-baited for 3 weeks with hay and apple pulp. Eight baited Clover traps (Clover 1956) were employed during the first winter, but were not used the second winter. Sixty-seven deer were trapped the first year, and 25 adult and yearling does were fitted with radio collars with an expected 3 year battery life (Table 1). Fawns were not collared until

Table 1. Trapping summaries for January and February 1990, and December 1990, at Rocky Flats, CO. Bracket numbers denote number of deer that received transmitters.

	January-February 1990		December 1990	
	Mule Deer	White-tailed	Mule Deer	White-tailed
Does	24 (24)	1 (1)	26 (16)	1
Bucks	16	1	15 (8)	2 (1)
Doe fawns	9	2	19 (19)	0
Buck fawns	15	0	23 (21)	1
Total	63	4	109	4

the second year when I began investigations on fawn survival and dispersal.

We trapped 83 deer during the second year, and radio-collared 16 adult and yearling does, 20 male fawns, and 19 female fawns (Table 1). Collars for fawns had a two year battery life, and were equipped with mortality sensors designed to double the rate of the signal pulse when motionless for 4 hours. Fawn collars were fastened with surgical tubing that degraded after 4 to 8 months. Male fawn collars were designed to drop off to avoid problems associated with neck swelling during the fall rut, whereas female fawn collars were designed to expand 15 cm once the tubing degraded. Adult bucks were not collared because of increases in neck size that occur with the onset of rut. Nine adult bucks and 1 male fawn received solar ear tag transmitters that were supplied by Richard M. Bartmann of the Colo. Division of Wildlife. CDOW was interested in the performance of this type of transmitter.

The first season of trapping, we aged and sexed deer, and marked them with an ear tag or radio-collar. During the second trapping season, we aged and sexed deer, weighed them, and measured total body length, left hind foot length, and maximum and minimum neck circumferences. Additionally, antler burr circumference, main beam length, and number and length of points were measured (Appendix 2). We also noted unusual markings, obvious external presence of disease, and any injuries.

In the first trapping season, there were 3 trapping-related mortalities; 1 in the drop-net, 1 in a Clover trap, and 1 after release. During the following season, there were no drop-net mortalities, and only one trapping-related death following release. Total trapping mortality for the two seasons was 2.2%.

Telemetry Methods

I used 2 telemetry methods to locate radio-collared deer. One involved a hand-held RA-2 "H" antenna with a TR-2 148-150 MHz receiver and TR-1 scanner/programmer made by Telonics, Inc., and was used from a vehicle or on foot. The second method was a system of permanent stationary antennas. The former method I used to collect daytime data, and the latter method was employed for night tracking during summer 1991. Throughout my thesis, unless otherwise noted, reference to telemetry use implies the hand-held antenna method and reference to deer implies radio-collared deer.

The buffer zone encompasses 26 km^2 of mostly open country with high visibility, and I encountered almost no signal bounce. An extensive network of dirt roads allowed me access to nearly all parts of the buffer zone. As a result, deer that remained on-site were relatively easy to locate on a year-round basis from a vehicle with a hand-held antenna. My technique was to "home in " on a particular frequency until I either saw the telemetered deer, or could target its location to a particular patch of vegetation.

During summer, I was less likely to sight deer, therefore deer locations were often estimated. During summer, 47.5% in 1990, and 16.8% in 1991, of deer locations were from visual observations, whereas 93% of the locations during winter were from visuals. I estimate that location error ranged from 0, for deer sighted, to an occasional maximum of 25 ha for deer not seen. The magnitude of error reflects the size of cover in which a deer was located, and because cover is sparse at Rocky Flats, I regard my estimated deer locations as fairly accurate.

I radio-tracked deer throughout the year with a concentrated emphasis in winter and summer (Table 2). Each tracking day, my field assistant or I drove through the buffer zone, and to off-site areas, as necessary, and located all telemetered deer. We recorded locations of marked deer on a dated photo-copied USGS topographic or photo-quad map of the study area, and on a pre-printed field form. The photo-copied study area maps had hand-drawn grid lines 1000 map meters apart that represented the Universal Trans Mercator (UTM) coordinate system. The x and y coordinates were later interpolated from the field maps by placing over the map a clear plastic sheet that had a pre-printed grid with line intervals corresponding to 100 m. Locations were estimated to the nearest 10 m. Other data collected included time that individual deer were located, aspect, group size, and activity. Any unusual sightings, and all wildlife sightings were recorded in a waterproof field notebook.

Tower Site Selection, Construction, and Accuracy Testing

The purpose of the permanent telemetry relocation system was to accurately locate telemetered deer at night within the two contaminated areas. The original intent was to use the towers during both day and

Table 2. Rocky Flats, CO radio-location schedule between January 1990 - August 1991.

Dates	Sampling Frequency	Purpose of data
20 Jan-31 May 1990	3 to 4x/month	Mortalities
1 June-22 Aug 1990	3x/week	Movements, mortalities
23 Aug-30 Dec 1990	1x/week	Movements, mortalities
31 Dec-29 Mar 1991	3 to 4x/week	Movements, mortalities, SWMU use
30 Mar-31 May 1991	2 to 3x/week	Movements, mortalities
1 June-24 Aug 1991	3x/week	Movements, mortalities, SWMU use

night because it was thought that this method would disturb deer the least. Because Rocky Flats deer are habituated to vehicles and habitats are open, I relied on the towers only for night work.

Towers were located on bluffs overlooking the 2 contaminated areas where interference with signal reception would be minimized (Figure 3). A tower, described in detail later, consisted of an elevated antenna enclosed at the base with a plywood shed which housed one observer, a small table upon which rested the antenna mast, and a few items of equipment. Only one area was monitored at this time using 3 towers, with observer in each tower. Towers 1, 2, and 3 monitored the south area, and towers 4, 5, and 6 served to monitor the north area. Deer locations were triangulated with azimuths from each of the 3 towers to the signal of a particular deer.

In order to locate an animal's position relative to a coordinate system, I determined the exact location of each receiving tower. I surveyed each of the 6 tower sites with a transit and used test wells at Rocky Flats as known reference points. Coordinates for each well were furnished by E. G. & G., which I converted from state plane to Universal Transverse Mercator (UTM) coordinates with the computer program COORTRAN (Umbach 1967, Claire 1973). With the transit, I obtained horizontal angles

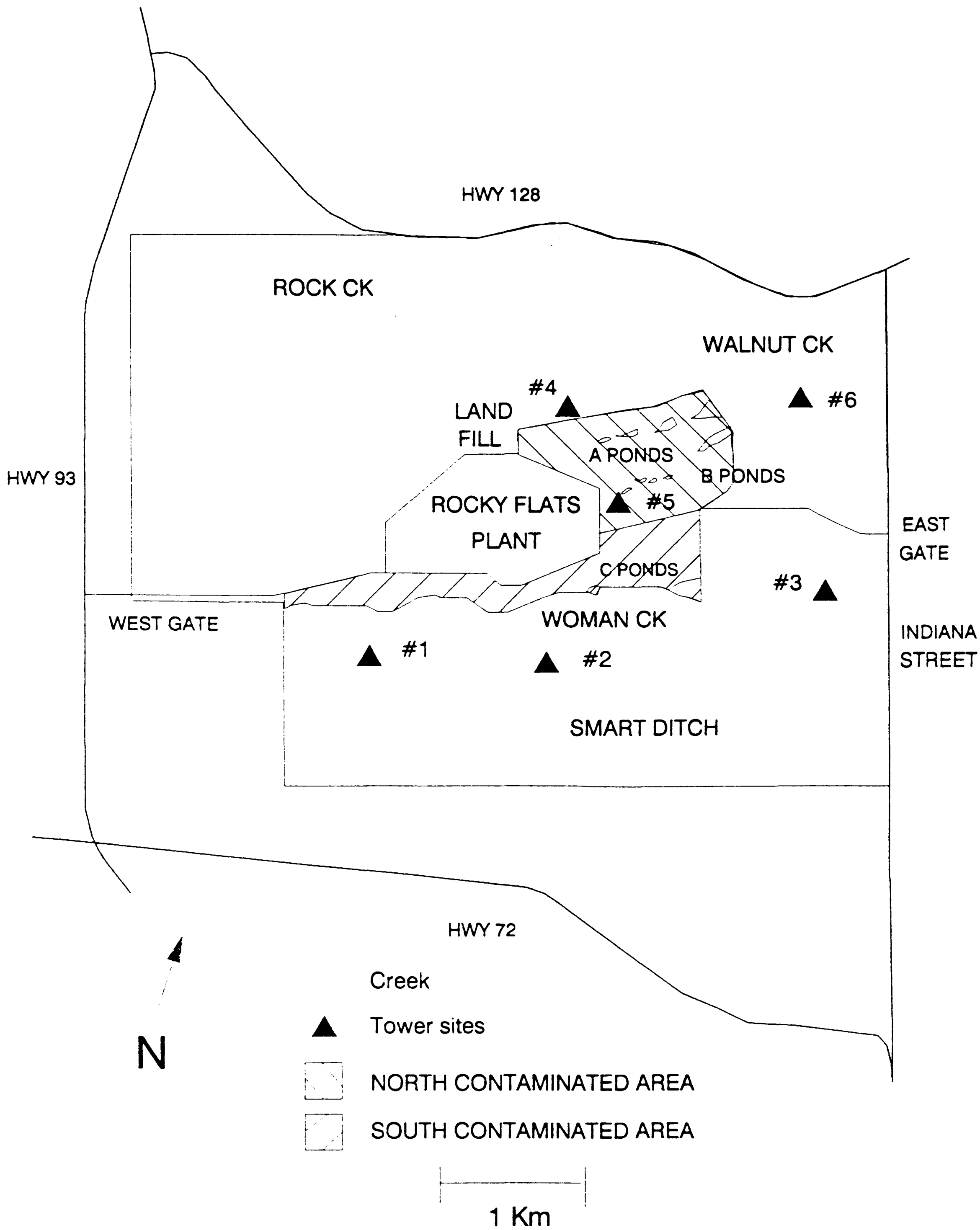

Figure 3. Telemetry tower locations at Rocky Flats, CO.

to three wells near each tower, reversed them 180°, and input them to Program TRIANG (White and Garrott 1984), which calculated the coordinates of each tower site. TRIANG (White and Garrott 1984) is the triangulation program I later used to determine locations of radio-collared deer relative to the towers.

The six 1.83 m^2 plywood tower sheds were built off-site and assembled on-site by bolting the walls and roof together. The wooden tables were also constructed off-site and then installed in each of the sheds. Soil excavation was not permitted, so to provide a secure base for the table, the legs were set in a 15 cm X 46 cm X 46 cm block of concrete, and the sheds were secured to the ground with two 48 mm diameter cables that went over the roof and fastened to "T" posts driven in the ground. The sheds had one 46 cm^2 plastic window and a 0.46 m X 1.83 m corrugated filon skylight. Propane heaters and lanterns provided heat and light during night tracking.

The receiving system for each tower was identical and consisted of dual array, vertically polarized, 6-element antennas from Cushcraft (Figure 4). The antennas were 1 m apart, bolted atop a 6.1 m mast, and utilized a null detection system. A null combiner was housed in a small box and fastened with hose clamps to the aluminum antenna boom. Coaxial cables from each of the 6-element antennas were joined at the combiner box at the top of the mast. A single coaxial cable ran from the combiner box down the inside of the mast to a receiver.

The mast was made of two telescoping lengths of 3.05 m electrical conduit (44.5 mm and 38.1 mm) which, when extended, were locked in place with 2 bolt pins. The mast and antenna were assembled and raised at each tower site after the sheds were assembled. The mast was grounded with

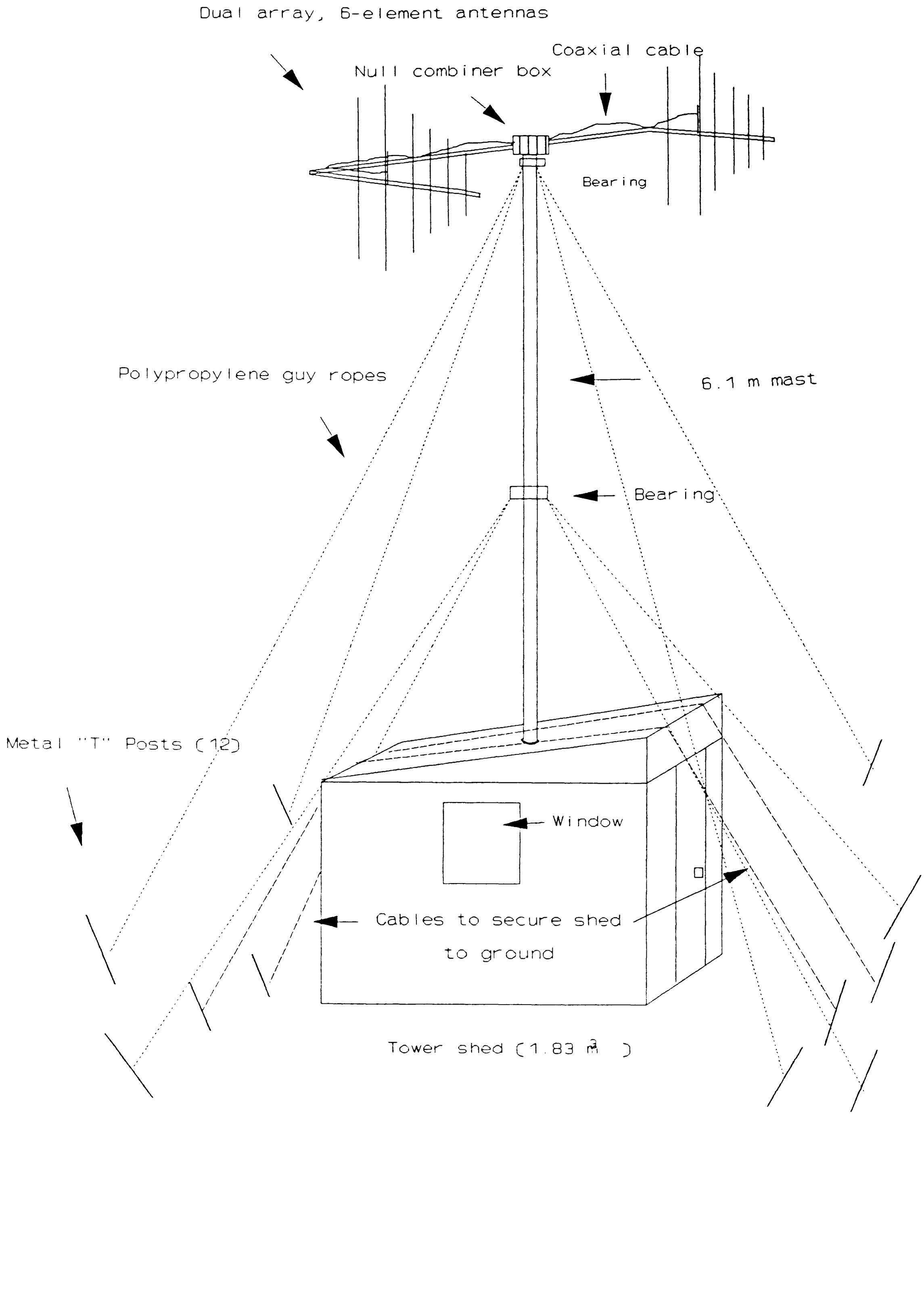

Figure 4. Diagram of telemetry tower used at Rocky Flats, CO.

stranded copper wire, and guyed with 8 polypropylene ropes fastened to 8 "T" posts. Four of the ropes were attached to the top of the mast by a metal bearing, and another 4 were attached to a mid-mast bearing. The 2 bearings allowed the mast to be turned without turning the ropes. The mast was turned from inside the shed with a wooden handle bolted to the mast. A table bearing was encircled with a mounted plastic compass protractor that served as a compass rosette. A pointer was affixed to the base of the mast, and the rosette was properly oriented so that the pointer denoted the true bearings to test transmitters.

After the 6 towers were fully assembled, considerable time was spent testing and adjusting each of the towers to ensure accurate bearings to signals. Bearings determined from radiotelemetry are estimates of the true bearing. Bearing accuracy is estimated by measuring the difference between the true and observed bearings to the signal relative to each tower, and has two components; bias and precision (Lee et al. 1985, White and Garrott 1990). Error is the difference between the true and estimated bearing, and bias is determined from the mean of multiple measurements of error. Precision is the amount of variation in repeated estimated bearings and is measured as the standard deviation (SD). The standard deviation allows placement of confidence limits on bearings to form error arcs. Intersection of two or more error arcs delineates an error polygon (Heezen and Tester 1967) and thus, the point estimate of the location has an associated confidence area estimate.

To determine bearing accuracy, my field assistants and I placed 5 test transmitters mounted on 45.7 cm wooden stakes near surveyed well heads within the bounds of each contaminated area, and compared observed bearings to the true bearings (Lee et al. 1985). True bearings were derived from surveying or trigonometry. Two observers were used for accuracy testing. One took bearings to each of the test transmitters without knowing its true bearing; the other operated the receiver and read the resulting bearings from the compass rosette. Repeated bearings were taken to each of the 5 test transmitters. Each transmitter was located 5 times in a randomized order for a total of 25 bearings per tower. Not all towers could receive signals from all 5 transmitters so accuracy was based on less than 25 bearings for some towers. Randomizing the order of signals reduced memorization of bearings by the observer. The formula for calculating the standard deviation (SD) for the towers is:

$$SD = \frac{[\Sigma\Sigma(e_{ij} - \bar{e}^2]^{\frac{1}{2}}}{(n-1)}$$

where e_{ij} = true bearing minus the estimated bearing for each bearing i and replicate j, $\bar{e}$ = mean error, and n = number of replicate bearings. The standard deviation for the 3 north towers is 1.69°, and 1.87° for the 3 south towers (Table 3).

During night tracking sessions, 3 observers would simultaneously track each deer each hour and record bearings to all signals heard. It took three night sessions before we were able to locate all frequencies in an hour. Each observer had a receiver with a scanner, headphones, two-way radio, and data sheets. The bearings were communicated to me by two-way radios and input to a Tandy 100 computer programmed with the triangulation program TRIANG (White and Garrott 1984). TRIANG (White and Garrott 1984) generated a plot of the bearing intersections from which

Table 3. Results of accuracy testing for all towers at Rocky Flats, CO. Replicate bearings were taken from each tower to 3-5 test transmitters. Sample size is the number of replicate bearings used to calculate mean bearing error and standard deviation.

Towers	Sample Size(n)	Mean Error($\bar{e}$)	Std Deviation (SD)
South Towers			
1,2,3	62	0.2225	1.8708
1,2	45	-0.3475	1.2319
North Towers			
4,5,6	60	0.2217	1.6912
4,6	45	0.5650	1.7051
5,6	40	- 0.0317	1.1423

I could determine whether bearings should be repeated. This program was essential for improving the quality of data while in the field.

The computer stores only the bearings, date and time they were input. The data were later downloaded to a PC which ran the PC version of TRIANG (White and Garrott 1984). In PC TRIANG (White and Garrott 1984), I used the Andrews estimator (Lenth 1981) to calculate the point estimate and the error ellipse for each set of bearings. The Andrews estimator performs better in the presence of signal bounce, has better coverage, less bias, and is less likely to generate an estimate when the data are poor (White and Garrott 1990) than either the Huber or maximum likelihood estimators by Lenth (1981). I used the point estimates as location estimates and used the error ellipses as an indication of estimate quality. Point estimates with error ellipses above 8 ha were discarded. This ellipse size was subjectively selected because contaminated area boundaries are not rigidly defined, and deer whose point estimates fall on a boundary (worse case scenario for determining "in" or "out"), may well receive some exposure to contaminants, even if deer are actually just outside the boundary. Therefore, an acceptable error ellipse of ≤ 8 ha was acceptable given the nature of contamination and the objectives of my analysis. Less than 3% of night locations were discarded because of unacceptable error ellipse size.

Discussion of Tower Performance

For safety, the towers were not operated during thundershower activity. Additionally, the towers were not operated when winds caused the mast and antenna to shake, because bearing accuracy was affected in an unquantified manner. Very strong winds prevented the antennas from being turned altogether. As a sampling consideration, absence of data during such weather conditions may cause a bias because deer may behave differently and occupy different areas than in fair weather. Based on my observations, deer behavior during summer thundershowers was variable. Deer sometimes became more active; some occasions they did not. Wind appeared to cause a change in deer use patterns. On several occasions in winter and spring, I observed deer groups bedded in the lee of a hillside, and deer groups moving swiftly, apparently to seek wind shelter. Few nights were windy during summer, but thundershower activity was common, thus, there may be some "fair weather" bias in my night tracking data.

There were several conditions that compelled me to generate location estimates from only 2 bearings. Most signals in the drainage bottom for the north contaminated area were in range for only 2 towers. Because of topography, there was no tower placement scheme where all 3 towers could receive signals from any location within this area. Also, signals from the solar ear tag transmitters could only be heard ≤ 2 km away, often from only 2 towers. Occasionally, signals in the far western part of the south area were out of range, or were too distant to obtain accurate bearings from Tower 3. In these instances, I used bearings from the other 2 towers and calculated location estimates using the standard deviation appropriate to the particular towers (Table 3).

MOVEMENTS

Information on movements of Rocky Flats deer is crucial in assessing the possible pathway of contaminants from deer to humans, and from deer to other areas off-site. Concurrent with my study is the analysis of Rocky Flats deer tissues for radionuclides, which aids in determining the type and amount of radionuclides transported by deer.

Knowledge of movements is also important from an ecological standpoint for determining whether dispersal has a role in population regulation for this herd. To document dispersal, and its effect on population dynamics, additional data are needed. Therefore, I do not expect to conclusively determine such phenomena, but will build a foundation for continuation of this study.

To study dispersal, it is necessary to differentiate dispersal from other movements, such as migration, and those movements which would be considered normal daily movements. For the purpose of my study, migration is defined as annual round-trip movement, whereas dispersal is defined as one way movement out of an area larger than a home range (Bunnell and Harestad 1983) "to a place where the animal will reproduce or would have reproduced had it survived and found a mate" (Howard 1960). Some definitions of dispersal include an additional requirement that an animal disperses from its birth range to a new area (Shields

1987, Greenwood 1983), which is termed natal dispersal. Since I cannot be certain that fawns collared in winter were born at Rocky Flats, I do not include any assumption regarding natal range in the definition of dispersal. An animal is classified as dispersed if it left its home range area, established a new home area, and did not return.

Methods

Deer were trapped and fitted with radio transmitters during the 2 years of my study (Table 1). Deer were then located according to the schedule in Table 2. I recorded locations on USGS topographic, or photo-quad maps in Universal Transverse Mercator (UTM) coordinates, input them to a spreadsheet program, and plotted them on digitized maps. of my study area.

I calculated home range size for does for summers 1990 and 1991, and for does and fawns for winter 1991. I used the minimum convex polygon (Mohr 1947), Jennrich-Turner 95% ellipse (Jennrich and Turner 1969), and the weighted bivariate normal (Samuel and Garton 1985) methods for home range calculation. Each estimator results in a different home range size, and I report the mean and standard deviation from each estimator.

I also plotted June locations of adult does for 1990 and 1991 to determine which areas were used most during fawning season.

I used Multi-Response Permutation Procedures (MRPP) (Mielke et al. 1981) to determine fidelity of does to summering areas. MRPP is based on sample locations, and compares the distribution of locations among years. I tested for significant differences in summer location patterns.

On-Site Movements and Activity Pattern Results

Deer at Rocky Flats are non-migratory and most remained on-site throughout the year (Figures 5 through 9). During winter, deer formed large, mobile groups averaging about 16 individuals, and tended to occupy open exposed areas. Groups overlapped in area, but seldom overlapped in membership. Certain groups predictably occupied particular areas in the buffer zone. One group occupied the northeast buffer zone; another used Rock Creek, the north firing range area, and occasionally the A ponds. On the south side; one group predictably occupied Woman Creek; another utilized Smart Creek, and the southernmost boundary area; and another group occupied the southeast buffer area. Occasionally, these major groups would break up into smaller aggregations, but deer would usually remain within the same area their major group occupied.

As summer approached, observed deer group size diminished to an average of 3-4 individuals, and does spread themselves out within the general area they occupied during winter and spring. Deer were sedentary and had smaller home ranges than during winter (Table 4). Does remained with their newborn fawns, and often with, presumably, last years' female fawn, until late summer. Adult bucks formed an association in summer, and I usually observed them in the southeast buffer zone. A few yearling bucks were sometimes seen with this group, but most yearling bucks were found in pairs away from other groups, or found alone near doe and fawn groups.

Brushy areas in all draws, especially in Rock Creek, were occupied by does during June 1990, and June 1991 (Figures 10 and 11). Areas with cattails such as the southern slopes of Woman Creek and the hillside south of the B Ponds also received heavy use by does. The most heavily

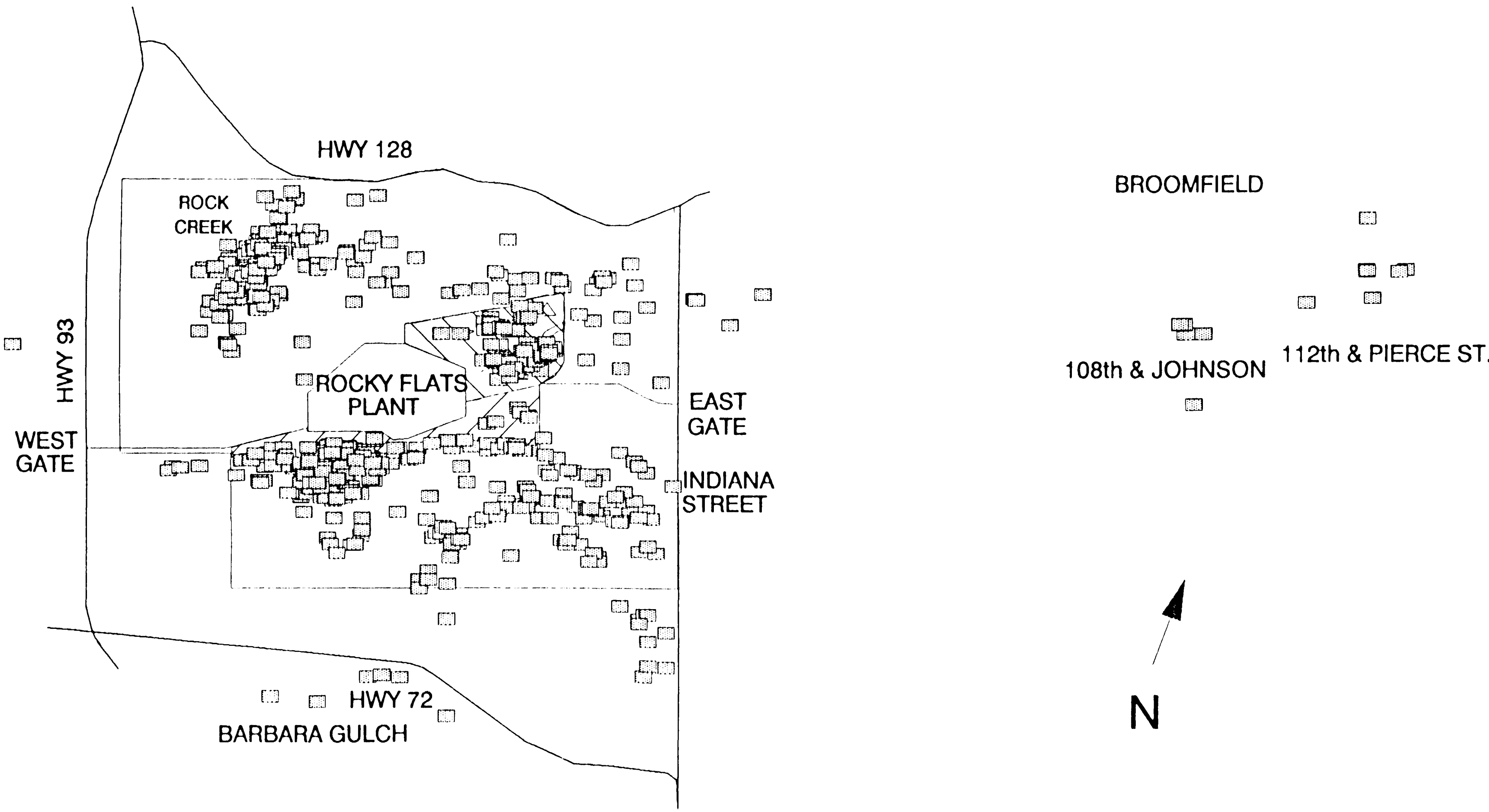

Figure 5. All summer 1990 locations of Rocky Flats radio-collared and ear-tagged deer. Summer dates are from 31 May to 22 August, 1990.

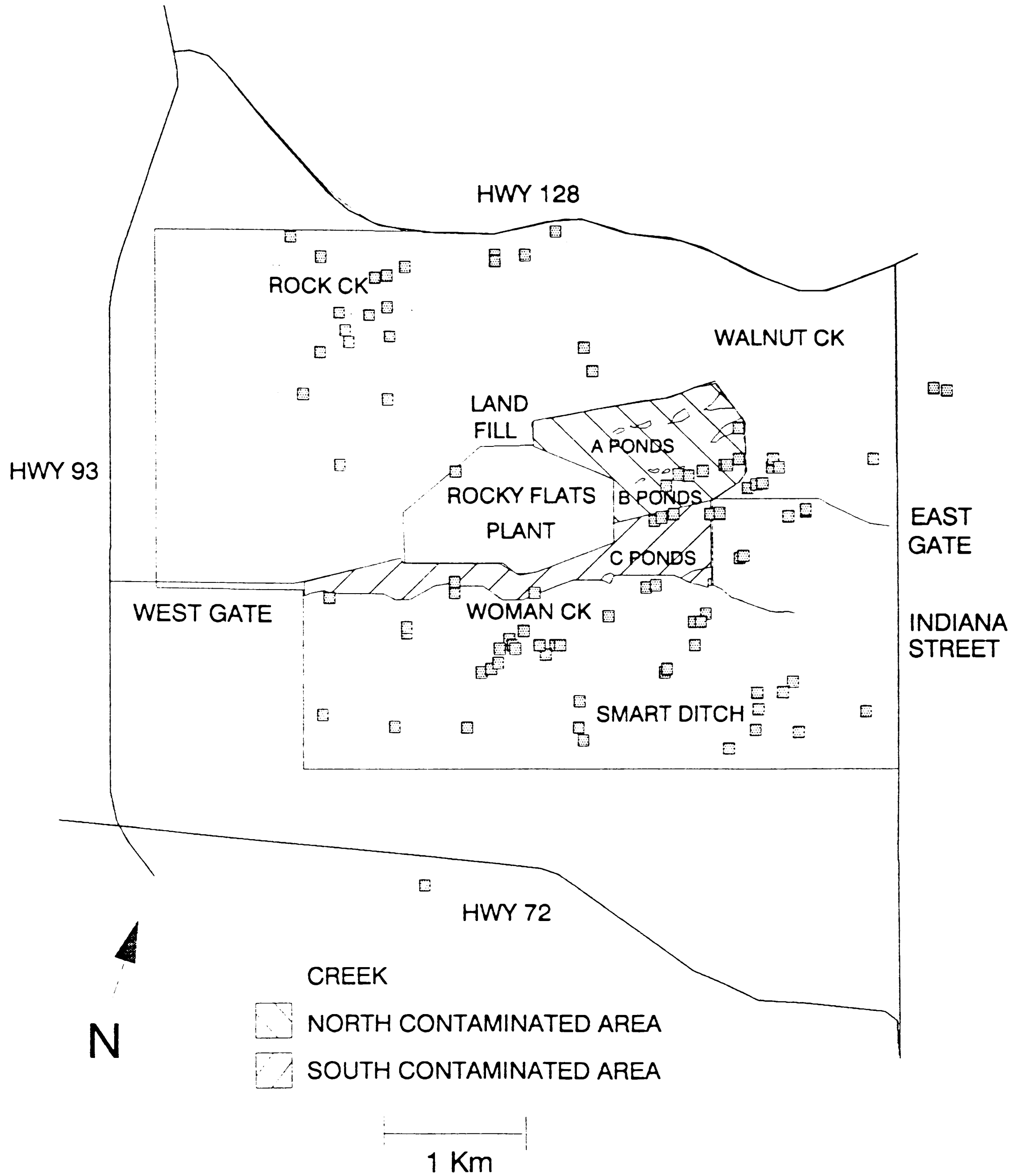

Figure 6. Locations of Rocky Flats radio-collared and ear-tagged deer during fall 1990. All locations taken between 9 Oct and 29 November, 1990.

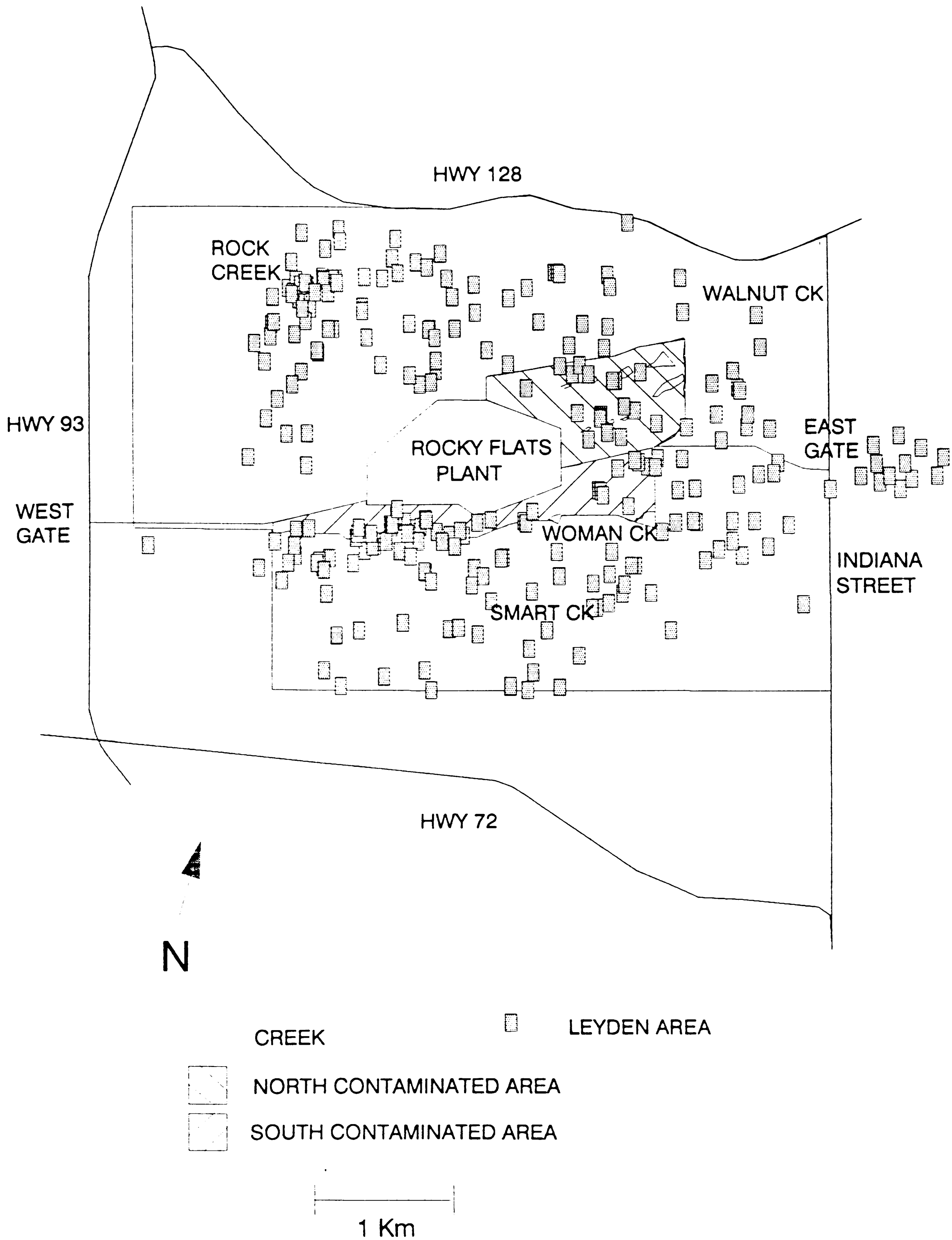

Figure 7. All winter 1991 locations of Rocky Flats radio-collared and ear-tagged deer. Winter dates are from 30 December 1990 to 29 March, 1991.

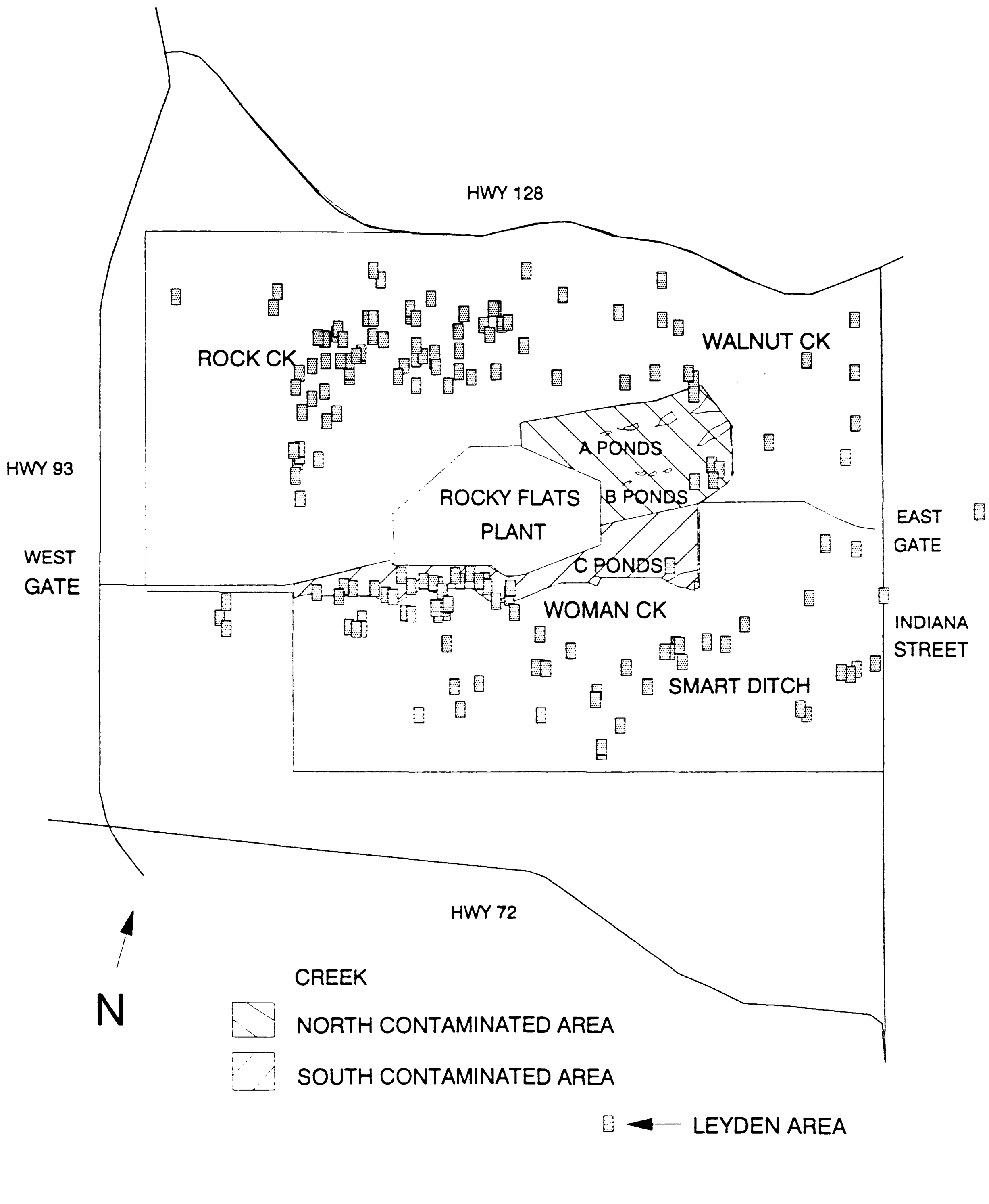

Figure 8. Spring 1991 locations of Rocky Flats radio-collared and ear-tagged deer. Spring dates are 4 April to 30 May.

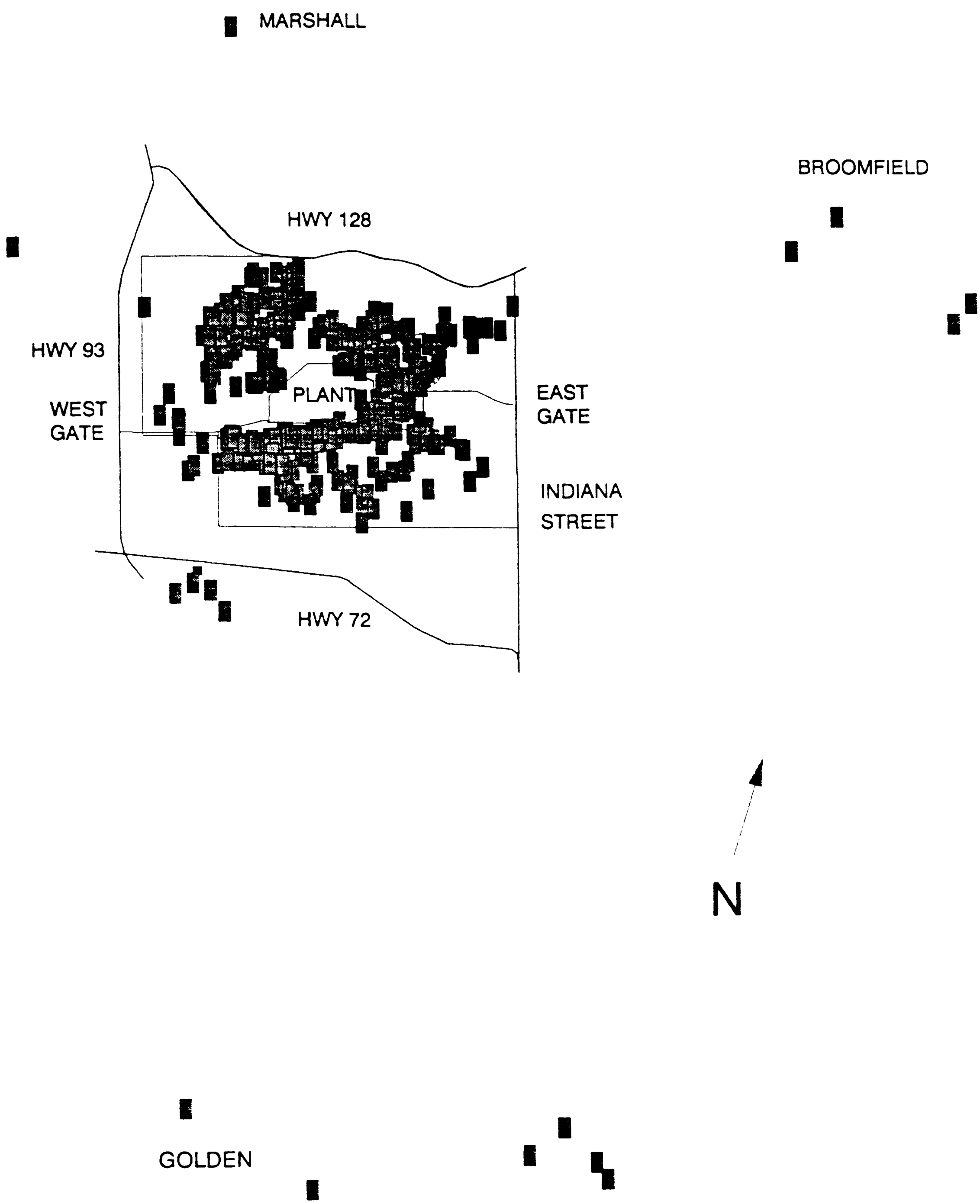

Figure 9. All summer 1991 locations of Rocky Flats radio-collared and ear-tagged deer. Summer dates are from 6 June to 24 August, 1991. Deer were found within security area.

Table 4. Mean seasonal home range sizes and standard deviation for Rocky Flats, CO does for summer 1990 and 1991, and does and fawns for winter 1991.

	Summer 1990, n=21	Winter 1991, n=70	Summer 1991, n=40
Min. Convex Polygon	1.916 km^2	4.762 km^2	1.613 km^2
Standard Deviation	1.604 km^2	1.803 km^2	0.978 km^2
J-T 95% Ellipse	3.258 km^2	9.058 km^2	3.767 km^2
Standard Deviation	2.874 km^2	3.742 km^2	2.141 km^2
Weighted Ellipse	2.233 km^2	6.753 km^2	2.428 km^2
Standard Deviation	2.249 km^2	2.994 km^2	1.565 km^2

used section of Woman Creek was a densely vegetated area, just south of the western portion of the security area.

I used Multi-Response Permutation Procedures (MRPP) (Mielke et al. 1984) to test for significant differences in summer location patterns for 15 does that were present both summers. Eight does showed fidelity to summer areas, and of the 7 does that had significantly different location patterns ($P < 0.04$), 2 were yearlings during the first summer.

During winter, deer would cross the east and west plant access roads. Several deer were killed crossing these roads. Most of these collisions occurred near the "raw water" pond on the west access road, and near the spray field on the east access road (Figure 2).

On-Site Movement and Activity Patterns Discussion

Mule deer in the plains and Colorado Front Range are mostly non-migratory and occupy small home areas (Burt and Grossenheider 1976, Hiatt 1977, Kufeld et al. 1989). Garrott et al. (1987) suggest that seasonal movements of deer in the mountainous west are prompted by energetic needs of the animals, and by the quantity and quality of

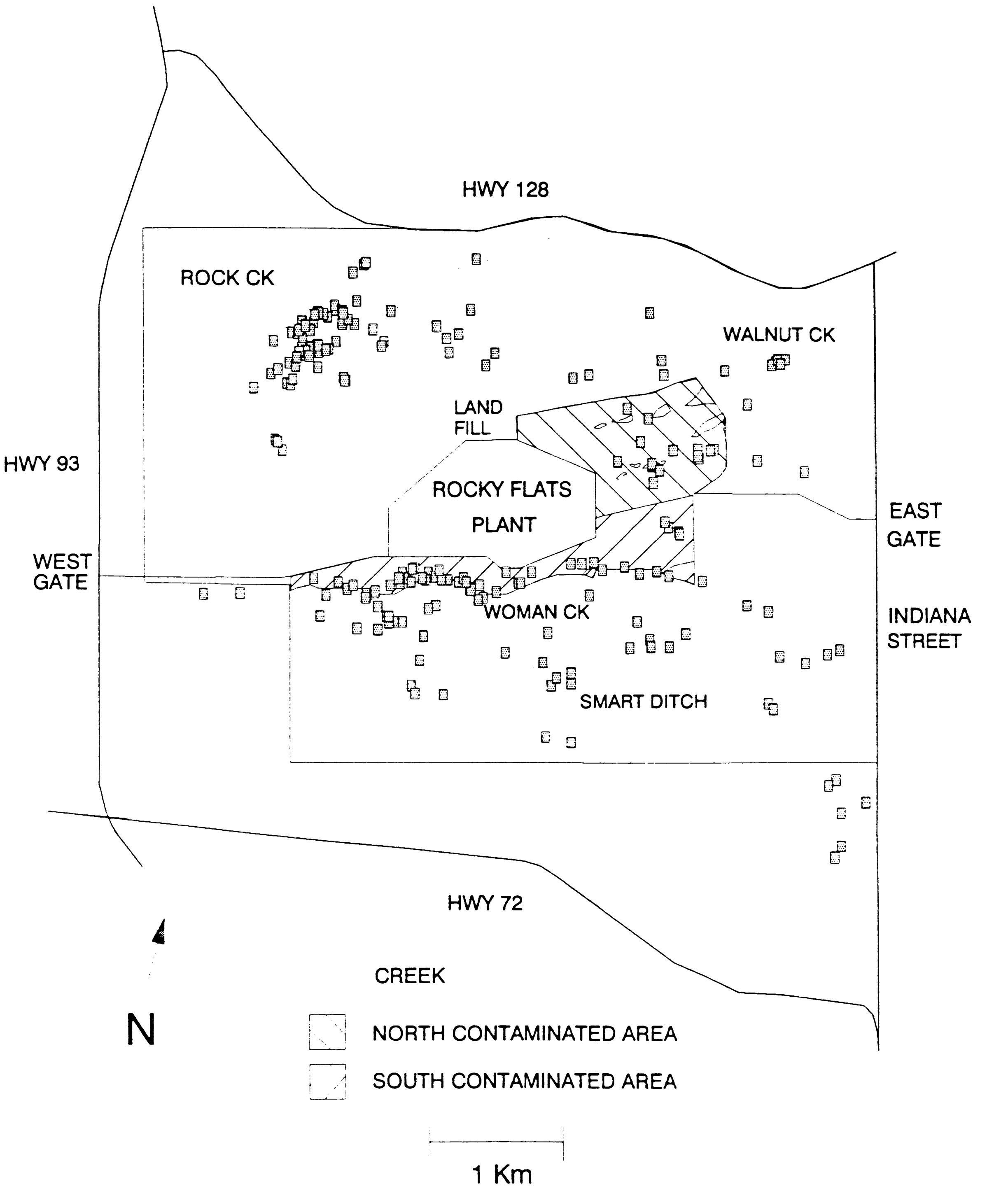

Figure 10. Locations of radio-collared adult does during fawning season, June 1990, at Rocky Flats, CO.

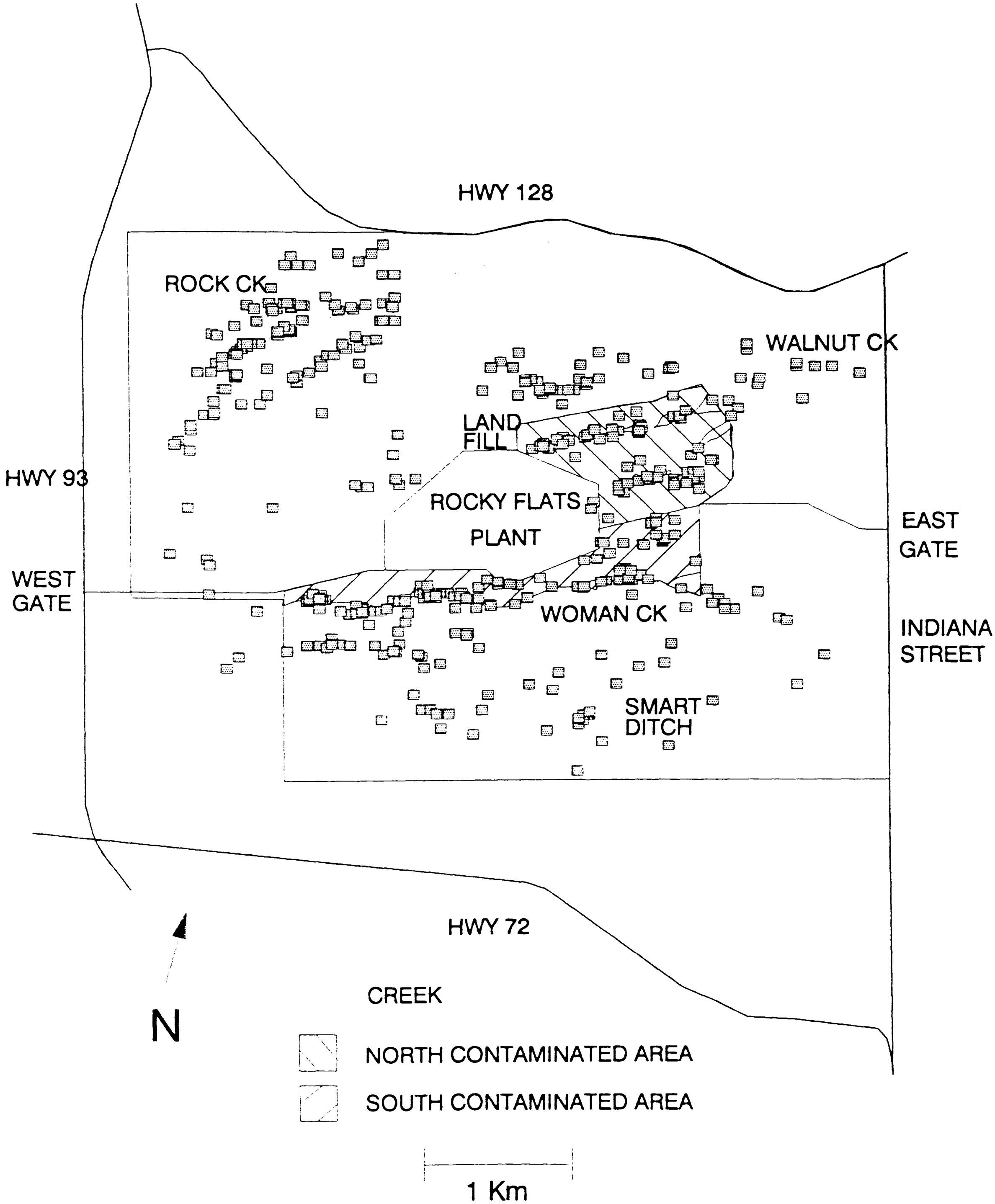

Figure 11. Locations of radio-collared adult does during fawning season, June 1991, at Rocky Flats, CO.

forage within the range of the animal. Kufeld et al. (1989) believe that non-migratory deer occupy a small home range because habitat quality is high enough to support them all year long. This line of reasoning suggests that Rocky Flats deer may occupy small areas, and remain on-site all year because the habitat is of sufficient quality to meet their energetic demands. There are other untested causal factors to explain their movement patterns such as absence of hunting, number of predators on-site relative to off-site, or "learning" from older deer, but these remain as speculation.

The results of the MRPP test for site fidelity suggest that about half of the does used their summer areas differently between 1990 and 1991. The tests, however, do not suggest the way that does used their summer areas differently between years. The difference may indicate an expansion or contraction of area used, or an overall change in area. Data show that half the deer tested changed their use of summer areas for some reason between years.

During fawning season, radio-collared does often used brushy areas along creeks especially in the Rock Creek area, Woman Creek, and to some extent in the A and B pond area. Cover is an important habitat component for does and fawns this time of year, and aids in concealing fawns from predators. Cover also offers protection from heat and wind (Geist 1981, and pers. obs.). Any negative impacts to vegetation in these areas may reduce the number of suitable sites for deer to use for protection from heat, wind, and predators, and may cause a shift in deer numbers or use patterns.

Off-Site Movement Results

Throughout my study, few deer moved farther than 1 km from Rocky Flats (Figures 5 through 9). Most of this movement occurred east of Rocky Flats, although deer were also occasionally found 100 m south of the west gate. One white-tailed doe was regularly found 500 m south of the southeast quarter of the buffer zone (Figure 5).

There were only 3 does that moved farther than 1 km from Rocky Flats. One doe was found dead, from an unknown cause, in Rawson Creek, about 2 km northwest of the Rocky Flats west gate. A second doe spent 2 summer months in 1990 in Barbara Gulch, south of Highway 72, returned to Rocky Flats for approximately 1 year, and was later found dead next to Highway 72. The third doe made the most extensive movements. She left Rocky Flats during early June 1990 and was later found 10 km east, near Broomfield (Figure 5) with 2 fawns. I later located her 4 km south of Rocky Flats in the Leyden Gulch area, south of Highway 72. She returned to Rocky Flats occasionally, but remained off-site during most of my study.

Most longer off-site movements were made by yearling males that left Rocky Flats during June and July 1991 (Figure 9). Unfortunately, this was the time that collars were designed to drop off, and data could only be gathered until their collars dropped. It may be possible that some yearling males dispersed sometime after dropping their collars on-site. Of 21 telemetered yearling males (1991 fawns), 9 lost their collars off-site. I picked up collars several hundred meters to 20 km from Rocky Flats in all directions, and many were dropped within days of the animals' last on-site location. Three yearling males lost their collars near Golden and may possibly have travelled farther. One of these, however, reappeared at Rocky Flats in August, and was identified by an ear tag number. The single yearling male with a solar ear-tag transmitter was twice tracked to Barbara Gulch, just south of Highway 72. This yearling was on-site at the end of summer, but was found dead during fall 1991, on a highway near Golden, CO. Other yearling males dropped their collars relatively distant from Rocky Flats; 2 dropped collars 7 km east; and 1 dropped its collar 5 km northwest of its last on-site location (Figure 9).

Three yearling females moved several kilometers off-site (Figure 9). Two yearling females, from different deer groups, left Rocky Flats in mid-June and were killed by vehicles in late July; one was killed near Marshall, 7 km north; and the other was killed 7 km east of the buffer zone, at Highways 36 and 121. A third yearling female was apparently hit by a train a few hundred meters southwest of Highway 72 and Highway 93.

It is possible that telemetered bucks used off-site areas more than I documented, but their solar transmitters did not operate constantly, and about half of them failed altogether. As a result, most of the information about deer movement was based on does, fawns, and telemetered yearlings.

Off-site movement discussion

Overall, there was little off-site movement by radio-collared does or fawns at Rocky Flats. Longer, off-site movements by deer were uncommon, except among yearlings. Adult does rarely disperse (Garrott et al. 1987), but juvenile deer, particularly males, are more likely to leave their natal range (Bunnell and Harestad 1983, Harestad and Bunnell

1983, Nelson and Mech 1984, Robinette 1966). Yearlings moved the farthest at Rocky Flats, and initiated their movements between May and July. This is a period of time when does are having young, and act aggressively towards associated yearlings (Geist 1981). I did observe a doe with two 2-month old fawns, aggressively chase away a yearling male who approached the doe and fawn group. Dispersal is low in other mule deer studies. Eberhardt et al. (1984a) found that 3 (8%) out of 37 monitored deer dispersed during a 2 year study. These deer, two 1-year-old females, and one 2-year-old male, moved 19 to 25 km between May and July. In addition, they found that 7 (19%) deer made temporary wandering movements of up to 15 km beyond their normal home range boundaries.

The long distance movements by yearlings in my study are indistinguishable from dispersal because of transmitter loss after mid-summer, or by death of the deer. Data indicate, however, that yearlings were more likely to move off-site than other age deer, they moved off-site between May and June, and incidently, were likely to become victims of collisions with vehicles. Yearlings are, therefore, the likeliest vectors for radionuclide transport. It may be that adult bucks made seasonal or long distance movements, but I could not conclusively determine this without an adequate sample of telemetered bucks, or fortuitous sightings of ear-tagged bucks.

DEER TISSUE COLLECTION AND ANALYSES

Deer from Rocky Flats are occasionally hunted off-site, and have reportedly been poached at times. Vehicle-killed deer are legal to harvest, and an undocumented number of deer that were killed near Rocky

Flats by vehicles have been salvaged for human consumption. Data on radionuclide levels found in deer tissues is essential for determining dose to humans who may consume deer, and to aid in assessing potential radionuclide transport.

I collected lung, liver, and rib bone samples from vehicle-killed deer found near Rocky Flats between June and October 1991 (Table 5). Tissues were submitted to the Department of Radiological Health Sciences at CSU for radionuclide analysis (see Appendix 6 for methods and results). Most of the deer sampled were either marked with an ear-tag or radio-collar. Whole or partial pieces of liver and one lung were collected and placed in separate plastic bags or snap-top bowls. Two to four whole ribs were stored similarly. Care was taken not to allow soil or vegetation particles to touch tissues. Muscle tissue was not sampled because of an extremely low plutonium deposition rate in such tissue. Plutonium, if present, will likely be found in ribs, liver, and lung tissues (Whicker and Schultz 1982, S. Ibrahim pers. comm.). Samples were labelled with date of death, date collected, location, tissue, age class, sex, tag or collar number, if any, and collector's name. Unmarked deer were assigned identification numbers sequentially. Samples were frozen until analysis. Samples were analyzed for plutonium and none had activities above detection limits (Appendix 6). Sample size was small, therefore I can not regard these results as representative of radionuclide levels in Rocky Flats deer tissues.

Table 5. Summary of deer tissue sampling from Rocky Flats, CO. Tissues collected were liver, lung, and rib bones.

Date	ID	Age and Sex	Tissue	Cause	Location
5/15/91	148.300/89	Adult doe	bones	Predation	On-site
7/15/91	148.430/89	Adult doe	bones	Unknown	On-site
7/26/91	149.250/89	Yearling male	All	Vehicle-killed	Indiana St.
8/17/91	Tag #222	Adult buck	All	Vehicle-killed	Indiana St.
8/21/91	unmarked	Fawn male	All	Vehicle-killed	On-site
9/13/91	149.210/90	Yearling male	All	Vehicle-killed	Indiana St.
9/26/91	148.530/89	Adult doe	All	Vehicle-killed	Indiana St.

POTENTIAL FOR DEER TO TRANSPORT RADIONUCLIDES

Based on annual movement patterns, the potential for deer to transport radionuclides off-site appears to be low. Hiatt (1977) reported 70% of ingested plutonium is expected to be excreted within 1 km of the area of ingestion, 91% within 2 km, and 100% within 5.2 km. My data suggest that Rocky Flats deer seldom move off-site, thus any ingested radionuclides would likely be excreted within the boundaries of the buffer zone, and deer may serve only to redistribute radionuclides within these boundaries. These findings do not contradict Hiatt (1977).

Based on results from radionuclide analyses of deer tissues, it appears that transport of radionuclides retained in tissues may be low. These findings also do not contradict the findings of Hiatt (1977). Because number of deer sampled was low, more deer will need to be sampled before a reliable assessment of radionuclides in deer tissues can be made.

DEER USE OF CONTAMINATED AREAS

One of my objectives was to quantify how much time deer spend in the 2 contaminated areas (Figure 2) on a seasonal basis. Deer found in these 2 areas may be more likely to receive exposure to radionuclides than in other parts of the buffer zone. Exposure may result in uptake of radionuclides through ingestion or inhalation of contaminated soil, plants, or water. In addition, contaminated soil adhered to the hide can be a source for radionuclide transport. Quantification of deer use provides information on the relative importance of these areas to deer, and is essential in interpreting radionuclide body burdens in deer.

I compared the relative use of contaminated areas to their availability with a chi-square test (Neu et al. 1974). The premise is that if deer select habitats randomly, the proportion of use will equal availability.

The null hypothesis that I tested was:

H_o: Deer utilize each contaminated area in proportion to its occurrence in the study area.

For example, each contaminated area comprises 4% each of the total area in the buffer zone. Therefore, if deer randomly choose areas to occupy, they should, on average, be found in one of the contaminated areas 4% of the time they are located. If a deer is found there more than 4% of the time, then that deer demonstrates preference, and conversely, if the deer is found there less than 4% of the time, it avoids the area. "Preference" does not necessarily mean that an animal needs these areas to survive, but merely indicates that a deer spends proportionally more time there than expected.

Methods

I determined relative deer use on the contaminated areas by locating telemetered deer, on a weekly basis, in each of those areas during winter and summer 1991 (Table 2). All days in the week and hours were sampled as equally as possible. Individual deer were noted as either "in" or "out" of a contaminated area. Presence of other wildlife was also noted (Appendix 3). For each season, I tallied the number of sampling occasions in which individual deer were "in" for each area, and used a chi-square procedure (Neu et al. 1974) to test for area preference. Data from each area were analyzed separately because the two areas were not monitored simultaneously, even though they are contiguous. I measured the area of each contaminated zone and the remaining buffer zone on a USGS topographic map with a dot grid. Each deer that was on-site and survived the season was included in my analysis, and all areas in the buffer zone were assumed to be equally available to all deer whether or not they actually utilized all areas.

I designed this part of my study to have 90% power to detect a 10% difference between relative use and availability, should there be such a difference. For this statistical power, each area was monitored a minimum of 41 times each season, and this sample size was derived from power calculations (Appendix 4). If deer used areas randomly, the expected number of observations a deer was found in each contaminated area (4% of total area), based on 41 locations, is 1.64 (4% of 41), or realistically, 2 observations. A 10% difference between use and availability denotes that deer were present $\geq$ 5 sampling occasions.

Winter monitoring occurred approximately 3 times a week between 12 February - 29 March 1991 for a total of 20 sampling days. Winter monitoring commenced later than planned because I was waiting for permission from E. G. & G. to track deer at night. When permission was formally denied, because of security concerns resulting from the Persian Gulf crisis, I proceeded, with daytime data collection only.

Because monitoring commenced late in the winter season, and it was not logistically feasible to monitor every day, several re-locations were performed in hourly intervals each tracking day, and sampling days had to fit availability of observers. An additional constraint on sampling was imposed by the security measures at that time. Security escorts were required each time we changed areas (e.g. north to south) in the buffer zone. Several times escorts took 2 hours or more to arrive. Sampling was better accomplished by taking several samples in the same area for that day. Although far from ideal, deer were located 6 times each sampling day, with one location per hour, between 0630-1130 or 1230-1730. Sample sizes for winter were 49 locations for the north area, and 43 for the south area.

I monitored the same areas in summer 1991 approximately 3 times each week from 4 June - 24 August. There were no constricting security measures, and data were collected from a vehicle during the day and from towers at night. Areas were sampled on randomly chosen dates and times, and were monitored twice during a sampling day, for a total of 22 sampling days. To reduce auto-correlation in daytime locations, 2 samples per side were taken 3-4 hours apart. I justify this interval on my observations that during summer, deer remained in small areas most of the day. Therefore, I determined that it made little difference if sampling intervals were 3, 5, or more hours apart.

Night tracking required a different sampling scheme because it involved 3 people and about 3 hours of set up time each night, including round trip transportation to Rocky Flats from Fort Collins. Therefore, for efficient use of time and personnel, deer were located 4 or 5 times each session. The south and north areas were monitored alternately each session, and alternately from 2030-0030 hours (5 samples) and 0130-0430 hours (4 samples). Each area was monitored 1 night every 2 weeks. Samples were 1 hour apart, with 17 samples per side.

The summer data set was separated into 2 data sets; one with 41 daytime locations per side, the other with 41 locations spread proportionally between day and night hours. The former data set I compare to the winter data set, but the latter I consider more representative of deer use because it contains both day and night data.

Results

Deer used both contaminated areas throughout the year. During winter 1991, 45.3% and 52.0% of deer used the south and north areas, respectively, more than expected ($P \leq 0.027$) (Figure 12). During summer 1991, 34.8% and 36.7% of deer used the south and north areas, respectively, more than expected ($P \leq 0.027$) (Figure 12, Table 6).

Percent deer use appears to be lower in summer for both areas, but there was no statistical difference for the north ($P = 0.11$), or the south ($P = 0.50$) areas. Also, during winter and summer, 24.0% and 34.8%, respectively, of deer were found fewer than 5 times in either area (i.e. showed no significant use ($P > 0.05$)) (Table 6).

Table 6. Results of chi-square analysis for individual preference of contaminated areas ($P < 0.027$) at Rocky Flats, CO. Summer data sets contain (1) all daytime data, and (2) night data with a randomly selected subset of day data. Deer present ≥ 5 sampling occasions demonstrated preference. Compiled from data in Appendix 5.

	Number of Deer (percent) Demonstrating Preference	
	South	North
Winter 1991 (n=75)		
daytime data	34 (45.3%)	39 (52.0%)
Summer 1991 (n=46)		
daytime data	18 (39.0%)	17 (36.7%)
day and night data	16 (34.8%)	17 (36.7%)

Comparison of Percent Deer Use	Chi-Square Significance Level
Winter, between south and north	p=0.41, not significant
Summer, between south and north (day)	p=0.83, not significant
North, between winter and summer (day)	p=0.11, not significant
South, between winter and summer (day)	p=0.50, not significant

	Number of Deer (Percent) that were Present in Both Areas	
North & South	Present ≥5 occasions	Present <5 occasions
Winter (day)	16 (21.0%)	18 (24.0%)
Summer (day)	4 (8.7%)	15 (32.6%)
Summer (day/night)	3 (6.5%)	16 (34.8%)

Discussion

Because winter data were collected from mid-February to late March, and data were not collected at night, winter data are not fully representative of winter deer use of contaminated areas. Ideally, monitoring should have commenced one week after trapping in December, and finished by mid-March. In contrast, the summer data set, which includes proportionate sampling from day and night, is more representative of deer use in the two contaminated areas.

In spite of winter sampling difficulties, my data suggest that each area received seasonal use by deer. Because each contaminated area provides forage, water, and some cover for deer, it was not surprising that several deer used each area significantly more than expected each season. There was no statistical difference in seasonal use of either area ($P \geq 0.11$), which suggests these areas are not preferred one season over another. Also, addition of night tracking data to the summer data set did not substantially alter the number of deer that showed significant use of either area. This suggests overall deer presence at night is similar in daytime.

More importantly, however, data identify individual deer that were found frequently in the same area (Appendix 5). If necropsies are performed on these deer, these data can be used to determine if there is a correlation between the amount of time deer spend in contaminated areas and radionuclide body burdens. In a similar study, Eberhardt et al. (1984b) found a positive correlation between these 2 variables. Because few deer were sampled during my study for body burdens, there are not enough data to determine whether residence time in contaminated areas is correlated with radionuclide levels found in tissues.

POPULATION ESTIMATION

Methods

It is difficult to count an entire population of deer in a natural setting because there are always a few animals that are well hidden, or are missed by observers. Therefore, I used the Lincoln-Petersen estimator (Peterson 1896, Lincoln 1930), which calculates the population size from the ratio of marked to unmarked animals sighted. I derived the population estimates using program NOREMARK (Neal et al., in review), and selected the estimator uncorrected for bias. The population size estimator for 1 marking occasion and 1 re-sighting occasion is:

$$\hat{N}=\frac{n_1 n_2}{m_2}$$

where n_1 = number of deer initially marked, n_2 = the number of deer seen, and m_2 = the number of marked animals seen. The associated 95% confidence interval is constructed as the profile likelihood interval.

The Lincoln-Petersen population estimator is accurate (i.e. without bias, and with good precision) when the following assumptions have been met. The population must be closed both demographically and geographically. This means there are no births, deaths, immigrants, or emigrants. To apply this estimator to the open deer population, I used telemetry to determine which marked animals were on-site within 24 hours of each count, thus "closing" the population for the re-sighting occasion (Kufeld et. al 1987).

Another assumption is that all animals have equal marking and equal sighting probabilities, but marking probabilities can differ from sighting probabilities. This assumption is violated when regularly interacting individuals are marked together, and when some individuals are more conspicuous than others. Lastly, no marks can be lost, and data must be recorded properly.

I conducted 2 deer population counts. The summer population was estimated on 17 July 1990, using a helicopter. For the purpose of the helicopter survey the buffer zone was sectioned on a map into 15 quadrants between 80 and 350 hectares in size. The quadrants were based on natural and man-made features that formed boundaries recognizable from the air. The 3 hour flight began at sunrise with myself, two other observers, and the pilot. Each quadrant was flown in a counterclockwise direction at approximately 300 m altitude. This altitude was the minimum altitude allowed by the Department of Energy. Deer were classified by species, presence of a collar, sex, and age. Any unclassifiable deer were denoted as "unknown".

I conducted the second count with a field assistant from a four wheel drive vehicle on 23 February 1991. Permission to use a helicopter was denied by the Department of Energy due to national security concerns at that time. We began just before sunrise, and counted and classified deer using a spotting scope and binoculars. The ground count lasted 5 hours, and with relatively little deer movement that day, it is not likely that we counted deer more than once.

There was no summer 1991 count because I did not receive security clearance for the use of a helicopter, and I felt the population could not be adequately counted from a vehicle during this time of year because deer are in dense cover. During summer, I saw 0%-25% of collared deer during tracking days. When only a small percentage of the marked population can be counted, the Lincoln-Petersen estimate is not very useful because it will have large variance.

Results

During the summer 1990 aerial count and the winter 1991 ground count, I observed 75% and 99% respectively, of the collared deer that were on-site that day. The associated confidence intervals reflect the precision of the estimate; the greater the percentage of marked animals seen, the tighter the confidence interval. The point estimate is higher

Table 7. Results of deer population estimates for summer 1990 and winter 1991 at Rocky Flats, CO.

	July 1990 Helicopter	February 1991 Ground
#Marked Does	15	34
#Marked Fawns	0	36
#Unmarked Does	55	53
#Unmarked Fawns	27	43
#Bucks	24	31
Total deer counted	122	197
Buck:Doe	36:100	35:100
Fawn:Doe	49:100	90:100
Fawn:Adult	28:100	67:100
Number of collars on-site	20	71
Percent of collars seen	75	99
Population estimate	161	199
95% profile likelihood confidence interval	136-220 deer	198-207 deer
Density of deer in buffer zone	4.8-7.4 deer/km^2	7.5-7.8 deer/km^2

for winter (199) than summer (161), but estimates have overlapping 95% profile likelihood confidence intervals. The buck:doe ratio remained constant, but the fawn:doe and fawn:adult ratio almost doubled from summer to winter (Table 7).

Discussion

There were a number of un-met assumptions that may affect the population estimate generated by the Lincoln-Petersen estimator. One such assumption is that animals have equal marking probabilities. Based on my observations, deer captured together at Rocky Flats tended to remain associated throughout winter and summer. Therefore, marked animals were more likely found together, rather than randomly dispersed in the population. The effect of this clumping has not been well researched (Neal 1990).

Another assumption that was violated is that animals have equal sighting probabilities. I suspect that strong heterogeneity in individual sighting probabilities existed between does and fawns during summer, but not in winter when fawns and does are close in size and are often in open areas. Does were usually visible throughout summer, but I seldom observed fawns until July because they are small and, presumably, were hidden in vegetation. The doubling of the fawn:doe ratio between summer and winter seems to suggest this heterogeneity of sighting probabilities in summer. Normally, the fawn:doe ratio decreases from summer to winter because of mortality of fawns in fall. Therefore, I do not regard the summer population estimate to be as accurate as the winter estimate when fawns, does, and bucks are in open areas, and thus, appear to have more equal sighting probabilities.

Neal (1990) found that heterogeneity of individual sighting probabilities affected population estimates more that other violations. Her computer simulations for a population with heterogeneity in individual sighting probabilities demonstrated an increase in percent relative bias, confidence interval length, and thus, poor coverage (mean = 75.0%), compared to a population with equal sighting probabilities.

An additional consideration concerning the quality of the 2 estimates results from the difference in sighting methods. Deer were counted and classified once from the helicopter, and up to 5 times during the winter ground count, resulting in a more thorough survey.

In comparison to an earlier study, Hiatt (1977) counted fewer deer in summer than in winter at Rocky Flats, but he attributed the seasonal decline to emigration. He qualified his findings by saying that the difference may be due, in part, to lower visibility of deer in summer, rather than emigration. I found that telemetered deer were year round residents (except for 3), and therefore, assumed that few deer, if any, migrated to or from Rocky Flats.

Hiatt's (1977) seasonal population estimates were about half of my estimates, and may be a result of differences in population estimation methods (direct count versus Lincoln-Petersen), or to a real difference in population size, or both. During Hiatt's (1977) study, Rocky Flats personnel sprayed herbicides annually, which caused vegetation to defoliate over large areas. Also, livestock grazed in the outer buffer zone until 1975 (Hiatt 1977). The cessation of these land practices may have allowed deer numbers to increase since the mid-1970's. Population data are needed for several years more before a reliable assessment can be made regarding trends in population size of Rocky Flats deer.

SURVIVAL

Estimation of the winter fawn survival rate gained importance during the first year of the study because few ear-tagged fawns from the first trapping season were seen again. For this reason, I suspected that most fawns either died their first year, or dispersed. Radio-locating fawns allowed me to assess their fates. Annual survival rates were calculated for adult does. Survival rates of adult and yearling bucks were not determined because few bucks had transmitters.

Methods

Annual survival rates were calculated for 24, and 35 adult radio-transmittered does in 1990, and 1991, respectively. Winter fawn survival rate was based on 21 male and 19 female fawns from 22 December 1990 to 21 April 1991, when the first male collar dropped off. Male fawn collars were designed to drop 4 to 6 months after attachment, and all dropped between 21 April and 24 August 1991. I located deer according to the schedule in Table 2.

Survival rates were calculated as the percentage of radio-collared deer that survived the time period. I used Program SURVIV (White 1983) to derive my estimates and the associated 95% binomial confidence intervals. Deer that died from trapping-related causes were excluded from the analysis. Mortalities of ear tagged deer were recorded, but were also excluded from the analysis because the fates of the remaining tagged deer are unknown. I used a chi-square test to determine significant differences between survival rates.

Results

The annual doe survival rates were 0.792 ± 0.083 (SE) and 0.857 ± 0.059 (SE) for 1990 and 1991, respectively, and were not statistically different ($P = 0.19$). Female fawn survival rate from 22 December to 21 April was 0.895 ± 0.043 (SE), and male fawn survival rate from the same time period was 0.952 ± 0.046 (SE). There was no statistical difference between male and female fawn survival rates ($P = 0.49$) (Table 8). Between January 1990 and November 1991, 27.5% of radio-collared deer (22 out of 80) died of various causes (Tables 9 and 10). Major causes of mortalities of radio-collared does and fawns were collisions

Table 8. Rocky Flats doe and fawn survival data for 1990 and 1991. Survival rate is the percentage of radio-collared deer that survived the time period. No trapping-related mortalities were included in analysis. Adult does were collared ≥ 18 months in age.

	Survival rate	95% Confidence Interval
Adult doe - annual (Jan 1990-Jan 1991, 12 mos.)	0.792	(0.629 - 0.954)
Adult doe - annual (Dec 1990-Dec 1991, 12 mos.)	0.857	(0.741 - 0.973)
Male and female fawns (Dec.- April, 4 mos.)	0.925	(0.843 - 1.007)
Female fawns (Dec.- April, 4 mos.)	0.895	(0.757 - 1.032)
Male fawns (Dec.- April, 4 mos.)	0.952	(0.861 - 1.043)
Female fawns → yearlings (Dec. - Nov., 11 mos.)	0.579	(0.356 - 0.801)

with vehicles (47.8%), and predation (21.8%) (Table 10). Most collisions occurred along Indiana Street, between 1 and 1.5 km north of the East Gate. A few collisions occurred on the same road, south of the East Gate. Within Rocky Flats, the most common location for collisions was along the West Access Road, near the "raw water pond" (Figure 2). Collisions occurred any time of day, but most deer-vehicle collisions on Indiana St. occurred during twilight or darkness.

During winter 1991, only 3 radio-collared fawns died (Table 9); one male drowned in one of the B ponds; one female was killed by a vehicle on plant site, and another female was killed by a coyote. I noted that fawn carcasses did not remain intact at Rocky Flats. On 4 occasions, I observed that coyotes had scattered fawn carcasses so that within two days most signs of a kill were obliterated at the kill site. Mortality of radio-collared fawns increased after 1 May, and most of

Table 9. Chronological listing of all known mortalities between January 1990 and November 1991 of deer that were radio-collared or marked at Rocky Flats, CO.

	Date	Identification	Age	Sex	Location	Cause of death
1.	2/17/90	148.560/89	A	F	Walnut Ck	Injury
2.	2/19/90	148.390/89	A	F	NW Buffer	Predation
3.	5/31/90	148.280/89	A	F	Rawson Ck	Unknown
4.	8/15/90	148.420/89	A	F	SE Buffer	Unknown
5.	9/2/90	TAG #110	A	M	Indiana St	Vehicle collision
6.	10/9/90	TAG #108	Y	M	Hwy 93	Vehicle collision
7.	10/26/90	148.610/89	A	F	NW Buffer	Unknown
8.	10/11/90	148.330/89	A	F	W.Access Rd	Vehicle collision
9.	12/16/90	149.100/90	F	F	A1 Pond	Trapping-related
10.	12/31/90	149.200/90	F	M	B5 Pond	Drowned
11.	2/2/91	149.160/90	F	F	W.Access Rd	Vehicle collision
12.	2/24/91	149.010/90	F	F	Landfill	Predation
13.	3/23/91	148.290/89	A	F	Indiana St	Vehicle collision
14.	4/23/91	148.300/89	A	F	SW Woman Ck	Predation
15.	5/4/91	149.020/90	F	F	Landfill	Predation
16.	5/5/91	149.180/90	F	F	Woman Ck	Predation
17.	5/17/91	149.320/90	F	M	Indiana St	Vehicle collision
18.	6/16/91	149.030/90	Y	F	Hwy 93 & 72	Collision with train
19.	6/16/91	149.390/90	Y	M	Woman Ck	Vehicle-rel. injury
20.	6/24/91	149.130/90	Y	F	Marshall	Vehicle collision
21.	6/30/91	149.300/90	Y	M	Hwy 36 & 121	Vehicle collision
22.	7/1/91	148.430/89	A	F	Woman Ck	Unknown
23.	7/10/91	149.170/90	Y	F	W.Access Rd	Vehicle collision
24.	7/25/91	149.250/90	Y	M	Indiana St	Vehicle collision
25.	7/28/91	149.090/90	Y	F	Hwy 36 & 121	Vehicle collision
26.	8/17/91	TAG #222	A	M	Indiana St	Vehicle collision
27.	8/29/91	TAG #124	A	M	Indiana St	Vehicle collision
28.	9/13/91	149.210/90	Y	M	Indiana St	Vehicle collision
29.	9/26/91	148.530/89	A	F	Indiana St	Vehicle collision
30.	10/17/91	148.310/89	A	F	Hwy 72	Vehicle collision

these deaths were attributed to collisions with vehicles. Fawns or yearlings that were victims of vehicle collisions after their collars were lost were identified by their ear tag numbers. The fates of the 15 remaining yearling males, who survived until their collars dropped, are unknown.

Table 10. Causes of mortality, by sex and age class, between January 1990 to November 1991, of marked deer at Rocky Flats, CO. Bracketed numbers reflect deer identified by ear tags only. Fawns born in 1990, and killed after 1 June 1991 were incorporated into adult summaries.

	Does	Bucks	Fawns	Row
Vehicle-related	8	[6]	3	17
Predation	2	-	3	5
Other	1	-	2	3
Unknown	4	-	-	4
Total	15	[6]	8	29

Breakdown of mortality causes, by percentage, of deer that were radio-collared at time of death, n=23.

Vehicle-related	47.8%
Predation	21.8%
Other	13.0%
Unknown	17.4%
Total	100.0%

Discussion

The winter of 1990-91 was mild, and therefore, the high survival rate of fawns was not unexpected. Fuller (1990) documented a comparable winter (Dec. - May) survival rate, for white-tailed fawns, of 89% during winters with shallow snow (13 - 16 cm), but found a 60% survival rate in winters with moderately deep snow (36 - 44 cm). White et al. (1987) documented lower annual mule deer fawn survival rates during winters with severe weather, than in relatively milder winters. Snow cover can impede or prohibit foraging, slow an escape from predators (Connolly 1981), and increase energy expenditure of movement (Mattfeld 1973). Snow depth seldom exceeded 15 cm, at Rocky Flats, and often melted within a day of falling.

Rocky Flats adult doe survival rates were comparable to those in a mule deer population in northwest Colorado. White et al. (1987) estimated 0.832 ± 0.030 (SE) annual survival rate for adult does in northwest Colorado over a 4 year period. Although Hiatt (1977) recorded mortalities, and probable causes, of all observed dead deer, no survival rates were calculated, most likely because, without telemetry, he was unable to reliably track the fates of a sample of deer with assigned identities. Similarly, I can not make a valid comparison to his observed proportion of mortality factors because his results were not based on a known sample size.

During the period of my study, predators did not play a big role in mortality of fawns that were 6 to 11 months of age. Although coyotes were observed almost daily in the buffer zone during winter, only one radio-collared fawn was killed by a coyote during winter. Deer were assembled in groups of up to 51 members, and this behavior may serve as an effective anti-predator strategy (Geist 1981, Messier and Barrette 1985). I observed does chasing coyotes away from deer during 3 different occasions, but I observed no incidence of chase by coyotes. Although coyote predation comprised 21.8% (5 out of 23) of all mortalities of radio-collared does and fawns, coyotes were active in scavenging nearly every vehicle-killed deer carcass that was not removed by humans. Another potential predator on-site was the golden eagle (*Aquila chrysaetos*), but I never observed or suspected predation by this raptor.

These data are preliminary as survival rates will vary on a yearly basis. Any statement regarding doe and fawn survival rates, and proportion of mortalities by various causes, based on one or two years of data is premature. Estimation of survival rates at Rocky Flats will presumably continue for several years more; thus, future data will be more representative of this deer population.

SUMMARY AND RECOMMENDATIONS

Rocky mountain mule deer were monitored using telemetry at Rocky Flats, CO, between January 1990 and August 1991 to identify movement patterns, use of contaminated areas, and potential to transport contaminants off-site. In addition, survival rates, and population size and characteristics were estimated.

Rocky Flats deer are non-migratory and seldom moved farther than 0.05 km from the buffer zone. Most deer that went off-site visited an area a few hundred meters east of the east gate, and deer occasionally used the area immediately south of the west gate. Yearling males were most likely to move the longest distances, and some travelled at least 20 km from the buffer zone.

Deer tended to occupy small areas within the buffer zone, and areas with cover received the most use. In particular, Rock Creek, Woman Creek, and the A and B Ponds received heavy deer use, especially by does and fawns in summer (Figures 5 through 11). Reduction in vegetation in these areas may reduce the number of sites suitable for protection from heat, wind, and predators, and may cause a change in deer numbers or shift in use patterns.

Based on annual movement patterns and deer tissue analyses, the potential for deer to transport radionuclides off-site appears to be low. Age class of deer that would most likely transport contaminants farthest off-site are yearling males that dispersed off-site. Sample size for number of tissue samples taken will likely need to be increased before any reliable estimate of radionuclide body burden in deer can be made.

Deer used both contaminated areas throughout the year. During summer, 34.8% and 36.7% of deer showed preference for the south and north areas, respectively. During winter, 45.3% and 52.0% of deer preferred the south and north areas, respectively.

Estimated deer population size during summer 1991 was 161 (95% confidence interval 136-220), and 199 (95% confidence interval 198-207) during winter. Winter 1991 buck:doe ratio was 35:100, and fawn:doe ratio was 90:100.

Annual doe survival rates were 0.792 ± 0.083 (SE) and 0.857 ± 0.059 (SE) for 1990 and 1991, respectively, and were not significantly different ($P = 0.51$). Fawn survival rate from 22 December 1990 to 21 April 1991 was 0.925 ± 0.042 (SE). Collisions with vehicles were the cause of 47.8% of all mortalities of Rocky Flats deer, whereas predation comprised 21.8% of mortalities of deer 6 months of age, and older. The most common location for collisions was on Indiana Street, 1-1.5 km north of the East Gate, followed by the Rocky Flats Plant west access road, near the "raw water pond". Reduced vehicle speed in these areas is probably the best measure to prevent deer-vehicle collisions. Because survival rates and proportional causes of mortality vary from year to year, several more years of data are needed to better estimate survival rates and mortality factors.

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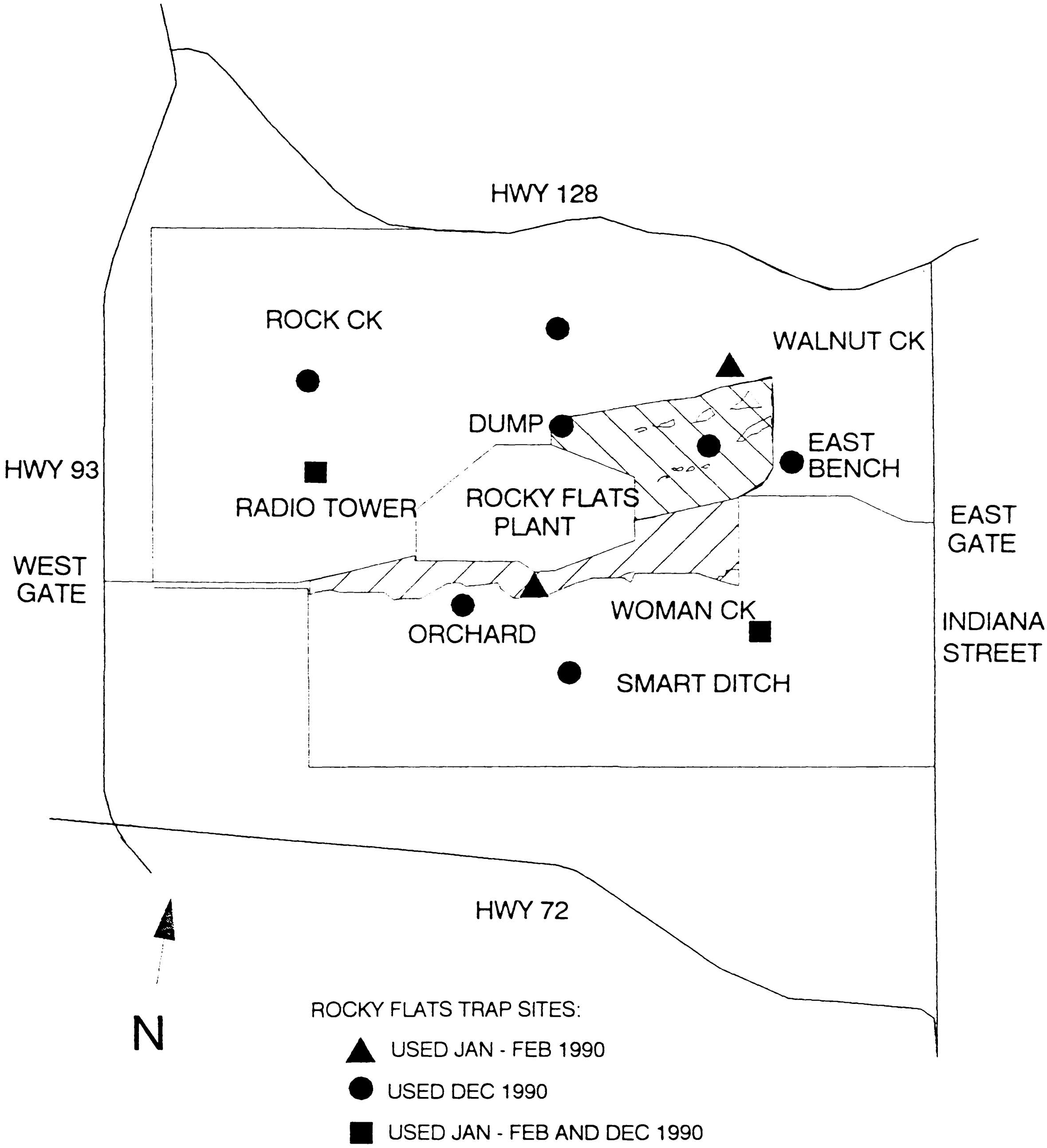
Appendix 1. Map of trapping sites for 1990 and 1991 at Rocky Flats, CO.



Appendix 2. Mean and standard deviation (STD) of weight (WT), body length (LEN), left hind foot length (LHF), and minimum (MIN_N) and maximum (MAX_N) neck circumference of deer trapped December 1990. Antler measurements for yearling and adult bucks were left antler circumference, right antler circumference, left length, right length, number of left points, and number of right points. No white-tailed or hybrid deer measurements were incorporated in summary statistics.

AGE CLASS	COUNT	Weight	SD	Body Length	SD
Yearl Doe	6.00	63.15	4.51	161.48	8.72
Adult Doe	20.00	67.68	4.90	162.96	8.46
Fawn Doe	19.00	36.64	5.55	131.00	11.64
Fawn Buck	23.00	42.72	5.44	139.20	7.18
Yearl Buck	4.00	65.65	3.67	158.38	6.10
Adult Buck	12.00	88.60	18.52	176.44	47.06

AGE CLASS	Left Hind Foot	SD	Min. Neck Circum.	SD	Max. Neck Circum.	SD
Yearl Doe	46.52	1.10	37.10	2.58	44.95	3.35
Adult Doe	47.38	1.23	38.10	2.15	45.32	5.11
Fawn Doe	41.52	2.05	29.76	2.68	35.54	3.55
Fawn Buck	43.54	1.49	32.33	1.99	37.50	3.45
Yearl Buck	48.15	0.86	43.25	0.25	47.25	3.90
Adult Buck	50.07	3.03	52.83	7.25	61.63	8.72

<u>Mean of Antler Measurements.</u>

L Circumference	R Circumference	L Length	R Length	L Points	R Points
8.86	9.63	45.35	45.80	2.91	3.60

Appendix 3. List of vertebrate species observed at Rocky Flats, CO, in each contaminated area, by season. List may not be complete. Winter 12 Feb - 29 March, Summer 1 June-24 August. N=North area S=South area.

Birds	Winter	Summer
American Wigeon (*Anas americana*)	N	-
American Robin (*Turdus migratorius*)	S	-
American Goldfinch (*Carduelis tristis*)	-	N, S
American Bittern (*Botaurus lentiginosus*)	-	N
Belted Kingfisher (*Ceryle alcyon*)	-	N
Black-crowned Night Heron (*Nycticorax nycticorax*)	-	S
Blue-winged Teal (*Anas discors*)	-	N
Brewers Blackbird (*Euphagus cyanocephalus*)	-	N
Bufflehead (*Bucephala albeola*)	N	-
Canada Goose (*Branta canadensis*)	N, S	N, S
Cinnamon Teal (*Anas cyanoptera*)	-	N, S
Common Nighthawk (*Chordeiles minor*)		
Common Goldeneye (*Bucephala clangula*)	N, S	-
Common Raven (*Corvus corax*)	N, S	-
Double-crested Cormorant (*Phalacrocorax auritus*)	-	N
Golden Eagle (*Aquila chrysaetos*)		
Great Blue Heron (*Ardea herodias*)	N, S	N, S
Great Horned Owl (*Bubo virginianus*)	N, S	-
Green winged Teal (*Anas crecca*)	N, S	-
Herring Gull (*Laurus argentatus*)	N	-
House Finch (*Carpodacus mexicanus*)	-	S
Killdeer (*Charadrius vociferus*)	N, S	N, S
Lark Bunting (*Calamospiza melanocorys*)	N, S	N
Mallard (*Anas platyrhynchos*)	N, S	N, S
Mourning Dove (*Zenaida macroura*)	-	N, S
Northern Flicker (*Colaptes auratus*)	N	-
Northern Oriole (*Icterus galbula*)		
Pheasant (*Phasianus colchicus*)	S	-
Red-tailed Hawk (*Buteo jamaicensis*)	N, S	-
Red-winged Blackbird (*Agelaius phoeniceus*)	N, S	N, S
Redhead (*Aythya americana*)	N, S	-
Ring-necked Duck (*Aythya collaris*)	N	-
Rough-legged Hawk (*Buteo lagopus*)	N, S	-
Say's Phoebe (*Sayornis saya*)	-	N
Western Meadowlark (*Sturnella neglecta*)	N, S	N, S
Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*)	-	S

Appendix 3. (continued.)

Mammals/Reptile/Amphibians	Winter	Summer
Bull Snake (*Pituophis melanoleucus*)		
Desert Cottontail (*Sylvilagus auduboni*)	N, S	N, S
Coyote (*Canis latrans*)	S	S
Muskrat (*Ondatra zibethica*)	-	N, S
Frogs/Toads		N,S
Longtail Weasel (*Mustela frenata*)	-	N
Prairie Rattler (*Crotalus viridis viridis*)		
Blacktail Prairie Dog (*Cynomys ludovicianus*)	N	N
Mule Deer (*Odocoileus hemionus hemionus*)	N,S	N,S
White-tailed Deer (*Odocoileus virginanus*)	S	S

Appendix 4. SAS (SAS Inst. 1985) program to determine sample size for a 10% difference for contaminated area use versus availability analysis with 90% power at alpha=0.05.

```
title 'Sample size determination for # locations';
data;
   array use {2}_temporary_;
   array avail {2}_temporary_;
   use {1} = 0.86; use {2} = 0.14;
   avail {1} = 0.96; avail {2} = 0.04;
   alpha = 0.05; df = 2-1;
   critchi = cinv(1-alpha,df);
      do n=35 to 50 by 1;
         noncent = 0.;
            do i=1 to 2;
               obs = use (i)*n;
               expect = avail (i)*n;
               noncent = (obs-expect)**2/expect + noncent;
            end;
       power = 1 - probchi(critchi,df,noncent);
       keep n alpha power;
       output;
      end;
proc print;
run;
```

Modified SAS Output:

Alpha	Sample Size	Power	
0.05	35	0.85522	
0.05	36	0.86475	
0.05	37	0.87372	
0.05	38	0.88215	
0.05	39	0.89007	
0.05	40	0.89752	
0.05	41	0.90450	← Summer-Both Areas
0.05	42	0.91105	
0.05	43	0.91718	← Winter-South
0.05	44	0.92293	
0.05	45	0.92831	
0.05	46	0.93334	
0.05	47	0.93804	
0.05	48	0.94244	
0.05	49	0.94654	← Winter-North
0.05	50	0.95037	

Appendix 5. Number of observations each deer was found within a contaminated area at Rocky Flats, CO, in by season. All values ≥ 5 are significant at the 0.05 level or better, with a chi-square test. Freq. = abbreviated radio frequency. Asterisk (*) denotes data taken during both day and night.

	Winter 1991		Summer 1991			
Freq.	South	North	South	North	South *	North *
8150	3	9	0	4	0	6
8250	24	0	0	0	0	0
8280	6	16	0	35	2	29
8300	25	0	.	.	.	.
8310	1	0	25	6	16	0
8320	25	0	36	0	32	0
8330	3	9	1	36	1	38
8340	1	0	1	0	0	0
8360	5	16	0	36	1	40
8370	0	0	0	0	0	0
8380	0	0	0	0	0	0
8390	3	9	0	0	0	2
8400	28	0	26	0	23	0
8410	1	0	16	17	17	16
8420	27	0	31	0	29	0
8430	27	0	.	.	.	.
8440	7	19	15	21	17	18
8450	28	0	0	0	0	0
8460	8	0	0	0	0	0
8510	4	9	3	17	4	18
8520	3	9	2	6	1	6
8530	6	19	2	13	0	13
8540	6	19	0	15	0	8
8550	7	17	0	21	0	13
8560	3	9	5	4	2	11
8570	28	0	36	0	36	0
8580	7	0	0	0	0	0
8590	29	0	36	0	35	0
8600	26	0	33	0	35	0
8610	3	9	0	16	0	13
8775	0	0	3	0	3	0
8950	0	0	10	0	0	0
8962	3	9	0	8	0	10
9000	4	19	25	8	15	9
9020	3	9	.	.	2	.
9030	4	0	.	.	19	.

Appendix 5. (continued)

ID	Winter 1991 South	Winter 1991 North	Summer 1991 South	Summer 1991 North	Summer 1991 South *	Summer 1991 North *
9050	3	9	3	9	2	7
9060	27	0	20	0	19	0
9070	1	0	4	0	4	0
9080	3	9	3	5	3	3
9090	6	17	.	.	.	.
9110	3	9	0	2	0	4
9130	4	0	.	.	.	.
9140	4	0	23	0	11	0
9150	3	9	0	2	0	3
9170	29	0	.	.	.	.
9180	30	0	.	.	.	.
9190	7	17	0	16	0	12
9210	3	5	.	.	.	.
9220	3	9	.	.	.	.
9230	7	19	.	.	.	.
9240	7	17	.	.	.	.
9250	7	17	.	.	.	.
9260	3	9	.	.	.	.
9270	3	9	.	.	.	.
9280	4	0	.	.	.	.
9290	1	0	.	.	.	.
9300	7	19	.	.	.	.
9310	13	0	.	.	.	.
9320	7	17	.	.	.	.
9330	3	9	.	.	.	.
9340	4	0	.	.	.	.
9350	3	9	.	.	.	.
9360	1	0	.	.	.	.
9370	29	0	.	.	.	.
9380	6	19	.	.	.	.
9390	28	0	.	.	.	.
9410	3	11	9	0	5	0
9420	1	0	.	.	.	.
9371	8	10	10	0	12	0
9401	0	3	0	3	0	1
9490	2	18	.	.	.	.
9632	6	15	11	1	6	2
9671	3	0	4	0	1	0
9689	3	6	8	0	5	0

Appendix 6. Report on plutonium analysis of Rocky Flats deer tissues. This report was submitted by Scott Webb, Dept. Radiological Health Sciences, CSU.

Introduction

The frozen deer tissue samples that were analyzed were provided by Kate Symonds of the Fishery and Wildlife Department, CSU. The samples were collected in July, August, and September of 1991 from carcasses found on the Rocky Flats nuclear weapons production facility located northwest of the greater Denver metropolitan area. Each deer was identified by either a tag number or a radio tracking frequency number. The portion of the samples that were analyzed were the entire liver, or one whole lung or 300-500 g of the middle rib. Liver, lung, and rib samples were analyzed for plutonium-239,240, and 238 from three deer. Liver and lung samples were processed from another deer and only the ribs from one deer were analyzed for a total of 12 samples.

Procedure

The samples were weighed, oven dried (100°C) for 24-48 h, weighed again, muffled (550°C) for 48-72 h, and finally reweighed to prepare the samples for radiochemistry. They were wet ashed in concentrated nitric and hydrochloric acids several times and then filtered to remove the insoluble matter. Plutonium-242 was added as an internal tracer to measure the radiochemical yield of the process. The plutonium in the liver samples was coprecipitated on iron present in the tissue, but a ferric chloride carrier was added to the lung tissues to provide the media for iron coprecipitation. Bone samples were coprecipitated on calcium oxalate after the addition of oxalic acid. All the precipitates were dissolved on 8 M nitric acid and the plutonium was converted to the +IV oxidation state using sodium nitrate in preparation for extraction.

The extraction system was the method developed by the Radioecology Group for the analysis of vegetation and soil samples from Rocky Flats. The plutonium was extracted from the acid by an organic phase transfer catalyst (ALIQOUT 336) and separated from natural radionuclides by sequential strippings using nitric and hydrochloric acids. The plutonium was then eluted from the organic with a hydrochloric acid and ammonium iodide solution. The extractant was electrodeposited onto a platinum disc in a sulfuric acid electrolyte then counted for more than 21 h on a silicon surface barrier detector system under vacuum. The detector was connected to a multi-channel analyzer to perform alpha spectroscopy on each sample.

Results

The laboratory technicians initially had some difficulties during the analyses of the deer samples. This was the first time they worked with samples weighing hundreds of grams, and the procedures were being developed and refined during the first batch of samples. The addition of an i internal tracer and the use of alpha spectroscopy, however, still allowed the quantitative determination of plutonium in the tissues. Radiochemical yields ranged from 27% to 80% with a mean of 59% (s.d.=17%), but the electroplate quality and the alpha spectrum quality were good to excellent for most samples. calcium interference on the rib electroplates caused most of the spectral degradation, but the low abundance of natural radionuclides, and the resulting alpha peaks, in the samples still allowed an accurate determination of plutonium-239.

All tissues had plutonium activities below detection limits. The minimum detectable activity, based on reagent blank samples, was 3 mBq for both $^{239,240}Pu$ and ^{238}Pu. One or two samples had activities above the acid blank value, but the standard deviation of that activity does not allow us to report a positive plutonium result. The results of the individual analyses are listed below. (The weight reported is the thawed weight, wet weight.)

Sample Identification	Pu-239 (Bq)	Std Dev Pu-239	Pu-238 (Bq)	Std Dev Pu-238	Wt. (g)
Acid Blank Activity from Vegetation	0.003	0.001	0.003	0.001	1
149.250/90 yearling male					
- liver	-2.218	0.791	-1.873	0.857	1189
- lung	-0.945	0.851	-2.212	0.829	743
Tag #222, adult male					
- ribs	-1.953	0.804	-0.858	0.913	184
Unmarked fawn male					
- liver	0.271	0.991	-1.846	0.863	420
- lung	-2.329	0.782	-2.376	0.821	370
- ribs	-0.736	0.860	-2.522	0.816	411
149.210/89 yearling male					
- lung	-1.131	0.838	-2.330	0.824	441
- liver	-1.670	0.831	0.133	1.011	686
- ribs	-1.776	0.810	-1.658	0.860	378
148.530/89 adult female					
- liver	-2.058	0.823	-0.225	1.075	880
- lung	-1.765	0.832	-1.959	0.864	297
- ribs	-2.077	0.789	-2.181	0.826	402