MOVEMENT PATTERNS OF COYOTES IN SOUTH CENTRAL WASHINGTON[1]

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Abstract: Ten coyotes (*Canis latrans*) fitted with radio transmitters on the U.S. Department of Energy Hanford Reservation in south central Washington were located daily over periods of 1–15 months. Because 82.9% of all locations were concentrated in only 6.9% of the total home range area, each home range was subdivided into an "impact area" and 1 or more "core areas." An "impact area" was defined as an area through which a coyote traveled and within which it might have interacted with other animals. "Core areas" were relatively small regions of concentrated use. No relationships were found between daily movements and relative and absolute changes in mean daily temperature and mean daily barometric pressure, or moon phases. The measured movement parameters of daily movement, core area size, and home range size, respectively, changed by seasons: fall, 3.1 km, 5.3 km^2, 98.6 km^2; winter, 4.7 km, 13.2 km^2, 143 km^2; spring, 2.6 km, 8.3 km^2, 58.2 km^2; summer, 3.3 km, 3.2 km^2, 54.5 km^2; overall, 3.4 km, 7.9 km^2, 92.4 km^2. Home ranges measured were larger than averages reported in the literature. The coyotes studied were subject to levels of disturbance lower than those reported for other populations.

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The primary objective of this study was to determine home range sizes for coyotes on the U.S. Department of Energy Hanford Reservation. Secondary objectives were to determine if the home ranges differed in size among seasons or between sex and age-classes. When this project was initiated, the results of studies of coyote movements obtained by radio tracking had not been published. Earlier studies were based on mark-recapture data (Murie 1940, Robinson and Cummings 1951, Young and Jackson 1951, Robinson and Grand 1958, Hawthorne 1971) and snow-tracking (Stebler 1951, Ozoga 1963, Ozoga and Harger 1966). During this study, 1 radio-tracking study was published (Gipson and Sealander 1972), and 3 were prepared as theses (Edwards 1975, Rucker 1975, Danner 1976). Since then, more theses and publications have emerged (Hibler 1977; Springer 1976, 1977; Woodruff 1977; Berg and Chesness 1978; Andelt and Gipson 1979; Litvaitis and Shaw 1980).

It was presumed that the population of coyotes on the Hanford Reservation was undisturbed compared to most coyote populations in the United States due to 2 factors. First, public access to the portions of the Reservation in Benton County was prohibited and strictly enforced, although sport hunting was allowed on the Grant and Franklin county portions and coyotes might have been legally harvested there. Second, no government-sponsored predator control programs had been conducted since 1970 on any part of the Reservation. The hypothesis was that movement patterns exhibited by this undisturbed coyote population would differ from those found in other studies, virtually all of which were conducted on heavily exploited populations.

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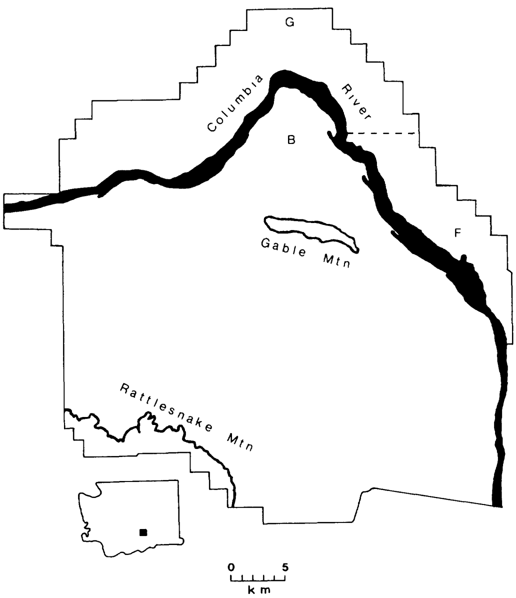

Fig. 1. The U.S. Department of Energy Hanford Reservation in south central Washington. B = Benton County; F = Franklin County; G = Grant County.

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STUDY AREA AND METHODS

The Hanford Reservation comprises an area of about 1,450 km^2 (Fig. 1). The region is a shrub-steppe (Daubenmire 1970), with a mean precipitation of 13 cm/year (Rickard et al. 1973). The most common plant community is the Sagebrush-Cheatgrass (*Artemisia tridentata–Bromus tectorum*) Association. A free-flowing stretch of the Columbia River passes through the Reservation, and the most common soil is alluvial sand. The portion of the Reservation that lies in Benton County varies from 120 to 150 m in elevation, and is bordered by hills on the western edge that reach 275 m and Rattlesnake Mountain at about 915 m. Gable Mountain, near the center of the Reservation, is a basaltic outcropping that reaches 338 m. The portions of the Reservation in Grant and Franklin counties lie at 270 m, forming 100-m bluffs along the north and east shores of the Columbia River.

Coyotes were captured in padded #3 Oneida-Victor steel traps with attached tranquilizer tabs (Balser 1965) of sodium pentabarbitol, or were shot from a helicopter with tranquilizer darts. Most trapped coyotes were anesthetized already; if they had not ingested enough of the tranquilizer tab, they were injected with 2.0 ml of a combination of ketamine hydrochloride and acepromazine maleate, regardless of body weight. This same mixture and dosage was used on darted coyotes. Before individual coyotes were fitted with radio collars, ages were estimated by tooth wear (Gier 1968), and sex was determined.

Radio equipment (tuned to approximately 151 MHz) was supplied by Davtron (Minneapolis, Minn.) and the Cedar Creek Biotelemetry Laboratory (Bethel, Minn.). Coyote locations were determined by triangulation from a permanently mounted Yagi antenna on top of Gable Mountain (Fig. 1) and a truck-mounted Yagi antenna.

An attempt was made to locate each coyote each day (usually morning) using the loudest-signal method (Springer

1979). In addition, some coyotes were monitored for 24-hour periods by simultaneous readings taken every 15 minutes from 2 sites by researchers who were in radio contact.

Locations of individual coyotes were plotted on U.S. Geological Survey maps by seasons. Only 1 location each day was used in data analysis; during 24-hour tracking periods, only the 1100-hour locations were included with the daily locations. Data were segregated by solar seasons to determine if differences by season existed. Each coyote-season was considered 1 sample, and weighted averages were compared to results from other studies in which few coyotes were located over periods longer than 4 months.

Distance between locations on consecutive days was measured; it was the average between the greatest and least distance between points of the 2 error polygons used to describe each location (Springer 1979). "Core areas," defined subjectively as high-use areas, were delineated by a modified minimum-area method (Barbaur and Harvey 1965). To calculate the sizes of core areas within a home range, the sizes of error polygons were considered (Springer 1979) such that the size was the average between the largest and smallest possibilities. Home ranges were delineated by using the minimum-area method (Mohr 1947).

Distances moved between consecutive daily locations were compared to changes in mean daily temperature and barometric pressure, both in relative and absolute terms. Meteorological data were collected hourly at a site near the center of the Reservation, by the Meteorology Department, Battelle Pacific Northwest Laboratories. Daily movements were also compared to phases of the moon: each new moon plus the 2 nights before and after vs. each full moon plus 2 nights before and after.

Table 1. Data on radio-collared coyotes from the U.S. Department of Energy Hanford Reservation, south central Washington, 1974–76.

Coyote	Sex	Estimated age (years)	Date captured	No. locations	Date last located
1	M	2	24 Oct 1974	96	13 Feb 1976
3[a]	M	1	19 Apr 1975	11	7 Feb 1976[b]
5	M	1	9 Dec 1974	117	13 Mar 1976[c]
6[a]	F	1	22 Apr 1975	4	30 Apr 1975
7[a]	F	2	19 Jun 1975	6	1 Oct 1975
8	F	3	19 Jun 1975	109	29 Jun 1976
10	F	3	17 Apr 1976	19	29 Jun 1976
11	M	4	20 Jun 1975	189	28 Jun 1976
12[a]	M	2	20 Jun 1975	10	30 Jul 1975[d]
16	M	1	5 Mar 1976	44	28 Apr 1976[d]

[a] Not located often during any single season. Resulting estimates of home range size are therefore conservative.
[b] Caught by a private trapper 3.5 km south of Hanford Reservation; the radio collar was removed and the coyote released.
[c] Transmitter battery quit on 7 March 1976, but coyote was seen on 13 March 1979.
[d] Found dead, cause unknown.

Densities of leporids and coyotes were determined using the strip-census technique (Flinders and Hansen 1973). Concurrently, a modified scent-post survey (Linhart and Knowlton 1975) with 100 scent stations was conducted on 4 consecutive nights to index coyote and leporid densities.

RESULTS AND DISCUSSION

Ten coyotes (6 trapped, 4 darted) were fitted with radio collars: 3 juvenile and 4 adult males, and 1 juvenile and 2 adult females (Table 1). In all, 605 daily locations were obtained, as well as 509 locations from 24-hour tracking periods.

Daily Movements

Distances moved between consecutive daily locations were determined for 319 location pairs (Table 2). These averaged 3.4 km, close to the 3.5 km reported by Danner (1976). However, this was greater than averages found in other studies:

Table 2. Movements of coyotes on the U.S. Department of Energy Hanford Reservation, south central Washington, 1974–76. Average error (Springer 1979) for distance was about 0.2 km, and for areas was about 1.7 km².

				Distance		Core area		Home range	
Season and year	Age[a]	Sex	Coyote	km	N[b]	km²	N[c]	km²	N[c]
Fall									
1974	ad	M	1	2.5	11	1.7	16	72.4	23
1975	ad	M	1	3.6	18	9.4	30	240.8	36
1975	ad	M	5	2.4	10	3.1	27	21.6	28
1975	ad	F	8	3.2	7	1.0	10	17.2	13
1975	ad	M	11	3.3	27	8.0	38	90.6	49
Weighted avg[d]				3.1	15	5.3	23	98.6	29
Winter									
1974–75	ad	M	1	4.9	4	0.2	3	84.2	8
1974–75	juv	M	5	1.9	7	1.6	20	38.3	23
1975–76	ad	M	1	10.3	7	7.7	6	313.3	15
1975–76	juv	M	3	[e]		[e]		128.9	5
1975–76	ad	M	5	1.5	11	0.4	22	29.0	24
1975–76	ad	F	8	8.5	19	37.0	28	295.5	34
1975–76	ad	M	11	3.4	25	21.5	38	165.9	42
1975–76	juv	M	16	2.6	10	0.1	5	23.0	13
Weighted avg[d]				4.7	12	13.2	15	143.4	19
Spring									
1975	ad	M	5	0.5	2	0.4	10	1.5	11
1975	juv	F	6	[e]		[e]		50.6	4
1976	ad	F	8	4.6	36	12.3	47	90.1	49
1976	ad	M	10	6.7	9	15.3	12	148.2	18
1976	ad	M	11	1.1	45	1.1	45	8.4	49
1976	juv	M	16	1.4	29	1.3	20	48.1	27
Weighted avg[d]				2.6	24	8.3	24	58.2	23
Summer									
1975	ad	M	1	3.7	9	2.0	12	115.6	16
1975	juv	M	3	2.4	1	[e]		82.4	5
1975	ad	M	5	2.2	11	2.7	23	22.8	24
1975	ad	F	7	[e]		[e]		53.7	6
1975	ad	F	8	13.6	1	1.0	9	10.1	9
1975	ad	M	11	3.3	20	6.5	33	68.8	35
1975	ad	M	12	[e]		0.1	3	10.0	5
Weighted avg[d]				3.3	8	3.2	14	54.5	13
Overall weighted avg				3.4	15	7.9	18	92.4	20

[a] Adults are considered to be individuals ≥2 years old or yearling females that have gone through estrus; others are classified as juveniles.
[b] Number of consecutive-day location pairs examined.
[c] Number of locations used to determine area.
[d] Weighted average distances were determined by multiplying each distance by N, summing these, and dividing by ΣN. Weighted average areas were determined by multiplying each area by $\sqrt{N}$, summing these, and dividing this sum by $\Sigma \sqrt{N}$.
[e] Insufficient data to permit determination.

1.4 km (Berg and Chesness 1978), 1.6 km (Andelt and Gipson 1979), and 1.8 km (Litvaitis and Shaw 1980). Daily movements were remarkably uniform throughout the year on the Hanford Reservation (Fig. 2). Only the distribution of daily movements in winter (4.6 km) was different from the average ($P < 0.025$), primarily due to the greater number of moves in excess of 6.0 km. The increase in daily

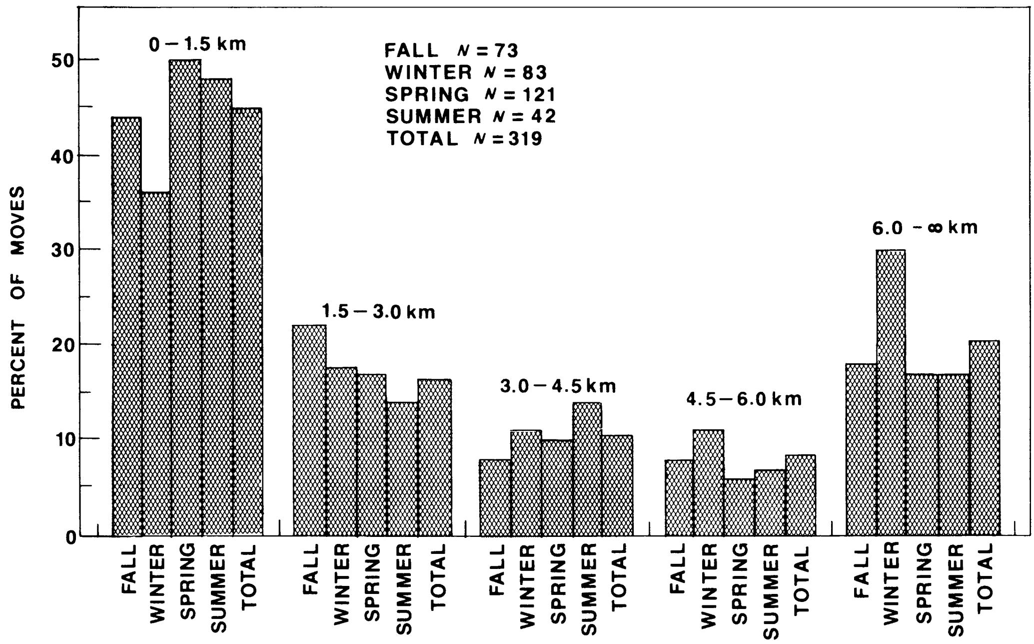

Fig. 2. Frequency distribution of distances between locations determined on consecutive days, by seasons.

movements during the winter was evident for each individual (Table 2). Because winter is the time when unpaired coyotes form pairs (Gier 1968), the increased daily movements could be related to the search for mates. This explanation is reasonable for a heavily exploited coyote population where pairs are likely to be disrupted. However, coyotes on the Hanford Reservation were minimally exploited. Changes in their daily movements were more likely due to changes in food availability than to changes in pair formation. Even if leporid abundance remained relatively constant throughout the year (which it does not), other prey items clearly decrease, such as Great Basin pocket mice (*Perognathus parvus*) and insects, both of which are important food items for Hanford coyotes (Stoel 1977). The subsequent decrease in average daily movements in spring could be related to den construction and raising young, or to the cessation of the mate search, or both.

Data for daily movements by juveniles were not collected for each season, but the overall average of 47 daily movements for juveniles was 2.1 km, less ($P < 0.05$) than the overall average (4.4 km) of 282 adult daily movements. Daily movements of females averaged 5.8 km, more ($P < 0.05$) than the overall average (3.0 km) of 209 adult male daily movements. It is important to note, however, that all data on adult female daily movements were obtained from only 1 individual, so that although her daily movements were significantly longer than adult male daily movements, this might not have been true for all adult female coyotes on the study area.

Attempts to correlate daily movements and relative and absolute changes in

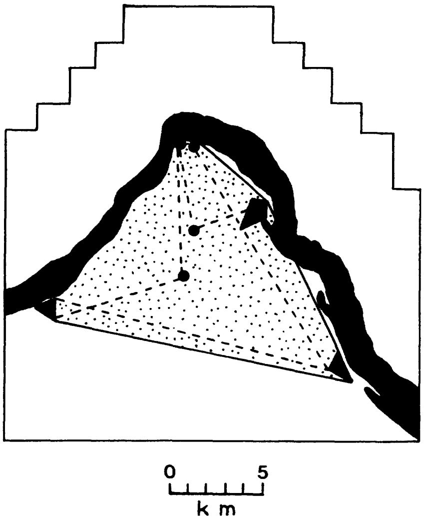

Fig. 3. Three core areas and the impact area within the home range of Coyote #1 during summer 1975. The impact area is stippled; core areas are solid polygons. Sequence of locations is indicated in dashed lines.

mean daily temperature and mean daily barometric pressure produced no statistically significant relationships. Daily movements also did not show any relationship to moon phases.

Core Areas

Daily locations for the coyotes occurred in clusters, and these were designated as core areas. Active den sites were found within some core areas in late winter and early spring but in general, the core areas were places where individual coyotes spent a great deal of time. Each home range was subdivided into 2 parts: 1 or more core areas and the remaining part that I define as the "impact area," an area through which an animal travels and on which its presence impacts occasionally (Fig. 3).

Burt (1943:351) defined home range as everywhere an animal travels in carrying out its normal activities, but "occasional sallies outside the area, perhaps exploratory in nature" were excluded. These movements should not be excluded. The home ranges of the Hanford coyotes may have been little else than core areas strung together by "occasional sallies" through the impact area. Every location should be included within an animal's home range by definition. Locations can then be assigned to core areas or impact areas, depending on how the points are distributed.

Core areas are somewhat more difficult to define. From Fig. 2, it is clear that nearly 50% of the daily movements were in the shortest range, 0.0–1.5 km. These would probably represent movements within a core area. Also, about 20% of the movements were in excess of 6.0 km, and were probably moves between core areas. Although the other 30% of the daily movements could possibly have been within or between core areas, examination of the actual distribution of locations for each coyote revealed that even an overall average move of about 3.4 km (Table 2) would normally be beyond the limits of a core area. Further, one would not expect most movements within a core area to extend from 1 side to another. Therefore, a modified minimum-area method (Barbaur and Harvey 1965) was employed, where the line segments were no more than one-half the average daily movement (Table 2) for that coyote during that season. A core area, therefore, was composed of 3 or more daily locations during 1 season that were within one-half the average distance of a daily move for that coyote. If a coyote had more than 1 core area, they were added together. The concept of core area is not new. That coyotes use portions of their home ranges more intensively than others has been noted elsewhere (Gipson and Sealander 1972, Edwards 1975, Rucker 1975,

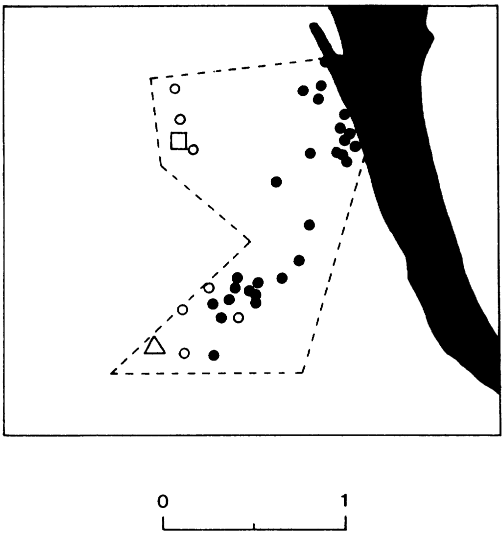

Fig. 4. Locations of Coyote #1 over a 24-hour period, beginning at 1100 hours, 9 November 1974. For clarity, not all intermediate locations are shown. Core area, as determined by 19 daily locations, is delineated by dashed lines. △ = location at start, □ = location at end. Open symbols represent daylight locations; closed symbols represent nighttime locations.

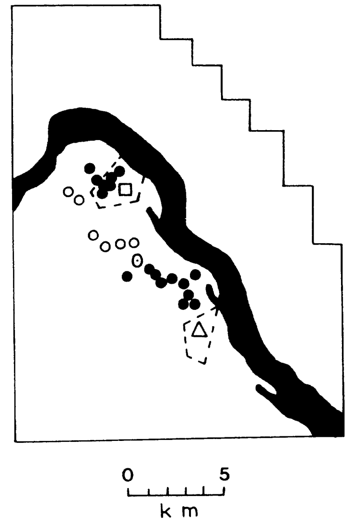

Fig. 5. Locations of Coyote #8 over a 24-hour period, beginning at 2000 hours, 15 November 1975. For clarity, not all intermediate locations are shown. Core areas, as determined by 13 daily locations, are delineated by dashed lines. △ = location on morning, 15 November; ⊙ = location at 1100 hours, 16 November; □ = location on morning, 17 November. Open symbols represent daylight locations; closed symbols represent nighttime locations.

Hibler 1977, Berg and Chesness 1978). Of these, only Hibler (1977) delineated these areas, although he called them "home ranges."

Size of core areas varied by animal and by season (Table 2). They were smallest in summer (well after parturition) and largest in winter. These changes are most likely due to a combination of denning activity and food availability.

Core area sizes for juveniles could be determined only 3 times, but they averaged only 1.0 km^2, below ($P < 0.05$) the overall average of 7.9 km^2 for the study. Average core area size for the 1 adult female was 12.8 km^2, larger ($P < 0.05$) than the average for adult males (5.3 km^2), although this indicates little about what the average core area size for all females might have been.

In general, core areas comprised only 8.5% of an animal's home range. However, 82.9% of all locations were within core areas. Data from 24-hour tracking periods showed that the Hanford coyotes either traveled throughout most of 1 core area in a single night (Fig. 4), or that they traveled between core areas (Fig. 5). No instance was observed of a coyote leaving a core area, traveling out into its impact area, then returning to the same core area. Because this was true in 6 of 6 instances, 24-hour tracking sessions were deemed unnecessarily time consuming and of little added advantage over a single location each day. Thus, core areas were not merely resting sites, but appeared to be areas where most of the foraging occurred as well. Impact areas were traveled through, but rarely was a coyote outside a core area for more than 2 consecutive days, except in winter,

Table 3. Average home range sizes for 2 or more coyotes by sex and age-class, ranked by size of adult male home ranges. Areas were estimated by the minimum area method except where noted.

	Adults[a]				Juveniles[a]	
	Males		Females			
Source	km²	N	km²	N	km²	N
This study[b]	97.8	15	117.8	5	54.3	6
Berg and Chesness 1978	67.9	10	16.3	17	5–8	17
Edwards 1975	65.0	2	69.5	4	[c]	
Andelt and Gipson 1979	56.5	3	54.3	2	[c]	
Hibler 1977[d]	53.0	9	66.2	6	56.2	19
Gipson and Sealander 1972[e]	33.2	5	13.2	3	11.9	2
Litvaitis and Shaw 1980	31.3	5	68.7	6	39.9	4
Rucker 1975	[c]		74.7	3	7.6	2[f]
Woodruff 1977[e]	[c]		45.9	4	22.8	2
Danner 1976	[c]		21.2	6	2.6	6

[a] Adults are considered to be individuals ≥2 years old or yearling females that have gone through estrus; others are classified as juveniles.
[b] Average home ranges for all coyote-seasons (the minimum area occupied by 1 coyote during any 3-month season). A coyote followed for 1 year yielded 4 coyote-seasons. Few of the studies reported here followed any coyotes for more than 4 months, thus all values are comparable.
[c] Sample size of fewer than 2 individuals.
[d] Hibler (1977) used "total area utilized" as "home range" is used here. Data from 1 adult male that used 427.6 km², and data from 2 adult females that used 469.1 and 236.8 km² were not included. If included, averages for adult males and adult females were 90.4 and 137.9 km², respectively.
[e] Home range sizes determined by the ellipse method (Hayne 1949).
[f] Home range size determined by modified minimum-area method (Barbaur and Harvey 1965).

when daily movements were relatively long.

Home Range

The sizes of home ranges for each coyote for each season varied (Table 2). Average home range sizes were considerably larger than those reported in other studies, for each sex and age-class (Table 3). Calculated sizes of home ranges tend to increase asymptotically as the number of locations increase. Thus, calculated home range sizes (Tables 2, 3) probably represent conservative estimates. However, inclusion of all core areas used within a home range during a season would have been more important than increasing numbers of locations in regard to determination of home range size. By entirely missing any 1 of the core areas (Fig. 3), the estimated home range of Coyote #1 would have been reduced between 20 and 50%; conversely, adding or missing 20 locations would make little difference, as long as the 3 core areas were indicated by at least 1 point each. The 2 locations to the north (Fig. 3) probably are within an undelineated core area. After obtaining at least 1 point from each core area, the home ranges in this study did approach asymptotes.

Calhoun (1955) suggested that there are 3 basic factors that affect home range sizes. First, the distribution of physical components (food, water, shelter) affects the frequency with which an animal visits any given area. Second, as components (such as food) become scarce, home range size tends to increase. Third, as population density decreases, home ranges of individuals within the population will increase.

On the Hanford Reservation, distribution of water seemed to be an important factor affecting home range sizes. The most readily available water was the Columbia River, and core areas tended to adjoin the River or to be within 5.0 km. Distribution of food appeared to be relatively uniform, but densities were low.

Black-tailed jack rabbits (*Lepus californicus*) comprised 30% of the coyotes' diet (Stoel 1977), yet occurred at densities averaging only 1 animal/3.6 km^2.

The presence of relatively small core areas suggests that some areas offered better conditions than others. I frequently noted that coyote scats found near the Columbia River contained fish scales and bones. Although I made no intensive examination of scats, I did observe coyotes catching fish (Springer 1980). Stoel (1977), however, found no fish parts in any of the scats he examined. Possibly, the core areas near the river offered higher concentrations of other prey, but this was not determined.

Densities of coyotes were about 1 coyote/5.4 km during the strip census. The scent-post-survey index was 63 (percent visitations × 10), relatively low when compared to other studies. The average index of the 11 lines run in Washington in 1976 was 109.5, and the highest was 245; the highest index in the United States was 583 in Texas (Roughton 1976). Danner (1976) reported an average monthly index of nearly 200 in Arizona. Home range sizes reported by Danner (Table 4) were substantially smaller than those at Hanford, as might be predicted based on differences in relative coyote densities between the 2 areas. However, despite this difference, the average daily movements found at Hanford and by Danner were nearly identical.

The presumed undisturbed nature of the Hanford coyote population proved to be not strictly true. Because of the large home range sizes, virtually each radio-collared coyote spent some time within areas where killing of coyotes was legally practiced. One of the study coyotes was trapped while off the Reservation, although it was released unharmed. Nevertheless, the majority of their home range areas were on protected land, a fact that may have contributed to the large home range sizes. Due to protection, the Hanford coyote population was probably more stable than other similarly studied populations, both in terms of numbers and perhaps more importantly in terms of social organization. This latter factor has not yet been studied intensively. However, it seems reasonable that a coyote moving about an area populated by relatives and other long-standing acquaintances might have fewer intraspecific agonistic encounters than a coyote in an area populated by strange individuals, the result of rapid and high dispersal rates in response to heavy exploitation rates. Social stability should produce stable territory boundaries, which could be established among family units as with wolves (Peters and Mech 1975). This in itself need not result in large home range sizes, but should when combined with low population levels and low food availability. Home ranges, impact areas, and core areas of different coyotes overlapped occasionally. Family relationships of radio-equipped coyotes were not determined, and therefore no territoriality could be shown either for individuals or family groups.

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