DETERMINING HOME-RANGE SIZE OF RESIDENT COYOTES FROM POINT AND SEQUENTIAL LOCATIONS

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Abstract: We examined the influence of using point and sequential locations for determining resident coyote (*Canis latrans*) home-range size with 3 different estimators: minimum convex polygon, 95% ellipse estimate, and 95% harmonic-mean activity area. For a given method, home-range size did not differ based on point and sequential locations. The time of day that locations were obtained and variation among individuals explained 91–93% of the observed variation in home-range size. The minimum number of point locations required to adequately delineate home-range size ranged from 23 to 33 and 28 to 36 during the day and night, respectively. The minimum number of tracking sessions necessary to delineate home-range size ranged from 4 to 6 and 5 to 9 during the day and night, respectively. We concluded that home-range size estimates for resident coyotes based on point versus sequential locations were not statistically different.

Coyote home-range size has been estimated using both the point method of locating animals and the sequential method with blocks of time 6–24 hours in length (see review by Laundré and Keller 1984). Sequential locations have been obtained at 15–60 minute intervals (e.g., Laundré and Keller 1981, Smith et al. 1981, Gese et al. 1988), which may result in significant autocorrelation between successive locations (Dunn and Gipson 1977; Swihart and Slade 1985*a,b*).

Swihart and Slade (1985*a,b*) demonstrated that autocorrelated observations yield less information for home-range estimation than do independent observations. However, Andersen and Rongstad (1989) concluded that home-range size estimates of red-tailed hawks (*Buteo jamaicensis*) based on point (random) versus sequential (autocorrelated) locations were statistically indistinguishable. For coyotes, the influence of point versus sequential locations on home-range estimation has not been thoroughly investigated. Recently, Reynolds and Laundré (1990) reported that estimates of home-range size and daily distance traveled for coyotes and pronghorn antelope (*Antilocapra americana*) were underestimated when sampling intervals based on statistically independent data were compared to autocorrelated, sequential locations. We examined the effect of point and sequential locations on estimation of resident coyote home-range size in southeastern Colorado.

STUDY AREA

The 1,040-km² study area was located on the Piñon Canyon Maneuver Site (PCMS), Las Animas County, Colorado. Climate was semiarid with mean annual precipitation of 26–38 cm. Mean monthly temperatures ranged from −1 C in January to 23 C in July. Elevations ranged from 1,310 to 1,740 m (U.S. Dep. Army 1980).

The central and western portions of the area were shortgrass prairie dominated by blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and galleta (*Hilaria jamesii*). Shrub-grasslands, associated with drainages,

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Table 1. Period tracked, sex, and Schoener ratios (t^2/r^2) (Schoener 1981, Swihart and Slade 1985a) for 12 coyotes radiotracked on the Piñon Canyon Maneuver Site, Colorado, 1984–88.

Coyote no.	Period tracked	Sex	Meth-od[a]	t^2/r^2 Day	t^2/r^2 Night
1	Mar–Aug 1986	M	P	1.71	2.22
			S	0.33[b]	0.74[b]
2	Mar–Aug 1984	F	P	1.27[b]	1.48[b]
			S	0.34[b]	0.30[b]
3	Jan–Jun 1984	M	P	1.51[b]	1.39[b]
			S	0.66[b]	0.67[b]
4	Mar–Aug 1985	M	P	1.65[b]	1.63[b]
			S	0.30[b]	0.73[b]
5	Mar–Aug 1985	M	P	1.72	1.96
			S	0.73[b]	0.92[b]
6	Mar–Aug 1985	M	P	1.63[b]	2.24
			S	0.36[b]	1.22[b]
7	Jul–Dec 1985	M	P	1.75	2.01
			S	0.38[b]	0.68[b]
8	Jan–Jun 1987	F	P	1.66[b]	1.44[b]
			S	0.35[b]	0.61[b]
9	Jan–Jun 1987	F	P	1.51[b]	1.82
			S	0.74[b]	1.01[b]
10	May–Oct 1986	F	P	1.62[b]	1.56[b]
			S	0.71[b]	0.68[b]
11	Sep 87–Feb 88	M	P	1.63[b]	2.36
			S	0.72[b]	0.45[b]
12	Jun–Nov 1986	F	P	0.57[b]	2.69
			S	0.55[b]	0.55[b]

[a] Method: P = point locations, S = sequential locations; n = 60 locations for each method.
[b] Successive locations were autocorrelated ($P < 0.05$).

were interspersed over much of the area and were dominated by four-winged saltbush (*Atriplex canescens*) and greasewood (*Sarcobatus vermiculatus*). The northern portions were limestone breaks dominated by pinyon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*). The Purgatoire River Canyon system formed the eastern boundary and consisted of sandstone canyons dominated by pinyon-juniper woodlands (U.S. Dep. Army 1980).

METHODS

We used 3 methods to capture coyotes: (1) a hand-held net gun fired from a helicopter (Barrett et al. 1982), (2) manual capture following aerial pursuit (Gese et al. 1987), and (3) manual capture from 3-wheel all terrain cycles. Each coyote was weighed, sexed, aged by tooth wear (Gier 1968), eartagged, and fitted with a radio collar.

Twelve resident, adult coyotes were used in this analysis (Table 1). We analyzed only resi-

dent coyotes because they displayed an affinity for 1 area or territory, and area-observation curves reached an asymptote (Gese et al. 1988). Transient or nomadic coyotes were not considered because they typically do not show an affinity for 1 area, and area-observation curves have multiple asymptotes or do not reach an asymptote (Bowen 1982, Roy and Dorrance 1985). We located radio-equipped coyotes with a portable receiver and a 4-element Yagi antenna or 2-element H-antenna. We used ≥2 compass bearings with an intersecting angle >20 and <160° to plot an animal's location. Maximum telemetry error was ±4°. We assumed telemetry error was consistent between point and sequential locations. Hence, resulting areal error did not influence comparisons for a given home-range area estimate based on point or sequential locations. Each location was plotted to the nearest 100-m grid intersection on a 1:24,000 USGS topographic map using the Universal Transverse Mercator system.

We used 2 relocating methods, point and sequential, for each coyote during both day and night resulting in 4 tracking strategies: day-point, day-sequential, night-point, and night-sequential. We collected 60 point locations (12–72 hr apart) for each coyote during the day (0600–1759 hr) and night (1800–0559 hr) for <6 months. We assumed collecting point locations >12 hours apart would ensure independence between successive locations because Swihart et al. (1988) calculated the "time to independence" for coyotes as 3.5 hours. In <6 months, 12 4-hour tracking sessions were conducted on each coyote during the day and night. Coyotes were relocated every 0.5 hour, but we used hourly locations to maintain equal sample size (i.e., 5 locations/tracking session × 12 sessions = 60 locations). Thus, we obtained 60 point and 60 sequential locations on each coyote during the day and night. Point and sequential locations were spaced throughout the time period. All 12 coyotes were not tracked during the same time period (Table 1).

We estimated home-range size based on minimum convex polygons (Mohr 1947, Southwood 1966), 95% ellipses (Jennrich and Turner 1969), and 95% harmonic-mean activity areas (Dixon and Chapman 1980, Samuel et al. 1985) with a computer program developed by J. R. Cary at the University of Wisconsin–Madison. We used these 3 estimators because they are the most commonly used in recent home-range analyses

Table 2. Analysis of variance testing the influence of time, method, and individual for 3 estimates of coyote home-range size, Piñon Canyon Maneuver Site, Colorado, 1984–88.

Home-range estimate	Source	df	Sum of squares	F	P
Minimum convex polygon	Time (T)[a]	1	375.20	27.6	<0.005
	Method (M)[b]	1	2.80	0.5	>0.250
	Individual (I)	11	897.22	4.3	<0.005
	I × M	11	65.15	2.9	<0.100
	I × T	11	149.57	6.6	<0.005
	M × T	1	17.52	8.5	<0.025
	Error	11	22.78		
95% ellipse	T	1	869.55	51.3	<0.005
	M	1	22.28	2.4	>0.100
	I	11	1,229.36	4.6	<0.005
	I × M	11	102.62	1.2	>0.250
	I × T	11	186.44	2.1	>0.100
	M × T	1	2.95	0.4	>0.250
	Error	11	89.10		
95% harmonic-mean	T	1	441.65	26.0	<0.005
	M	1	0.40	0.1	>0.250
	I	11	1,442.98	5.2	<0.025
	I × M	11	105.44	1.5	>0.250
	I × T	11	187.05	4.2	<0.050
	M × T	1	1.76	0.3	>0.250
	Error	11	68.66		

[a] Time: day vs. night locations.
[b] Method: point vs. sequential locations.

(e.g., Laundré and Keller 1984, Andersen and Rongstad 1989, Gese et al. 1989). Area-observation curves (Odum and Kuenzler 1955) were constructed for each coyote to ensure that 60 locations adequately described a home range. An adequate sample size of locations was indicated when the area-observation curve reached an asymptote that increased <1% in home-range size with the addition of 5 point locations or 1 tracking session, similar to the methods of Odum and Kuenzler (1955) and Fuller and Snow (1988). We tested for independence between successive pairs of locations using Schoener ratios (Schoener 1981, Swihart and Slade 1985a). Schoener ratios were calculated for each entire data set to measure autocorrelation both within and between tracking sessions.

We used 3-way ANOVA, blocking for individuals, to examine the influence of time (day vs. night) and method (point vs. sequential) on home-range size. We blocked for individuals because variation among individual home ranges was previously found to be due mostly to habitat components within the home range (Gese et al. 1988). Our ANOVA procedures followed those outlined by Damon and Harvey (1987:106–109) for 3-way ANOVA where 2 factors (time and method) are fixed, and 1 factor (individual) is random. We present results for a mixed model with all 2-way interaction terms included. Approximate tests for the influence of individuals are those outlined by Damon and Harvey (1987: 91–92). Power analyses are based on least significant difference procedures (Snedecor and Cochran 1980:234, Damon and Harvey 1987: 164–165).

RESULTS

Mean home-range size determined from minimum convex polygons was 9.0 ± 0.9 (SE), 8.3 ± 1.1, 13.4 ± 1.6, and 15.1 ± 2.0 km² for day-point, day-sequential, night-point, and night-sequential tracking, respectively. Ninety-five percent ellipses averaged 12.6 ± 1.2, 11.2 ± 1.2, 20.6 ± 2.1, and 19.8 ± 2.0 km² for day-point, day-sequential, night-point, and night-sequential tracking, respectively. Ninety-five percent harmonic-mean activity areas averaged 11.3 ± 1.3, 11.1 ± 1.9, 17.0 ± 2.2, and 17.5 ± 1.9 km² for day-point, day-sequential, night-point, and night-sequential tracking, respectively. For a given estimator, home-range size did not differ during either the day or night based on point versus sequential locations (Table 2). Most variation (91–93%) in home-range size was explained by the time (day vs. night) that locations were collected (19–35%), variation among individual coyotes (49–65%), and the interaction

between time and individual (7–12%) (Table 2). Most of the variation in adult, resident home-range size on our study area was due to habitat components within an individual's home range. Sex, season, and year did not significantly influence coyote home-range size estimates (Gese et al. 1988). Method of data collection (point vs. sequential) was not a significant source of variation except through its interaction with method in minimum convex polygon home-range estimates. Inspection of 2-way class means (Damon and Harvey 1987:53–54) indicated that this significant interaction was attributable to a single coyote that had an unusually large minimum convex polygon home range at night. This coyote's minimum convex polygon home-range estimate based on sequential locations (33.4 km²) was considerably higher than that based on point locations (24.5 km²). Protected least significant difference (LSD) comparisons indicated that neither minimum convex polygons, 95% ellipses, nor 95% harmonic-mean activity areas differed significantly based on the method of data collection. Power analyses indicated that we would have detected differences of 2–4 km² for all 3 home-range area estimators (alpha = 0.05 and 0.10; beta = 0.10 and 0.15) in LSD comparisons.

Minimum sample sizes, as defined by the asymptote of the area-observation curve, required to adequately delineate home-range size were obtained for all coyotes. Minimum sample size for the day-point tracking regime ranged from 23 to 33 locations; night-point required a minimum of 28–36 locations. The minimum number of tracking sessions for day-sequential tracking ranged from 4 to 6; night-sequential required a minimum of 5–9 tracking sessions. Minimum sample sizes were correlated with the size of each individual home range (r = 0.63, 46 df, P < 0.001). More locations or tracking sessions were required to adequately delineate larger home ranges. Nine of the 12 coyotes used in our analysis were followed for >1 year resulting in >20 tracking sessions per animal and >100 point locations per animal with no further increase in home-range size.

All sequential locations during both day and night were significantly autocorrelated (Table 1). Point locations were autocorrelated in 9 of 12 cases during the day, and 5 of 12 cases were autocorrelated during the night (Table 1). The season in which the coyote was tracked may have contributed to significant autocorrelation

between successive locations. All 5 females were tracked during the whelping and pup-rearing seasons; all 5 showed a lack of independence for day locations, whereas 3 of 5 (60%) showed significant autocorrelation between successive point locations at night. Five of 7 males were tracked during the whelping and pup-rearing season. Three of 5 (60%) males exhibited significant autocorrelation between point locations during the day, and 2 of 5 (40%) exhibited significant autocorrelation between point locations at night. The 2 males tracked during nonwhelping seasons exhibited significant autocorrelation in only 1 of 2 point location data sets during the day, and no point locations at night were significantly autocorrelated (Table 1).

DISCUSSION

Coyote home ranges have been estimated with point locations, "bursts" of sequential locations, or both point and sequential locations. However, the effect of using point or sequential locations in coyote home-range size estimation is not known (Laundré and Keller 1984). Although Woodruff and Keller (1982) indicated that home-range estimates from sequential locations may be smaller than estimates from point locations, they provided no details (i.e., experimental design, statistical analysis, or sample sizes). Swihart and Slade (1985a,b), using Monte Carlo simulations, found that estimates of home-range size from autocorrelated data were smaller than corresponding estimates calculated with independent locations for both minimum polygon and minimum convex polygon home-range models. They further concluded that autocorrelated observations yielded less information in home-range use estimates than did independent locations. However, Andersen and Rongstad (1989) demonstrated that estimates of home-range size, using minimum convex polygons, 95% ellipses, and 50% harmonic-mean activity area, did not statistically differ between point and sequential locations for red-tailed hawks. Recently, Reynolds and Laundré (1990) found that coyote home-range size and daily distance traveled were underestimated when subsamples of statistically independent locations were compared to the total sample of autocorrelated, sequential locations.

The number of locations used influences home-range size estimates (Stickel 1954, Jennrich and Turner 1969, Bekoff and Mech 1984). We found that the minimum sample size of point locations

to adequately delineate home-range size was similar to estimates needed to describe gray wolf (*Canis lupus*) territories (Fuller and Snow 1988), but below the estimated 100–200 locations reported to be required for coyotes (Hibler 1976, Woodruff and Keller 1982, Laundré and Keller 1984). Our estimates of 4–6 and 5–9 tracking sessions to delineate day and night home ranges, respectively, is similar to the results of Smith et al. (1981) and Laundré and Keller (1984).

A short time interval between successive observations can result in a high degree of autocorrelation (Dunn and Gipson 1977, Schoener 1981). We expected significant autocorrelation between sequential locations in our study due to nonuniform spatial home-range use related to foraging, resting, denning, or other biological functions that result in a multimodal, asymmetric distribution of points (Samuel et al. 1985, Samuel and Garton 1987). Furthermore, autocorrelation between successive point locations was probably influenced by the season in which coyotes were tracked. All females and 5 of 7 males were tracked during the whelping season when females were more likely to be near den sites than males, resulting in locations clustered around a focal point and significant autocorrelation during both day and night. Andelt et al. (1979) and Harrison and Gilbert (1985) also found that during nursing and weaning females were closer to and spent more time near dens than did males. The lack of independence between successive locations for females during the whelping season indicated that home-range use may differ from males, even though home-range size did not differ statistically between the sexes (Gese et al. 1988). However, because Schoener ratios are based solely on the distance traveled between successive locations in relation to the average distance from the center and do not consider the time interval between locations, we believe that temporal independence was maintained between point locations that were collected >12 hours apart (Swihart et al. 1988).

Using point versus sequential locations did not affect home-range size estimates for resident coyotes. In addition, the use of sequential locations provides information on temporal patterning of activity areas or home-range use (Swihart and Slade 1985b, Samuel and Garton 1987), activity patterns, and at night, social interactions and habitat use when the animal is actively moving through its home range (Smith et al. 1981).

Similarly, biological and logistical considerations (Heezen and Tester 1967, Smith et al. 1981, Laundré and Keller 1984) may influence how location data are collected. As long as an adequate time frame is employed, sequential data can be used to accurately estimate home-range size for resident coyotes.

LITERATURE CITED

ANDELT, W. F., D. P. ALTHOFF, AND P. S. GIPSON. 1979. Movements of breeding coyotes with emphasis on den site relationships. J. Mammal. 60:568–575.

ANDERSEN, D. E., AND O. J. RONGSTAD. 1989. Home-range estimates of red-tailed hawks based on random and systematic relocations. J. Wildl. Manage. 53:802–807.

BARRETT, M. W., J. W. NOLAN, AND L. D. ROY. 1982. Evaluation of a hand-held net-gun to capture large mammals. Wildl. Soc. Bull. 10:108–114.

BEKOFF, M., AND L. D. MECH. 1984. Simulation analyses of space use: home range estimates, variability, and sample size. Behav. Res. Methods, Instruments, and Comput. 16:32–37.

BOWEN, W. D. 1982. Home range and spatial organization of coyotes in Jasper National Park, Alberta. J. Wildl. Manage. 46:201–216.

DAMON, R. A., JR., AND W. R. HARVEY. 1987. Experimental design, ANOVA, and regression. Harper and Row Publishers, Inc., New York, N.Y. 508pp.

DIXON, K. R., AND J. A. CHAPMAN. 1980. Harmonic mean measure of animal activity areas. Ecology 61:1040–1044.

DUNN, J. E., AND P. S. GIPSON. 1977. Analysis of radio telemetry data in studies of home range. Biometrics 33:85–101.

FULLER, T. K., AND W. J. SNOW. 1988. Estimating winter wolf densities using radiotelemetry data. Wildl. Soc. Bull. 16:367–370.

GESE, E. M., O. J. RONGSTAD, AND W. R. MYTTON. 1987. Manual and net-gun capture of coyotes from helicopters. Wildl. Soc. Bull. 15:444–445.

———, ———, AND ———. 1988. Home range and habitat use of coyotes in southeastern Colorado. J. Wildl. Manage. 52:640–646.

———, ———, AND ———. 1989. Changes in coyote movements due to military activity. J. Wildl. Manage. 53:334–339.

GIER, H. T. 1968. Coyotes in Kansas. Kansas State Coll. Agric. Exp. Stn. Bull. 393. 118pp.

HARRISON, D. J., AND J. R. GILBERT. 1985. Denning ecology and movements of coyotes in Maine during pup rearing. J. Mammal. 66:712–719.

HEEZEN, K. L., AND J. R. TESTER. 1967. Evaluation of radio-tracking by triangulation with special reference to deer movements. J. Wildl. Manage. 31:124–141.

HIBLER, S. J. 1976. Coyote movement patterns in Curlew Valley with emphasis on home range characteristics. M.S. Thesis, Utah State Univ., Logan. 112pp.

JENNRICH, R. I., AND F. B. TURNER. 1969. Measurement of non-circular home range. J. Theoretical Biol. 22:227–237.

LAUNDRÉ, J. W., AND B. L. KELLER. 1981. Home-range use by coyotes in Idaho. Anim. Behav. 29:449–461.

———, AND ———. 1984. Home-range size of coyotes: a critical review. J. Wildl. Manage. 48:127–139.

MOHR, C. O. 1947. Table of equivalent populations of North American small mammals. Am. Midl. Nat. 37:233–249.

ODUM, E. P., AND E. J. KUENZLER. 1955. Measurement of territory and home range size in birds. Auk 72:128–137.

REYNOLDS, T. D., AND J. W. LAUNDRÉ. 1990. Time intervals for estimating pronghorn and coyote home ranges and daily movements. J. Wild. Manage. 54:316–322.

ROY, L. D., AND M. J. DORRANCE. 1985. Coyote movements, habitat use, and vulnerability in central Alberta. J. Wildl. Manage. 49:307–313.

SAMUEL, M. D., AND E. O. GARTON. 1987. Incorporating activity time in harmonic home range analysis. J. Wildl. Manage. 51:254–257.

———, D. J. PIERCE, AND E. O. GARTON. 1985. Identifying areas of concentrated use within the home range. J. Anim. Ecol. 54:711–719.

SCHOENER, T. W. 1981. An empirically based estimate of home range. Theoretical Population Biol. 20:281–325.

SMITH, G. J., J. R. CARY, AND O. J. RONGSTAD. 1981.

Sampling strategies for radio-tracking coyotes. Wildl. Soc. Bull. 9:88–93.

SNEDECOR, G. W., AND W. G. COCHRAN. 1980. Statistical methods. Seventh ed. Iowa State Univ. Press, Ames. 505pp.

SOUTHWOOD, T. R. E. 1966. Ecological methods with particular reference to the study of insect populations. Methuen and Co. Ltd., London. 391pp.

STICKEL, L. F. 1954. A comparison of certain methods of measuring ranges of small mammals. J. Mammal. 35:1–15.

SWIHART, R. K., AND N. A. SLADE. 1985a. Testing for independence of observations in animal movements. Ecology 66:1176–1184.

———, AND ———. 1985b. Influence of sampling interval on estimates of home-range size. J. Wildl. Manage. 49:1019–1025.

———, ———, AND B. J. BERGSTROM. 1988. Relating body size to the rate of home range use in mammals. Ecology 69:393–399.

U.S. DEPARTMENT OF THE ARMY. 1980. Draft environmental impact statement for training land acquisition. Fort Carson, Colo. 284pp.

WOODRUFF, R. A., AND B. L. KELLER. 1982. Dispersal, daily activity, and home range of coyotes in southeastern Idaho. Northwest Sci. 56:199–207.

ERROR IN TELEMETRY STUDIES: EFFECTS OF ANIMAL MOVEMENT ON TRIANGULATION

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Abstract: We used Monte Carlo simulations to investigate the effects of animal movement on error of estimated animal locations derived from radio-telemetry triangulation of sequentially obtained bearings. Simulated movements of 0–534 m resulted in up to 10-fold increases in average location error but <10% decreases in location precision when observer-to-animal distances were <1,000 m. Location error and precision were minimally affected by censorship of poor locations with Chi-square goodness-of-fit tests. Location error caused by animal movement can only be eliminated by taking simultaneous bearings.

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Telemetry triangulation is commonly used for obtaining location estimates of animals. The accuracy of a location estimate "is a function of tower locations, the animal's location relative to the towers, and precision of the bearings from the tower to the animal" (White and Garrott 1986:509), where towers refer to the antennas used by observers to obtain bearings. For triangulation from fixed antennas where bearings are obtained simultaneously, an animal has only 1 location relative to the antennas. However, many studies employ a single mobile antenna to sequentially obtain all bearings for a single location estimate. The time delay due to changing