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A TRACK COUNT FOR ESTIMATING MOUNTAIN LION *Felis concolor californica* POPULATION TREND

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Abstract

Reliable estimates of status and population trend are critical for conservation of large terrestrial carnivores, but are usually lacking due to the high costs of sampling across large geographic areas. For detecting population trends of mountain lion Felis concolor californica, *we evaluated counts of track sets on 48 randomly chosen quadrats in California. Each quadrat contained 33·8 km of transect on dusty, dirt roads, which were chosen by local wildlife biologists. A count of track sets by one person on all quadrats was more efficient than recording presence/absence by local survey teams. We estimated an efficient sample size of 44 quadrats in California after applying our data to a general formula for contagious distributions. This sample size can be reduced substantially by choosing new transect locations based on associations of tracks with topography and habitat. Tracks were most likely found on roads along 1st- and 2nd-order streams, on mountain slopes and knolls/peaks, and in oak woodland and montane hardwood–conifer forest. A changing mountain lion population can be detected with an inexpensive, periodic track survey and self-stratifying, non-parametric tests.*

Each track survey across California can be finished in 30 days. The many mountain lions and the variety of environmental conditions included at this extraordinarily large spatial scale permit estimates of: (1) trends among population strata in quadrats that are clustered according to typical number and age/sex class of track sets; (2) population size and demography after individuals are identified by their tracks, and after linear density on roads is calibrated from spatial density at intensive study sites; and (3) spatio-temporal associations with bobcat Felis rufus, *black bear* Ursus americanus, *coyote* Canis latrans, *and fox* Vulpes vulpes *and* Urocyon cinereoargenteus.

Keywords: California, conservation, *Felis concolor*, habitat, population trend, road transect, track count.

INTRODUCTION

Many populations of large terrestrial carnivores are declining, e.g., tiger *Panthera tigris* (Seal *et al.*, 1987), snow leopard *Panthera uncia* (Fox *et al.*, 1991), wolves *Canis lupus* (Schonewald-Cox & Buechner, 1991), and possibly mountain lions *Felis concolor* (Dixon, 1982). Knowing the status and population trends of these species will be critical for their conservation and management. Attenders of the Third Mountain Lion Workshop (Smith, 1989) voted overwhelmingly that population census and trend should be the priority mountain lion research, a sentiment shared by the most complete reviewer of mountain lion literature (Anderson, 1983). However, standard monitoring programs exist for only a few carnivore populations globally. The widespread distribution of mountain lions in California provided an opportunity for developing an indirect sampling method, which can be adapted for use with some other large carnivore populations.

Indirect sampling methods involve counts of tracks or other sign for estimating population size of rare or cryptic animals (Dice, 1941; Scattergood, 1954). They are usually less costly than direct sampling, in which animals are found and counted (Morris, 1955; Davis & Winstead, 1980). Indirect sampling is thus more efficient than direct sampling when it provides comparable information at less cost (Eberhardt, 1978). Direct sampling across large areas is prevented by high cost (Fitzhugh & Gorenzel, 1986), so regional populations of carnivores are often estimated by extrapolating estimates from direct sampling in small areas. Population trends are obtained by comparing extrapolated estimates among years. For example, the California Department of Fish and Game (CDFG) used sequential population estimates during the 1970s–1980s to argue that the mountain lion population increased in California from about 1000 (Koford, 1978) to 5100 (CDFG final environmental document on mountain lions, 1988). This 'population trend' was corroborated by anecdotal evidence, including livestock depredation records, road accidents, and sightings (Fitzhugh & Gorenzel, 1986; Mansfield, 1986). However, these estimates were derived from different investigators and types of study.

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Kutilek *et al.* (1983) proposed a population index using presence/absence of mountain lion tracks on road transects surveyed by volunteers. Karanth (1987) suggested track surveys for monitoring tiger populations in India. Track surveys on road transects are convenient for some large-bodied species of Felidae, because individuals of these species often travel along roads and trails (Koford, 1978; Karanth, 1987). However, such road travel might be influenced by roadside habitat and other factors (Stanley & Bart, 1991; Smallwood & Fitzhugh, 1992). These influences need to be related to track counts, quantitatively.

Our goal was to develop administrative and analytical procedures for a practical mountain lion population index based on counts of track sets. The initial track counts provided a foundation for future sampling that can reveal population dynamics and ecological associations of mountain lion and other carnivores in California.

METHODS

Local teams, consisting of one driver and one professional wildlife biologist, established transects for mountain lion tracks along dusty dirt roads during 1985. The teams surveyed these transects during the summers of 1985 and 1986. Smallwood surveyed these transects during 1986 and 1992 (Smallwood, 1994). A few transects were changed before the 1986 survey because they were gravelled, paved, or impractical. Six more transects were lost by 1992 to pavement or oiling for timber harvest.

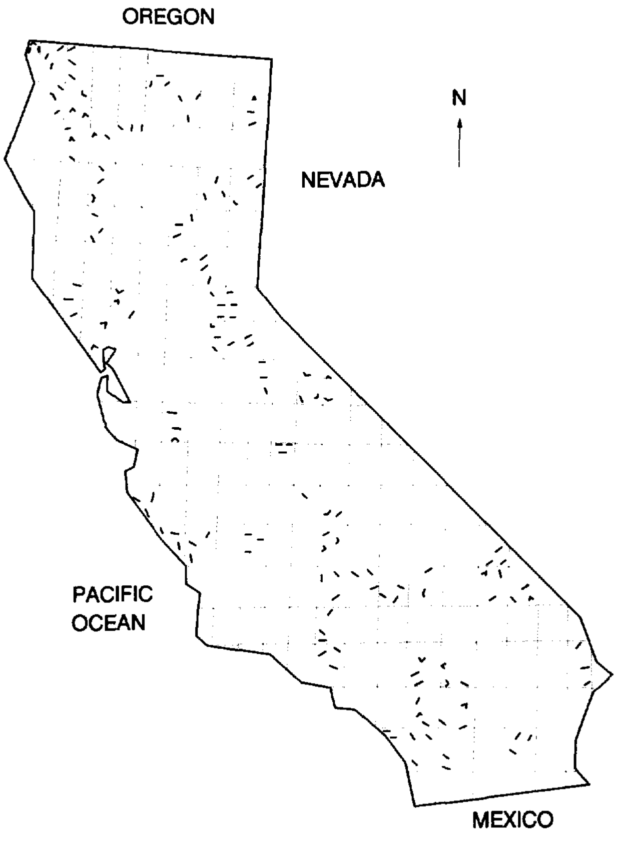


Fig. 1. Locations of quadrats and transects used in the 1986 California mountain lion track surveys (transects are not to scale). The 1992 transect locations were shown in Smallwood (1994).

We divided California along 0·5° latitude and longitude lines into quadrats of 50 km^2. We selected survey quadrats randomly and independent of habitat, except from areas that were mostly urban or agricultural, inaccessible by road, or were coast and border areas where most of the quadrat was ocean or in another state. Local biologists chose road transects within quadrats (Fig. 1) according to our written guidelines. Quadrats contained up to three 11·3-km road transects ≥16 airline km apart unless separated by deep canyons or urban areas. We assumed such barriers would decrease the chance for counting track sets made by the same individual on both transects. Transect location was restricted by local land use, ownership patterns, and available dirt roads that were accessible by two-wheel-drive cars and trucks. Two quadrats at the state border had only enough space for two transects. An east–west transect orientation was requested for low sun angles and better track visibility.

Local teams were given written instructions for data collection and tracking methods, and tracings and dimensions from tracks of mountain lion, bobcat, dog *Canis familiaris*, coyote, and black bear. Local teams recorded presence/absence of mountain lion tracks on each quadrat, while travelling at 5–8 kph. Dust ratings (Van Dyke *et al.*, 1986) were required at the beginning, middle, and end of each transect and at track locations. Local survey teams sketched one track from each track set onto a pre-printed grid, and they recorded heel pad width, widest toe width, and an odometer reading. We used each sketch to verify that a mountain lion made the track (Smallwood & Fitzhugh, 1989).

Smallwood surveyed from a motorcycle at 10–16 kph, because the greater field of view allowed more speed (Fitzhugh & Gorenzel, 1985). He recorded the number of track sets on each transect, including their locations, indicated directions of travel, and aspect of the road. A ‘track set’ was a contiguous series of pugmarks, presumably made by the same animal. Tracks were traced from each track set onto acetate (Panwar, 1979; Fitzhugh & Gorenzel, 1985). All this information was also recorded during 1992 for black bear, coyote, dog, bobcat, and fox (we did not distinguish between red fox and grey fox). These data were used for assessing whether the mountain lion survey could be extended to other carnivore species. Smallwood also mapped habitats and topography every 0·8 km or when either variable changed. Habitat and topography were tested for association with the mountain lion track sets found during 1986 and 1992, and with track sets of the other species found during 1992.

We measured association with the following formula (Smallwood & Fitzhugh, 1992; Smallwood, 1993):

$$M_{Y,X} = \frac{Y_x}{\Sigma Y * \frac{X}{\Sigma X}} = \frac{OBSERVED}{EXPECTED},$$

where Y_x is the number of 0·16 km road segments where a species' track set occurred with the Xth topography or habitat, or with tracks of the Xth species. The observed and expected numbers of transect segments where tracks were found were rearranged for a χ^2 test, and their ratio measured the occurrence of tracks with the Xth associate as a multiple of that to be expected by chance.

We estimated a 1985 sample size of 55 quadrats with the binomial equation, guessing we would find tracks on 50% of the quadrats. In 1986 we lowered our sample size to 50 quadrats because there were too few survey teams available. Smallwood's survey data from non-desert quadrats were used for estimating an efficient sample size for the future. Smallwood's survey data fit the negative binomial distribution (χ^2 = 3·85, d.f.= 5, p = 0·84, Bliss & Fisher, 1953), so we estimated sample size with a general formula for sampling contagious distributions (Elliott, 1971):

$$n = \frac{t^2}{D^2}\left(\frac{1}{\bar{X}} + \frac{1}{k}\right),$$

or simplified by Eberhardt (1978) to:

$$n = \left(\frac{C}{\bar{X}}\right)^2,$$

where t is Student's t at α = 0·05; D is the index of precision of mean estimate, or the standard error/arithmetic mean; $\bar{X}$ in our case is the mean track sets/quadrat; k is the coefficient of contagion; C is the coefficient of variation; and $C^2 = (1/\bar{X} + 1/k)$. The sample size, n, decreases with increasing $\bar{X}$ or D.

We compared track detection between the two 1986 surveys on completed quadrats, i.e. quadrats where tracks were found or all transects were surveyed when tracks were not found. We also compared the administrative ease, costs, and reliability of the surveys, including a third survey option that combined the others. Reliability was measured by track identification errors. 'Errors' were track sketches that showed claw marks, fewer than three heel lobes, or the wrong size track.

RESULTS

The 1986 counts of mountain lion track sets in California gave consistent, reliable information at low cost. The local biologists found tracks on 20 (55·6%) of the 36 completely surveyed quadrats, and Smallwood found tracks on 21 (55·3%) of 38. Local biologists misidentified 9·5% (three) of the tracks they sketched, and five (14·3%) teams did not provide sketches. Mountain lion tracks were found on 72% of the 29 quadrats (84% of the 25 non-desert quadrats) that were surveyed by both Smallwood and the local teams. The least costly survey for mountain lion tracks was done by one person on all quadrats. However, both surveys and a third survey option were not expensive (Table 1).

Using the sample mean ($\bar{X}$ = 1·26) and contagion coefficient (k = 1·05) from Smallwood's survey with a precision of 40% (D = 0·4) of the true mean at 95% confidence (t = 2), we estimated an efficient sample size of 44 quadrats. A mean within 30% of the true mean at 90% confidence required 52 quadrats. However, the mean used to estimate sample size was conservative because the 15 most productive quadrats were not surveyed entirely. Smallwood found six times the track set density on these quadrats (0·108/km on an average of 19·7 km) than on the remaining 19 quadrats that were searched completely (0·0185/km). An efficient sample size would have been 37 quadrats with D = 0·4 and 95% confidence had he surveyed all 33·9 km/quadrat, and track sets/km remained constant for the unfinished quadrats.

Table 1. Potential costs for the California mountain lion track survey

Costs base on 1986 surveys	Options: 1[a]	2[b]	3[c]
Person-days			
Coordination and preparation	14	5	14
Data analysis	5	5	5
Tracking	44	30	88
Total person-days	63	40	107
Dollar costs ($)			
Personnel	6,300	4,000	10,700
Supplies[d] (maps)	333	333	333
Duplication	220	20	220
Postage	110	10	110
Travel fuel @ $1·00/gal	198	246	285
Total dollar cost ($)	7,131	4,609	11,315

[a] Use the established volunteers.
[b] ≥1 pair of experts surveys all transects with motorcycles.
[c] An expert tracker surveys all quadrats, but accompanied by a local volunteer at each quadrat.
[d] This cost will lessen with time as maps will be replaced only occasionally.

The discovery of carnivore tracks was associated strongly with topography and habitat in 1992 (Tables 2 and 3). Tracks of carnivore species were absent on most transect segments, and co-occurred mostly where adult mountain lion tracks were found (Fig. 2). Carnivore tracks were found more often than expected by chance along mountain streams, on mountain slopes, knolls and peaks, and in mast-producing habitats. Mountain lion and black bear families left tracks along streams, on mountain slopes, and in open-floor, mast-producing habitats more often than expected. Their tracks occurred together 26 times more often than expected by chance, but they avoided road segments where tracks of most other carnivore species were found. Coyote tracks were found in basins and on plateaus three times more often than expected by chance, and were least associated with tracks of other carnivores. Tracks were found more often than expected by chance for fox on knolls and peaks, dog on basins and plateaus and in

Table 2. Associations, $M_{y|x}$, between carnivore tracks and topography

	Ridge top	Ridge slope	Stream	Mountain slope	Knoll/ peak	Basin/ plateau	Total (km)	χ^2 (5 d.f.)[a]
Km surveyed, 1986–1992	253	274	135	123	7	45	838	
Felis concolor	0·5	0·8	2·3	1·3	1·9	0·0	40	112·10**
Adults only	0·5	0·9	2·2	1·3	2·2	0·0	35	94·73**
Families	0·8	0·2	2·9	1·5	0·0	0·0	5	23·38**
Km surveyed, 1992	146	149	75	78	4	25	476	
Felis rufus	1·1	1·1	1·8	0·3	0·0	0·0	3	4·11$^{\text{ns}}$
Ursus americanus	0·4	1·0	1·5	1·9	0·0	0·0	69	149·97**
Adults only	0·7	1·5	1·0	1·0	0·0	0·0	43	48·68**
Families	0·0	0·1	2·6	3·6	0·0	0·0	26	338·47**
Canis latrans	1·1	0·8	1·1	0·7	0·0	2·8	51	66·83**
Both fox spp·	1·1	0·6	0·9	1·7	5·1	0·1	30	53·02**
Canis familiaris	0·9	0·7	1·2	0·1	0·0	5·6	42	327·95**

[a] Probability of committing a Type I error while rejecting the null hypothesis is denoted by ** for $p < 0·001$, * for $p < 0·05$, and $^{\text{ns}}$ for $p > 0·05$.

chaparral (they often occurred with human tracks), bobcat in conifer forest with an understory, and for adult black bear and fox in clearcuts. Only canids preferred sage, sage/pine and mature conifer forest. Most of the road segments that had tracks of two or three native carnivore species were along mountain streams and in riparian and montane hardwood–conifer forest.

Topography and habitat influenced the aspect of the road travelled by the carnivore species (Fig. 3). For example, adult mountain lions and coyotes preferred to travel along streams on the uphill side of the road, adult black bears preferred the middle, and families of mountain lion and black bear preferred the downhill side. However, most carnivores preferred the downhill side of the road in montane hardwood–conifer forest and the uphill side in both conifer and montane hardwood–conifer forest with understories. Foxes preferred to use a different aspect of the road than was preferred by adult mountain lions.

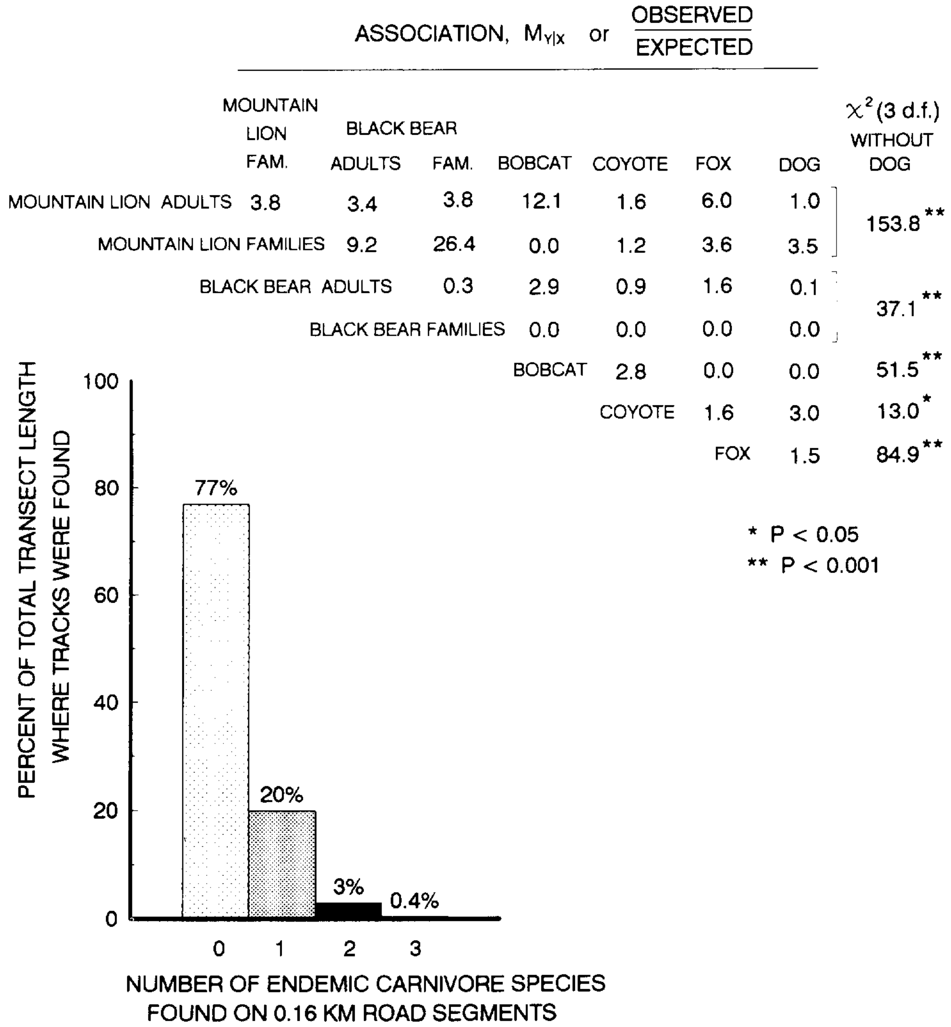
Transect orientation also influenced our success in finding tracks (Fig. 4). Adult mountain lion tracks on 0·16 km road segments indicated travel was east–west on 67% of them in the Coast Range, south on 70% in the Sierra Nevada, and east on 76% in the Southern Mountains. Tracks of mountain lion families indicated their travel was 69% west in the Coast Range and 100% south in the Southern Mountains. Most of the other carnivores traveled in different directions than did mountain lions, and their directions of travel were also non-random.

Table 3. Associations, $M_{y|x}$, between carnivore tracks and habitat[a]

	Chap	Rip	MaC	Cu	MHCu	MHC	OW	PS	Sage	Cut1	Cut2	χ^{2}[b]
Km surveyed 1986–1992	145	19	183	77	13	310	12	17	24	16	22	
Felix concolor	0·7	0·4	0·7	0·4	2·8	1·5	3·2	0·6	0·0	1·3	0·3	83·44**
Adults only	0·7	0·4	0·7	0·3	3·2	1·5	2·6	0·7	0·0	1·4	0·3	76·4**
Families	0·6	0·0	0·7	0·8	0·0	1·5	7·6	0·0	0·0	0·0	0·0	25·5*
Km surveyed, 1992	84	10	97	42	8	171	6	9	14	16	22	
Felis rufus	0·0	0·0	1·1	1·9	6·5	1·2	4·5	0·0	0·0	0·0	0·0	19·5*
Ursus americanus	0·1	1·7	0·4	0·6	0·0	2·0	0·0	0·0	0·0	1·1	1·2	285·3**
Adults only	0·2	2·8	0·6	0·9	0·0	1·5	0·0	0·0	0·0	1·8	1·9	117·3**
Families	0·0	0·0	0·0	0·0	0·0	2·7	0·0	0·0	0·0	0·0	0·3	277·7**
Canis latrans	1·0	3·1	1·4	0·9	2·8	0·4	4·3	3·2	2·8	0·2	0·2	216·3**
Both fox spp·	1·1	1·3	0·2	0·4	0·0	1·3	8·2	3·0	0·0	1·0	1·5	183·3**
Canis familiaris	1·4	1·5	1·3	0·2	2·3	0·5	0·0	3·3	1·8	1·5	0·7	91·3**

[a] Chap = montane, mixed, or chamise-redshank chaparral; Rip = Riparian — willows or reeds, distinct from the surrounding habitat; MaC = mature forests of mixed or single-species stands of conifer with little or no understory; Cu = early-successional conifer forests with an understory; MCHu = montane hardwood–conifer forest with an understory; MHC = montane hardwood conifer forest with little or no understory; OW = oak woodland; PS = sage mixed with pines or juniper; Cut1 = clearcut on one side of the road; Cut2 = clearcut on both sides of the road.

[b] Probability of committing a Type I error while rejecting the null hypothesis is denoted by ** for $p < 0·001$, * for $p < 0·05$, and $^{\text{ns}}$ for $p > 0·05$. There were 10 d.f.



ASSOCIATION, $M_{Y|X}$ or $\frac{\text{OBSERVED}}{\text{EXPECTED}}$

	MOUNTAIN LION FAM.	BLACK BEAR ADULTS	BLACK BEAR FAM.	BOBCAT	COYOTE	FOX	DOG	χ^2(3 d.f.) WITHOUT DOG
MOUNTAIN LION ADULTS	3.8	3.4	3.8	12.1	1.6	6.0	1.0	153.8**
MOUNTAIN LION FAMILIES		9.2	26.4	0.0	1.2	3.6	3.5	
BLACK BEAR ADULTS			0.3	2.9	0.9	1.6	0.1	37.1**
BLACK BEAR FAMILIES				0.0	0.0	0.0	0.0	
BOBCAT					2.8	0.0	0.0	51.5**
COYOTE						1.6	3.0	13.0*
FOX							1.5	84.9**

* $P < 0.05$
** $P < 0.001$

Fig. 2. Frequency distribution and interspecific associations of carnivore track sets found on 0·16 km road segments. Mountain lion and black bear 'families' included tracks of juveniles, whereas 'adults' did not.

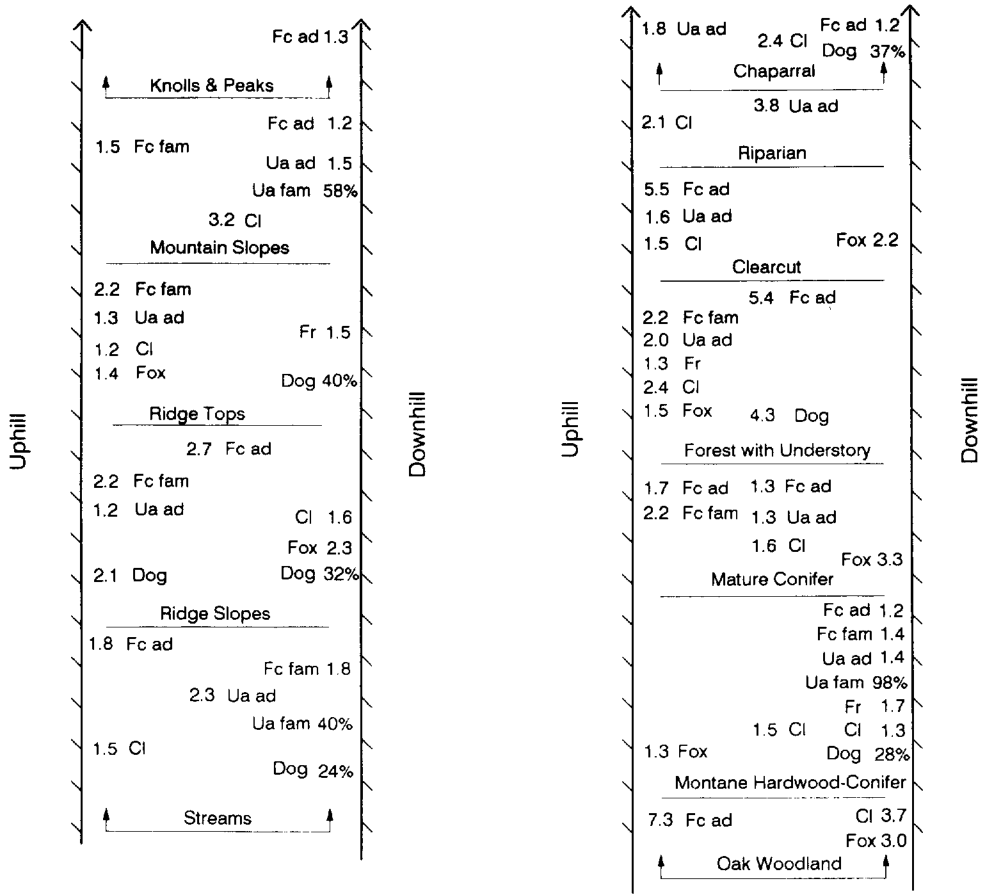
DISCUSSION

The California mountain lion track survey revealed a population decline and a demographic shift from 1986 to 1992, both of which were associated with timber loss (Smallwood, 1994). The survey was also inexpensive, easy to administer, and flexible to changes in personnel and road conditions. Dividing the 33·9 km of survey transect into three parts within a quadrat helped ensure a better distribution of the survey within the quadrat, and provided flexibility to future changes in road conditions and accessibility. This transect distance enabled one person or team to complete the survey in one day. All road transects were in mountain lion breeding range, but we lacked access to much of the lowland habitat because it was privately owned, and to high-elevation summer range because most of it was roadless. We also did not foresee the environmental effects on the spatial distribution of track sets, which could only be observed by sampling over a large geographic area.

Tracking surfaces were not prepared prior to survey because this would have doubled the field time. Van Sickle (1990) benefited little by dragging a tree along the road to eliminate old tracks. Vehicle traffic kept a dusty surface on most of our survey roads, and obliterated tracks within a few days. Smallwood (1994) found no significant association between dust ratings and track-finding success. No bias should occur if both intra-quadrat traffic and weather are similar among survey dates.

Local survey teams mostly followed our recommendation of east–west transect orientation. Many of them told us they sought to further their likelihood of finding mountain lion tracks by locating transects on or near the tops of ridges, which were often oriented north–south in the Coast Range and Southern Mountains, and east–west in the Sierra Nevada. However, mountain lions avoided ridge-tops, given their incidence (Table 2). They mostly travelled along 1st- and 2nd-order streams that flowed off mountains or ridges as tributaries to larger streams. These roads were mostly transverse to the dominant orientation of ridges. The sample size, cost and effort can be reduced substantially by selecting transects based on topographic and habitat associations, and on orientation.

Many of the survey transects could be relocated or extended to nearby topography or habitat where



Number of 0.16 km stretches of transect with tracks on				Topography		Habitat	
Uphill	Middle	Downhill aspect		χ^2	d.f.	χ^2	d.f.
22	14	120	***Felis concolor* adults (Fc ad)**	20.3	8	124.5^{**}	10
10	0	12	***Felis concolor* families (Fc fam)**	16.7^{**}	3	10.1^{*}	2
77	43	43	***Ursus americanus* adults (Ua ad)**	38.5^{**}	6	66.6^{**}	10
2	0	158	***Ursus americanus* families (Ua fam)**	1.3	2	0	1
14	0	4	***Felis rufus* (Fr)**	0.8	3	2.7	3
65	30	67	***Canis latrans* (Cl)**	54.0^{**}	6	86.7^{**}	12
82	0	42	**Fox spp. (Fox)**	26.1^{**}	3	59.9^{**}	5
4	4	147	***Canis familiaris* (Dog)**	47.2^{**}	3	18.6^{**}	6

* $P < 0.05$
** $P < 0.001$

Fig. 3. Preferences, $M_{y|x}$, for uphill, middle or downhill aspects of the road used by carnivore species as topography and habitats changed. Black bear families and dog used the downhill side of the road overwhelmingly so their preferences were expressed by percentages.

mountain lions are more likely to travel along roads. For example, the likelihood of finding mountain lion tracks would increase 2·3-fold by placing all transects along streams, and 1·9-fold by placing transects on mountain slopes (Table 2). Similarly, the length of transect with tracks would likely increase >10% by placing all transects in oak woodland, or >8% by placing them in montane hardwood–conifer forest with an understory (Table 3). Mountain lion track sets would be found more often by also locating transects at elevations >1800 m and on roads with multiple crossroads (Smallwood & Fitzhugh, 1992).

Tracks of other carnivores would also be found more often by surveying more productive transects for mountain lion tracks (Fig. 2). The co-occurrences of tracks from different carnivore species might have been facilitated by their travel along different aspects of the road and in different directions. Future track surveys might reveal trends among mountain lion population strata and in interspecific interactions after accounting for organization in road use by carnivore species and their age/sex groups.

The use of track surveys for population trend would be more informative if sex/age classes could be estimated from track dimensions. In lieu of a more quantitative analysis of track measurements from mountain lions of known age and sex, we approximated age and sex classes from rear heel widths known to be from different mountain lions. Data were from the 1986 survey and other surveys we did in northern California using similar methods. We assumed that rear heel widths >52 mm were adult males, between 43 and 52 mm were mostly adult females, and < 43 mm were juveniles (modified from Shaw, 1983) Our adult male:adult female:juvenile ratio was 1·0:1·0:0·1 (n = 45)

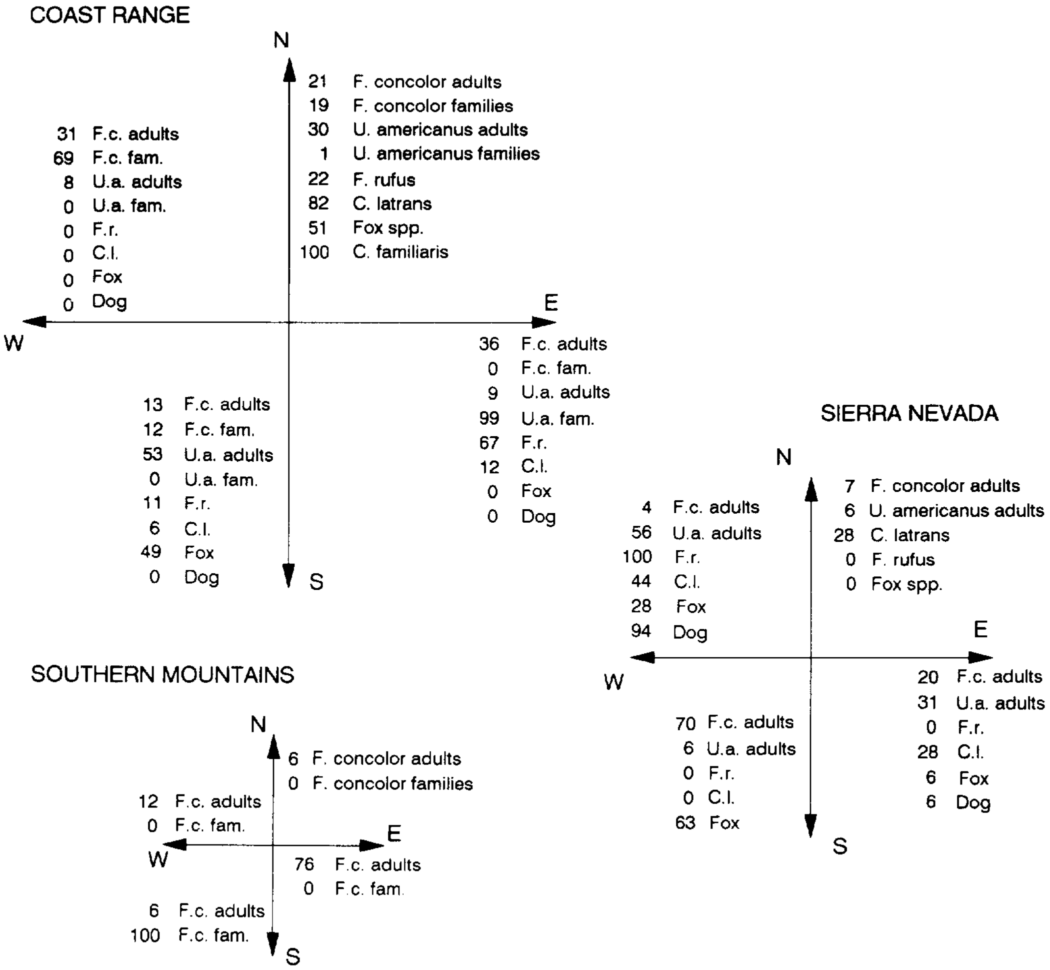


Fig. 4. Directions of travel that were indicated by track sets found on roads. Numbers denote percentages of 0·16 km road segments where tracks were found.

based on heel widths. It differed from Hornocker's (1970) age/sex ratios of 0·75:1·0:1·4 (n = 63) estimated from a radio-telemetry study of an unhunted population in Idaho (Currier, 1983). Mothers with kittens (aged 0–12 months) on a Utah study area (Barnhurst & Lindzey, 1989) were radio-located together 67% of the time, but their tracks were found together only 25% of the time. Therefore, juveniles probably did not travel along roads in proportion to their number. Mountain lion families also travelled in different directions and more along the downhill side of the road than did adults.

The most appropriate tests for detecting population change or trend with our track count data were the Wilcoxon matched-pairs signed-ranks test for change between two samples, and the Friedman two-way analysis of variance test and its multiple comparison procedure for $\geq$ 3 samples (Daniel, 1990). These tests are self-stratifying, independent of distributional constraints, and account for block effect, which is desirable for making comparisons, or 'analytical sampling' (Eberhardt, 1978). Cochran's Q test (Daniel, 1990) appeared most suited for $\geq$3 samples of presence/absence data.

After several surveys, quadrats could be clustered according to the average number of track sets found in them. Then these clusters could be regressed against time. The relative dynamics among the clusters could be inferred to represent the rates of change between lower- and higher-quality habitats, or dynamics between population sinks and sources. Such a procedure could account for block effects that might otherwise hinder detection of population trend. Differences among cluster dynamics would be determined by analysis of covariance (Neter *et al.*, 1985) or by comparing signs and magnitudes of time-series coefficients with analysis of variance.

The power of tests in detecting a mountain lion population trend by track counts partly depends on the daily variation in finding track sets within each quadrat. Morris (1955) attributed such variation to positive and negative error. Positive error would occur if we record 1-week-old tracks but we intend to record only 2-day-old tracks. Negative error occurs when vehicle traffic or cattle destroy more track sets than normal. Our positive error should be slight because most tracks showed clear detail indicative of having been made recently. Mountain lions usually travel far enough along roads that some evidence of tracks would be seen after a day of vehicle traffic. Daily variation should mostly depend on mountain lion behavior, transect location, and weather. Preliminary estimates of daily track count variation are encouraging, though not convincing (Kutilek *et al.*, 1983; Fitzhugh & Gorenzel, 1985).

Population trend can now be estimated more reliably by track counts. We have improved track discrimination among species and individuals, and we collected ecological information that can be related to the trend(s), and can account for unforseen survey biases. Species can be identified from tracks with greater precision by examining characteristics in addition to track dimensions. Direction of travel, topography and habitat also typify species' track locations. We developed a quantitative method for identifying mountain lion individuals by their tracks (Smallwood & Fitzhugh, 1993), which can now be used for estimating linear densities on roads. It is being improved with the use of digital imagery and new track measurements. Rigorous track surveys, in which non-count data are examined, will help the investigator understand and correct for survey biases, such as behavioral differences in road use between age/sex classes. Finally, population trend is usually more reliable and interesting when it can be related to ecological factors.

Our track count method would be more useful if it were calibrated with direct sampling efforts to provide population estimates (Eberhardt, 1978; Eberhardt & Simmons, 1987). However, the relationship between the mountain lion population and the number of track sets found on transects is unquantified, except for small sample sizes (Van Dyke *et al.*, 1986, Van Sickle, 1990). Mountain lion track density was related weakly, but significantly, with population size (Van Dyke *et al.*, 1986). It related more strongly with home ranges crossed by the transects (Van Sickle, 1990), which might be influenced by topography (Reichman & Aitchison, 1981) and transect orientation. Track counts detect different cohorts at different rates (Barnhurst & Lindzey, 1989), so changes in management that alter the number of transient animals might alter the track-finding rate independent of population size. Therefore, track counts for population trend should be coordinated with intensive track counts on smaller areas, preferably with direct sampling of individuals of known age and sex. In this way, the proportion of transients in that year's population can be estimated, and the track count can be related to independent estimates of density.

Recommendations for managing track counts for a population trend

We asked all survey teams to survey on the same day because we sought to avoid counting tracks from the same mountain lion on >1 quadrat. This was impractical. Standard methods are more important through time than space, because quadrats probably vary in the likelihood of finding tracks (Fitzhugh & Gorenzel, 1985; Van Sickle & Lindzey, 1991). For example, the number of track sets found on a quadrat might depend on local population density, and whether transects cross ≥1 home range or travel path. For these reasons, consistency in method among surveys should be more important than expending a considerable effort to ensure one mountain lion cannot leave tracks on two quadrats. Accuracy of an index for population trend is not as important as its precision and efficiency (Eberhardt, 1978; Verner, 1985). If local biologists are used, they should be asked to survey within a well-defined, short time period so the survey coordinator can make adjustments, such as completing unfinished quadrats.

The mean and acceptable precision affect sample size and efficiency. Our sample size estimate probably was conservative because our mean was less than it would have been had all transects been completed. Using a larger sample size than 44 quadrats would increase costs proportionately and would decrease the confidence interval around the mean with less efficiency as the sample size is increased. The recommended sample size of 44 quadrats in California will allow flexibility for future decreases in the mean and for failures to survey some quadrats. Precision also would increase by averaging the track sets found in each quadrat from several surveys conducted each year. The field costs would multiply by the number of surveys per year.

We recommend excluding quadrats in desert areas because the coarse, dry sand obscures detail in tracks, making them difficult to identify. If desert quadrats are used, transects should be placed on dusty mountain roads and analysed separately.

We recommend that, on lands normally accessible to the public, the agency should conduct the survey using two trained people on motorcycles, or vehicles that provide the best view of the transect. Multiple surveys per year would require at least two teams of two trackers each. Fewer trackers who use standard methods would increase consistency among years (Morris, 1955).

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