An improved estimate of trail detectability for snow-trail surveys

Gary P. Beauvais and Steven W. Buskirk

Abstract Mammal trails in snow commonly are counted to obtain measures of the species' relative occurrence. In this context, number of detected trails usually is controlled for variation in distance surveyed and trail accumulation time, but not for variation in visibility and persistence of trails across species and sites. Using artificially created mammal trails, we found that trail visibility varied with size of track, exposure to weather, and time since snowfall. We propose a new measure of trail detectability that controls for this variation and can be used to produce more comparable indices of relative occurrence based on data from snow-trail surveys.

Key words mammal tracks, population surveys, sampling effort, snow tracking

Observing tracks in snow is a powerful and traditional technique for studying mammal distributions (Seton 1937, Murie 1940). Species are readily identified by characteristics of tracks (single footprints) and trails (sequences of tracks made by single animals) (Murie 1974, Halfpenny 1986, Forrest 1988), and snow preserves a relatively continuous record of animal movements between successive snowfalls. Snow-trail surveys, in which trails in snow are counted along transects, are especially useful to determine distributions of rare and wide-ranging species (Halfpenny et al. 1995). Unlike tracking techniques that use attractants and artificial surfaces (Linhart and Knowlton 1975, Zielinski 1995), snow-trail surveys operate on a continuous tracking medium and do not alter natural behaviors or habitat use.

Snow-trail surveys have been used to estimate size of populations (Hyashi 1978, Becker 1991), but more commonly to generate indices of relative occurrence that can be compared across species and habitat types (Pulliainen 1981, Thompson et al. 1989). Because the number of detected trails varies with distance surveyed and amount of time animals have had to create trails, such indices usually take the form of a trail-detection rate: (number of detected trails)/(kilometers surveyed * days since snowfall). This "kilometer-day" measure of trail detectability (Raine 1983, Theberge and Wedeles 1989) is analogous to the trap-night used in trapping studies. For a particular species and habitat, standardizing the number of detected trails by the number of kilometer-days used to detect them ostensibly produces an index of relative occurrence that is comparable to such indices for other species and habitats.

This method, however, fails to control for an important third component of trail detectability: visibility or persistence of trails. Trails in snow are detected visually, and poor trail visibility can cause trackers to miss trails. Two processes reduce trail visibility over time: (1) snow settles and hardens so that trails made soon after snowfall are more visible than those made later; and (2) wind, sublimation, and melting reduce the visibility of trails once they are made. Importantly, these processes probably differ by species and habitats; tracks of small species are more delicate than those of larger ones, and habitat structures such as vegetation affect exposure to wind and sun. The kilometer-day does not account for variation in trail visibility, so comparisons of relative occurrence indices based on the kilometer-day may be confounded.

To control this variation, we first measured the visibility of artificially created mammal trails in snow relative to track size, weather exposure, and time

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since snowfall. We then modified the kilometer-day to create a new measure of trail detectability that controls for variations in trail visibility and can produce more comparable indices of relative occurrence from snow-trail survey data.

Methods

We conducted field work at 6 locations in the Big Horn Mountains, north-central Wyoming (Table 1). We experienced no unusual extremes of temperature, snowfall, or wind during the study. At 1,210 m elevation at the base of the mountain range, mean daily wind speed was 10.8 km/hr and mean daily peak gust was 33.8 km/hr during the study (National Climatic Data Center, Asheville, N.C.). Despain (1973) presented a detailed description of the vegetation, climate, and geology of the area. Each of our 6 study locations encompassed 4 sites of differing weather exposure: (1) in clearing, no vegetation above snow surface within 20 m, exposed to prevailing winds (northwest); (2) at edge of forest and clearing, exposed to prevailing winds; (3) in closed-canopy forest, 10 m from nearest clearing; (4) in closed-canopy forest, ≥10 m from nearest clearing.

We plotted the surface area of a single track in snow against body weight, and identified 3 track-size clusters in the winter assemblage of mammals >75 g body weight in the Big Horn Mountains (Figure 1). We estimated track surface area as the product of average track length and width (Forrest 1988). For species whose track size differs widely between front and hind feet—e.g., snowshoe hare (*Lepus americanus*)—we used the surface area for the larger track. We estimated body weight as the average weight from the ranges reported by Clark and Stromberg (1987) and Silva and Downing (1995). By comparing artificial tracks to actual mammal tracks in fresh snow, we designed artificial tracks that approximated the average surface area and depth of the tracks in each cluster. Large tracks were created by dropping a 1,620-g block of wood with an 11.0 cm x 8.2 cm "track" surface from a height of 35 cm onto the snow surface. Medium tracks were similarly created with a 675-g, 7.6 cm x 6.6 cm block dropped from 5 cm. Small tracks were created with a 130-g, 4.8 cm x 3.7 cm block dropped from 2 cm.

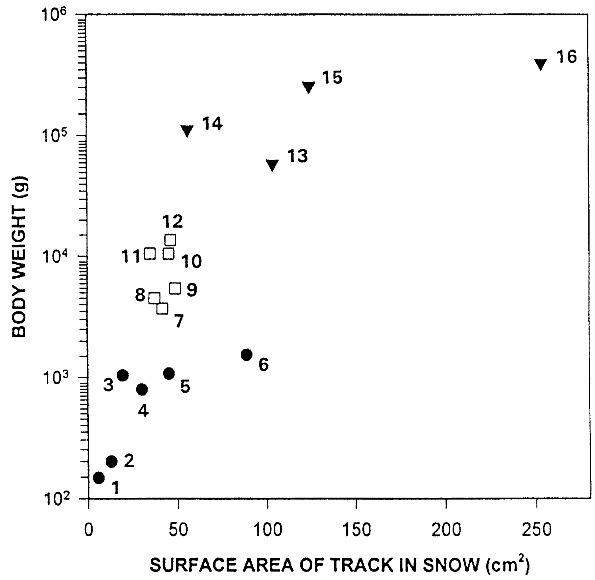

Figure 1. Body weight and surface area of a single track in snow for 16 species of mammal. Weight axis is logarithmically scaled. Small (•), medium (□), and large (▼) clusters are indicated. 1=*Mustela erminea* and *M. frenata* (average of both); 2=*Tamiasciurus hudsonicus*; 3=*Mustela vison*; 4=*Sylvilagus nuttallii* and *S. auduboni* (average of both); 5=*Martes americana*; 6=*Lepus americanus*; 7=*Lepus townsendii*; 8=*Vulpes vulpes*; 9=*Procyon lotor*; 10=*Erethizon dorsatum*; 11=*Lynx rufus*; 12=*Canis latrans*; 13=*Puma concolor*; 14=*Odocoileus hemionus*; 15=*Cervus elaphus*; 16=*Alces alces*.

Between late November 1994 and early February 1995, we measured the visibility of artificial trails once at each location following new snowfalls of at least 5 cm. At each location, the following procedures were performed separately for each combination of track size and site exposure:

We created a trail of 10 artificial tracks 12-24 hours after snowfall

Table 1. Description of 6 study areas[a] in the Big Horn Mountains, approximately 20 km southwest of Buffalo, Wyoming.

Site number	Location		Elevation (m)
	Latitude	Longitude	
1	44 17′ 06″	106 56′ 57″	2397
2	44 16′ 00″	106 56′ 46″	2416
3	44 15′ 06″	106 56′ 27″	2440
4	44 12′ 56″	106 55′ 26″	2549
5	44 09′ 45″	106 55′ 00″	2386
6	44 08′ 30″	106 58′ 42″	2535

[a] Each site was about 4 ha in size, occurred on a relatively flat slope (0°–10°), and included one herbaceous meadow about 1 ha in size surrounded by closed lodgepole pine (*Pinus contorta*) forest (mean diameter-at-breast-height 15–25 cm).

Table 2. Visibility of 3 artificial mammal trails in snow, Big Horn Mountains, Wyoming. Trails were made on successive days following a snowfall, and each trail was composed of 10 medium-sized tracks placed at the edge of forest and clearing.

Number of days since snowfall	Visible proportion of each trail[a] trail #1	trail #2	trail #3	Trail visibility index[b]
1	1.0			(1.0) / 1=1.00
2	0.9	1.0		(0.9+1.0) / 2=0.95
3	0.6	0.6	0.9	(0.6+0.6+0.9) / 3=0.70

[a] The visible proportion of each trail=number of visible tracks / 10.
[b] The trail visibility index for each day since snowfall=the average visible proportion of trails made on and previous to that day.

ended; we termed this "trail 1" because it was created on the first day since snowfall. The trail was oriented north to south, and tracks were positioned to mimic the trail of the species within the appropriate size class. Trail length therefore ranged from 3-4 m for a trail of small or medium tracks to 5-6 m for a trail of large tracks. Immediately after this trail was created, each track in the trail was scored as either "visible" or "not visible." Tracks were scored "not visible" when they produced no visible marks or only minor marks indistinguishable from natural irregularities of the snow surface. Using these scores, we calculated the proportion of trail 1 that was visible as: (visible tracks/10 tracks). This proportion represented the reduction in trail visibility from snow hardness on the first day since snowfall.

After 24 hours, a new trail (trail 2) of 10 artificial tracks was created parallel to trail 1 at a distance of about 3 m. Each new track was scored, and the visible proportion of trail 2 was calculated. This proportion represented the reduction in trail visibility caused by snow hardness on the second day since snowfall. Also, tracks in trail 1 were rescored, and the visible proportion of trail 1 on the second day since snowfall was calculated. This proportion represented the reduction in trail visibility caused by trail weathering between the first and second days since snowfall. After another 24 hours, trail 3 was created (3 m away from and parallel to trail 2) and scored, trails 1 and 2 were rescored, and the visible proportions of trails 3, 2, and 1 were calculated. We continued recording visible proportions of old and new trails each day until a new snowfall. Observers never walked within 1 m of any trail, and used the same walking paths each day to minimize disturbance to each site.

For each day following a snowfall, we calculated the average visible proportion of all old and new trails, and recorded this average as the trail-visibility index for that day. Because it was based on the visibility of both old and new trails, this index measured reductions in trail visibility from both snow hardness and trail weathering. Also, because it was an average of several proportions, this index was scaled between 0 and 1 and was comparable across days (Table 2).

For each combination of track size and site exposure, the rate of change in trail visibility was estimated by the slope of the linear least-squares relationship between the trail-visibility index and number of days since snowfall. At the end of data collection, we had 6 independent estimates (1 from each location) of the rate of change in trail visibility for each combination. We used analysis of variance (SPSS/PC+, second edition) to compare these rates by track sizes and site exposures. For each unique size-by-exposure combination, we estimated a final model by first averaging the estimates of slope and intercept from similar trails within each site, then averaging the site means to produce the final parameter estimates.

To produce a new measure of trail detectability that included trail visibility, we assumed that the probability of trail detection was proportional to trail visibility. In this context, the kilometer-day should be reduced by an amount equal to the reduction in trail visibility for a given track size, site exposure, and day since snowfall. Thus, our new measure of trail detectability was the traditional kilometer-day multiplied by the trail-visibility index predicted by the final least-squares relationship for the appropriate track size, site exposure, and day since snowfall. Because this new measure was a modification of the kilometer-day, we termed it simply "modified kilometer-day."

Results

Because new snowfalls ended data collection at each location, not all locations produced data for the same number of days following a snowfall. Data collection extended for 4, 6, 7, and 8 days at 4 locations, and 5 days at each of 2 locations. Visual inspection of the scatterplots of trail-visibility index vs. number of days since snowfall confirmed that linear least-squares equations fit the data better than non-linear equations.

Two-way analysis of variance revealed that rate of change in trail visibility differed with track size (F=3.4, df=2, P=0.040) and site exposure (F=3.8, df=3, P=0.014). Because there was no significant 2-way interaction (F=0.328, df=6, P=0.920), we examined the effects of track size and site exposure separately. Trail visibility decreased faster for trails of smaller tracks (Figure 2*a*) and trails in more exposed sites (Figure 2*b*).

Because the visibility of trails of medium-sized tracks decreased at a rate intermediate to those of trails of small and large tracks, we retained the 3 original track sizes in the final analysis. However, we recognized only 2 exposure classes: 1 encompassing the original classes 1, 2, and 3 ("exposed"), and 1 of original class 4 ("protected"). We estimated the final least-squares relationships between the trail-visibility index and number of days since snowfall for the 6 distinct size-by-exposure combinations, and combined these relationships with transect length and trail accumulation time to form 6 new models of trail detectability (Table 3).

Discussion

Rate of degradation in trail visibility varied markedly and intuitively with track size (Figure 2*a*) and site exposure (Figure 2*b*). Trails of large tracks in protected sites were the only trails whose visibility did not decline between the first and eighth days since snowfall. In this situation, the kilometer-day equals the modified kilometer-day (Table 3). However, snow hardness and trail weathering reduced trail visibility for all other combinations of track size and site exposure. Trails of medium and small tracks in exposed sites had relatively low visibility even on the first day after a snowfall, indicating rapid snow hardening following a storm. Because the modified kilometer-day is adjusted for these variations in trail visibility, it will produce relative occurrence indices that are comparable across species and habitats.

As an example, consider 2 snow-trail surveys performed on the fifth day following a snowfall. Survey 1 detects 1 trail of a species with medium-sized tracks along a 1-km transect in an open meadow. Survey 2 detects 1 trail of the same species along a 1-km transect in dense forest. Standardizing the data by kilometer-days, we conclude that the species occurs with equal frequency in each habitat (0.20 trails/kilometer-day). However, we know that trail visibility degrades faster in the exposed habitat, so the probability of detecting trails there is less than in the protected habitat. Using the modified kilometer-day to correct for this, we conclude that the species occurs 45% more frequently in the exposed habitat (0.32 trails/modified kilometer-day) than in the protected habitat (0.22 trails/modified kilometer-day).

Alternatively, when planning a series of trail surveys, trackers can use our models to estimate the additional sampling effort necessary to apply to

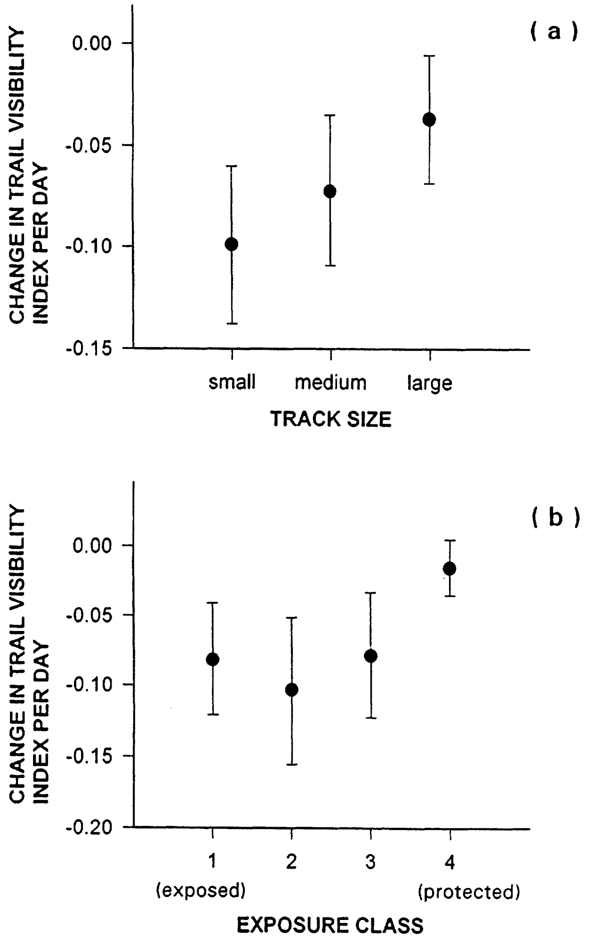

Figure 2. Mean rates of change in the visibility of artificial mammal trails in snow for (*a*) 3 track sizes and (*b*) 4 site exposures, Big Horn Mountains, Wyoming. Small tracks=about 20 cm^2, shallow; medium tracks=about 50 cm^2, intermediate depth; large tracks=about 100 cm^2, deep (exact area and depth depended on snow conditions). Exposure class 1=in meadow, no vegetation above snow surface within 20 m, exposed to prevailing wind; class 2=at edge of meadow and forest, exposed to prevailing wind; class 3=in closed-canopy forest <10 m from meadow; class 4=in closed-canopy forest $\geq$10 m from meadow. The trail-visibility index was the average visible proportion of trails made on and previous to a given day. Rate of change in trail visibility was estimated as the slope of the linear least-squares relationship between the index and number of days since snowfall. Error bars show 95% confidence intervals for means; n=24 for each size; n=18 for each exposure class.

Table 3. Detectability of mammal trails in snow for 6 combinations of track size and site exposure. Units of trail detectability are "modified kilometer-days." km=length of the survey transect in kilometers; # days=number days since the most recent snowfall.

Track size[a]	Site exposure[b]	Mammal trail detectability	95% confidence interval	
			Intercept	Slope
small	exposed	y[c]=km * # days * [1.11 - 0.12 (# days)]	0.95, 1.27	-0.19, -0.05
medium	exposed	y[c]=km * # days * [1.07 - 0.09 (# days)]	0.92, 1.22	-0.16, -0.02
large	exposed	y[c]=km * # days * [1.05 - 0.05 (# days)]	0.93, 1.17	-0.12, 0.02
small	protected	y[c]=km * # days * [1.04 - 0.03 (# days)]	0.98, 1.10	-0.08, 0.02
medium	protected	y[c]=km * # days * [1.02 - 0.02 (# days)]	0.98, 1.06	-0.05, 0.01
large	protected	y[c]=km * # days * [1.00 - 0.00 (# days)]	1.00, —	-0.00, —

[a] small tracks=about 20 cm^2, shallow; medium tracks=about 50 cm^2, intermediate depth; large tracks=about 100 cm^2, deep. Exact track area and depth depended on snow conditions.

[b] exposed sites=in clearings, at edges of forest and clearings, or in closed-canopy forest <10 m from nearest clearing; protected sites=in closed canopy forest $\geq$10 m from nearest clearing.

[c] where y=predicted modified kilometer-day.

exposed sites to ensure that the probability of detecting the target species there is the same as in protected sites. For example, assume that the target species has medium-sized tracks, and a 2-km survey will be performed in protected habitat 5 days following a snowfall (9.2 modified km-day). To correct for differences in trail visibility, a survey in exposed habitat should be 2.97 km long if it is performed on the same day (9.2 modified km-days).

Similar rates of degradation in trail visibility in exposure classes 1, 2, and 3 (Figure 2*b*) were unexpected and might have resulted from the movement of loose snow by wind. The abrupt change in vertical structure at edges of clearings and forests alters wind flow, causing redistribution of wind-borne snow (Ffolliott et al. 1965, Gary 1974). This obviously reduced the visibility of trails in exposure class 2 and may have extended far enough into the forest to similarly affect trails in exposure class 3. Also, tracks in exposure class 1 often became frozen into the snow due to daytime surface thawing and subsequent nighttime refreezing. If these frozen tracks were shallow, wind-borne snow did not accumulate in them and the trails remained relatively visible even under windy conditions.

Figure 3. Tracks of a snowshoe hare crossed by tracks of a red squirrel.

Therefore, trail visibility may be more accurately predicted by detailed climatic variables, such as wind speed and incident sunlight, than by a general ranking of site exposure. However, models of trail detectability based on such variables would be impractical because they would require measuring these variables along actual sampling transects. Even for relatively small transect systems, continuous monitoring of detailed climatic conditions would be difficult.

Our models of trail detectability are applicable to snow-trail surveys that record only those trails made since the last snowfall, even though some trails are detectable after being snowed on. Our models do not estimate the visibility of snowed-on trails, and the number of days since snowfall is a poor estimator of accumulation time for such trails. Also, our trail-detectability models are based on linear relationships between trail visibility and number of days since snowfall. We predict that these relationships become non-linear after 8 days following a snowfall. As older trails approach complete invisibility, they will contribute less and less to the trail-visibility index for a given day since snowfall and the relationships should level out. Therefore, our trail-detectability models may not be applicable to surveys performed >8 days since the most recent snowfall.

Also, we emphasize that this study analyzed trail visibility and not trail "identifiability." In exposed areas, it is common to encounter trails and tracks that are so degraded that it is impossible to identify them as to species. This is especially true in areas harboring many species (e.g., small and medium-sized canids) whose trails and tracks are similar even when fresh. In our experience, however, a tracker can usually follow unidentifiable trails into protected microsites, such as the lee side of fallen trees, where identification is possible. This strategy is widely recommended (Forrest 1988, Halfpenny et al. 1995), but may be difficult in areas of high exposure.

Other aspects of snow-trail surveys are beyond the scope of this project, but still demand the attention of those using the technique. Among these is the question of how differential movement rates affect interspecies comparisons of trail abundances. Obviously, mobile species, e.g., coyote (*Canis latrans*), leave more trails over a larger area than more sedentary species, e.g., North American porcupine (*Erethizon dorsatum*). Although this will not affect comparisons of trail abundances between areas for the same species, it will confound interspecies comparisons. Also, as with any sampling technique, researchers must be aware of how transect placement can bias trail-abundance data. For example, trail surveys are often conducted along roads because of the relative ease of travel. However, roads may be preferred travel corridors for some species, e.g., coyote, and avoided by others, e.g., bobcat (*Lynx rufus*). Thus, the abundance of trails along a road may not indicate abundance of animals in adjacent habitats, and interspecies comparisons would again be confounded.

Traditional techniques of field naturalists are sometimes overshadowed by newer and more technology-intensive methods. However, with slight adaptations, traditional techniques often can meet the demands of modern wildlife science. Foremost among these adaptations is careful consideration and control of variation in the environmental conditions under which data are gathered. The trail-detectability models presented here control such variation and allow data from snow-trail surveys to be used in rigorous tests of hypotheses concerning the distribution and abundance of mammals.

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Literature cited

Becker, E. F. 1991. A terrestrial furbearer estimator based on probability sampling. Journal of Wildlife Management 55:730-737.

Clark, T. W., and M. R. Stromberg. 1987. Mammals in Wyoming. University of Kansas, Lawrence.

Despain, D. G. 1973. Vegetation of the Big Horn Mountains, Wyoming, in relation to substrate and climate. Ecological Monographs 43:329-355.

Ffolliott, P. F., E. A. Hansen, and A. D. Zander. 1965. Snow in natural openings and adjacent ponderosa pine stands on the Beaver Creek watersheds. United States Forest Service Research Note RM-53.

Forrest, L. R. 1988. Field guide to tracking animals in snow. Stackpole, Harrisburg, Pennsylvania.

Gary, H. L. 1974. Snow accumulation and melt along borders of a strip cut in New Mexico. United States Forest Service Research Note RM-279.

Halfpenny, J. C. 1986. A field guide to mammal tracking in North America. Johnson, Boulder, Colorado.

Halfpenny, J. C., R. W. Thompson, S. C. Morse, T. Holden, and P. Rezendes. 1995. Snow tracking. Pages 91-163 *in* W. J. Zielinski and T. E. Kucera, technical editors. American marten, fisher, lynx, and wolverine: survey methods for their detection. United States Forest Service General Technical Report PSW-157.

Hyashi, C. 1978. A new statistical approach to estimating the size of an animal population: the case of a hare population. Mathematical Science 3:117-130.

Linhart, S. B., and F. F. Knowlton. 1975. Determining the relative abundance of coyotes by scent station lines. Wildlife Society Bulletin 33:119-124.

Murie, A. 1940. Ecology of the coyote in the Yellowstone. United States Department of the Interior Fauna Series No. 4.

Murie, O. J. 1974. A field guide to animal tracks. Second edition. Houghton Mifflin, Boston, Massachusetts.

Pulliainen, E. 1981. A transect survey of small land carnivore and red fox populations on a subarctic fell in Finnish forest Lapland over 13 winters. Annales Zoologici Fennici 18:270-278.

Raine, R. M. 1983. Winter habitat use and response to snow cover of fisher (*Martes pennanti*) and marten (*Martes americana*) in southeastern Manitoba. Canadian Journal of Zoology 61:25-34.

Seton, E. T. 1937. Lives of game animals. Volume 1. Country Life, Garden City, New York.

Silva, M., and J. A. Downing. 1995. CRC handbook of mammalian body masses. CRC, Boca Raton, Florida.

Theberge, J. B., and C. H. R. Wedeles. 1989. Prey selection and habitat partitioning in sympatric coyote and red fox populations, southwest Yukon. Canadian Journal of Zoology 67:1285-1290.

Thompson, I. D., I. J. Davidson, S. O'Donnell, and F. Brazeau. 1989. Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. Canadian Journal of Zoology 67:1816-1823.

Zielinski, W. J. 1995. Track plates. Pages 67-89 *in* W. J. Zielinski and T. E. Kucera, technical editors. American marten, fisher, lynx, and wolverine: survey methods for their detection. United States Forest Service General Technical Report PSW-157.

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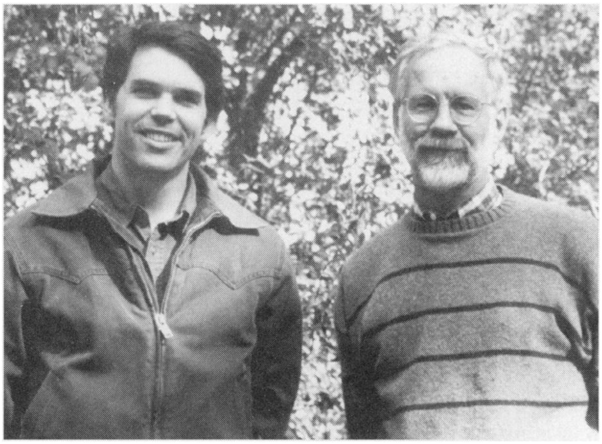

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