DISTINGUISHING TRACKS OF MARTEN AND FISHER AT TRACK-PLATE STATIONS

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Abstract: Managing and conserving uncommon mammals, such as fisher (*Martes pennanti*) and American marten (*M. americana*), depend upon a reliable mechanism to index their populations. In parts of their ranges where these species are not commercially harvested, baited track stations provide an alternative means to collect data on distribution and abundance. Although tracks of many species can be identified using unique qualitative traits, distinguishing tracks of these closely related, similar-sized mustelids requires a quantitative approach. We present a general method to collect mensurative data from track impressions on carbon-sooted track plates and use this approach to distinguish tracks of fisher and American marten. We used 80 tracks from 21 individuals to develop a discriminant function that distinguishes tracks of adults of each species. The linear combination of 3 variables, all associated with the palm (interdigital) pad, correctly classified 95 (100%) test tracks. This result makes it possible to positively identify both species without using more expensive photographic bait stations and will facilitate development of regional survey and monitoring approaches for marten and fisher.

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Trapping marten and fisher is prohibited in many western states, and low quotas for fisher make it virtually closed in several additional states. Therefore, traditional sources of information on the distribution of these species are unavailable in many regions. Moreover, both species are designated as management indicator species by national forests in 4 regions of the U.S. Forest Service in the western United States, due to their association with old-growth forests (Buskirk and Powell 1994), and conservation of both species, especially fisher (Powell and Zielinski 1994), is of increasing concern. Marten and fisher are also potential competitors (de Vos 1952, Clem 1975) whose ranges overlap in several regions of North America (Gibilisco 1994). Understanding spatial and temporal interactions of marten and fisher is critical, especially as formal conservation assessments (Ruggiero et al. 1994) and strategies are developed. A cost-effective, nonlethal means of assessing distribution and abundance of marten and fisher is necessary.

Sooted aluminum track plates, baited with meat or scent, are used to collect data on distribution and abundance of wild mammals (Mayer 1957, Barrett 1983, Raphael and Marcot 1986, Raphael 1994). Recording tracks, generally from fine soil, has been the basis of carnivore survey efforts for many years (Wood 1959, Linhart and Knowlton 1975, Roughton and Sweeny 1982), but widespread use of a carbon-sooted surface, especially in combination with a white imprint surface (Fowler and Golightly 1993), has enhanced this approach. This method is inexpensive, easy to use, and less prone to technical difficulties than are remotely triggered camera systems (Zielinski and Kucera 1995).

There are no widely accepted means of distinguishing tracks of fisher and marten. Track identification guides (Murie 1975) usually treat track traits as invariable and offer only anecdotal suggestions for distinguishing tracks and trails found in natural substrates. The only key to tracks from sooted track plates (Taylor and Raphael 1988) does not provide a reliable means to distinguish species within a number of pairs or groups that possess similar tracks. This key also considers only track "negatives" on aluminum, not the more detailed track "positives" on a white imprint surface.

Marten and fisher tracks are difficult to distinguish on the basis of size, presumably due to the overlap of male marten and female fisher track size (Taylor and Raphael 1988). Certain qualitative traits, such as the shape and connectedness of palm pad components, hairiness of the track, and absence of particular toe pad impressions may help differentiate marten and fisher, but exceptions to these traits are not uncommon. Our goals were to introduce a method for collecting data from these tracks in a standardized fashion and to present an analytical technique capable of distinguishing marten and fisher tracks that are collected from sooted track plates.

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METHODS

Track Library

We collected tracks from known individuals of 2 marten subspecies *M. a. sierrae* and *M. a. actuosa,* and 2 groups of fisher, previously recognized as subspecies *M. p. pacifica* and *M. p. pennanti.* Although grounds for subspecific differentiation are questioned (Hagmeier 1959), we refer to fisher populations by their subspecific names for convenience. We chose populations of each species from among those expected to be sympatric over part of their ranges and to ensure that the model developed to distinguish species was general. In California, subspecies of interest were *M. p. pacifica* and *M. a. sierrae.* However, *M. a. sierrae* is a small subspecies of marten (Hagmeier 1961), and conclusions based on tracks from this subspecies may be inadequate for the entire species. We chose to include *M. a. actuosa,* a large subspecies of marten whose tracks may be most similar in size to those of female fisher. We augmented the sample of Pacific fisher (*M. p. pacifica*) tracks with those from eastern fisher (*M. p. pennanti*) to increase sample size, as well as to account for its occurrence due to reintroductions in some western states.

We collected *M. a. actuosa* tracks from a captive population held at a commercial mink ranch in Idaho. We collected *M. a. sierrae* tracks in the field from wild individuals in Lassen, Shasta, and Tahoe counties, California. We collected *M. p. pennanti* tracks from a group of 6 captive individuals that originated in Massachusetts but were held at Humboldt State University and collected *M. p. pacifica* tracks in the field in Shasta and Trinity counties, California.

We collected tracks from captive animals by placing a 20- × 80-cm sooted aluminum plate (partially covered with white contact paper) in either a wooden or aluminum enclosure within each animal's cage. The animal was either coaxed to walk across the plate or the observer waited for the animal to enter the enclosure of its own accord. We collected tracks from wild animals as they were released from traps and walked across sooted plates enclosed in wooden boxes abutting the trap. To avoid collecting tracks from running animals, we placed an obstruction near the end of the sooted plate to encourage the animal to walk across the plate with the caution we assumed was characteristic of a wild animal visiting a track station. We collected all tracks from 1991 to 1993 and estimated them to be from individuals ≥ 1 year of age and of adult size.

We collected only tracks on white contact paper and based all conclusions on this type of impression. We stored contact sheets individually in acetate document protectors. Tracks missing $\geq 33\%$ of the major features and tracks with poorly defined pad margins were considered illegible and excluded from analysis.

Track Mensuration

Right and Left Foot Distinctions and Pad Definitions.—We assumed most tracks used were forefoot impressions; most tracks collected from plates enclosed in boxes in the field will be from forefeet because it is common for animals to enter head first and to back out or turn around before their hind feet touch the contact paper. Impressions of hind- and forefeet have 5 toe pad impressions and a similar interdigital pad morphology (Taylor and Raphael 1988). While the forefoot is unique in the presence of a heel pad, this feature is seldom recorded on track impressions. Furthermore, confidence intervals of the means of 4 basic track dimensions overlap by $\geq 50\%$ when the hind- and forefeet of fisher and marten are compared (Taylor and Raphael 1988). We did not distinguish between hind- and forefeet in analyses.

Before toe and interdigital pads are identified, it is necessary to determine whether the track was made by the right or left foot. This can be assessed using 4 rules, presented in order of reliability. First, the medial-most digit (the "thumb"; 1 in Fig. 1) was generally smaller and posterior to the remaining toe pads and was often even with the largest interdigital pad. Second, a small metacarpal pad (I1) was posterior and lateral to the thumb, quite close to the main interdigital pads (I2, I3, and I4). The thumb (1) and the metacarpal pad (I1) are on the medial side of the track. Thus, if they were on the left side of the track, the track was from the right foot. When both pads were lacking, the location of a heel pad (H), present on forefoot only, was used to determine left or right foot. This pad was posterior to the interdigital pad and was angled such that its anterior margin was directed toward the lateral (outside) portion of the track. If none of the above indicate left or right foot, the relative location of the outermost toe pad (5 in Fig. 1) and the pad lateral to the thumb (2) was assessed. In general, pad 5 was smaller than pad 2 and its anterior margin was posterior to that of pad 2. Once left or right foot was established we identified toe pads as 1, 2, 3, 4, and 5 (medial to lateral), while the interdigital pad was segmented in 3 primary pads, I2, I3, and I4 (medial to lateral), a metacarpal pad, I1, and a heel pad, H (Fig. 1).

Reference Point (Origin) Formation.—Our methodology aims to standardize measurement techniques and reduce variation introduced during measurement. A single reference point was created that becomes the origin of a Cartesian grid superimposed on the track. The ordinate was created by drawing 2 lines: 1 connecting the medial margins of 2 and I3, and 1 connecting the lateral margins of 5 and I3 and bisecting this angle. A line was drawn perpendicular to the ordinate at the anterior margin of I3 to create the abscissa (Fig. 1). This coordinate system maintained precision in Cartesian measurements while providing a reference point from which numerous measurements could be derived.

Preliminary Variables

We generated a list of 144 linear, angular, and areal variables involving all toe and interdigital pad components. These measurements included 5 general track dimensions (Taylor and Raphael 1988), as well as more specific measurements. For this initial analysis, we measured the 144 variables from 15 tracks from 3 male *M. a. actuosa* and 15 tracks from 3 female *M. p. pacifica*, the subspecies-sex pair we assumed most likely to overlap in size.

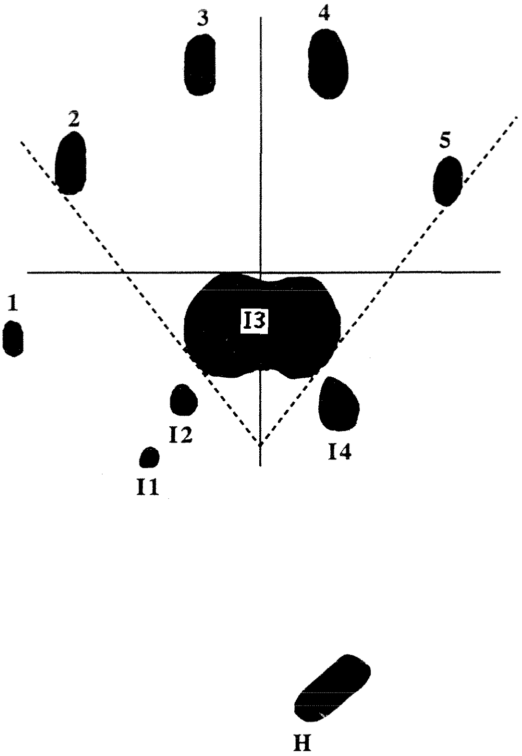

Fig. 1. Schematic diagram of right marten or fisher forefoot track collected from sooted track impressions on white contact paper. Toe pads are identified with numbers (1–5), while interdigital pads and the heel pad are represented with letters (I1–I4, H). The ordinate of the Cartesian grid is formed by bisecting the angle of intersection created by lines joining the medial margins of 2 and I3, and the lateral margins of 5 and I3.

Measurement Techniques

We collected data from photocopied track impressions, and 1 observer recorded all measurements. Photocopies do not alter track dimensions (Zielinski, unpubl. data) and provide an easier medium than contact paper originals to measure tracks. Throughout the study, we visually inspected photocopies against originals and recopied if loss of resolution occurred.

We used T square and triangle to guide measurements along Cartesian axes. We measured linear variables to the nearest 0.01 mm using electronic and digital calipers, and we measured angles to the nearest 0.5 degrees using a protractor. We measured areas with gridded acetate overlays. Using 6.35-mm grids, we measured pad areas, and we used a grid with 0.7-mm dots placed every 5.0 mm to measure interpad areas. For pad areas, we counted only squares ≥50% filled. For interpad areas, we counted every other dot bordering the area boundary.

Univariate Analyses

Gross Track Morphometrics.—We first compared track length and width to understand potential overlap between sexes, species, and subspecies. From our library of legible tracks, we measured track length and width for the following number of tracks (no. of individuals in parentheses): 16 (6) female *M. a. actuosa,* 42 (11) male *M. a. actuosa,* 7 (3) female *M. a. sierrae,* 30 (6) male *M. a. sierrae,* 32 (5) female *M. p. pacifica,* 5 (3) male *M. p. pacifica,* 29 (3) female *M. p. pennanti,* and 11 (3) male *M. p. pennanti.* We compared confidence intervals and ranges for these 8 groups. Additionally, we evaluated qualitative traits thought to be potentially useful in distinguishing species. We assumed martens to be characterized by (1) hairier track impressions, (2) interdigital pad impressions (I2, I3, I4) that are not connected, and (3) the absence of a thumb (pad 1) impression. Hairiness was difficult to evaluate objectively, in part because molt status was unknown for animals that contributed to our sample. We categorized degree of connectedness between interdigital pads I2 and I3 and between I3 and I4 as complete connection (no visible break between pad impressions), ambiguous connection (a visible break of ≤1.0 mm between pad impressions), and complete separation (visible break of >1.0 mm between pad impressions).

Variable Reduction.—Univariate analyses included comparisons among 4 classes: male *M. a. actuosa,* male *M. a. sierrae,* female *M. p. pacifica,* and female *M. p. pennanti.* Given the number of variables initially included (144), we anticipated that many would be correlated. To reduce this pool of variables, we retained variables if they were easy to measure precisely and had (1) standard deviations <5, (2) coefficients of variation <10%, and (3) occurred on ≥75% of all tracks. Of similar variables we also retained the 1 variable with the greatest difference between species groups. Finally, we used correlation matrices to further reduce the number of variables used in univariate analyses.

After this initial variable reduction, we used 1-way analysis of variance (ANOVA) to test for group differences of the remaining variables. We evaluated significant ($P = 0.05$) ANOVA using the Ryan-Einot-Gabriel-Welsch multiple range test (SAS Inst. Inc. 1988:135).

Multivariate Analysis

Distinguishing Species.—We used discriminant function analysis to develop an algorithm capable of distinguishing tracks collected from adult fisher and marten. To limit variables initially used in discriminant function analysis, we followed a guideline of ≥5 observations in each group for every variable used in developing the functions. We selected final variables on the basis of interpretation of univariate results, correlation matrices, and ease of measurement considerations.

To develop the simplest discriminant function possible, we computed several species-level discriminant analyses and correlated the canonical discriminant scores with each variable involved in the function. We dropped the least correlated variable from subsequent analyses. We continued this procedure until classification success dropped below 95%. For each variable involved in the first canonical discriminant function, we conducted single variable discriminant analysis. We followed the same procedure including only the general track dimensions, specified by Taylor and Raphael (1988), to compare results. We used linear discriminant functions for variable combinations involving equal covariance matrices and quadratic functions for those with unequal covariance matrices (Klecka 1980).

We assessed classification success of each discriminant function using a separate test dataset involving 95 tracks from all sex and subspecies combinations. None of these tracks was used in the process of developing discriminant functions.

RESULTS

The Track Library

We eliminated approximately 25% of the track plates from the track library due to illegible tracks. The remaining track plates provided 230 *M. a. actuosa* tracks (19 M:17 F), 33 *M. a. sierrae* tracks (6:3), 35 *M. p. pacifica* tracks (3:5), and 52 *M. p. pennanti* tracks (3:3).

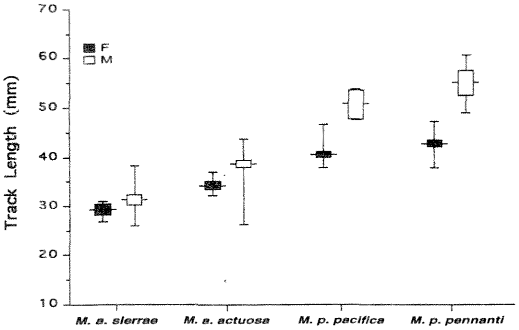

Fig. 2. Means of overall track length, measured from the most anterior toe pad to the most posterior interdigital pad segment, plotted with ranges and 95% confidence intervals for tracks collected from male and female marten and fisher in California and Idaho (1991–93). Means are from 7 female and 30 male *M. a. sierrae* (from 3 and 6 individuals, respectively), 16 female and 42 male *M. a. actuosa* (6:11), 32 female and 5 male *M. p. pacifica* (5:3), and 29 female and 11 male *M. p. pennanti* (3:3) tracks.

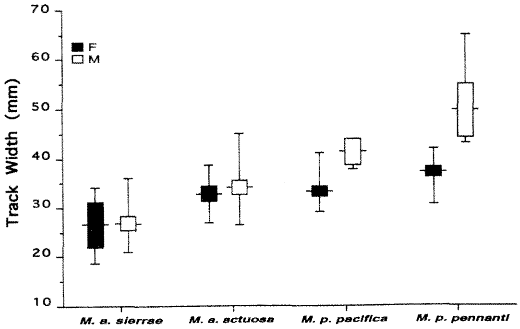

Fig. 3. Means of overall track width, measured as the widest spread of the toes, plotted with ranges and 95% confidence intervals for tracks collected from male and female marten and fisher in California and Idaho (1991–93). Means are from 7 female and 30 male *M. a. sierrae* (from 3 and 6 individuals, respectively), 16 female and 42 male *M. a. actuosa* (6:11), 32 female and 5 male *M. pennanti pacifica* (5:3), and 29 female and 11 male *M. p. pennanti* (3:3) tracks.

Univariate Analyses

Level of Replication.—Nested ANOVA involving subspecies, individual, track plate, and tracks indicated that the track accounts for most variation not attributable to subspecies. For 11 variables tested (A18, K113, K202, Y121, Y122, Y123, X121, TR1, TR2, TR4, TR5), the contribution of the individual and track plate to variation not attributable to subspecies averaged 6.15 and 6.26%, respectively. The track itself accounted for more variation, averaging 27.05% ($F = 33.9$; 3, 40 df; $P < 0.001$). Thus, the manner in which the individual leaves each track impression creates more variation in track dimensions than the inter-individual, or inter-track plate variation. This provided justification for conducting analysis on tracks, rather than the means of track dimensions for the same individual.

Track Morphometrics.—Comparison of ranges and confidence intervals of track length and width for 8 groups confirmed the overlap in morphology reported by Taylor and Raphael (1988) to be due to overlap between male marten and female fisher (Figs. 2 and 3). Although confidence intervals overlapped only for male *M. a. actuosa* and female *M. p. pacifica*, ranges overlapped for several combinations. Of the tracks considered legible, 22% were missing toe pad 1 and 15% were missing palm pad I2 (Fig. 1). Approximately as many fisher as marten tracks lacked I2, but about 80% of the tracks missing toe pad 1 were from marten. Previous observations have suggested that a continuous impression between I3 and I4 was a means of identifying a track as fisher. However, this was unreliable. Only 27.5% of the fisher tracks showed complete connection between the 2 pads; the number approached 50% for those with ambiguous connection between I3 and I4. In only about 2% of the marten tracks were I3 and I4 completely connected, while about 5% were within 1.0 mm of each other. The medial interdigital pad (I2) was completely connected to I3 for about 5% of the fisher tracks and none of the marten tracks.

Univariate Analyses.—We measured 35 variables for 20 male *M. a. actuosa*, 20 male *M. a. sierrae*, 20 female *M. p. pacifica*, and 20 female *M. p. pennanti* tracks from 9, 5, 4, and 3 individuals, respectively. Twenty-six variables met ANOVA assumptions and were considered in further analysis. Only the width of I2, the height of I3, the height of I4, and the combined area of I2, I3, and I4 differed between species, while numerous variables differed between subspecies (Table 1).

Multivariate Analysis

Variable Reduction.—Twenty-two variables met our multivariate normality criteria. This subset included all gross track dimensions (Taylor and Raphael 1988). Some variables (e.g., the width of the center interdigital pad, I3) were included in multivariate but excluded from previous univariate analyses due to heteroscedasticity of group variances. Likewise, some vari-

Table 1. Analysis of variance (3 df) results for 35 track attributes for 2 subspecies of male marten and female fisher (20 tracks/subspecies) (collected from sooted aluminum track plates in Calif. and Id. [1991–93]).

	Multiple range statistic[b]					
Variable[a]	F	Overall P	*M. a. sierrae*	*M. a. actuosa*	*M. p. pacifica*	*M. p. pennanti*
A18	3.69	0.015	63.80A[c]	65.12A	72.27B	63.52A
A20[d]	1.79	0.156	1.50A	1.54A	1.50A	1.52A
A23	16.45	<0.001	22.55A	31.30B	23.25A	25.45B
K9[d]	41.64	<0.001	1.11A	1.28C	1.20B	1.26C
K113	36.32	<0.001	19.69A	24.79B	24.16B	23.52B
K19[d]	11.69	<0.001	0.89A	1.01B	0.98B	1.03B
K202	17.08	<0.001	14.72B	17.56A	17.32A	17.82A
Y3	11.60	<0.001	10.60A	13.06BC	13.90B	12.18C
Y4	25.95	<0.001	5.29A	6.93B	7.32BC	7.99C
Y121	52.89	<0.001	3.85A	3.50A	5.87B	7.02C
Y122	53.27	<0.001	6.02A	6.74A	9.18B	9.36B
Y123	58.33	<0.001	4.55A	5.01A	8.36B	9.08B
X4	12.15	<0.001	3.65A	4.56B	4.85B	4.85B
X7[d]	6.45	<0.001	0.69A	0.87B	0.74A	0.76B
X121	36.58	<0.001	3.11A	3.37A	4.95B	5.50B
X123	39.26	<0.001	3.71A	4.70B	6.77C	7.25C
P3	19.27	<0.001	2.21A	3.99B	2.20A	1.89A
P4[e]	29.91	<0.001	1.58A	1.87A	0.61B	0.82B
P9[e]	33.47	<0.001	2.48A	2.88B	3.05B	3.51C
P10[d]	84.84	<0.001	1.33A	1.58BC	1.54B	1.61C
P13	7.74	<0.001	3.60A	5.10B	5.50B	5.45B
P15[d]	8.22	<0.001	0.46A	0.59B	0.65B	0.68B
P16[e]	111.45	<0.001	3.73A	3.99A	5.79B	6.03B
TR1	108.33	<0.001	31.92A	39.26B	40.68B	43.19C
TR2[d]	48.15	<0.001	1.43A	1.55C	1.51B	1.56C
TR3	53.21	<0.001	11.66A	14.22B	15.79C	16.75C
TR4	70.05	<0.001	14.81A	17.78B	22.45C	23.64C

[a] Variables defined in Appendix.

[b] Ryan-Einot-Gabriel-Welsch multiple range test (SAS Inst. Inc. 1988:135).

[c] Means with the same letter are not different ($P > 0.05$).

[d] Log_{10} transformation.

[e] Square-root transformation.

ables considered appropriate for univariate analysis were not appropriate for multivariate analysis. These changes resulted largely from pooling subspecies; our primary concern in multivariate analysis was to distinguish species, not subspecies. Interpretation of ANOVA results and correlation matrices reduced the number of variables to 5 for development of our classification algorithm. These variables were all located near the origin: the $\log_{10}$ width of I2, the width of I3, the length of I4, the width of I4, and the $\log_{10}$ of the combined areas of I2, I3, and I4.

Discriminant Analysis.—Discriminant analysis using these 5 variables indicated classification success for numerous variable combinations; the best and simplest involved only the total width of I3. Discriminations based on gross track dimensions (Taylor and Raphael 1988) were less successful than other variable combinations, but still performed well (Table 2).

The most successful 3-variable function included easy to measure linear variables: length and width of the central interdigital pad (I3) and length of the lateral interdigital pad (I4). This function resulted in comparable success as the function using only the width of I3 ($\kappa = 1.0$, $SE_{\kappa} = 0.1070$). The area of interdigital pads I2, I3, and I4 was eliminated because it was comparatively difficult to measure and did not increase discriminating ability.

Classification Guidelines.—We present the following classification algorithm for unknown tracks suspected to be either adult marten or adult fisher collected from sooted aluminum plates. If $(4.595 \cdot \text{width I3}) + (3.146 \cdot \text{length I3}) + (0.906 \cdot \text{width I4}) - 80.285 > 0$, classify the track as fisher, if <0 classify the track as marten.

DISCUSSION

The discriminant functions provide an unambiguous way to classify fisher and American marten tracks collected from contact paper on

Table 2. Classification success for 17 discriminant functions using test data from 37 fisher and 57 marten tracks (independent from those used to create the functions) collected from sooted aluminum track plates in California and Idaho (1991–93), presented with 95% confidence intervals around Cohen's *κ* (Titus et al. 1984).

Variables[a]	Type of function[b]	% correctly classified	*K* ± 95%
P16a[c], Y122, Y123, X122, X123a[c]	Quadratic	100	1
P16a[c], Y122, Y123, X122	Quadratic	97.87	0.9550 ± 0.0630
P16a[c], Y123, X122	Quadratic	97.87	0.9550 ± 0.0630
Y122, Y123, X122	Linear	100	1
P16a[c], X122	Quadratic	97.87	0.9556 ± 0.0621
P16a[c]	Quadratic	97.87	0.9550 ± 0.0630
Y122	Linear	97.87	0.9558 ± 0.0618
Y123[c]	Linear	93.61	0.8650 ± 0.1066
X122	Linear	100	1
X123a[c]	Quadratic	87.23	0.7351 ± 0.1429
TR1, TR2, TR3, TR4	Quadratic	89.36	0.7661 ± 0.1399
TR1, TR3, TR4	Quadratic	84.04	0.6438 ± 0.1686
TR3, TR4	Linear	95.74	0.9091 ± 0.0889
TR1	Quadratic	72.34	0.4150 ± 0.1951
TR2	Quadratic	51.06	0.0123 ± 0.2370
TR3	Quadratic	90.43	0.7985 ± 0.1278
TR4	Linear	94.68	0.8867 ± 0.0984

[a] Variables defined in Appendix.

[b] Quadratic functions used when covariance matrices were unequal.

[c] Log$_{10}$ transformation.

sooted track plates. Nearly 100 test tracks, different from those used to develop discriminant functions, were correctly classified to species on the basis of 3 quantitative traits. These all involved elements of the interdigital pad and were therefore near the origin of the Cartesian space used to describe the track. This is likely due to less latitude for variation here than in track attributes further from center. The angle of presentation and the proportion of body mass placed on a foot can influence splay of toes (Panwar 1979, Smallwood and Fitzhugh 1993). Perhaps this is also the reason why gross track measurements, such as track length and width, produced discriminant functions that were less successful at classifying unknowns than palm pad features.

The nonarbitrary measurement grid of Cartesian axes that is scaled to the individual track is a crucial element of the protocol, because it eliminates measurement errors that occur when arbitrary reference lines are overlaid on the tracks that often have different orientations. While origin placement may be different for different species, and a different subset of variables may prove explanatory, the basic approach should be the same for distinguishing tracks of other closely related species.

Qualitative traits that were previously thought to be useful in identifying marten and fisher were not as successful as the discriminant function based on quantitative traits. Interdigital pad impressions I3 and I4 were separated in 50% of the cases for fisher, compared with 95% for marten. The most reliable qualitative trait was the presence or absence of a thumb impression; 80% of all tracks missing pad 1 were from marten. If interdigital pads I3 and I4 are connected and pad 1 is present, the track is more likely from a fisher than a marten. However these are subjective assessments that rely on high quality track impressions, and frequent exceptions to these rules make them less reliable than the multivariate discriminant function described here.

Examination of confidence interval overlap, and some ANOVA analyses, suggested that single variables might distinguish marten and fisher tracks, but we recommend a multivariate function. Although confidence intervals did not overlap for species comparisons for some individual variables, ranges always did. Therefore, there was a possibility that some tracks could be incorrectly classified, and we were interested in discovering a method that would correctly classify 100% of the cases. Moreover, ANOVA and the interpretation of confidence interval overlap does not provide a critical, diagnostic score that can separate the 2 groups. Secondly, although we could have recommended a single-variable discriminant function that resulted in a threshold score, we decided to include 3 variables to minimize the possibility that measurement error could contribute to a misclassification. Although there was 1 single-variable function that produced perfect results, and several functions that produced near-perfect classification, the possibility that observer and photocopy errors could increase misclassification by inexperienced users is a concern. The second and third variables take little time to measure, especially if their inclusion provides insurance against misclassification due to observer measurement error. Finally, 3 variable functions should be more robust to interspecific variation than a single-variable function, and therefore should have a greater potential of correctly classifying tracks from populations not included in our sample.

Because our objective was to correctly classify marten and fisher tracks, we assume that practitioners are capable of determining that an unknown track is from one of these species. Tracks of most other sympatric forest carnivores can be easily distinguished from marten and fisher with adequate training. However, other mustelid tracks may resemble those of marten and fisher (Taylor and Raphael 1988). Also, it is important to determine whether all salient elements of a track impression are present before using the function to attempt an identification. Fisher tracks, for example, that have indistinct or incomplete impressions of interdigital pad features can be mistakenly classified as marten.

Analyses should also be conducted on as many tracks as are available on each track plate. We recommend collecting data from all tracks on a plate that have the requisite features. These should each be classified independently, rather than using a mean value created by averaging all tracks on the plate. There may be situations where some tracks on a single plate are categorized as marten and others as fisher. This may either be a correct conclusion, due to visits by both species where they occur together, or may involve a misclassification. In these cases it will be important to know the proportion of tracks attributed to marten and fisher; information that will be lost by creating a plate mean.

Our approach was designed to classify adults of each species, so we warn users that the data summarized and the classification guidelines recommended here have not been tested on juveniles. Juvenile fisher presumably have marten-sized tracks for an unknown period of time. If these tracks also share interdigital pad features with marten due to some allometric relationship with size, they may be misclassified as marten on the basis of our guidelines. Once tracks from juveniles become available similar analyses should be conducted using dimensionless variables, such as residuals from the regression of a scalar denominator and a numerator variable of interest (Atchley et al. 1976, Reist 1985), so that a single function enables classification of fisher and marten of all ages. With additional work, our approach could be used to distinguish subspecies, sexes, and perhaps individuals. Sex identification could provide useful demographic data that heretofore has been attainable only by trapping. Individual identification would require much larger sample sizes, but work on mountain lion tracks indicate that it may be possible (Smallwood and Fitzhugh 1993).

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APPENDIX

Variable definitions for marten and fisher track impressions collected from sooted aluminum track plates (Fig. 1). Linear measurements are to the nearest 0.01 mm, areas are measured with acetate grid overlays, and angles are measured with a protractor to the nearest 0.5 degrees.

Angles result from the intersection of 2 lines drawn from specified margins of certain pads: A17—created by the intersection of a line drawn from the medial margin of 2 (in Fig. 1) to the medial margin of I3 and a line drawn from the lateral margin 5 to the lateral margin I3; A18—lateral margins of 2 and 3 with medial margins of 4 and 5; A20—anterior margin 2 and origin with anterior margin 3 and origin; A22—anterior margin 2 and origin with anterior margin 5 and origin; and A23—anterior margin 3 and origin with anterior margin 4 and origin.

Closest distances are the closest distance between well-defined portions of 2 pads: K9—distance between 2 and 4; K14—distance between 3 and 4; K19—distance between 4 and 5; K202—distance between 4 and I3; and K232—distance between 5 and I3.

Cartesian distances are distances from the abscissa or ordinate, or the total length or width of a pad: Y4—total length of 2; Y9—ordinate to anterior margin 5; Y121—total length I2; Y122—total length I3; Y123—total length I4; X5—abscissa to lateral margin 3; X7—abscissa to lateral margin 4; X121—total width I2; X122—total width I3; and X123—total width I4.

Areas and palm pad morphology involve linear measurements as well as areas: P3—distance between I2 and I3; P4—distance between I4 and I3; P9—area contained within the triangle created by connecting lines from the center of I2 and I3, the center of I4 and I3, and the posterior margins of I2 and I4; P10—area contained within the pentagon created by connecting the center of I3 to the center of 2 to the center of 3 to the center of 4 to the center of 5 to the center of I3; P13—area of 3; P14—area of 4; P15—area of 5; and P16—area of primary palm pad (3 segments [I2, I3, I4]).

Taylor and Raphael (1988) measured these overall track dimensions: TR1 is the anteriormost toe margin to the posteriormost palm pad margin, TR2 is the widest spread of toes, TR3 is the total height of palm pad, and TR4 is the total width of palm pad.