The Use of Track Plates to Identify Individual Free-ranging Fishers

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Abstract

Effective methods for monitoring fisher (*Martes pennanti*) populations are needed. Track plates offer a number of potential advantages but the inability to identify individuals has limited their application in fisher population measurement. Three sources of tracks are examined: tracks gathered from both free-ranging and live-captured animals utilizing track plates and tracks generated from feet supplied by fur trappers. These are examined to determine the range of variation in multiple tracks of the same foot and whether this variation is less than encountered when comparing different feet. Fisher feet are unique for all practical purposes, while variation between multiple tracks of the same foot is much less than variation between different feet. The quality of tracks gathered from track plates in the field is sufficient to apply these methods. A computer-based method is described whereby fisher tracks may be compared to determine if they were made by the same foot. Foot-pad patterns may be used as a substitute for conventional marking of live-captured animals. A potential computer software tool for automated comparison of fisher tracks is described.

Acknowledgements

In looking back on this project I was a bit stunned to realize the number of people who aided me in various ways and without whom this work would not have been possible. Even though I cannot take the space here to thank them all, some deserve special notice.

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Finally, I want to express my sincere thanks to Dan Taylor, who suffered through every iteration and phase of this work and without whose unflagging guidance none of this would have been possible.

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Introduction

Although fishers (*Martes pennanti*) have largely recovered their original range in the East and Midwest (Powell 1993), their presence in western North America is relatively rare and it is likely that they are absent from large portions of their original range there (Aubry and Lewis, in litt., Powell and Zielinski 1994, Zielinski et al. 1995). A number of researchers have noted an association between fishers and late seral stage conifer forests (see Allen, 1983, Buskirk and Powell 1994), making management for continued fisher presence in western forests a potentially contentious issue that warrants thorough study. Cost-effective monitoring techniques are needed to assess the condition of rare and declining fisher populations (Raphael 1994), but there is a lack of reliable and cost-effective methods that can be applied to populations that are not subject to harvest (Strickland 1994).

Estimating Fisher Abundance

Numerous methods have been applied to estimate the abundance of fishers. While each has proven useful in some situations, all have disadvantages that limit their overall value.

Habitat surveys

Habitat surveys, such as those based on the model developed by U.S. Fish and Wildlife Service (Allen 1983) are relatively inexpensive, utilizing habitat information that is routinely collected by forest managers (Raphael 1994). Habitat surveys indicate potential areas suitable for occupancy by the target species and say nothing about whether those areas actually support a population. Their use in population estimation (likely in combination with other measures of abundance) is based on the assumption that the availability of suitable habitat is the main factor limiting population size. With fishers, the existing evidence often fails to support this assumption (Powell 1993).

Indexes

Indirect measures of abundance, commonly formulated as indexes, may provide information on population density if data are collected in a standardized manner (Strickland 1994). The limitations imposed by these standards can be a major weakness.

The frequency of encountering tracks in snow has been discussed as a measurement of fisher abundance (Strickland 1994). While snow tracking avoids various biases often associated with the use of bait or lures, the researcher must consider such factors as time elapsed since the last snowfall and the effects of weather on the persistence and quality of tracks (Raphael 1994). Appropriate snow conditions are rare or nonexistent in some areas of the fisher's range (Raphael 1994).

Visits to track plate stations can be used as an index of abundance (Routledge 2000, Zielinski and Stauffer 1996) but the extent of behavioral responses to track plate presence by fishers is largely unknown and could lead to errors in estimates of abundance (Hamm et al. 2002). Also, the use of track plates to assess abundance has so far been hampered by the inability to determine the independence of multiple detections at a plate or at nearby plates, leading to the potential for incorrect conclusions due to pseudoreplication and other effects (Hamm et al. 2002). Zielinski and Stauffer (1996) addressed this issue by using a relatively small grid of track plate stations as the sampling unit with the spacing of these grids set to ensure independence.

In regions where fur trapping of fishers takes place, it is common to use trapper success records as an indication of population changes. These are susceptible, though, to a number of sources of bias (Raphael 1994) such as trapper effort that varies with fur prices. Strickland (1994) suggests that harvest data may be increasingly difficult to get in the future due to reduced trapping pressure. She cites low fur prices, increased production by “ranches” raising captive animals, and pressure from the anti-trapping movement. Also, this source of information is not available to managers who need it most, those charged with monitoring rare and declining populations.

Problems associated with all index-based methods include their low power to detect population changes and inability to provide absolute abundance numbers (Thompson et al. 1998). Since few indexes have been calibrated in absolute terms their use is primarily as indicators of relative density. Indeed, some assert that such calibration is virtually impossible and that indexes, at least as they are typically implemented, are largely unreliable (Anderson 2003).

Live-Capture Methods

Methods based on live-trapping and marking have many advantages over habitat studies and index methods, advantages that convey the potential for greater accuracy. Although fishers tend to violate the assumptions often made in employing capture/recapture methods (e.g., equal trapping susceptibility between individuals, absence of behavior modification due to trapping, etc., Powell and Zielinski 1994), the methodology has been sufficiently developed (Otis et al. 1978, White and Burnham 1999) that these issues can be accommodated given sufficient sampling effort. The primary disadvantages of capture-based methods are the potential for trapping-related mortality and cost (Raphael 1994). Strickland (1994) concludes that live trapping is simply too expensive to use on a large scale.

Although Foresman and Pearson (1998) reported that individual fishers could sometimes be identified from photographs by size and markings (thus obviating the need to capture and mark the animals), they imply that this is not generally possible. Infrared triggered cameras might be used for re-sighting after the initial capture and marking thus potentially reducing labor in subsequent recaptures. The added cost of the camera equipment, however, can effectively cancel out this benefit, generally limiting camera-based re-sighting to coverage of small areas only (Harrison et al. 2002).

Using cameras to re-sight previously captured fishers requires the use of easily distinguished markers. York (1996) reported on the retention of plastic ear tags used to mark fishers. Fishers of varying ages were marked with a tag on each ear. When animals were recaptured after a period varying from 1 to 27 months, the retention rate for at least one tag was 0.82, a tendency that would contribute to overestimation of the population size in a mark / re-sight study.

DNA-based Methods

Recent advances in microsatellite analysis have made it possible to identify individuals through DNA recovered from hair snares or feces (Kohn et al. 1999, Woods et al. 1999) with many new applications of these techniques being reported regularly. These studies have achieved success versus a wide variety of study goals, such as the determination of population size, home range, sex ratios, inbreeding level, dispersal rates (through statistical analysis), hybridization and other taxonomy issues (Taberlet et al. 2001). Little has been published, however, describing their use for inventorying fishers. Hair snares are reported to exhibit low detection rates for fishers (Fowler and Golightly

1994, Raphael 1994) although Mowat and Paetkau (2002) reported some success using them in an estimate of population size for American marten (*Martes americana*).

Despite rapid increases in their demonstrated usefulness, DNA-based methods are not without their limitations. For example, in comparing a DNA-based method to the more traditional mark-resight approach for inventorying swift foxes, Harrison et al. (2002) found that re-sighting with infrared triggered cameras resulted in greater accuracy than microsatellite analysis of DNA recovered from scats, although it is unclear whether similar issues would apply to fishers. The cost of laboratory analysis remains a stumbling block in the way of wider application of this technology (Woods et al. 1999).

Track Plates

Mayer (1957) first described the use of the smoked paper to capture tracks of rodents as they enter and leave burrows. Tracks show up on the sooty surface much more readily than they would in soil. Barrett (1983) contained the smoked surface in a box, making it more suitable for use in detecting forest carnivores. Fowler and Golightly (1991) modified Barrett's design with addition of white shelf-paper (Con-Tact® brand or similar), a great improvement over previous methods. Animals entering the box first walk on the sooted surface. Soot is transferred by the feet to the slightly adhesive shelf-paper where it is deposited in the form of highly detailed tracks. Tracks left on the shelf-paper are often much clearer and more distinctive than those made on the sooted surface, often allowing one to distinguish between even closely related species (Orloff et al. 1993, Zielinski and Truex 1995).

Attempts to use materials other than soot have failed to clearly improve on the method. Some early efforts utilized ink (Lord et al. 1970) or liquid talc (Brown 1969), both of which proved more difficult to use than soot (Orloff et al. 1993). Orloff et al. (1993) describe the use of carpenters chalk as an alternative to soot. It is sprayed on using a garden mister after dispersal in isopropyl alcohol. The results are described as being almost as detailed as soot, but the material is easier to apply and remove, especially in the field. One need only wipe with a dry cloth, wash with water, and let dry. The author did report that the nozzle of the mister clogged easily. Zielinski (1995) found that chalk does not work well in even moderately damp conditions, however, and could not recommend it over soot.

Some steps can be taken to improve the quality of tracks recovered from track plates beyond what has been described in the USFS protocol (Zielinski 1995). Boxes may be installed with the open end facing slightly downhill to minimize the possibility of precipitation damage to the sooted surface (Fowler and Golightly 1994). Extending the top of the box by 20 cm to form an awning over the entrance has been found to help in this as well (Fowler and Golightly 1994, Mowat et al. 2001).

Potential Advantages of Track Plates

Some authors have noted that track plates would be more useful for accurately estimating abundance of fishers if there was some way to identify individuals (Fowler and Golightly 1994, Hamm et al. 2002). Without this ability, one is forced to ignore multiple visits to a single track plate station, making the measurement of population change less sensitive (Fowler and Golightly 1994).

Track plates have a number of attractive features:

- Fowler and Golightly (1994) consider the track plate’s simplicity to be a great asset. They maintain that more complicated field methods require greater skill and are prone to failure.

- The use of track plates is non-intrusive, which is especially important when dealing with threatened and endangered species (Jewel et al. 2001).
- In addition to gathering information on the target species, track plate surveys can be especially efficient by providing additional information on prey species (Fowler and Golightly 1994) and other carnivores (Raphael 1994, Zielinski and Stauffer 1996) with little or no additional effort.

Foot Morphology

Whipple (1904) described the common structural details found on the foot-pads of mammals. In species that lack highly developed prehensile capability, the pads are typically covered with rows of wart-like structures arranged in concentric curves about the summit of the pad. This is largely the case for fishers (Figure 1).

Whipple, furthermore, offered evidence that such structures are ontogenetically similar to the more intricately developed ridges that occur on the pads of the higher primates (i.e., their fingerprints) and seem to serve a similar purpose, namely "increased friction, whether in walking or apprehension."

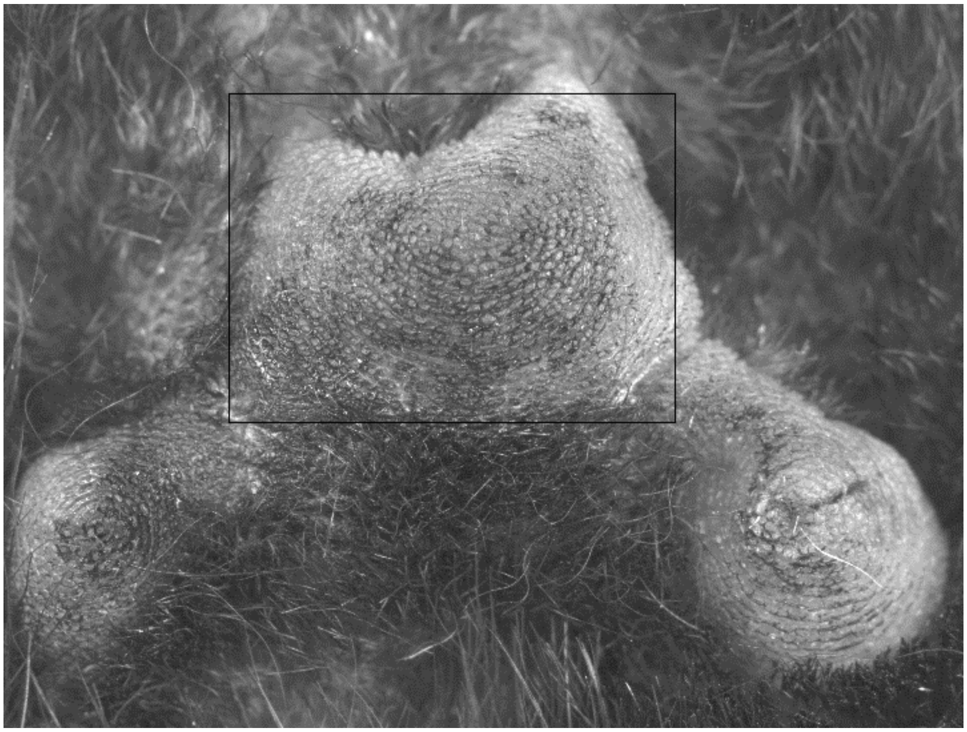

Figure 1. A close-up of the metacarpal pad from the left front foot of a fisher. The portion of the pad examined in this study is outlined.

Biometric Applications

Numerous studies have shown the applicability of naturally occurring characteristics for distinguishing individuals (Goddard 1966, Karanth 1995, Peterson 1972, Scott 1978, van Lawick-Goodall 1968, and others). Many of these do not address the possibility of duplication of patterns; their complexity and obvious variability are assumed to result in combinations that are, if not unique, at least practically so. Others (e.g., Miththapala et al. 1989, Pennycuick and Rudnai 1970) apply rudimentary information theory techniques (Shannon 1948) to estimate the likelihood of a duplicate occurring in a given population based on the observed frequency of occurrence of the various characters utilized.

In the case of fisher pads, even a cursory examination of a number of individuals gives the impression that pattern variation is great. Tracks gathered in the field, however, sometimes lack the clarity, detail, and completeness necessary to show all of this variation or, at times, even a significant portion of it. It becomes important, therefore, to develop some indication that the information contained in a track is adequate. A simple information theory approach, however, is difficult to apply for patterns of such complexity (Pakanti et al. 2002).

The use of naturally occurring patterns to distinguish between individuals can never be absolutely reliable because of the possibility, however small, that similar patterns will occur by chance (Pennycuick and Rudnai 1970). Thus an estimate of the likelihood of duplication is generally the best one can hope for (Pennycuick 1978). The probability of duplication of any given pattern within a population depends on its rarity (which is related to complexity and, thus, the information content contained in the pattern) and the size of the population under investigation (Pennycuick 1978). If the population is small then relatively simple patterns that do not contain much information may still prove useful in distinguishing between all individuals.

Tracks in Soil

Several researchers have attempted to demonstrate that individual animals can sometimes be distinguished by their tracks. Panwar's (1979) work with tigers (*Panthera tigris*) has spawned similar attempts to use track measurements (often aided by multivariate statistical analysis) in a number of felid species (Riordan 1998, Smallwood and Fitzhugh 1993) as well as rhinoceroses (*Diceros bicornis,* Jewell et al. 2001). In the last case (Jewell et al. 2001), the authors also mention that indentations and cracks in the plantar cushion of rhinos are often used by trackers who claim to be able to distinguish between individuals (see also Liebenberg et al. 1999), although this has not been thoroughly tested. Stander et al. (1997) provided evidence that individuals of various species can sometimes be identified from the size and shape of tracks, stride length and other characteristics.

Tracks from Track Plates

Foresman and Pearson (1998) cautioned that, while individuals with unique features (such as a scar on the foot bottom) could occasionally be identified with track plates, they did not believe that gross-level measurements such as foot size can generally be used for this purpose. Hamm et al. (2002) agree.

Human Fingerprint Studies

The method presented here considers details on a finer scale than has been examined previously. As such, the problem of identifying individual fishers from the structural pattern of their foot-pads shares more in common with human fingerprint analysis than it does with the published work dealing with identifying wildlife. The sub-discipline of fingerprint forensics known as poroscopy, identification based upon the size, shape, relative position and the frequency of the pores (Ashbaugh 1982), is particularly applicable.

Attempts to demonstrate that human fingerprints are unique have generally followed two approaches, one empirical and the other theoretical (Pakanti et al. 2002). In the first, a large number of prints are collected and compared using some defined matching technique. This method is time consuming and, depending on the definition of the matching criteria, may be somewhat subjective. Theoretical methods involve creating a statistical model of the patterns encountered followed by an attempt to estimate the probability of false association. Central to this approach is determining how much discernible information is contained in the available image. This can be enormously complex and often only approximations are possible (Pakanti et al. 2002). Reviews of attempts to demonstrate the individuality of human fingerprints can be found in Roddy and Stosz (1997) and Pakanti et al. (2002).

Computer-Aided Recognition of Individuals

Numerous computer software tools exist for the cataloging and identification of human fingerprint patterns (German 2002). Most of these mimic the long-established matching methods applied by forensic fingerprint examiners, namely determining the relative location and directional orientation of features known as minutiae (Galton 1892). These features consist mainly of end points and bifurcations of the fingerprint ridges. Largely due to the structural differences between human fingerprints and fisher foot-pads (i.e., ridges versus wart-like bumps), a preliminary assessment determined that these software tools are of limited use for analyzing fisher tracks (C. Herzog, unpublished data).

Based in part on work done with marine mammals (Hammond et al. 1990), Kelly (2001) described how a computer-assisted pattern matching system could be applied to catalog and recognize a large number of individual cheetahs (*Acinonyx jubatus*) according to their pelage marking. Krijger (2002) developed a system to accomplish this for zebras (*Equus sp*.), utilizing several analytical methods to match stripe patterns.

Study Objectives

This study attempts to determine whether individual fishers can be recognized from tracks made at track plates, as suggested by Foresman and Pearson (1998), by examining the patterns present in the tracks due to the morphology of the metacarpal pad. To that end it has the following objectives:

1) To demonstrate that there is a low likelihood of encountering two animals in any given population with metacarpal pad patterns so similar as to be indistinguishable.

2) To estimate the likelihood that two partial tracks were made by the same foot based on a quantitative determination of similarity.

3) To investigate whether these patterns are evident in a large percentage of tracks collected using track plates.

4) To determine whether patterns are reproduced faithfully in tracks repeatedly made by the same foot.

5) To describe a method for comparing tracks to determine if they were made by the same foot.

6) To describe the characteristics of tracks that allow ready comparison by this method.

7) To describe a potential software tool for automated comparison of tracks.

Track Characteristics

Figure 2 shows the metacarpal pad of an exceptionally clear fisher track. At least three levels of detail might be examined for variation as an aid in identifying individuals. First is the *overall size and shape* of the track outline. As has been noted above, it is unlikely that sufficient variation will be seen at this level for practical purposes, although clearly if a large difference between two tracks was encountered then this level of detail might prove useful as an ancillary source of information.

The second level of detail potentially of use in the recognition of individuals can be seen in the *patterns formed by the curving rows*. The dots that make up these rows are impressions of the wart-like bumps on the bottom of the foot, and the third level of detail is provided by the *size, shape, and spacing of these dots*. My investigation focuses mainly at this third level.

A basic premise of this study is that the patterns present on fishers' metacarpal pads do not change during the study period (which could conceivably extend throughout the life of an individual). My investigation does not attempt to confirm this last point, although I note that Whipple (1904), based on the structural and ontogenetic similarity to human fingerprints, thought it likely that these patterns would, like human fingerprints, persist throughout an animal's lifetime.

Figure 2. A portion of an exceptionally clear track made by the same part of the foot shown in Figure 1. While also a left front, this one is from a different animal. The dots in the image are impressions of the wart-like bumps that cover the pad.

Sources of Variation

Key sources of variation in the patterns present in fisher tracks that might require analysis include sampling variation associated with gathering multiple tracks of a single foot and variation among individual feet. The nested nature of these sources of variation could complicate quantitative analysis and thus pose a great challenge. The approach chosen here, where the study's parameters were structured so that each successive level of variation was large compared to the preceding level, was specifically selected to avoid the need for such complexity.

Non-uniform or inconsistent contact of the foot and contamination from foreign materials (forest debris, for example) are typical causes of sampling variation, which tend to obscure the primary area of interest for this study: comparing the feet of different individuals.

Materials and Methods

Digitizing Tracks

Digital images of the tracks were created at a resolution of 2400 dpi with a desktop image scanner (Hewlett Packard 4570c). Distances were measured by counting pixels with an image processing program. Prior to this, calibration tests were performed on the scanner to ensure that both horizontal and vertical measurements made in all regions of the instrument's working surface were both accurate and repeatable. It was determined that, for measurements of the type made in this study, accuracy was limited essentially by the measurement resolution (that is, the pixel size), approximately 0.01 mm.

The Matching Method

Any application of the principles described in this study will depend on a convenient, practical method of comparing tracks to determine whether they were made by the same foot. In the course of performing this study, tracks were digitized as described above and compared using an image processing package. (ImageJ, described below, is recommended but others such as Microsoft® Paint will also work) The comparison process followed these steps:

1. Each image was opened in a separate window and that window was then maximized.
2. Based on the overall outline of the metacarpal pad, the images were shifted relative to each other so that they were roughly aligned. One image obscured the

other so that only one could be seen at a time. The zoom feature was adjusted so the region of interest filled the screen.

3. The matching portions of the tracks were identified by switching rapidly between the two images. (This may be easily done when using ImageJ by repeatedly pressing the TAB key.) When suitable alignment of two tracks from the same foot was achieved, matching portions were readily apparent, generally exhibiting the appearance of motion as the two images were alternately displayed. Achieving this appearance of motion was the key indication that two patterns were similar.
4. If no matching areas were apparent with the initial alignment, small adjustments (roughly equal to the spacing between two adjacent dots) of the relative position of the two images were made and step 3 was repeated. Both horizontal and vertical adjustments were systematically made until all practical alignments had been examined.
5. Failure to identify a sufficiently similar (see equation 3 and related discussion) matching portion resulted in the conclusion that the two tracks were made by different feet.

Variation between Multiple Tracks Made by the Same Foot

Two sources of multiple tracks made by the same foot were used. Fishers captured as part of a survey performed in California by the U.S. Forest Service (Zielinski et al., in litt.) were induced to walk on a series of track plates, providing a well-controlled method of collecting tracks known to have been made by a single individual. Tracks gathered in New York State's Adirondack Mountain region (Kays et al., unpublished data, using track plates as described by Zielinski, 1995) were also used, taking advantage of the fact that free-ranging fishers often leave multiple tracks of the same foot during a track plate visit. When multiple tracks were encountered on a sheet of shelf-paper, they were assumed to have been made by a single individual and examined to determine the extent of variation between them.

To quantify this variation, multiple tracks of the same foot that were judged to be of good quality were examined (Table 1). Specific pairs of dots from the same row were located in each track. Pairs chosen were representative of the variety of spacings encountered, some tending to be close together and others farther apart. The centroid-to-centroid distance of the dots in question was measured (Figure 3).

Individual	Foot	Number of Tracks Examined	Dot Pairs Examined
A (unknown gender)	Left	10	5
A	Right	7	7
B (male)	Left	8	12

Table 1. Summary of tracks examined to show variation within multiple tracks from the same foot.

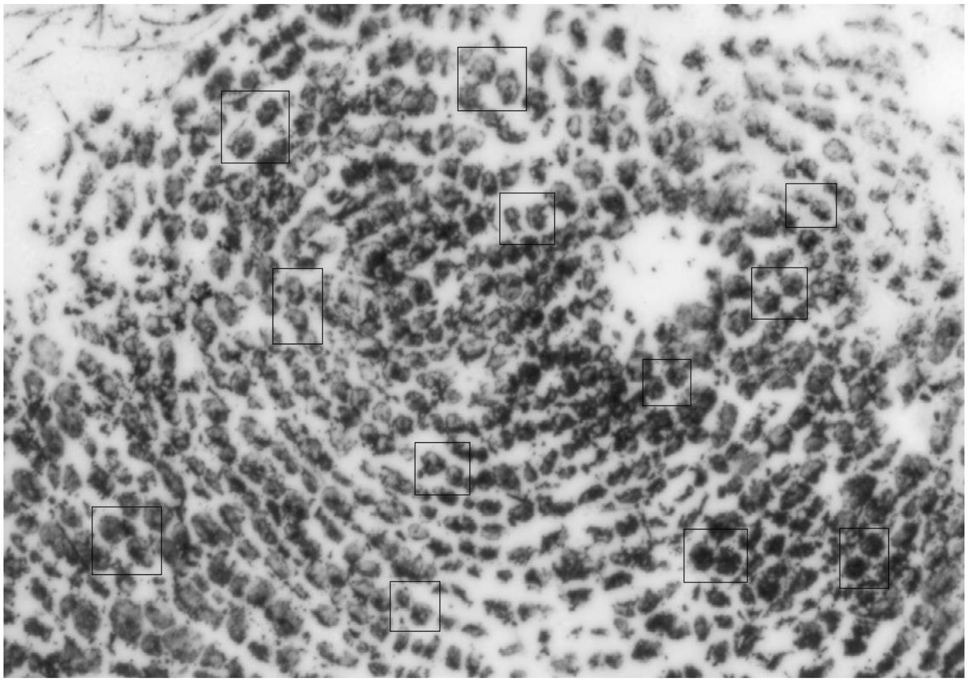

Figure 3a.

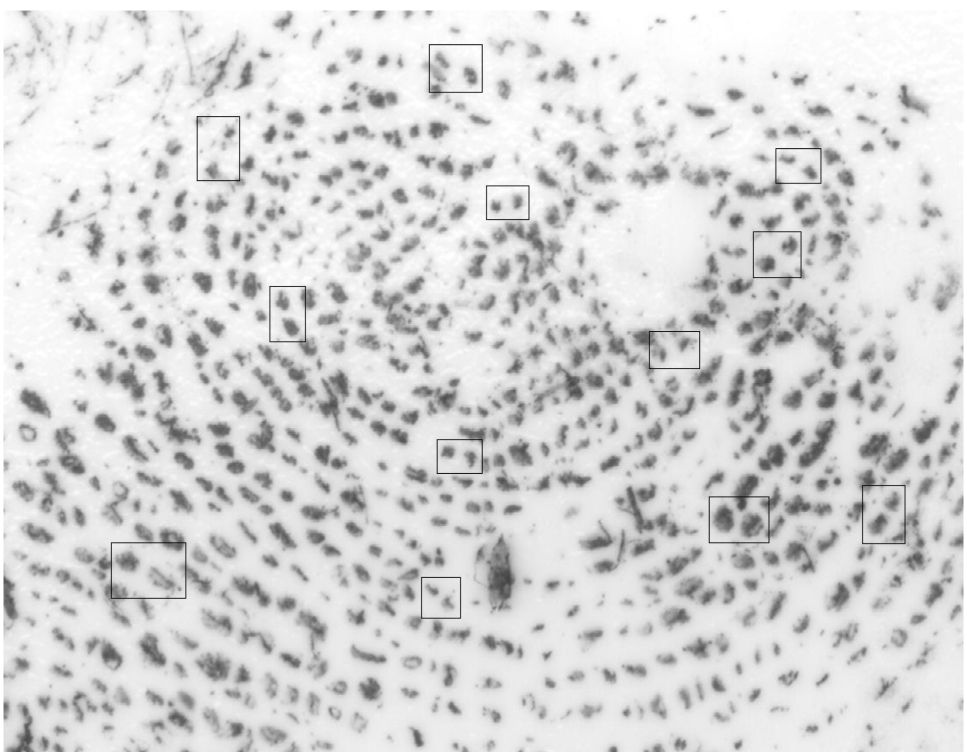

Figure 3b.

A portion of two tracks made by the same foot, each a close-up view of the metacarpal pad. Corresponding dot pairs are highlighted in both images. The spacing between these dot pairs was measured for use in the examination of variation between multiple tracks made by the same foot.

Modeling Pattern Rarity

The matching method described above uses the consistency of the spacing between dots to allow recognition of tracks made by the same foot. Such a procedure requires that the patterns generated by these dot patterns be unique (or practically so). Evidence of their uniqueness was addressed using the following model. In addition to demonstrating that the overall variation in foot-pad patterns is sufficient, the model was used to estimate the rarity of an arbitrarily sized portion of the pattern. This is important because the representation of the metacarpal pad found in a typical track is often incomplete and is nearly always less clear and detailed than the images presented above.

To perform a quantitative analysis of pattern rarity I propose a probabilistic model of the dot pattern resulting from a relatively small portion of the track. Any small region of the metacarpal pad may be modeled by a series of parallel rows of dots. Dots within each row are separated by spaces that vary within some limits. This may be visualized by examination of figure 4. In it we see a conceptualization of a portion of the dot pattern, visible as three rows. The spacing between dots within any row varies and it is these variations that are examined. Dot spacing is measured from the centroid of one dot to that of another.

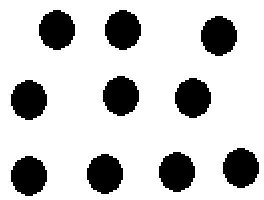

Figure 4. Conceptualization of a portion of the dot pattern resulting from structures found on a fisher's metacarpal pad, as described by the probabilistic model developed in the text.

If the range of variation in the spacing between adjacent dots within a row is examined in a number of tracks made by different feet and the results plotted in a histogram, the most commonly occurring spacing may be readily determined. The probability of occurrence for this most common spacing can be designated $P(R_0)$. Assuming that the spacing between any pair of dots is independent of the spacing of other nearby pairs, the most common arrangement will be when all spacings are equal to this median value. (If the spacing between neighboring dot pairs is strongly interdependent then calculation of the rarity of any given pattern is greatly complicated). Because any deviation from this pattern of equal dot spacing represents a less likely combination, the probability of occurrence of the most common condition constitutes an upper limit on the probability of occurrence for any portion of a row containing the same number of dots. This probability may thus be used as a conservative estimate of pattern rarity.

Furthermore, the maximum probability of occurrence for any pattern of n dots in a row may be estimated as the product of the probabilities of occurrence for each dot pair (again, assuming the spacing of each dot pair can be considered independent of all other pairs in the row). Thus, the maximum probability of occurrence for a particular pattern of n dots within a row, P_n, is given by:

$$P_n \leq P(R_0)^{(n-1)} \qquad \text{(Equation 1)}$$

The matching method described above compares the metacarpal pad portions of two tracks and facilitates identification of similar dot spacing in each. Equation 1 may be used to estimate how many dots must be matched in order to know with some degree of certainty that the two tracks were made by the same foot. As mentioned, this is important because tracks gathered in the field are not as complete and detailed as shown in figure 2. Generally only a portion of the metacarpal pad will be suitable for comparison. The possibility that two tracks made by different feet will match by chance alone can be set arbitrarily small by increasing n, the number of dots found to be in common between two tracks.

Variation Among Feet

Data collected in analyzing the rarity of foot-pad patterns (demonstrating the ability to distinguish between feet and, thus, individuals) were measured in tracks made from severed feet supplied by fur trappers, an example of which can be seen in figure 2. Because these lack the pliability of live feet, multiple tracks made by the same foot are extremely consistent in the patterns they produce and exhibit virtually no variation in the features utilized with this matching method. Thus, these tracks are a good way to examine the variation between individual feet without concern for variations between multiple tracks made by the same foot. They were made by applying ink to the foot-pads and then pressing the pad onto paper, much in the same manner that human fingerprints are recorded.

Fourteen feet from 10 individuals (6 M : 4F) were examined. The sample included both left and right feet (10L : 4R) and the distance between centroids of adjacent dots within the same row was measured. One hundred measurements were performed on each foot for a total of 1400 measurements. The results were plotted in a histogram. The probability of occurrence for the most common spacing, $P(R_0)$, could then be readily determined by comparing the number of occurrences of the most common spacing to the total number of measurements made.

Possible Autocorrelation of Dot Spacing

As noted above, the rationale for this examination depends on the assumption that spacing between any pair of dots is independent of the spacing of other nearby pairs. To investigate this possibility, I identified a number of cases (N=100) where three dots were obviously located in a row and measured the centroid-to-centroid distance between them, each set of three dots resulting in two spacing measurements. I then determined the correlation coefficient between these paired distances.

As a further measure of the magnitude of this effect, I identified 196 cases of the most common spacing (0.22-0.28 mm, see Results). Of these I was able to measure 306 adjacent spaces (out of 392 possible - the rest fell either at the end of a row or in an unclear part of the track). The percentage of these spaces that also fell within the most common spacing was compared to the overall distribution histogram described above.

Assessment of the Quality of Tracks Gathered from the Field

A number of tracks collected from track plates in the field were analyzed to determine whether they were of sufficient quality to allow identification of individuals. These tracks were gathered as part of a general survey of carnivores in New York State's Adirondack Mountain region (Kays et al., unpublished data). A series of track plates (as described by Zielinski, 1995) were positioned with 500 meter spacing along 3.5 km of forest trail. All trails were spaced sufficiently far apart that the likelihood of a single individual fisher visiting stations on more than one trail would be very low. The number of fishers that might have access to any trail's track plates was not known. Stations were checked approximately every two days to replace baits and shelf-paper as needed.

The fisher tracks from a single trail were compared with each other in an attempt to determine the percentage of plates that had at least one matchable track and, where possible, whether tracks from different visits were sufficiently similar to suggest that multiple visits were made by an individual.Page: 24

[0] All tracks on each sheet were assumed to have been made by a single individual, thus once a track from sheet "a" was determined to be very similar to one from another sheet, no further comparisons of tracks from sheet "a" were made. In cases where no tracks from a sheet could be matched to any other sheet, an assessment of track quality (see Results, Track Quality) was made in an attempt to explain whether the lack of matches was due to poor track quality or the detection of a new individual.

Results

Figures 5a-5c show portions of three different right front tracks. Although readily distinguishable from figure 2 (which is from a left foot) the general pattern of rows is similar in each, suggesting that row curvature is of limited use in distinguishing between individuals.

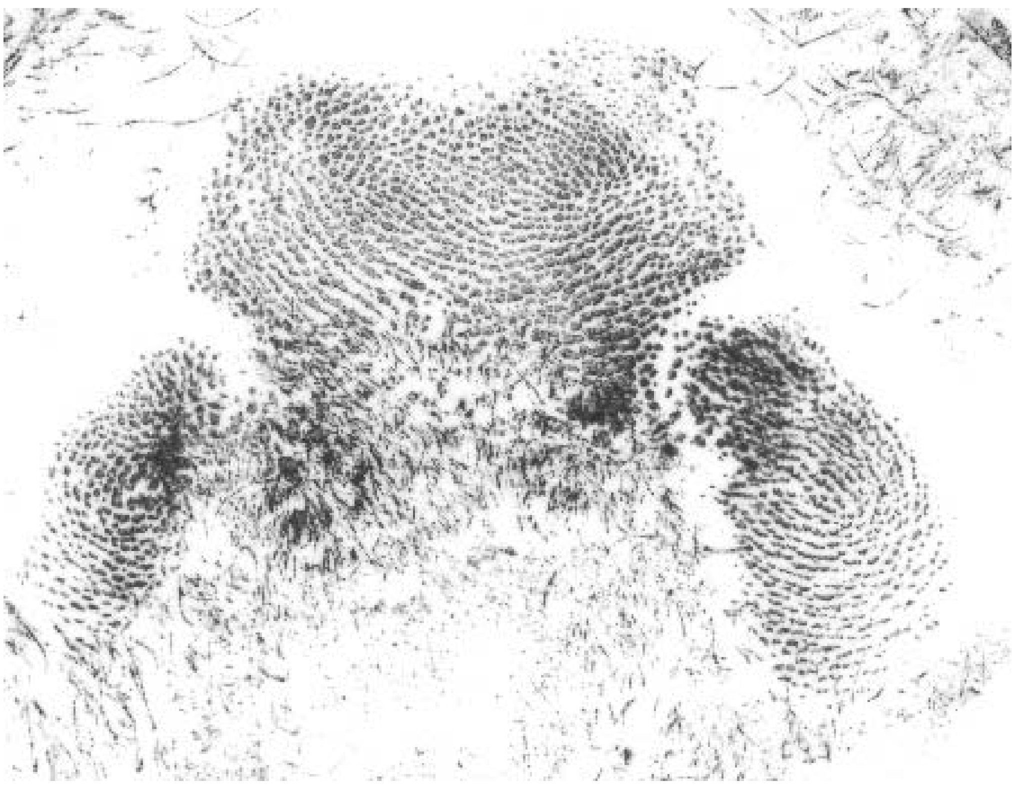

Figure 5a.

Figure 5b.

Figure 5c.

These three images, each a portion of a different right front track, depict the similarities and differences encountered between individual fishers. The pattern of the rows is similar for each track but the dots making up those rows vary in size and spacing.

The Matching Method

The method assumes that the rotational alignment of the images is similar. This property is easily controlled for reasonably complete images during the digitizing process. One may simply adopt a standard orientation for all images using the outline of the metacarpal pad as a guide. In this there is no need for great precision. A small amount of rotational misalignment actually helps one to notice the matching areas, giving the appearance of rotating movement when the images are switched. Rotating movement seems to be easier for most people to recognize, probably because as the images are switched the distance any feature appears to move increases with the distance from the apparent center of rotation. This property is often easier to recognize than simple linear translation. Approximately 5-10 degrees of misalignment seems to be optimal for most people. If necessary, the degree of rotational alignment can be controlled with many image processing programs by digitally rotating the image.

Even if the alignment of the two images is fortuitous and little rotational misalignment is present in one portion of the image, some misalignment will generally be obvious in another region because the pliability of the living foot (probably in concert with other variables) does not allow for perfect reproduction in multiple tracks. This pliability becomes more apparent for features that are widely spaced on the pad so that, when examining a small portion of the track, the local effect of the pliability is limited and matching is more readily apparent.

If two portions of the image appear to match, a compelling method to verify the result involves shifting the relative position of the images so as to place one dot directly above its counterpart in the second image. If rotational misalignment is present, this dot should now become the apparent center of rotation. Repeating this process with several different dots should allow you move the center of rotation arbitrarily across the image. In each case a new center of rotation will be noted and all other nearby dots will appear to rotate about that center.

Variation between Multiple Tracks Made by the Same Foot

Some tracks did not reproduce every dot pair with sufficient detail and clarity to enable measurement, thus the number of examples of any dot pair varied from 5 to 10. The standard deviation of the spacing for any given dot pair varied from 0.01 mm to 0.03 mm, with 0.02 mm being a typical value (Table 2).

Dot Pair	N	$\bar{x}$	σ	Dot Pair	N	$\bar{x}$	σ
1	9	.251	.023	13	6	.450	.008
2	9	.271	.009	14	8	.354	.013
3	8	.268	.016	15	8	.507	.025
4	7	.263	.015	16	8	.388	.021
5	10	.374	.029	17	7	.289	.009
6	6	.320	.019	18	8	.306	.014
7	5	.293	.006	19	7	.268	.013
8	7	.356	.033	20	8	.292	.015
9	6	.234	.017	21	7	.354	.009
10	6	.243	.007	22	6	.308	.020
11	7	.232	.009	23	6	.332	.011
12	6	.229	.015	24	6	.334	.007

Table 2. The variation of spacing between two adjacent dots from a row as encountered in multiple tracks of the same foot.

Dot pairs thus can be said to reproduce with reasonable fidelity in multiple tracks made by the same foot. If this degree of variation is small compared to the statistically encountered variation in dot pairs across a track and across multiple tracks then there is reason to believe that multiple tracks made by the same foot can be recognized as such. This level of variation is examined next.

Variation Among Feet

The distribution of measurements of centroid-to-centroid spacing between pairs of adjacent dots found in the same row (N = 1400) is shown in figure 6.

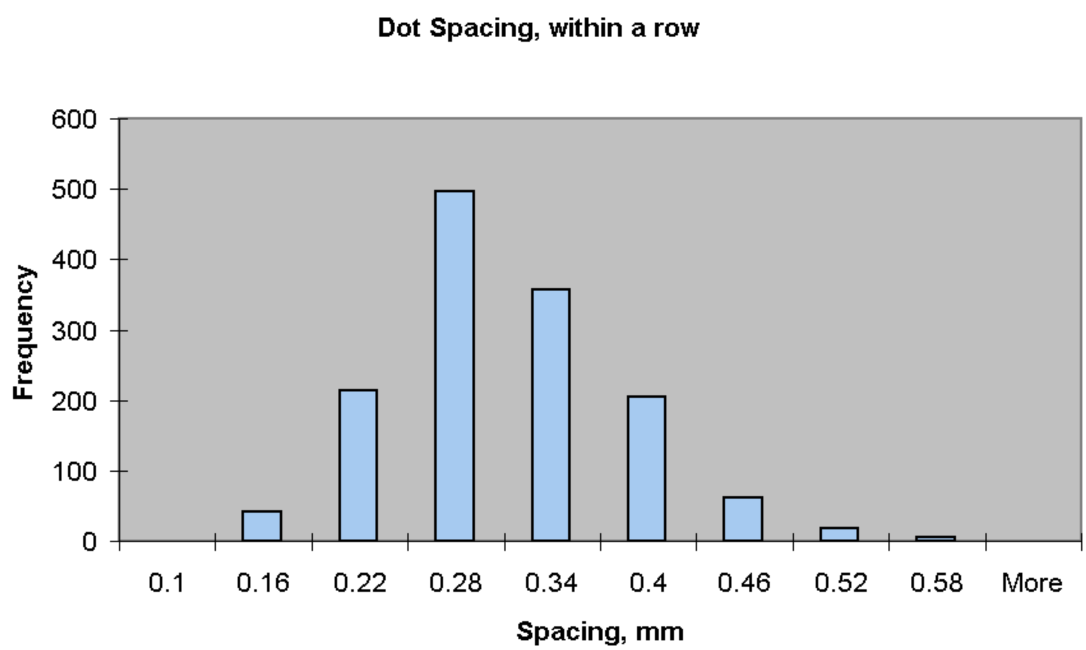

Figure 6. Histogram depicting the encountered distribution of spacings between two adjacent dots from the same row, measured on the left and right forefeet of 10 fishers.

The histogram bin size was chosen to be 0.06 mm. This represents three typical standard deviations for the variation of a pair of dots among multiple tracks of the same foot (0.02 mm, as seen in the previous section), consistent with the notion that the nested nature of these two sources of variation may be neglected.

Of 1400 measurements, 496 (approximately 35%) fell into the most common size bin, from 0.22 to 0.28 mm, with all other spacings being more rare. Thus, the most common pattern for any row of dots must be when each space falls within this range. If spacing between neighboring dot pairs within a row can be considered independent then, according to equation 1, the probability of encountering a row of n dots with any given spacing configuration, P_n, is described by:

$$P_n \leq 0.35^{n-1} \qquad \text{(Equation 2)}$$

Examination of Possible Autocorrelation of Nearby Spaces

The correlation coefficient of neighboring spaces between dots of the same row was found to be 0.30, a statistically significant (statistical power = 0.92 for $\alpha = 0.05$) but fairly mild (proportion of explained variance $r^2 = 0.09$) correlation.

In making 306 measurements of spaces adjacent to dot pairs that were, themselves, of the most common spacing, one would expect by the results depicted in Figure 6 that 35%, or approximately 107, would fall into the most common range of 0.22-0.28 mm. In fact, with the sample examined there were 108, reflecting virtually no increased tendency for adjacent spaces to measure the same. Thus, it would appear that the spacing of any pair of dots is largely independent of the spacing of its neighbors within the same row and, therefore, equation 2 may be used to estimate the probability of occurrence of a dot pattern.

Track Quality

The highest quality tracks (that is, those that prove to be the easiest to match with another track of the same foot) exhibit the following characteristics:

- Full coverage of the main portion of the metacarpal pad – The greater the clear area of the track, the more likely it can be matched with another from the same foot.
- Dots that are dark and distinct – These are easier to match than those that are very light (where little carbon is transferred from the sooted surface to the contact paper) or those where the dots tend to merge.
- Lack of smudging due to movement
- Not obscured by debris or other tracks
- Excessive distortion is not present

Distortion

In contrast to the relatively simple task of matching high quality tracks of a single foot, some tracks exhibit one or more types of distortion that significantly increase the difficulty of matching. One class of distortion deserves specific description and is exemplified in figure 7. The track in figure 7a is typical of those made by this animal's left front foot. Tracks such as depicted in figure 7b, also made by the same foot, are less common (both tracks were taken from the same sheet of paper). Dot features can be seen to correspond between the two images although the metacarpal pad of the second image is compressed in the vertical direction when compared to the typical track. Tracks such as these may be created with less than the normal amount of pressure being applied by the foot, causing less spreading of the pad structures. Often the dots are smaller and lighter than those of the typical track, perhaps reflecting the lower pressure, and this characteristic is helpful in recognizing the condition. Distortion like this is especially common in the side "wings" of the metacarpal pad, contributing to the difficulty in using these areas to match tracks.

Figure 7a.

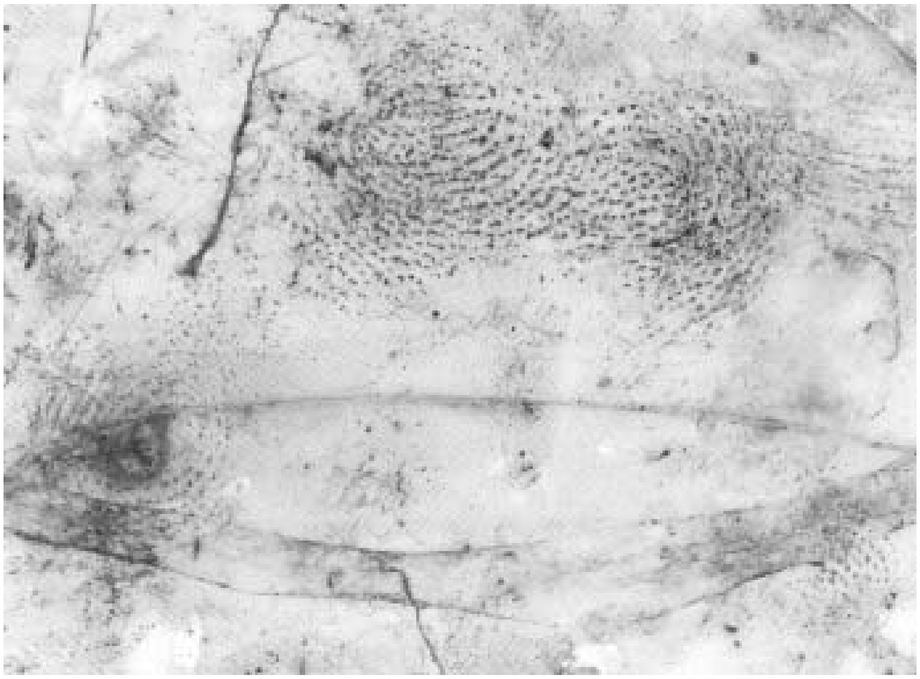

Figure 7b. These two images show one common type of distortion that can make matching tracks difficult. The first can be considered normal, while the second image is compressed in the vertical direction.

Adirondack Data

Ten trails resulted in multiple fisher detections, either at different stations along the trail, on different days, or both (Table 3). Out of 62 sheets collected from these trails displaying at least one fisher track, 85% yielded tracks of suitable quality to allow matching. Matching was deemed possible when a substantial portion (see equation 2) of the metacarpal pad of at least one track exhibited distinct dots. Most of the matchable detections on any given trail were found to exhibit similar dot patterns, suggesting that these visits were the result of one individual. Only two trails produced tracks that clearly suggested visits from more than one individual. For both of these trails, the detection of a dot pattern distinctly different from the majority of tracks occurred on only one occasion.

Trail	No. of Detections	No. of Detections with Matchable Tracks	No. of Distinct Dot Patterns Detected	Notes
Dragoon	2	0	1≤ x ≤ 2	Track size and row structure consistent with a single individual.
Honey Hill	2	2	1	
Jenkins	6	3	1≤ x ≤ 4	All matchable detections shared similar dot patterns.
Smith	3	3	1	
True Brook	3	3	1	
Whiteface	3	3	1	
Hoffman	4	2	1≤ x ≤ 3	All matchable detections shared similar dot patterns.
Raybrook	13	10	1≤ x ≤ 5	9 detections sharing similar dot patterns.
Chaisson	14	12	1≤ x ≤ 3	All matchable detections shared similar dot patterns.
Sargent Pond	15	15	2	14 detections sharing similar dot patterns.
Total	**62**	**53**		

Table 3. Results of an attempt to determine the percentage of field-gathered tracks that offer sufficient quality to permit matching. Tracks that share similar dot patterns may be the result of repeated visits by an individual.

Discussion

Justification for the Model

The model used to analyze the rarity of metacarpal pad patterns represents a great simplification of the complex pattern found on a typical pad. Justification for the use of this model is made in several points.

First, the matching method as it is described here calls for searching for similarly small dot arrays in both the candidate and reference tracks. Tracks gathered from the field are generally not as clear as the examples given here. Portions will be obscured due to various factors. If two tracks of the same foot happen to provide clear detail in corresponding areas of the pad, however, it is possible to verify that the dot spacing is very similar.

While it is true that some areas of the pad do not exhibit obvious rows, the warts found in these regions clearly tend to be arranged in a less orderly manner than warts found in rows. This disorder contains information that may be used to recognize a track as coming from a particular foot. Thus, row structures, due to their inherent order, are likely the regions that contain the least amount of information and should prove the most difficult to distinguish from foot to foot.

In examining only spacing between dots, the method ignores dot size and shape, factors which contribute to the ability to match patterns but which would complicate the analysis of the model. Ignoring this source of information, which often proves of significant assistance in the matching process, means the results of the analysis can be considered conservative. Furthermore, the size and shape of dots has been observed to vary from track to track at times (Figure 7), making these details less reliable than the spacing of dots.

Similarly, while the curvature of the rows (the second level of detail as described in the introduction) contains information that might at times prove useful in matching tracks, the analysis ignores this property and any information contained therein. Depending on the desired confidence level (as described by equation 3), dot patterns that may be matched with adequate confidence are sometimes so small that curvature is not apparent.

Left Foot versus Right

Comparison of the general pattern formed by the curving rows seen in figures 2 and 5 suggests that the typical patterns are more or less bilaterally symmetric, with left and right metacarpal pads being, at least roughly, mirror images of each other. This is most clearly evident in the location of the center of curvature for the arcs formed by each row of dots. In each of the right foot tracks, this center is located in the upper right of the main portion of the metacarpal pad. In the left foot's track, this center is located in the upper left portion of the pad. Through observation of this characteristic it is generally possible to distinguish between left and right tracks.

No evidence is presented as to whether one can determine if a left and a right front track were made by the same individual. The assumption that a left and a right track on the same sheet of shelf-paper were both made by the same individual was followed throughout the study. It would likely be difficult to test the validity of this assumption.

Pattern Rarity

If a sufficiently long row of dots is found to be present in two tracks then the probability that they were made by different feet can be set arbitrarily low. In practice, limiting the matching process to dots found in a single row is unnecessarily restrictive. The probability of occurrence for dot patterns consisting of more than one row will still decrease exponentially as the number of intra-row spaces increases regardless of the number of rows that make up the pattern. In this more general case, the maximum probability of occurrence for any pattern of dots, P, will be described by:

$$P \leq (0.35)^y \qquad \text{(Equation 3)}$$

where y is the number of intra-row spaces contained within the portion found to be in common between the two tracks in question. With over 1000 dots typically present in a fully detailed metacarpal pad, the probability of occurrence of two similar pads by chance alone can be seen to be vanishingly small.

Probability of Falsely Matching Tracks

Due to factors already mentioned, one can expect to match only a portion of each dot pattern for any two tracks of the same foot. The analysis of the model suggests that the probability of a false match can be predicted by noting the number of dot features that match between the two tracks. More dots in the matching area imply greater confidence that two tracks were, indeed, made by the same foot. Due to the exponential nature of equation 3, the probability of a false match decreases rapidly as the number of dots (or, more strictly keeping with the analytical approach used here, the number of spaces between dots) increases. Table 4 illustrates this.

Number of Intra-row Spaces	Maximum Probability of a False Match
10	3×10^{-5}
15	1×10^{-7}
20	8×10^{-10}

Table 4. Maximum probability of encountering two metacarpal pads that exhibit similar dot patterns in the same part of the pad by chance alone, as predicted by equation 3.

The figures in Table 4 assume that the portions of the tracks being matched are extracted from exactly the same part of the metacarpal pad. The chance of a false match would increase if, say, a dot array from the upper left portion of the candidate track was matched against all similar sized arrays located throughout the reference track. While extreme cases are easily avoided, one must allow for such factors as incomplete tracks, distortion of the track due to the flexible nature of the foot-pad, and errors in alignment of the two tracks. A thorough attempt to match two tracks requires a certain degree of shifting of the relative position of the two images. The net result of this is an increase in the probability of a false match over what equation 3 indicates, albeit one that is difficult to quantify.

There are further complications to be considered. Recall that several simplifying assumptions were made in arriving at equation 3, assumptions that tended to make the equation conservative in its prediction. These effects would tend to cancel the degradation described in the last paragraph. It is clear that a rigorous determination of the probability of falsely matching tracks made by two different individuals would be very complicated indeed, with many factors in common with the similar question regarding human fingerprints, a matter that has yet to be thoroughly resolved despite intense effort on the part of many researchers (Pakanti et al. 2002).

Depending on the goals of the study, knowledge of the home range and other aspects of fisher autecology for the population in question might provide a useful input in determining how many dots need to correspond between two prints in order to safely conclude they were made by the same individual. Fishers are thought to exhibit a strong tendency for intrasexual territoriality throughout most of the year (Arthur et al. 1989, Powell 1979). This assumption, along with information about home range size (reported to be on the order of 20 to 50 km sq for males, 8 to 30 km sq for females, Powell and Zielinski 1994), recruitment, and an estimate of the likelihood of encountering transient or dispersing animals, could provide a useful upper limit on the number of individuals that might be encountered in a given study area. Considering these factors, the number of animals that could be responsible for a track collected from any individual track plate station might be on the order of 10. Thus, depending on the goals of the study, matching even as few as 10 dots (see table 4) between tracks may be suitable to conclude that two tracks were made by a single individual.

Ensuring Sufficient Matching Effort

A positive indication that two tracks match is reasonably clear. If two tracks don't seem to match, though, one must consider whether it is because they are from different feet or because the matching was not done properly.

If the overall size of the metacarpal pad and general pattern of rows seem to correspond between two tracks and yet no obvious alignment can be made when the images are overlaid, a "brute force" approach will often work. It is somewhat tedious, but sequentially shifting one image relative to the other by small amounts and checking for correspondence (that is, the sense of motion when switching between images) may reveal a match that might be missed otherwise. The distance the image is moved for each shift should correspond approximately to the spacing between typical pair of neighboring dots.

The shifting process must take place in both horizontal and vertical directions until all possible combinations of alignment within some limits are tried. The process is perhaps best learned though attempting it with images known to have been made by the same foot. Begin with the two images aligned by gross characteristics as well as is possible. I suggest picking a prominent dot in the reference image and mark it, say with an “x”. Switch back and forth between the reference and candidate images, periodically moving dots in the candidate image so they align with the marked dot in the reference, until all possible combinations within reason have been tried. With practice and appropriate software this process takes less than 5 minutes.

Quantitative Aspects of the Matching Method

The matching method described here appears at first glance to be almost entirely qualitative, with no obvious relationship to the quantitative analysis. Actually, the visual effect (a sensation of motion when toggling between images) described above does rely on some level of quantitative correspondence between the two images, although the level capable of eliciting the effect probably varies from person to person and generally will not be known. Accurate measurements could be made any time an apparent match is noted, however, to ensure that differences between the two images fall within the limits allowed by the model and its accompanying analysis. When comparing good quality tracks, though, this approach rarely seems necessary. Although the matter will depend on the desired confidence level established for the study being performed, the degree of correspondence between two good quality tracks of the same foot will likely far exceed any reasonable minimum criterion. The issue, then, attains importance only when lower quality images are used. A priori exclusion of these images from consideration would make the question moot at the expense of reduced sample size.

The Adirondack Data

The practicality of using fisher tracks to identify individuals in a population study will depend on being able to recognize at least one track from a high percentage of track plate visits. Track plates with no identifiable tracks must be eliminated from the sample and can only be compensated for with additional track collection effort, which tends to counter the potential low cost benefit of the method.

The results from analyzing the Adirondack track plates are encouraging. The percentage of visits that resulted in matchable tracks was quite high and this bodes well for the use of the method in performing fisher surveys.

Given the close spacing of the track plate stations (500 m separation for a total of 3.5 km trail coverage) and the generally accepted characteristics of fisher ecology discussed above, it might not be surprising if most visits on any trail were the result of a single individual. As presented here, however, this is a poor test of the ability to recognize individuals by their tracks. A blind test with tracks generated by animals of known identity would be much more appropriate for that purpose.

Track Quality

Poor track quality results in greater difficulty in identifying corresponding dot patterns between tracks and thus greater likelihood that a track from a previously encountered fisher may be incorrectly identified as having been made by a new individual. It is important, then, that track quality be considered in some consistent manner.

I have found it useful to categorize tracks according to three-levels of track quality. The *best* quality tracks contain distinct dots in all or most of the main portion of the metacarpal pad, with relatively few dots that are smudged or obscured in some manner. Tracks that meet these criteria make the most useful reference tracks against which candidates are compared. *Fair* quality tracks are those that exhibit the qualities of a good track over only a portion of the pad, perhaps half of the pad or less. Assuming the portion is large enough for the desired level of confidence, these tracks can be readily matched to good quality tracks or to other fair quality tracks if the clear area is shared by each. *Poor* quality tracks cannot be determined to be matchable a priori. These include the following:

- Tracks that lack the minimum number of distinct dots to be matched confidently
- Partial tracks or tracks that are so incomplete or distorted that orientation of the candidate track vis-à-vis the reference track is not possible.

The benefit of track quality ratings becomes obvious when one attempts to interpret data from the field. The process is facilitated greatly by concentrating on the high quality tracks first. Once a good quality left and right front track are found for a given individual (assuming that only the tracks of a single individual will be found on each sheet of paper), these high quality tracks can then be used as reference tracks against which others may be compared. Matching is aided by keeping track of results in a spreadsheet showing date, location, image file names, quality rating and assigned identity.

Practical Issues in Track Processing and Storage

The centroid-to-centroid spacing of a typical adjacent pair of dots measured approximately 0.3 mm, a value so small that error in measuring these structures is a potentially significant problem. This issue was addressed in this study through the combined use of high resolution digitization of the track and readily available image analysis software. While lower resolutions can be used (and certainly simplify the task of scanning and storing the tracks), eventually a reduction in the ability to match tracks accurately will be encountered. Color details are of little if any value in the analysis and file sizes can be minimized if only gray scale information is recorded, with 256 gray levels proving more than sufficient.

It is common practice to store tracks by inserting the shelf-paper into clear plastic document protector sleeves. Tracks are thus protected and yet remain visible through the plastic. Although this method can be cumbersome to apply in the field it has generally proven adequate in my study with a couple of noteworthy shortcomings. First, care must be exercised to ensure that the shelf-paper is not wrinkled or bubbled when inserting it into the document protector sleeve. Wrinkles disrupt the relative position of track features when the image is digitized and if the clear plastic sheet is not in smooth contact with the shelf-paper over the entire surface of the track then optical distortion can occur during scanning. Also, some of the fine details of the track may occasionally be damaged when they come in contact with the plastic sheet.

An alternate method of digitizing tracks that avoids these difficulties is to photograph them in the field with a high resolution digital camera (4 megapixel minimum resolution recommended) before storing the tracks in a protector sleeve. A suitable camera will have sufficient close focusing capability that the entire frame can be filled with the metacarpal pad, a span of approximately 2.5 cm. Care must be exercised to ensure that all tracks are recorded at the same scale, an issue that is avoided when using the desktop scanner. A stand for the camera capable of holding the lens a fixed distance from the track is essential, as is an auxiliary light source.

If copies of tracks are to be made, care must be taken to maintain image resolution. Digital transfer of images without reducing resolution is the surest method. Photocopies of tracks have proven to be inadequate, lacking both the resolution and accuracy of scale necessary for the matching method employed here.

Use as a Substitute for Conventional Marking Methods

One potential use of the principles outlined in this document is as a substitute for conventional marking, such as the use of ear tags. Foot-pad patterns may be recorded, stored, and compared to patterns collected in the future in order to recognize when an individual is recaptured. The technique is non-invasive and could effectively address the problems associated with lost tags.

Figure 8 show two examples of a track taken from an anaesthetized, captive fisher by applying ink to the metacarpal pad and then pressing the foot to paper. A high degree of correspondence between the images is obvious and, if these tracks had been recorded during successive captures, one would have little difficulty concluding they were made by the same individual.

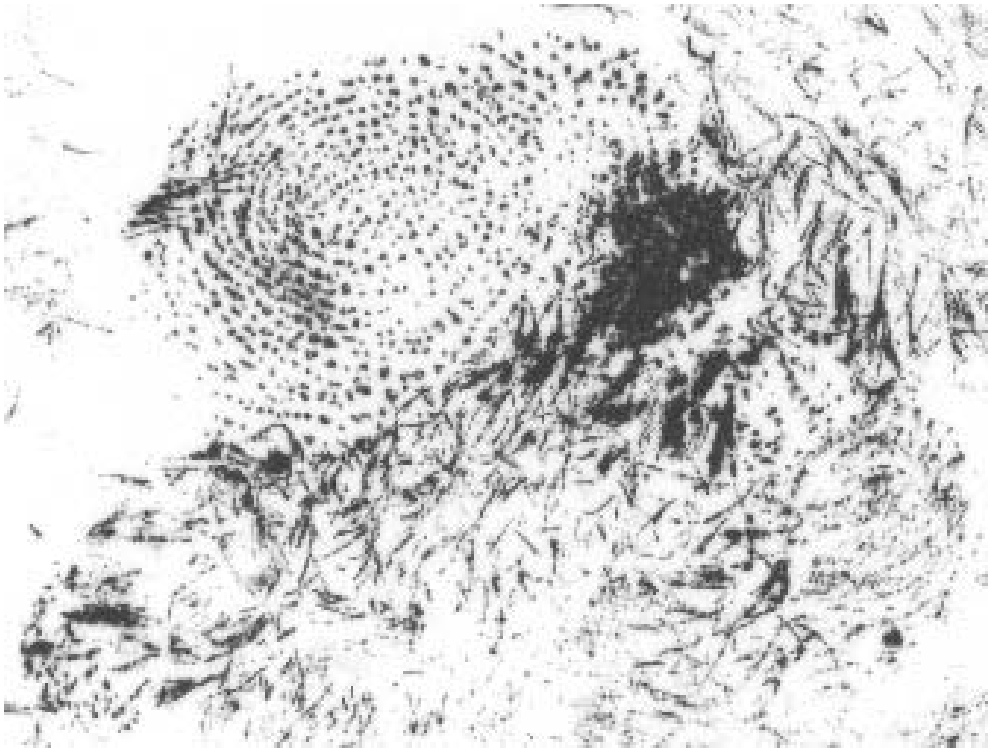

Figure 8a.

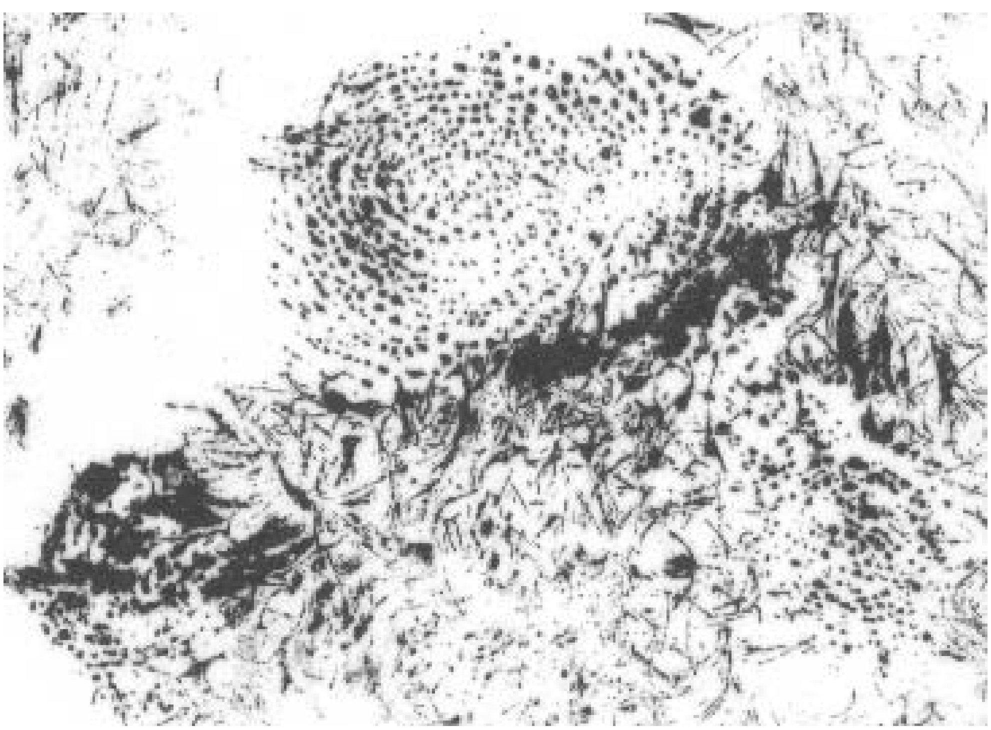

Figure 8b.

Two tracks of the same foot, generated by applying ink to the metacarpal pad of an anesthetized fisher and pressing the foot to paper. Many similarities between the two may be noted.

It should be noted that no attempt was made in this study to compare a track gathered in this manner with one collected from a track plate. Although the dot pattern will necessarily show similarities between the two, the ability to recognize these different types of track should be verified before use.

An alternative method that would eliminate this question might be to have the animal walk across a track plate before release, thus generating tracks in a realistic manner. Two issues not normally seen with the typical track plate setup might be encountered. The first is that the animal's behavior may be agitated and result in poor quality tracks due to smudging. Track quality should be verified before release. Secondly, in the normal walking gait of the fisher, the rear tracks will tend to fall on top of the front if the track-plate setup used allows this. Such might be the case if the enclosure allows the animal to walk fully across the plate from one end to the other. This problem is typically not encountered with the standard field implementation (Zielinski 1995), where the baited end of the box is placed against a rock, tree or log. The animal either backs out of the box after retrieving the bait or turns to leave in such a way that the front tracks are not stepped on.

Recommendations for Future Work

A Test of the Ability to Match Tracks

The matching method developed here was applied to tracks collected in the field, but the number of individuals that contributed to the pool of tracks was unknown. Ideally, the method should be tested using tracks that have been confirmed, by an independent method, to be from particular individuals. The goal of such a test could be to identify the number of individuals represented within a group of tracks. A blind test could be devised using tracks that are known to have been made by identified individual fishers. (Such a set of tracks was referred to in the Materials and Methods section, Zielinski et al., in litt.)

To accurately represent what might be encountered in a true application of the methods, the test should probably be structured as if a number of tracks of both left and right front feet and of varying quality were recovered from a single track plate sheet. The test subject would be told which track plate sheet each track belonged to. Multiple sheets showing tracks from certain individuals should be included (the Adirondack data described in this study suggest that 6 to 10 tracks of the same foot would not be an unrealistic upper limit in some cases) as well as instances where a foot is represented by only a single track.

Development of a Computer Assistance Tool

Several automatic fingerprint identification systems (AFIS) intended for use with human fingerprints were tested during the course of this study to examine their applicability to fisher tracks. Results were generally poor (C. Herzog, unpublished data), largely because these systems are almost exclusively designed to emulate the techniques employed by human fingerprint examiners, namely the identification and matching of points of minutia (that is, ridge endings and bifurcations). Although the wart-like structures of fisher foot-pads do form rows, they lack the true ridges associated with human fingerprints. The applicability of the AFIS tools to fisher track matching corresponded to their ability to render these rows as ridges. Even the best, though, would correctly match only the very clearest fisher tracks, a degree of detail lacking in most field-quality tracks.

It is probable, though, that specialized software tools could be developed to aid in matching fisher tracks. These could be based on interpreting the tracks as patterns of dots rather than ridges, in a similar manner to that described above. While it seems unlikely that a computer program would rival the ability of an experienced human to match low quality images, such a tool might aid in quickly comparing a large quantity of images in an objective and consistent manner with very little training. A test such as the one described in the previous section would be an ideal way to evaluate the effectiveness of a computerized track matching system.

One challenge faced by developers of fingerprint analysis software that would also have to be addressed by any fisher track recognition system is the issue of image rotation. While, as described above, a small amount of rotational offset between the candidate and reference images can actually aid the human who is matching tracks visually, this offset tends to cause difficulties in automated matching systems (Roddy and Stosz 1997). An algorithm insensitive to rotation would be desirable and one possible implementation that has not been described to date is described next.

Refer to figure 9. Two dots in one row and a third dot from an adjacent row can be envisioned as forming a triangle. Such a triangle can be completely specified by the length of its sides alone so that, if it appeared in two tracks, regardless of the degree of rotation present it would be possible to recognize the triangle without regard for rotation or any angular measurements whatsoever. A sufficient quantity of such triangles in common between two tracks would suggest they were generated by the same foot.

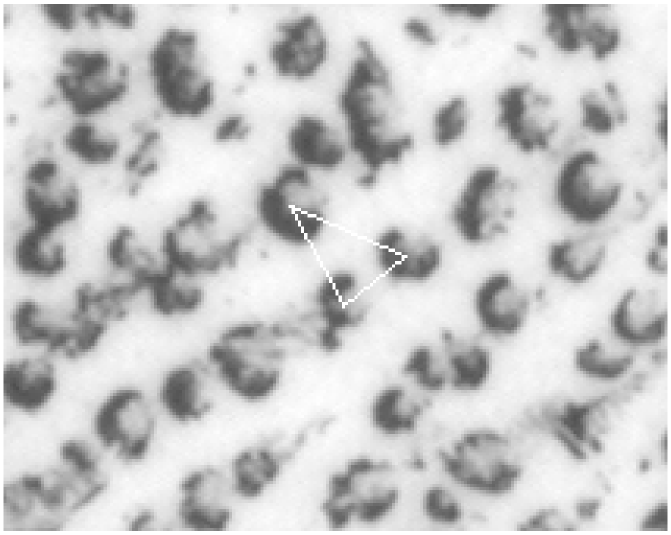

Figure 9. Extreme close-up view of the dot pattern in a fisher track. Two dots from the same row along with a third dot from an adjacent row form a triangle that may be particularly amenable to use as the distinguishing feature in a computer-matching tool. The tool would look for similar triangles in other tracks.

Just as Krijger (2002) did with zebra stripe matching, such a system could be developed relatively easily as an accessory program (known as a "plugin") for the public domain image processing software package ImageJ.

ImageJ is written in the Java programming language and has many desirable features for applications such as the one examined in this study, including the ability to run under many operating systems, full image processing functionality, and freely available source code (Rasband 2003). The program is maintained by the author, Wayne Rasband (wayne@codon.nih.gov), of the Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA. It is available at no cost over the Internet from http://rsb.info.nih.gov/ij/ .

Based on experience gained matching tracks in the manner described above, here is one view of how such a system might function. A new image would be opened in ImageJ by the user. He would manually define the region of interest (the main portion of the metacarpal pad) with a series of mouse clicks and then run the match-routine plugin. The plugin would:

- Apply a threshold routine to convert the 256-level gray scale image to 2-levels (black and white).
- Search for adjacent dots that have merged into one larger dot and sever them, thus restoring some dots that would otherwise be lost.
- Find the x-y coordinates for the centroid of each dot larger than a certain size.
- Identify sets of three dots whose spacing suggests they correspond to adjacent warts on the foot-pad. These would be considered as a triangle.
- The length of the sides of this triangle would be compared to triangles recorded for other tracks previously stored in the database.
- The process would be repeated for each three dot set that meets the spacing criteria.
- A matching score would be developed based on the number of similar triangles that are found.
- The user will be given the option of filing the track under examination as either new or another example of a track already in the database.

A substantial portion of the functionality described above already exists in ImageJ (threshold adjustment, finding dot centroids, exporting x-y coordinates to external applications such as spreadsheets and database programs, etc.), further easing development of such a package.

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