WHAT IS REVEALED IN A MOUNTAIN LION'S HEEL: USING HEEL SHAPE TO ASCERTAIN IDENTITY

MELISSA M. GRIGIONE[1], Division of Environmental Studies, University of California, Davis, CA 95616
PRABIR BURMAN, Department of Statistics, University of California, Davis, CA 95616

ABSTRACT: This study refines a method developed by Smallwood and Fitzhugh (1993), which attempted to discriminate between individual mountain lions (*Puma concolor*) in the field by using measurements of their tracks. During January-March 1996, we followed 10 radio collared mountain lions in the Sierra Nevada mountains of California and obtained photographs of their tracks in the soil and snow. In addition, track measurements were obtained from 4 mountain lion carcasses from different parts of California in 1996-1997. We analyzed heel pad variability to discriminate between mountain lions. Measurements of each track were taken every 10 degrees from the center of the heel pad until the entire heel pad was characterized by a series of linear measurements, corresponding to a particular angle measurement. After measurements of each heel pad were made, a curve was produced by cubic spline modeling which was indicative of a particular heel pad for each mountain lion. Confidence bands were placed around each curve and a graphical comparison was then made between track sets. The results of this analysis indicate that for both types of track sets, it is difficult to distinguish between mountain lions based on levels of heel pad variability. We conclude that measurements associated entirely with mountain lion heel pad lack discriminatory power and make recommendations about what types of measurements could be used to efficiently and accurately assess an animal's identity.

Key words: California, identification, mountain lion, *Puma concolor*, tracks

2000 TRANSACTIONS OF THE WESTERN SECTION OF THE WILDLIFE SOCIETY 36:21-26

Mountain lions (*Puma concolor*) have received elevated levels of publicity during the last decade due to increases in incidents involving mountain lions and humans or domestic animals. Since 1991 in the United States and Canada, 4 people have been killed and others injured (Beier 1991, Jackson 1998). Two of these deaths were in California, a state where mountain lions are an important management concern. Records compiled by the California Department of Fish and Game (CDFG) indicate that from 1973 to 1995 verified mountain lion depredation incidents have risen from 21 to 331 per year (Torres et al. 1996). Despite the occurrence of mountain lion-related deaths in California, the public recognizes mountain lions as an integral part of California's wildlife heritage. CDFG endorses potential management solutions that are biologically sound, ensuring the survival and viability of mountain lion populations while simultaneously promoting public safety (Torres et al. 1996).

When a mountain lion kills or seriously injures a human or domestic livestock, it is common practice to measure the width — and sometimes length — of the track of the offending animal's heel pad (as found in the soil near to the mortality site). Single measurements, like heel pad width and length, obtained from mountain lion tracks in the field have been used to determine the size, sex and identity of individual mountain lions in California and other western states (Shaw 1979, 1980, Fitzhugh and Gorenzel 1985, Fjelline and Mansfield 1988, Cunningham 1995, Germaine et al. 1997). Despite the convenience of the heel-width measurement, Grigione et al. (1999) found that based on a single-factor analysis of variance, heel pad width is a poor estimator of individual identity when used alone. Our previous analysis used Fisher's discriminant analysis to discriminate between mountain lions based on the magnitude (or size) of measurements taken over the entire track (heel pad and toes). Whether more variable regions of the heel pad existed was beyond the scope of the Fisher's analysis. By focussing entirely on the heel pad, this manuscript uses cubic spline modeling to detect variability associated with the shape of mountain lion heel pads.

In light of the need for biologically sound management practices for mountain lions, developing a statistically defensible methodology to locate and potentially remove offending mountain lions should be a component of any long-term management strategy. Removing just any mountain lion from the population neither reduces the chances of a similar event from occurring nor qualifies as biologically sound management.

The purpose of this study is to use heel pad shape to identify individual mountain lions and to reveal areas of the heel pad that may exhibit greater levels of variation than the single-measurement of heel pad width. Officials associated with mortality events have little time to conduct detailed analyses of mountain lion heel pads. We propose a more rigorous approach to understanding the variation associated with the mountain lion heel pad. We intend to highlight areas of the heel that could be useful in identifying individual mountain lions.

[1]Present address: 176 Gaylor Road, Scarsdale, NY 10583; mmgrigione@iname.com

METHODS

Two data sets were developed to determine if individual mountain lions occupying the same and different geographical areas could be identified by heel pad measurements: (1) tracks were obtained from ten radio collared mountain lions inhabiting the Owens Valley near Bishop, California (Bleich et al. 1996, Pierce et al. 1998, Grigione et al. 1999), and (2) tracks were obtained from dead mountain lions found throughout California.

Live Animals

During January-March 1994, we used a 35 mm Nikon camera on a tripod to photograph tracks in soil or snow from 10 radio collared mountain lions occupying an area near Bishop, California. Each track photographed had a ruler and a 6.5 cm^2 box placed next to it for standardization of scale and geographical information systems (GIS) conversion. Our sampling unit for this data set was a track set, defined as a group of four or more tracks from any foot made by the same mountain lion at one particular point in time. In all cases, the photographer was accompanied by an individual who used telemetry equipment to confirm the identity of the radio collared mountain responsible for each track set. Track data, however, were collected using a double blind design: we did not know from which collared animals we were following and collecting track data from. Only after our analysis was complete did we find out which mountain lion was responsible for each track set. An advantage of this study was that tracks made by many different mountain lions could be found under the same soil conditions and under quite variable environmental conditions, including different substrates, different terrain, and during different times of day. This enabled us to separate individual variability from environmental variability. Two methods were used to make track measurements: computer digitization using Arcinfo GIS, and hand measurements using a ruler and a transparent dot count grid (Grigione et al. 1999). In all, we photographed 12 track sets, 9 sets from 3 different individuals and 3 sets whose identity was uncertain because they came from 2 mountain lions that were in close proximity to each other.

Carcasses

Tracks were obtained from 4 adult and 1 juvenile mountain lion. The carcasses were frozen at the date of death. After the carcasses were thawed, ink was spread on each rear heel pad and a print of each track was transferred to a piece of construction paper. Six replicate impressions were made for each paw.

Track Measurements

A box was drawn around each heel pad with the left and right lower track lobes being the two points from which the lower line of the box was drawn (Figure 1). A parallel line, drawn 3.8 cm above the lower line, comprised the upper part of the box. Two side lines were drawn perpendicular to the upper and lower lines; the side lines,

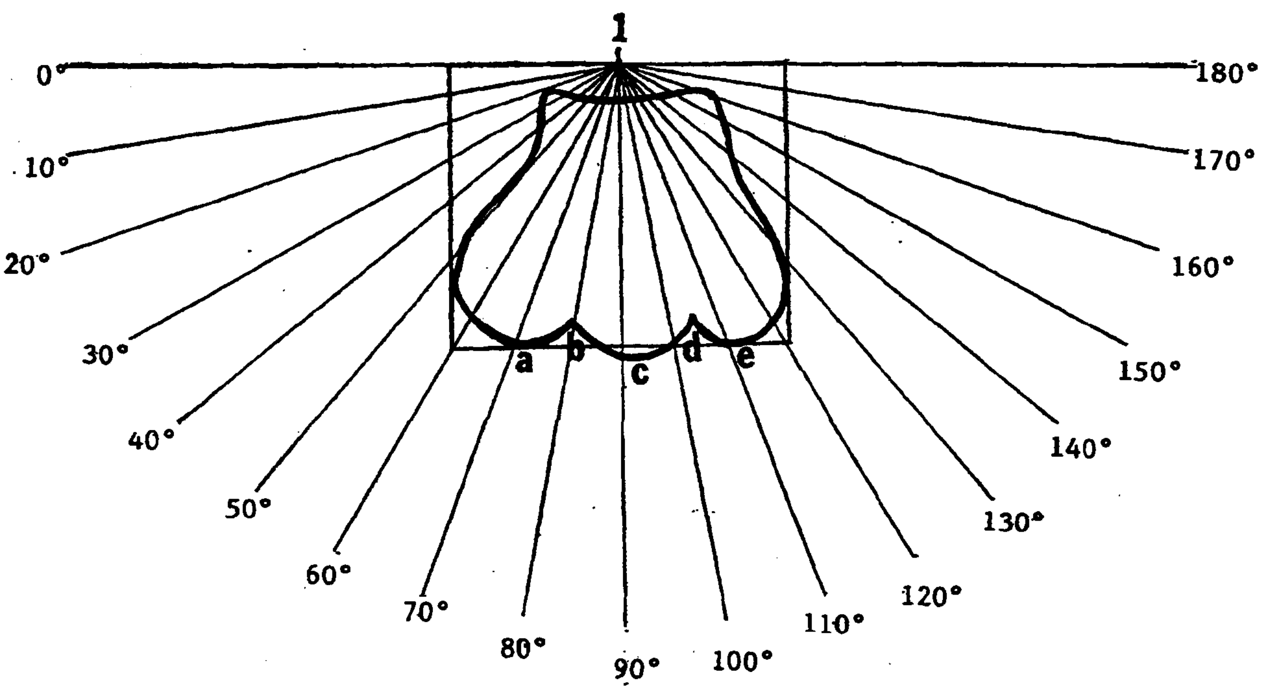

Figure 1. Measurements of Mountain Lion Heel Pads, With Center Point (1), High Points (b,d) and Low Points (a,c,e) labeled.

which were drawn tangentially to the widest points of each heel pad, completed the box. These boundaries guaranteed inclusion of the full heel pad into our measurements and minimized variation associated with the anterior arch of the heel pad. A point was located on the top of the box that was equidistant from each sideline. From this point, angles at 10-degree intervals were drawn from 0-180 degrees. At each 10-degree interval, linear measurements were made (Figure 1). The measurements began at the center point and ended where the heel pad ended. In addition, 5 points which correspond to the three lobes of a heel pad (3 "low" points) and where these lobes intersect (2 "high" points), were recorded for each heel pad (Figure 1).

Model Development

Our analysis of heel pads consisted of mathematical modeling of heel shape by cubic splines, construction of confidence bands, and comparison of various track sets graphically (Rao 1973, DeBoor 1978, Johnson and Wichern 1988; Appendix). After measurements of each heel pad were made, a shape and confidence band of each heel pad was produced. Using this method, shapes were compared graphically to determine if each heel shape belonged to the same or a different mountain lion, and where the areas of greatest variability were.

RESULTS

For both data sets, it was difficult to distinguish between mountain lions based on their heel pads alone (Figures 2 and 3). Upon visual inspection of our data, we did not observe differences in the degree of intersection between track sets belonging to the same versus different mountain lions. As can be seen from the graphs, there is little difference in intersection amongst all of the track sets.

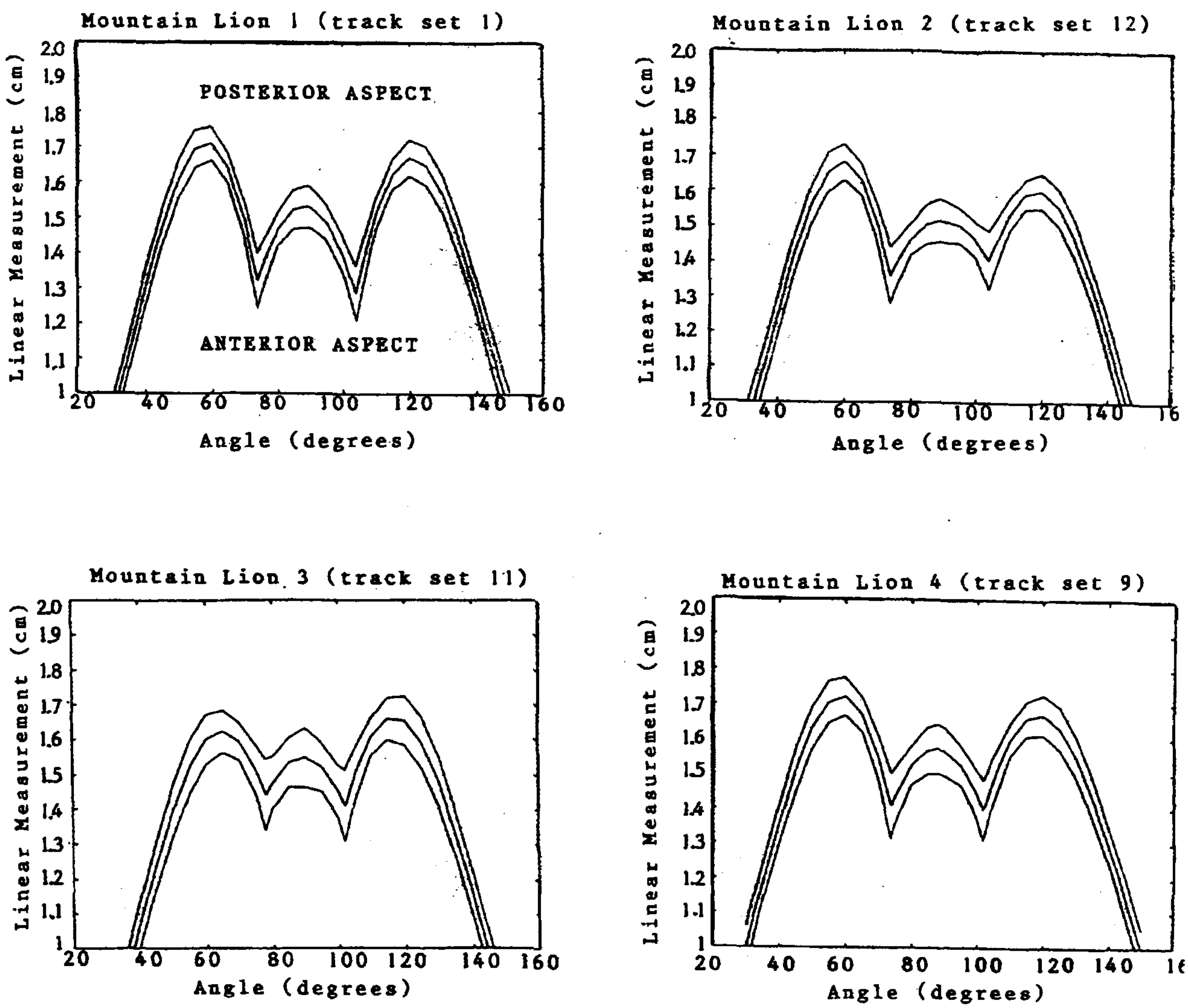

Figure 2. Shapes of mountain lion tracks obtained from live animals.

Live animals

Between 1 and 6 track sets were obtained for 4 mountain lions in different substrates (Figure 2). Mountain lion 3 had only 2 tracks within its track set; however, its heel shape appeared similar to the other mountain lions, which had a larger number of tracks per track set, with confidence bands of similar widths. We were unable to obtain suitable track information on all of the radio collared animals. Heel shapes in this analysis varied in their widths across the x-axis and the position of their high points and low points on the y-axis. Nevertheless, the amount of x,y variation that occurred between mountain lions was similar to the amount of variation we observed between track sets from the same mountain lion.

Carcasses

In total, heel shapes were obtained for 4 adult mountain lions (Figure 3). We were unable to obtain a heel shape, with confidence bands, for the juvenile animal because its heel pad was so small that few measurements could be made (there were no measurements for angles 0-50° and 120-180°). Because we were able to obtain more track replicates from carcasses than for the live animals, we were able to analyze left and right rear tracks separately. When we overlaid heel pad shapes, we noted a complete overlap between the left and right heel shapes of mountain lion 1, whereas mountain lions 2, 3 and 4 showed less overlap between left and right heel shapes. However, when we overlaid left heel shapes and right

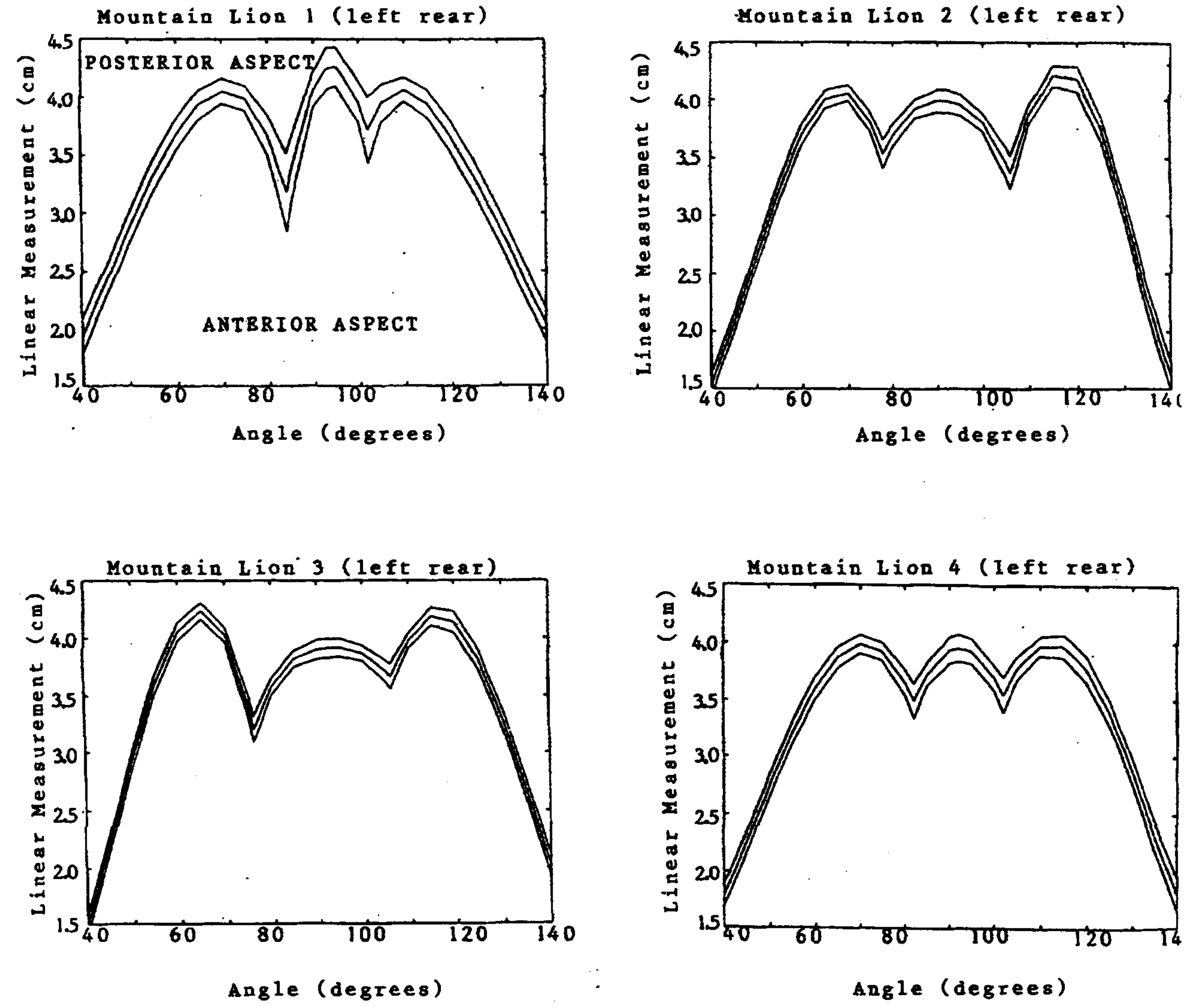

Figure 3. Shapes of mountain lion tracks obtained from carcasses.

heel shapes for the four adult mountain lions combined, the overlap we observed was similar to the amount of overlap found within an individual's left and right heel shape. An exception was mountain lion 1, whose heel shape for both left and right tracks, appeared quite different than the others.

DISCUSSION

Our heel pad analysis did not discriminate between live or dead animals. Tracks from dead animals exhibited less variability than live-animal tracks because there was no substrate or light variation: prints were taken directly from the individual animals. Despite this, the lack of variation associated with heel pads was similar within and between mountain lions for both dead and live animals.

This analysis confirms that the shape of mountain lion heel pads, like measurements associated with heel-pad width, have limited ability to distinguish between individual mountain lions. Our first analysis revealed which measurements, when used on their own, had the strongest ability to discriminate between mountain lion track sets (Grigione et al., 1999). However, these measurements overwhelmingly came from the anterior aspect of the track.

This analysis indicates that heel pad measurements may not be useful for individual recognition of mountain lions - especially when heel pad measurements are not considered along with more reliable measurements associated with toes of the track. Along with Grigione et al. (1999), we suggest that identification of individual mountain lions based entirely on heel pad measurements has little validity. Although heel pad measurements have been used as a way to determine a mountain lion's identity, they probably cannot provide information which leads to biologically sound management solutions for mountain lions or for promoting public safety on their own. The parts of the mountain lion track that show the largest amount of discrimination between individuals are most likely not the highly evolved structures, such as the heel pad, but maybe the more trivial features of each track, such as 1 of the 4 toes.

ACKNOWLEDGMENTS

This project was made possible by financial and logistic support from the California Department of Fish and Game, the University of California Public Service Research Program, the University of California White Mountain Research Station, the University of California-Davis Center for Statistics in Science and Technology - National Science Foundation Fellowship, the University of California-Davis School of Veterinary Medicine, and the Stockton Sportmen's Club. We thank V.C. Bleich, J.L. Davis, and J.W. Oestergard, from the California Department of Fish and Game, for assistance with radio-locating mountain lions. We thank P. Grant, T. Allis, J. Cody, J. Oliver, and M. Pitkin, from the University of California-Davis, for help with preparing mountain lion tracks for digitization and computer analyses. Drs. M.L. Johnson, C. Schonewald, K.S. Smallwood, and D. Van Vuren, from the University of California-Davis, and Dr. V.C. Bleich, from the California Department of Fish and Game, are thanked for their thorough review of this manuscript.

LITERATURE CITED

Beier, P. 1991. Cougar attacks on humans in the United States. Wildlife Society Bulletin 19:403-412.

Bleich, V.C., B.M. Pierce, J.L. Davis, and V.L. Davis. 1996. Thermal characteristics of mountain lion dens. Great Basin Naturalist 56:276-278.

Cunningham, S.C., L.A. Haynes, C. Gustavson, and D.D. Haywood. 1995. Evaluation of the interaction between mountain lions and cattle in the Aravaipa-Klondyke area of southeast Arizona. Arizona Game and Fish Department, Final Report #17.

DeBoor, C. 1978. A practical guide to splines. Applied Mathematical Sciences, Volume 27. Springer-Verlag, New York, USA.

Fitzhugh, E.L., and P. Gorenzel. 1985. Design and analysis of mountain lion track surveys. Pages 78-87 in California-Nevada Wildlife. Western Section of The Wildlife Society.

Fjelline, D.P., and T.M. Mansfield. 1988. Method to standardize the procedure for measuring mountain lion tracks. Pages 49-51 *in* Proceedings of the third mountain lion workshop, December 6-8 in Prescott, Arizona, USA.

Germaine, S.S., K.D. Bristow, and W. Zarlingo. 1997. Mountain lion surveys in southwestern Arizona. Arizona Game and Fish Department, Final Report.

Grigione, M.M., P. Burman, V.C. Bleich, and B.M. Pierce. 1999. Identifying individual mountain lions *Felis concolor* by their tracks: refinement of an innovative technique. Biological Conservation 88:25-32.

Jackson, P., editor. 1998. Cougars, mountain lions: whatever, they are in the news. Catnews 29: 14-15.

Johnson, R.A., and D.W. Wichern. 1988. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, USA.

Pierce, B.M., V.C. Bleich, J.D. Wehausen, and R.T. Bowyer. 1999. Migratory patterns of mountain lions: implications for social regulation and conservation. Journal of Mammalogy 80:986-992.

Rao, C.R. 1973. Linear statistical inference and its applications. Wiley Eastern Private Limited, New Delhi, India.

Shaw, H.G. 1979. A mountain lion field guide. Arizona Game and Fish Department, Special Report #9.

Shaw, H.G. 1980. Ecology of the mountain lion in Arizona. Arizona Game and Fish Department, Federal Aid in Wildlife Restoration Project W-78-R.

Smallwood, K.S., and E.L. Fitzhugh. 1993. A rigorous technique for identifying individual mountain lions *Felis concolor* by their tracks. Biological Conservation 65: 51-59.

Torres, S.G., T.M. Mansfield, J.E. Foley, T. Lupo, and A. Brinkhaus. 1996. Mountain lion and human activity in California: testing speculations. Wildlife Society Bulletin 24: 451-460.

Appendix

For any track set, let t_j=10j, j=0,...,18, be the angles from which measurements are made. $Y(t_j)$ is the length from the center point to the end of the heel pad at each angle. Let $\mu(t)$ be the true distance from the center point to the end of the heel pad for each mountain lion. Then we can write:

$$Y(t)=\mu(t)+\varepsilon(t)$$

where $\varepsilon(t)$ is the error of measurements associated with the track. The basic analysis consists of modeling $\mu(t)$ by cubic splines (DeBoor 1978), estimating the parameters by the least squares method, and constructing a confidence band for $\mu(t)$ using Scheffe's method (Rao 1973) for simultaneous confidence intervals. Cubic splines were used because they most appropriately fit the shape of our data. Splines enabled us to combine more than one cubic equation so that we could produce a series of smooth curves, representative of mountain lion heel pad shapes. The confidence bands for different track sets can be examined for the amount of overlap to determine whether or not they belong to the same animal.

Two knots (a point where two cubic equations intersect) were added to our model at t=60° and 120°; these knots represent the two high points where the three heel pad lobes intersect. In order to model the high points, we let the data select two additional knots, s_1 and s_2, and then added linear splines at these knots. The reason for adding linear splines at these points has to do with the sharpness of the two high points. We then placed a cubic spline with a knot at the middle point s of these two knots, providing a total of five knots. The model looks like:

$$Y(t)=\beta_0+\beta_1 t+\beta_2 t^2+\beta_3 t^3+\beta_4(t-60)_+^3+\beta_5(t-s_1)_+ +\beta_6(t-s)_+^3+\beta_7(t-s_2)_+^3+\beta_8(t-120)_+^3+\varepsilon(t)$$

$$= \mu(t,\beta) + \varepsilon(t),$$ say, where for any real number u_+ denotes max(u,0).

This model is representative of a cubic spline equation, with fixed left and right edges (at 60° and 120°) and three angles between these edges that are variable.

If there are k tracks in a track set, then for the i[th] track, I=1,...,k, let the observations be $Y_i(t_j)$, j=0,.....,18. The method for estimating the ß's consists of minimizing:

$$Q(\beta,s)=\Sigma_{1\leq i\leq k}\Sigma_{0\leq j\leq 18}\,[Y_i(t_j)-\mu(t,\beta)]^2$$

with respect to s_1, s_2 and $\beta_0,\ldots,\beta_8$. For a grid of points $s_1<s_2$, Q is minimized with respect to ß by the method of least squares. Then this minimum value of Q is minimized over the grid of points, s. Finally, we use the method of construction of simultaneous confidence intervals to obtain a confidence band for μ. This band estimates where our "true" curve should lie. Our curve is comprised of many different points, each with its own confidence estimate. When confidence estimates are joined, we have a simultaneous estimate, or a simultaneous confidence interval, for our curve.