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Original Article

Sex Determination of Amur Tigers (*Panthera tigris altaica*) From Footprints in Snow

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ABSTRACT The Amur tiger (*Panthera tigris altaica*) population in China, once widespread, is now reduced to an estimated 20 individuals widely dispersed over a large area. The Chinese government is making concerted efforts to restore this population from the contiguous Russian population. However, they face a challenge in finding an effective monitoring technique. We report on the development of a robust, non-invasive and cost-effective technique to identify the sex of Amur tigers from snow footprints. Between December 2011 and December 2012, we collected 523 digital images of left-hind footprints from 40 known captive Amur tigers (19 F, 21 M), of age range 3–13 years (F mean age $= 8.07 \pm 0.18$, M mean age $= 8.36 \pm 0.19$; $F = 1.18$, $P > 0.05$). Images were captured with compact digital cameras according to a standardized photographic protocol (Alibhai et al. 2008). Using JMP software from the SAS Institute, 128 measurements were taken from each footprint according to the protocol developed by Alibhai et al. (2008), and were subjected to a stepwise selection. With just 10 variables, and testing with both Jackknifing and 50% holdout methods, the resulting algorithm for sex determination gave 98% accuracy for individual footprints. The algorithm derived from captive tiger footprints of known sex was then used to identify the sex of 83 footprints from 8 trails collected from unknown free-ranging Amur tigers in the winter from the end of 2011 to the beginning of 2012. The algorithm predicted 5 trails from females and 3 from males. This technique is a potentially valuable tool for monitoring the recovery of Amur tiger populations at the landscape scale in northeastern China. © 2014 The Wildlife Society.

KEY WORDS Amur tiger, China, footprints, non-invasive monitoring, *Panthera tigris altaica*, pugmarks, sex-determination from footprints, snow footprints, trails.

The Amur or Siberian tiger (*Panthera tigris altaica*) is the largest sub-species of tiger and is primarily found in southeastern Russia and northern China. In the 1960s it was close to extinction but its population has recovered and numbers around 450 today (wwf.panda.org). Poaching and habitat destruction with very low prey base have reduced the population, which formerly ranged broadly over northeastern China, to an estimated 20 animals (Sun 2011). However, the landscape remains potentially valuable habitat (Kang et al. 2010) and the Chinese government is making concerted efforts to encourage Amur tigers to recolonize from the larger but contiguous population in the Russian Far East.

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Monitoring Amur tigers in China using conventional techniques has proved to be challenging (Zhang et al. 2012). At present, there are 3 main methods being used to monitor tigers: 1) mark–recapture population estimates based on photographs of tigers obtained using camera-traps in a few selected tiger reserves (Kawanishi and Sunquist 2004); 2) line-transect surveying, indices of snow-track encounter rates calibrated to tiger densities used in the Russian Far East (Miquelle et al. 1996, Hayward et al. 2002); and 3) molecular biology and individual identification using DNA of feces and hair (Russello et al. 2004), sometimes used in combination with the 2 methods above. The line-transect survey method is inappropriate for the assessment of low-density tiger populations in China. For example, a survey area of 1,735 km^2 and a length of survey route of 609 km were surveyed and no Amur tiger, or sign, was found (Jiang et al., WWF-China report 2010–2011, unpublished data). Also, DNA samples from free-ranging tigers are hard to find in the field in China. For example, Hunchun Nature Reserve only collected 7 fecal samples of Amur tigers during 2 years fieldwork from 2009 to 2010, but they found many more snow tracks of Amur tigers (Jianmin Lang, Hunchun Nature Reserve, personal communication). Chinese experts have begun using camera-traps to monitor tigers but these are effective only in small areas where there are known routes that tigers use. Zhang et al. (2012) reported that the information network combined with footprint identification may work because footprints and trails in snow are easier to find and collect, which provide a potentially richer source of information.

Various studies have indicated that it is possible to use footprints in sand or mud to identify species, individuals, and sex (Riordan 1998; Jewell et al. 2001; Sharma et al. 2003, 2005; Alibhai et al. 2008; Law et al. 2013). The process of discriminating footprints by sex has evolved in 3 stages: 1) based on the shape description of the footprints (McDougal 1977, Sankhla 1978; Panwar 1979*a*,*b*); 2) based on simple comparison of measurements (Gogate et al. 1989, Sagar and Singh 1993); 3) based on the statistical analysis of one or several measurements (Bhattacharya 1967, Gore et al. 1993, McDougal 1999, Sharma et al. 2003, Sharma and Wright 2005).

For the past decades, censuses of the contiguous Russian Amur tiger population have employed a combination of field signs (scat, tree markings, urine, etc.) and snow footprints. The latter have been employed particularly for sex determination. The width of the front pad has been the identifying standard, which combined with the other signs has been used to assess tiger individual numbers (Abramov 1961, Matyushkin et al. 1996, Smirnov and Miquelle 1999). However, this technique has depended on the manual measurement of a few features directly from snow footprints, and does not provide sufficient resolution to permit discrimination between adult female and subadult male tigers with the front pad width range overlapping (Miquelle et al. 2006).

We report here on a robust algorithm for identifying the sex of Amur tigers from their footprints in snow. Initial trials with free-ranging tigers indicate that this will be a community-friendly, cost-effective, and non-invasive tool for field monitoring.

STUDY AREAS

Footprints were collected from captive and free-ranging Amur tigers in northeastern China (see Fig. 1). Captive Amur tiger footprints were collected from the Hengdaohezi Amur tiger breeding center in the Heilongjiang Province of northeastern China, where records are kept on date of birth and parentage for >300 Amur tigers. Footprints from free-ranging Amur tigers were followed in the Dongfanghong Forestry Bureau of Heilongjiang Province in Wandashan mountains of northeastern China, where a small but relatively stable Amur tiger population has remained for the past 10 years.

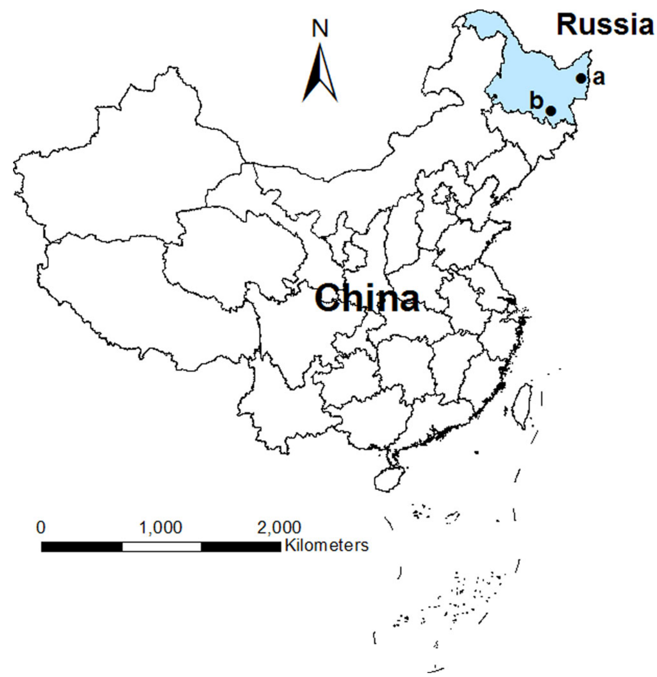

Figure 1. Heilongjiang Province (blue); location (a) Dongfanghong Forestry Bureau in Wandashan mountains; location (b) Hengdaohezi Amur Tiger Breeding Center near Mudanjiang city in China.

METHODS

Definition of Terms

Footprint: One footprint.

Trail: An unbroken series of footprints made by a single animal.

FIT: The footprint identification technique (Jewell et al. 2001, Alibhai et al. 2008).

Footprint Image Data Collection and Analysis Tools

We collected footprints using a basic compact digital camera, a carpenter's folding ruler and label paper to record photo information with the image. We analyzed footprint data using the FIT add-in in JMP® (SAS Institute, Inc., Cary, NC) software. We collected footprints from all 4 feet, for possible future reference, but needed only the left-hind footprints for the analysis.

We identified several new challenges in working with footprints in snow. Initially we found that the paper labels, used to record footprint information on the image, became wet in snow. We circumvented this problem by manufacturing a small card slot from soft transparent plastic and glued it to the back of the ruler and used a dry-erase pen to write the detail information directly on the soft plastic card slot. The hand-writing left by the dry-erase pen could be cleaned easily by any cloth. This adapted ruler is a useful addition for the long-term use of the monitoring tool, and like the other equipment is cheap and easy to use (see Figs. 2 and 3a).

We used only footprints with clear outlines of the 4 toes and metapodial pad for analysis. We imported them into JMP Software, where a FIT customized script allowed the extraction of 128 measurable variables (distances, angles, and

Figure 2. Technique for taking the footprint image of an Amur tiger using a compact digital camera.

areas) of each footprint to provide a comprehensive geometric profile (Alibhai et al. 2008 and see below).

Footprint Collection From Captive Amur Tigers

Footprints from tigers of known sex were required to develop an effective algorithm to classify by sex. Captive animals, for which accurate records were held, were ideal for this purpose. We collected sets of left-hind footprints in snow from 40 captive Amur tigers whose ages ranged from 3- to 13-years-old for both females (277 footprints) and males (246 footprints). The number of left-hind footprints collected from known individuals varied from 3 to 21, with a mean value at 13.1.

During the sampling period there was unusually little natural snow in the study area, so we had to develop a method to cover the tiger enclosures with snow that would approximate natural conditions. We gathered what fresh snow was available to cover the tigers' outdoor enclosures, spread it and then sieved it to imitate natural snow fall. We experimented with different depths of snow and found a depth of 3–5 cm (1–2 cm firm snow plus 2–3 cm un-compacted snow) provided the clearest footprints. The tigers were attracted to walk on it normally with food and calls from their keepers. We collected footprints from trails only if the animals were walking at a normal walking pace and footprint outlines were clear.

We then photographed the footprints according to the FIT protocol (Alibhai et al. 2008). We selected clear footprints and placed the ruler as the scale on bottom and left hand axis in relation to direction of travel, making sure the ruler did not obscure detail (see Fig. 2). A photo label containing the date and name of photographer, animal identification (ID), and footprint number, was included in each image.

We also had to develop an assessment of image quality for photography, based on the clarity of the outline of the metapodial pad and toes. We did this over the research period, gradually refining the technique as we progressed. Figure 3 gives information on the clarity of images required.

Another challenge presented by snow conditions was the lack of contrast presented by the high reflectivity of the snow substrate. We were able to work around this limitation by photographing images early morning and late afternoon when there was some contrast, and providing artificial lighting from a flashlight when conditions were overcast and visibility very poor. Images were taken from directly overhead (checked by a second person), ensuring that the frame was filled by the footprint, ruler, and label card. We found the best images were obtained taking the image from 30 cm to 50 cm above the footprint.

Collection of Footprints From Free-Ranging Amur Tigers

To locate and collect footprints from free-ranging Amur tigers, we employed local informants in the winter from the

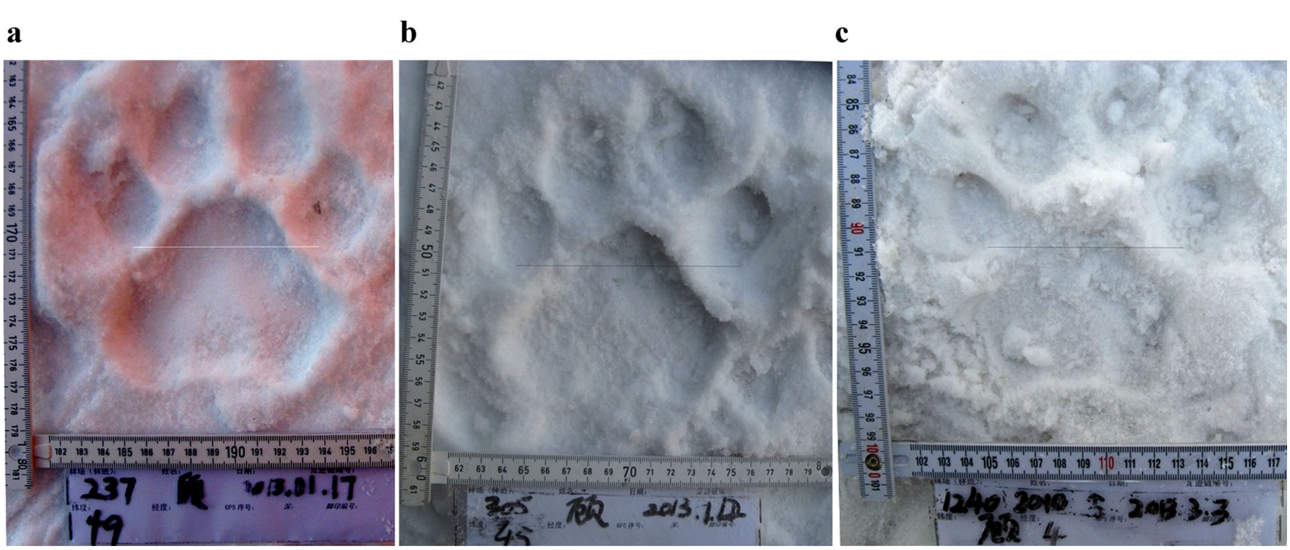

Figure 3. Image (a) is good-quality image (with clear outline) of an Amur tiger footprint, as taken during winter 2011–2012 in northeastern China. Image (b) is poorer quality image but it is still possible to determine the outline. Image (c) could not be used for analysis.

end of 2011 to the beginning of 2012. Information relating to trail sightings was provided by villagers and local patrollers in Amur tiger range areas, and on receipt we went directly to the reported site to follow the trail as soon as possible. Our objective was to get multiple high-quality left-hind footprint images from each trail.

Despite challenging field conditions, it was not difficult to find clear footprints. Experience showed that Amur tigers prefer walking on level terrain such as frozen rivers, roads, ridges, or farmland where clear footprints are easily found (see Fig. 4). Often following these areas with downed dead wood, or neighboring big rocks led to more favorable substrates. However, occasionally footprints were found in very deep snow, and proved challenging to image. Sometimes, in very deep snow, it was necessary to manually remove some snow around the footprint to keep the ruler and the outline of the footprint in the same plane. There are many causes of snow footprint degradation, including fresh snowfall, wind, ice overflow, and melt-out, but snowfall was the most common cause (82%) of footprint degradation in January and February, while footprints created in March degraded faster (lasting on average 2.1 days) because of warm weather and wind (Hayward et al. 2002). Footprints on snow were relatively stable without new snowfall in January and February; this provided good opportunities to collect high-quality footprints during the research period.

The method of collecting footprints from free-ranging tigers was the same as that for captive tigers. However, because the identity of the animal was in each case unknown, we recorded trail numbers as follows: The first trail we photographed was trail 1, and the footprints in it were recorded as 1a, 1b, 1c, etc. The second trail was trail 2, and footprints in it recorded as 2a, 2b, etc. If a trail was obscured or broken at any point, the next set of images was allocated a different number. Global Positioning System locations were also recorded for each trail, along with habitat information.

Figure 4. Example of the clear trails left by free-ranging Amur tigers in northeastern China during winter 2011–2012.

Extracting a Geometric Profile From Digital Images

This process has been reported by Alibhai et al. (2008) for white rhino (*Ceratotherium simum*) footprints on sand, and is here reported as a new development and application for Amur tiger snow footprints. We processed images to extract measurements, the set of which we refer to as the geometric profile. Each image was orientated so that the front toes were at the top. We cropped images if necessary to remove extraneous space, leaving only the footprint, ruler, and photo label in the image.

We optimally enhanced brightness and contrast for each image, so that toes and metapodial pad could be outlined clearly. We then placed 2 markers on the image—one at the lowest point of each side toe. We then rotated the image until a line joining these 2 points was horizontal, and we sized the image (keeping the aspect ratio fixed) until it fitted comfortably into the JMP graphics window. We marked 25 points on each footprint, from which we extracted 128 measurable variables using FIT scripts in JMP software (see Fig. 5; Table 1).

Data Analysis

For sex identification, we used 523 footprints from 40 captive tigers, 19 females (277 footprints) and 21 males (246 footprints). Animal ages ranged from 3 years to 13 years for both sexes without significant age differences between groups (F mean age $= 8.07 \pm 0.18$, M mean age $= 8.36 \pm 0.19$; $F = 1.18$, $P > 0.05$). We used linear discriminant analysis in JMP to discriminate sex. Linear discriminant analysis is a technique used to identify a linear combination of variables that characterize or separate different classes of objects, in this case sex. We used the JMP Stepwise Variable Selection function to select the variables that provided best discriminating power based on their F ratios. This function also has the added advantage of excluding highly correlated variables. By plotting the number of variables included in the analysis against the predicted level of accuracy of sex identification, we were able to establish the number of variables that would provide an effective predictive model (see Fig. 6).

To validate the level of accuracy of sex discrimination using linear discriminant analysis, we used 2 holdout methods—Jackknife, and partitioning the data into training and test sets. Jackknifing tests sequential subsets of data, excluding every footprint in the data set in sequence, where partitioning splits the data to enable testing of one set against an algorithm derived from the other. An algorithm derived from all the variables, consisting of the 10 best discriminating variables generated by the captive tiger footprint data was used as a predictive model to determine sex for unknown free-ranging tiger footprint data.

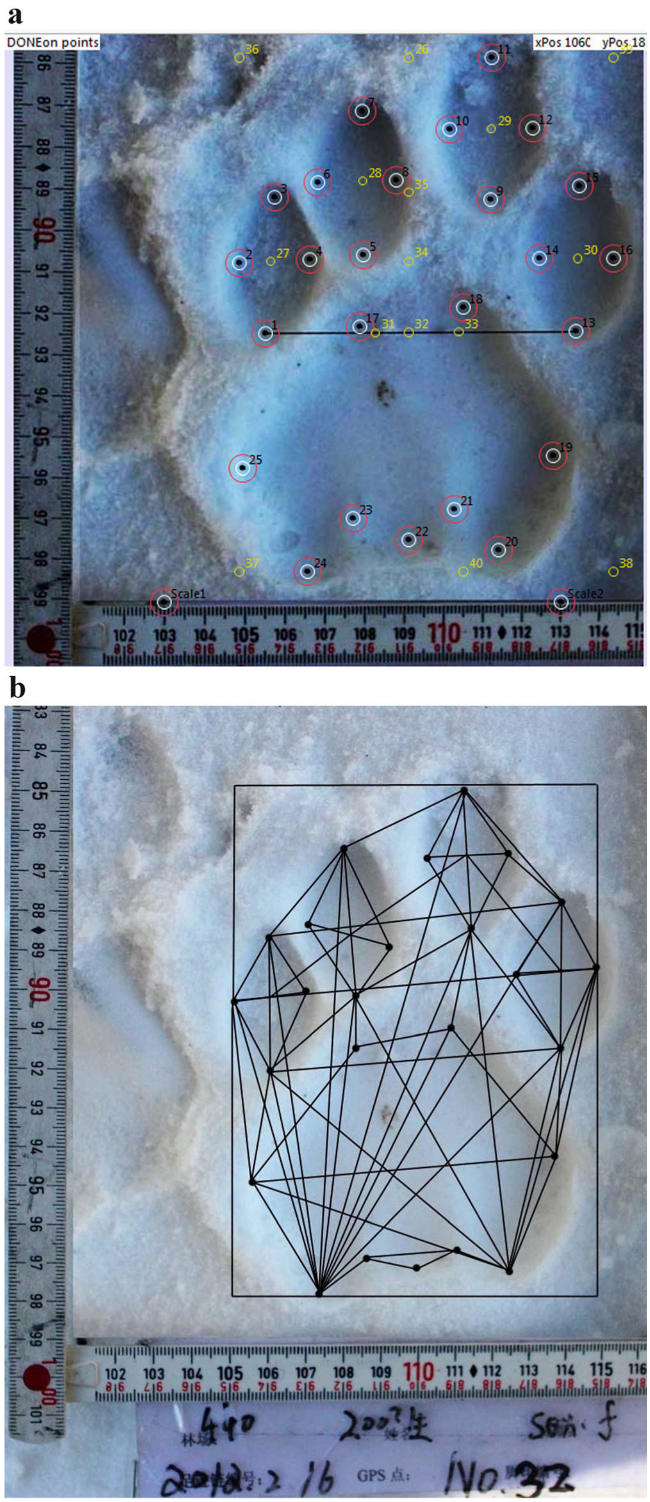

Figure 5. (a) Amur tiger's left-hind footprint images, as collected during winter 2011–2012 in northeastern China, marked in JMP software with 25 landmark points (marked 1–25) and derived points (26–40). (b) The same image showing the derived points and lines, from which 128 morphometric variables are drawn. These constitute the geometric profile of the footprint.

RESULTS

Sex Discrimination Model for Captive Amur Tigers

Variables with the highest discriminating power were selected using the stepwise selection feature in JMP. To avoid using too many variables and over-fitting we used linear discriminant analysis to plot the number of variables against the sex-prediction accuracy for all the footprints. Figure 6 shows that the asymptote was reached with 8–10 variables, and we thus opted to use 10 variables selected stepwise. Figure 7 shows a plot of the first 2 canonical variables generated using linear discriminant analysis using 10 variables. Out of 523 footprints, 11 were misclassified (7 female footprints classified as male and 4 male as female).

A Jackknife validation procedure on the captive tiger data set using 10 variables selected stepwise resulted in 13 footprint misclassifications, giving an accuracy of sex determination of 97.5%. These few misclassifications were likely due to subtly distorted footprints, themselves perhaps due to sudden gait or substrate change. To further validate the level of accuracy, we randomly allocated 50% of the captive footprint data set to a training set and 50% to a test set using a discriminant validation platform in FIT. This procedure was iterated 5 times, each time the partitioning being carried out randomly. The levels of accuracy for the training sets ranged from 96.9% to 98.4% and for the test sets from 97.4% to 98.5%.

Application in Free-Ranging Amur Tigers

Using the sex discrimination algorithm generated with the captive data set, we attempted to predict the sex of the free-ranging tiger footprints. We selected the 83 qualified free-ranging tiger footprints from 8 trails in 5 forest farms and performed discriminant analysis using 10 variables. Table 2 shows the outcome of sex prediction of footprints from free-ranging tigers using discriminant analysis. The result showed that 5 trails were from female Amur tigers and 3 trails were from males. As Table 2 shows, for all trails, the majority of footprints (92%) were either classified as male or female for each trail.

DISCUSSION

Collecting and Measuring Footprints

We collected only hind footprints, because during normal walking, the hind footprints often register over those of the front feet, resulting in fewer intact front footprints (Sharma et al. 2005). To facilitate field-collection and minimize the requirement for footprint collection, we developed the system to use only left-hind footprints. Riordan (1998) found that the misclassification rate for the right-hind footprints was slightly higher than that for the left hind. By comparison, Indian experts sampled trails that had ≥5 clear impressions of left and right-hind feet (Sharma et al. 2003), and Russian experts just measured width of the front pad, which is a standard measurement used for Amur tigers (Abramov 1961, Matyushkin et al. 1996, Smirnov and Miquelle 1999).

We decided to take as many measurements as was practically possible (128) to extract the maximum discriminating power from the footprints, while Sharma et al. (2003, 2005) had taken 93 measurements. We included many of the same variables that earlier studies (Gogate et al. 1989, Gore et al. 1993, Das and Sanyal 1995) had identified as being

Table 1. The number of variables extracted from the footprint images from Amur tigers in northeastern China during winter 2011–2012, reported as lengths (L), angles, and areas. The variable dimension numbers 01–25 refer to the landmark points and 26–40 to the derived points (see Fig. 5). Variables 81–88 were generated at the intersection of 2 vectors (e.g., V81 refers to vector from points 01 to 05 and 09 to 13).

Variable no.	Variable dimensions[a]	Variable no.	Variable dimensions[a]	Variable no.	Variable dimensions[a]	Variable no.	Variable dimensions[a]
V1	L 01–03	V33	L 03–07	V65	L 14–15	V97	L 02–37
V2	L 05–07	V34	L 07–11	V66	L 15–16	V98	L 02–36
V3	L 09–11	V35	L 11–15	V67	L 13–16	V99	L 26–36
V4	L 13–15	V36	L 15–19	V68	L 17–19	V100	L 11–26
V5	L 02–04	V37	L 03–25	V69	L 18–25	V101	L 11–39
V6	L 06–08	V38	L 17–27	V70	L 27–28	V102	L 16–39
V7	L 10–12	V39	L 17–28	V71	L 28–29	V103	L 16–38
V8	L 14–16	V40	L 17–29	V72	L 29–30	V104	L 24–38
V9[b]	L 17–18	V41	L 17–30	V73	L 01–31	V105	L 24–37
V10[b]	L 19–25	V42	L 18–27	V74	L 31–32	V106	L 18–40
V11	L 22–24	V43	L 18–28	V75	L 32–33	V107	L 13–24
V12	L 20–22	V44	L 18–29	V76	L 13–33	V108	L 09–24
V13[b]	L 21–23	V45	L 18–30	V77	L 02–34	V109	L 05–24
V14	L 01–22	V46	L 05–25	V78	L 16–34	V110	L 01–24
V15	L 05–22	V47	L 09–25	V79	L 03–35	V111	L 01–13
V16	L 09–22	V48	L 13–25	V80	L 15–35	V112	L 36–37
V17	L 13–22	V49	L 01–19	V81	ANGLE AT INTER 01&05-09&13	V113	L 02–16
V18	L 22–31	V50	L 05–19	V82	ANGLE AT INTER 03&07-11&15	V114	L 03–15
V19[b]	L 05–31	V51	L 09–19	V83	ANGLE AT INTER 05&01-24&20	V115	L 03–24
V20	L 22–33	V52	L 01–02	V84	ANGLE AT INTER 09&13-20&24	V116	L 07–24
V21	L 09–33	V53	L 02–03	V85	ANGLE AT INTER 03&01-01&13	V117	L 11–24
V22	L 22–32	V54	L 03–04	V86	ANGLE AT INTER 07&05-01&13	V118	L 15–24
V23	L 32–34	V55	L 01–04	V87	ANGLE AT INTER 11&09-01&13	V119[b]	Area 1
V24	L 34–35	V56	L 05–06	V88	ANGLE AT INTER 15&13-13&01	V120[b]	Area 2
V25	L 26–35	V57	L 06–07	V89	ANGLE 01-22-05	V121	Area 3
V26	L 01–05	V58	L 07–08	V90	ANGLE 05-22-09	V122	Area 4
V27	L 05–09	V59[b]	L 05–08	V91	ANGLE 09-22-13	V123	Area 5
V28	L 09–13	V60[b]	L 09–10	V92	ANGLE O2-25-19	V124	Area 6
V29	L 13–19	V61	L 10–11	V93	ANGLE 16-19-25	V125	Area 7
V30[b]	L 19–20	V62	L 11–12	V94	ANGLE 01-24-05	V126[b]	Area 8
V31	L 24–25	V63	L 09–12	V95	ANGLE 05-24-09	V127	Area 9
V32	L 01–25	V64	L 13–14	V96	ANGLE 09-24-13	V128	Area 10

[a] The areas were generated using the most peripheral points in each case. Area 1 = whole image, Area 2 = toe 5, Area 3 = toe 4, Area 4 = toe 3, Area 5 = toe 2, Area 6 = pad, Area 7 = points 1, 5, 9, and 13 and the proximal pad points, Area 8 = points 1 and 13 and the proximal pad points, Area 9 = points 1, 5, 9, and 13 and points 19 and 25, Area 10 = points 1 and 13 to the most distal toe points (3, 7, 11, and 15).
[b] Ten variables used for discriminating sex.

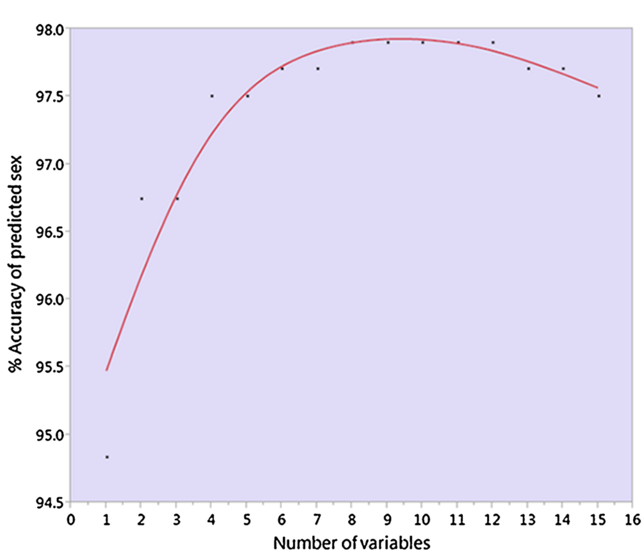

Figure 6. The asymptote of the number of morphometric variables and the footprint accuracy for images of Amur tiger footprints collected during winter 2011–2012 in northeastern China.

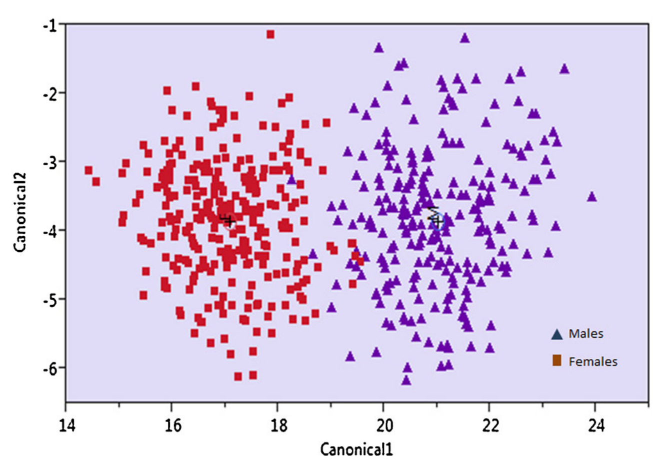

Figure 7. The distribution of male (triangle) and female (circle) Amur tiger footprints, collected during winter 2011–2012 in northeastern China, using 10 morphometric variables. Number of misclassified = 11; Percent of misclassified = 2.103; −2 Log Likelihood = 63.699.

Table 2. The sex prediction results of the snow footprints of 8 free-ranging Amur tigers' trails, as collected during the winter of 2011–2012 in northeastern China.

Trailname[a]	No. of tracks/trail	No. of tracks classified as female	No. of tracks classified as male	% tracks/trail classified as male or female[b]	Predicted sex
HYS	13	11	2	82	F
QY	12	11	1	91	F
WLD-B	14	13	1	92	F
XNC-A	13	13	0	100	F
WLD-A	7	5	2	71	F
XNC-B	5	0	5	100	M
QS-B	13	0	13	100	M
QS-A	6	1	5	80	M

[a] HYS = Haiyingshan, QY = Qiyuan, WLD = Wulingdong, XNC = Xinancha, and QS = Qingshan.
[b] The percentage of footprints within the trail (i.e., from one animal) that were assigned to the final predicted sex.

useful. We always used 10 variables to build and test the sex-discrimination model, but these 10 variables (out of the original 128 variables) might be different every time, depending on the selection of data fed into the model. This experience was also reported by Sharma et al. (2003).

Data Objectivity of Footprint in Snow

Field monitors were confident in using the digital cameras to record footprints after a short training period, so there was no element of tracing or copying images (Rishi 1997). The process of data collection is therefore accessible to local people in northern or snowy landscapes, and can also include a valuable contribution from citizen scientists toward data collection.

In our experience, when the footprint was in deep snow (>5 cm), snow on the surface obscured the real outline and shape details of footprint below. In addition, the footprint appears smaller in deep snow than the same one in shallow snow, because the distance between the ruler and the outline of footprint increases. Conversely, if the footprint is in very shallow snow (<3 cm) there is insufficient depth to hold detail. Therefore, in captive situation or in the free-ranging, it is advisable to record footprints in a snow depth of around 3–5 cm and also to keep the ruler and the outline of the footprint at the same plane when taking the footprint image. During this research we also found snow substrates to be relative stable; thus, it is possible to find and collect high-quality snow footprint data in the field (Hayward et al. 2002).

The Effect of Sample Size and Modeling Methodology for Sex Discrimination

This study has developed more rigor in discriminating sex from footprints in several ways. Firstly, with regard to data collection, we have used a significantly larger number of footprints for each animal and collected footprints from many more animals than before (see Riordan 1998; Sharma et al. 2003, 2005). We excluded the influence of age, because we have used a wider age range of 3–13 years with no significant difference between male and female. Secondly, we have instituted a rigorous quality-control photo protocol and filtering system for images to be used. We extracted the data from footprint images, not tracings. Thirdly, using the discriminant validation platform in JMP, which provides a stepwise function, we were able to validate our model effectively using Jackknifing and holdout method by randomly apportioning the data into training and test sets.

Lastly, we have developed a single piece of user-friendly software (FIT) that will enable us to complete the image processing and data analysis in one software platform.

MANAGEMENT IMPLICATIONS

We consider footprints in the snow the best means of determining the presence of Amur tigers in northeastern China. In decades of monitoring history of Amur tigers in both Russia and China, field workers have identified Amur tigers by sex or individual using simple standard-front pad width measurements, and using assumptions about individual range. The major limitation in this system has been the difficulty in discriminating between adult females and subadult males. China faces an additional monitoring challenge because of the very low Amur tiger population density. The new Amur tiger monitoring network (Zhang et al. 2012) requires a more accurate method, and we are confident that FIT can provide this. This technique may also be able to help us assess the number of resident female Amur tigers. Female Amur tiger dispersal range is limited and their daily movement is shorter than that of males (Goodrich et al. 2010); therefore, we believe that female resident tigers are an indicator of local tiger population recovery.

The use of the non-invasive footprint identification technique has positive management implications with respect to monitoring approach. Footprint collection does not disturb or interfere with the natural ecology of the animal, and evidence suggests (Jewell 2013) that non-invasive approaches lead to better scientific outcomes in conservation monitoring.

In summary, the advantages of FIT are its ease of use for landscape-scale monitoring of Amur tigers and a potentially valuable tool for the ongoing assessment of recovery of this species in China. We are currently investigating individual and age identification of Amur tigers and communicating with our Russian colleagues to adopt this non-invasive and cost-effective method as a single unified approach to Sino–Russian transboundary populations, so that this endangered population can be cost-effectively assessed and protected.

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