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Spotting the cheetah; Identifying individuals by their footprints.

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Abstract:	The cheetah (Acinonyx jubatus) is Africa's most endangered large felid and listed as Vulnerable with a declining population trend by the IUCN1. Cheetah conservationists face two major challenges; conflict with landowners over the killing of domestic livestock, and concern over range contraction. Understanding of the latter is poor2. Namibia is believed to support the largest number of cheetah of any range country, but current estimates range from 2,9053 to 13,5204. The disparity is likely a result of the different techniques used in monitoring. Current techniques, including invasive tagging with VHF or satellite/GPS collars, can be costly and unreliable in challenging Namibian field conditions. The footprint identification technique (FIT)5 is a new tool accessible to both field scientists and also citizens with smartphones, who could greatly increase the amount of data on cheetah numbers and distribution in Namibia. FIT analyses digital images of footprints captured according to a standardized protocol (http://wildtrack.org/citizen-science/photographing-footprints/). Images are optimized

	and measured in JMP data visualization software from the SAS Institute. Measurements of distances, angles and areas of the footprint images are analyzed using a robust cross-validated pairwise discriminant analysis based on a customized model. The final output is in the form of a Ward's cluster dendrogram. A user-friendly graphic user interface (GUI) allows the user immediate access and clear interpretation of classification results. Because each species has a unique anatomy, FIT algorithms are species specific. FIT runs in JMP, using JMP scripting language (jsl) that can be written for the footprint anatomy of any species. An initial classification algorithm is built from a training database of footprints from that species, collected from individuals of known identity. An algorithm derived from a cheetah of known identity is then able to classify free-ranging cheetah of unknown identity. FIT predicts individual cheetah identity with an accuracy of >90%.
Author Comments:	I agreed with Allison Diamond that we would submit some video to contribute towards the final video collection by JoVE. I have highlighted in the ms where video contributions occur and am able to upload these when the journal requests.
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Question	**Response**
If this article needs to be "in-press" by a certain date to satisfy grant requirements, please indicate the date below and explain in your cover letter.	

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To: Journal of Visualised Experiments
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11th August 2015

Dear JoVE Editorial team,

We are submitting a manuscript, "Spotting the Cheetah; Identifying individuals by their footprints" for consideration by JoVE. This technique is based on digital images and a very interactive software graphic user interface, so is ideally suited for explanation by a video journal rather than a static manuscript

The author contributions are as follows:

Zoe C Jewell: Fieldwork and data analytics
Sky K Alibhai: Fieldwork, software design and data analytics
Florian Weise: Fieldwork testing
Stuart Munro: Fieldwork testing
Marlice Van Vuuren: Fieldwork testing and animal management
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TITLE: Spotting the Cheetah: Identifying individuals by their footprints

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KEYWORDS:

Footprint identification, cheetah (*Acinonyx jubatus*), non-invasive monitoring, conservation, endangered species, image recognition, statistical modeling, JMP software

SHORT ABSTRACT:

The cheetah (*Acinonyx jubatus)* is an iconic endangered species, but conservation efforts are challenged by habitat shrinkage and conflict with commercial farmers. The footprint identification technique is a new approach to monitoring cheetah; a robust, accurate and cost-effective image classification system in JMP software (www.jmp.com) from the SAS Institute (www.sas.com).

LONG ABSTRACT:

The cheetah (*Acinonyx jubatus*) is Africa's most endangered large felid and listed as Vulnerable with a declining population trend by the IUCN[1]. It ranges widely over sub-Saharan Africa and in parts of the Middle East. Cheetah conservationists face two major challenges; conflict with landowners over the killing of domestic livestock, and concern over range contraction. Understanding of the latter remains particularly poor[2].

Namibia is believed to support the largest number of cheetah of any range country, around 30%, but current estimates range from 2,905[3] to 13,520[4]. The disparity is likely a result of the different techniques used in monitoring.

Current techniques, including invasive tagging with VHF or satellite/GPS collars, can be costly and unreliable in challenging Namibian field conditions. The footprint identification technique (FIT)[5] is a new tool accessible to both field scientists and also citizens with smartphones, who could greatly increase the amount of data on cheetah numbers and distribution in Namibia.

FIT analyses digital images of footprints captured according to a standardized protocol (http://wildtrack.org/citizen-science/photographing-footprints/). Images are optimized and measured in JMP data visualization software from the SAS Institute. Measurements of distances, angles and areas of the footprint images are analyzed using a robust cross-validated pairwise discriminant analysis based on a customized model. The final output is in the form of a

Ward's cluster dendrogram. A user-friendly graphic user interface (GUI) allows the user immediate access and clear interpretation of classification results.

Because each species has a unique anatomy, FIT algorithms are species specific. FIT runs in JMP, using JMP scripting language (jsl) that can be written for the footprint anatomy of any species. An initial classification algorithm is built from a training database of footprints from that species, collected from individuals of known identity. An algorithm derived from a cheetah of known identity is then able to classify free-ranging cheetah of unknown identity.

FIT predicts individual cheetah identity with an accuracy of >90%.

INTRODUCTION:

The cheetah (*Acinonyx jubatus*) is Africa's most endangered felid and listed as Vulnerable with a declining population trend by the IUCN Red List of Threatened Species[1.]

The global cheetah population is estimated to be between 7-10,000 individuals[1] and Namibia is recognized as the largest stronghold of free-ranging cheetah, with perhaps more than a third of the world's population [4,6,7]. Rough estimates for Southern Africa in 2007 placed Namibia's cheetah population at 2,000 with the next nearest range state Botswana with 1,800, followed by South Africa (550), Zimbabwe (400), Zambia (100), Mozambique (<5), and several states unassessed[7].

Namibian authorities have a clearly stated vision of "Secure, viable cheetah populations across a range of ecosystems that successfully coexist with, and are valued by, the people of Namibia" (ref: http://cheetahandwilddog.org/linksav.html).

However, livestock and game farming are major land uses in Namibia [8,9] and landowners regularly trap and kill cheetah on their properties in an attempt to reduce predation of livestock or valuable wildlife. More than 1,200 cheetah were removed from 1991 to 2006, but not all such 'offtakes' were recorded [10]. Moreover there is debate on whether or not this is an effective solution to farmer-cheetah conflict. It is suggested that removal of animals perceived as causing conflict, by killing or translocation is less effective than mitigation of conflict by other means, such as better livestock protection[11]. Rates of survival for 12 months post translocation vary from 18%[11] to 40%[12.]

Collecting reliable data on the numbers, identity and distribution of cheetah in Namibia is key to addressing human-cheetah conflict situations. Current cheetah monitoring techniques range from targeted questionnaires from the Namibian Ministry of Environment and Tourism to stakeholders[4] to opportunistic observations by tourists and government reports[4], to the use of camera-traps[13], GPS or VHF collars[10,14], farmer interview surveys[8], and even spot pattern[15]. However, comparison of the efficacy of these techniques without a common benchmark or quantification of survey effort is difficult. Each has limitations; GPS satellite and VHF collars are expensive and often unreliable, targeted questionnaires have limited scope and camera-traps have limited range.

Estimates produced by these different methods vary widely. Marker[10] highlighted the need for a more coordinated approach:

'A variety of methods have been used on the farmlands to estimate cheetah population density, producing a range of estimates from 2.5 (+/- 0.73) cheetahs/1,000 km2 using radio telemetry (Marker 2002) to 4.1 (+/- 0.4) cheetahs/1,000 km2 using camera trapping… This variation highlights the problem of using different methods to estimate density, but so far no single, effective, repeatable technique has been identified which could be used across the wide range of habitats that cheetahs occupy in Namibia, and this remains a problem for effective cheetah monitoring and conservation'.

This challenge sparked the development of a robust, cost-effective and flexible tool for monitoring cheetah. FIT was first developed for black rhino[16] and subsequently adapted for a wide range of species including white rhino[17], Amur tiger[18], mountain lion[19], and others.

Various studies have indicated that it is possible to use footprints to identify large carnivores by species, individuals, and sex. The process graduated from simple shape description of footprints[20] to a comparison of measurements[21], to statistical analysis of one or several measurements [16,17,22-30] and shape analysis[31]. These efforts have had varying success, depending largely on the rigor of the data collection and analytical processes, and the number of test animals used to develop the training datasets.

There are several practical advantages of using footprints. The first is that images can be collected alongside other non-invasive approaches (e.g. camera-trapping, DNA collection from hair/feces etc.) with very little extra effort or cost. Secondly, footprints are, where substrate permits, the most ubiquitous sign of animal activity.

FIT is the first robust footprint identification technique described for cheetah, and is applicable at any site where footprints are found. Footprints must be defined enough that the toes and heel of the print can be seen clearly with the naked eye. Field operators must familiarize themselves with the basic anatomy of the cheetah foot and be able to identify prints in the area of interest, and distinguish them from prints of any other sympatric large carnivores. FIT can either be used as a census technique (e.g. how many cheetah are represented by the footprints collected?) or as a tool to monitor specific individuals. Footprints can also be used as 'marks' in mark-recapture analyses, using FIT to identify individuals, and then calculate local densities of the species. FIT data collection requires only a basic digital camera and scale.

PROTOCOL: (green highlights for JoVE video editing)

1.Collecting footprints

Ethics statement: FIT is a non-invasive technique. For the training dataset, only registered captive cheetahs with permit documentation from Namibia's Ministry of Environment and Tourism were used. Cheetah (see videos 1a,b,c,d) were encouraged to walk along a sand trail to leave prints. If they were unwilling to walk the sand trail for any reason the collection was stopped and resumed at a later date. **Safety statement:** Cheetah were never left unguarded (2 people) and were placed in separate holding facilities where possible. Tame cheetah were lured directly over a sand trail to make footprints. Other less tame animals were lured from outside the enclosure.

Terminology: **Track:** One footprint; **Trail:** An unbroken series of footprints made by a single animal.

1.1 Patch preparation and protocol

1.1.1 Materials required: Fine rake, or coarse rake and tamper, hand sprinkler or watering can, two standard rulers (cm) or one carpenters' folding ruler for framing the print, a standard digital camera (minimum resolution 1200.1600 pix), an umbrella for shade if necessary, standard FIT footprint label with data recording spaces for: name of photographer, date, footprint series, discrete print ID, animal ID, location and depth if > 2cm). (http://wildtrack.org/citizen-science/photographing-footprints/).

1.1.2 Work early morning or late afternoon for maximum light contrast on the prints. If this is not possible, artificial shade from an umbrella can improve heel and toe pad definition when the sun is overhead.

1.1.3. Use either natural substrate or a thin layer of builders' sand 1cm-2cm laid out as a path about 2-3m wide for between 3m – 15m along a perimeter fence or habitual movement path. (Video 2 & 3)

1.1.3 Wet and smooth the substrate with standard gardening tools to improve print quality and definition. Remove leaves and pebbles, if present. (Videos 4,5,6)

1.1.4 Lure the cheetah across sand path with a food reward. Once prints are made, lead the animal away from the path. (Videos 7 & 8)

1.1.5 After each footprint trail is imaged (see below) brush the tracks away and prepare the surface for recording the next trail. (Video 16

1.2 Luring known individuals over the sand trail to collect the FIT training dataset.

Only collect left hind prints for the training dataset. These are easily identified with a little experience. The left hind foot has the leading toe (toe 3), toe 4 and toe 5 making a slope to the left. Front feet are broader and more symmetrical than hind. (Videos 9 & 10

1.3 Imaging the footprints using the FIT protocol

1.3.1. Draw a circle around each left hind footprint in the trail. (Video 9)

1.3.2 The first footprint is imaged as follows. Place a metric scale about 1cm below and to the left of the footprint. Under the scale, and not touching the footprint, place a photographic ID slip (link), and write in the pre-allocated spaces the name of photographer, date, footprint series, depth (if >2cm) discrete print ID, animal ID and location. (Videos 11,12,13,14)

1.3.3. Straddle the print and point the camera lens directly overhead the footprint, to avoid any parallax error in the image with relation to the scale or photo ID slip. Use a tripod or assistant to check if necessary. (video 15)

1.3.4. The footprint, rule and photo ID slip must completely fill the frame and the lens-to-print distance is then usually 10cm-50cm (video 15)

1.3.5 When around 20 good quality left hind prints have been recorded the collection for that animal is complete and another animal is introduced.

2. Image feature extraction prior to FIT analysis (Figs and table highlighted in yellow)

2.1 Open FIT as an add-in to the JMP data visualization software. FIT runs on a JMP script in the coding language jsl. The FIT main menu is shown in Fig. 1.

2.2 Import the first footprint image into the image feature extraction window of FIT. A feature extraction template guide is shown on the left of the window.

2.3 Press the 'resize' button to ensure that the footprint image fits inside the graphics window. Then place two rotation points at the lowest points on the outside toes (toes 2 and 5) and select 'rotate'. The image is rotated to the horizontal on the line joining those points, to standardize orientation.

2.4 If the substrate is more than 1cm deep, make a depth correction using the substrate depth button.

2.5. Place two scale points at the required scale. For the cheetah this is 10cm, set on the scale factor box.

2.6. Using the template on the left of the graphics window, place 25 landmark points sequentially. A prompt will appear on the top left of the image to show the sequence of points.

2.7 Select ‘Derived points’ to generate a further fifteen points derived from the landmark points. This process augments the number of variables available for the algorithm development.

2.8. Complete all data fields for the footprint image; cheetah, track, trail, date, time and location point (GPS). Fig 2 shows stages 2.2-2.8.

2.9 Press the ‘append row’ button to send 136 scripted variables (distances, angles, areas) to a row in the FIT database.

2.10 Repeat stages 2.1 to 2.9 for all footprints until the database is populated with the x.y coordinates for each landmark and derived point, and all the calculated variables for each footprints.

3. Development of FIT algorithm for cheetah

3.1 Pairwise robust cross-validated discriminant analysis

3.1.1 From the main menu, now select and open the robust cross-validated pairwise analysis window (Fig 3). Carry out a pairwise comparison of trails using the training database of known individuals. This is done sequentially using the customized model in FIT. The model uses a classifier to determine the likelihood of a pair of trails belonging to the same individual or two different individuals (Fig 4).

3.1.2 Create an algorithm by testing the accuracy of classification based on number of variables (measurements) and the contour probability (the confidence interval around the centroid value). Data are visualized as a cluster dendrogram using the Wards clustering method (Fig 5a). Figures 5b & c show different estimates of cheetah numbers obtained by testing different variable and contour probability inputs.

3.1.3 Select the algorithm that consistently gives the highest accuracy. An adjustable threshold value allows the algorithm to be set to produce the outcome that best approximates to the number of animals known in the training database (Fig 5a).

3.2 Full holdback trial for validation

Validate the algorithm for both the expected number of individuals and the accuracy of the clustering classification using holdback trials, and randomly apportioning the individual cheetah in the dataset to test and training sets (Fig 6).

REPRESENTATIVE RESULTS:

Individual identification

781 footprints (M:F 395:386) belonging to 109 trails, from 38 individuals, were collected for the training dataset. Table 1 gives a summary of data collected.

Using several holdback trials, the accuracy of individual identification was consistently >90% for both the predicted number of individuals and, just as importantly, the classification of trails i.e. whether the trails from the same individual (self trails) and those from different individuals (non-self trails) were classified correctly. A cluster dendrogram representing all 38 individual cheetah is shown (Fig. 7a). There were 109 trails, generating a total of 5,886 pairwise comparisons. Of these there were 46 misclassifications giving an accuracy of 99% (Fig. 7b).

Figures and Tables

Table 1. Summary of collected data. The number of cheetah, number of footprint images collected, range of footprints per cheetah, number of trails, range of trails per cheetah and age-range of cheetah.

Fig. 1. The opening main menu window in FIT (the footprint identification technique). FIT is an image identification add-in, to the JMP data visualization software from SAS, designed to classify footprints by individual, sex and age-class from morphometric measurements. FIT also uses mapping capability in JMP which enables analysis of temporal and spatial distributions. A graphic user interface allows the seamless navigation between different options.

Fig. 2. The feature extraction window. Capabilities include drag and drop images, automatic resizing to fit window, rotation of images for standardization, substrate depth factoring etc. Pre-assigned landmark points are manually positioned and generate a series of scripted derived points to enable the extraction of metrics in the form of distances, angles and areas. The output is in the form of a row of data providing the x.y co-ordinates and the metrics.

Fig. 3. Pairwise data analysis window in FIT. Once a database of measurements has been created, the pair-wise analysis window is designed to help validate the data and/or test for data from unknown populations. The analysis is based on a customized model incorporating a constant, reference centroid value (RCV), which compares pairs of trails sequentially [16,17]. The final output is in the form of a cluster dendrogram which provides a prediction for the number of individuals and the relationship between the trails.

Fig. 4. Pairwise comparisons. The figure shows the outcome of a pair-wise comparison of trails from the same individual (A) and two different individuals (B) based on a customized model developed in JMP. The classifier incorporated into the model is based on the presence or absence of overlap between the ellipses. Note that the analysis is performed for each pairwise comparison in the presence of a third entity, i.e. the reference centroid value (RCV).

Figs. 5a, b & c. A dendrogram of a sample of trails from seven cheetahs showing the correct prediction when the algorithm is optimized (a) and when the algorithm is suboptimal (b & c). The algorithm is based on three adjustable entities, the number of measurements used, the ellipse size (confidence interval used) and finally, the threshold value that determines the cut-off value for the clusters.

Fig. 6. A holdback trial carried out sequentially by varying the proportion of cheetahs in the test and training sets. Rather than apportioning cheetahs to training and test sets arbitrarily, an analyses was performed sequentially increasing the test set size. For each test set, 10 iterations were performed with cheetahs being selected randomly for each iteration. For each test set, this allowed a mean value to be calculated. The figure shows the varying test size plotted against itself (red), and on the y axis the predicted value for each test size iteration (green) and the mean predicted value for each test size (blue). The plot demonstrates that even when the test set size is increased considerably (n=28) compared with the training set size (n=10), the mean predicted value is similar to the expected value.

Fig. 7a. Dendrogram showing the predicted outcome when all 109 trails from 38 cheetah are included in the analysis. Note the fidelity of the trails forming the clusters. Interestingly, of the misclassifications, many were between littermates e.g. cheetah Letotse /Duma and Vincent/Bonsai.

Fig.7b. Classification table. With 109 trails, a total of 5,886 pairwise comparisons were carried out. There were 46 misclassifications giving an accuracy of 99%. The algorithm construction factors in the balance of the accuracy achieved for self and non-self trails, i.e. deciding on the number of measurements and the ellipse size (contour probability).

DISCUSSION:

This paper has outlined the theoretical application of FIT and its potential as a new cost-effective, community-friendly approach to monitoring, and hence helping conserve cheetah. The next steps in the wider application of the tool will be more extensive field testing with cheetah populations in range areas.

The footprint identification technique differs from previous attempts to identify individuals from footprints in several key respects; a standardized and rigorous footprint collection protocol, a streamlined graphic user interface software, the orientation and optimization of images prior to analysis, and a new statistical model for classification.

Working with footprints has one obvious limitation - the substrate must permit their clear impression. Partial prints or poor quality prints provide insufficient detail[32]. However, large areas of cheetah range are ideal for footprint collection, and for small otherwise unsuitable areas it may even be possible to circumvent this limitation by placing artificial sand trails to collect footprints. These footprint impression pads can be effectively used in combination with camera-traps, for example at known cheetah marking posts/trees.

Because FIT is non-invasive, it does not cause any disturbance to the ecology or behavior of the animal. Many studies have shown the potential and real risk of capture, immobilization, handling, and fitting of instrumentation, the cost incurred in such practices, and the risk of collecting unreliable data[33]. FIT has another advantage in conservation management. Based on traditional tracking skills, and cost-effectiveness, it is able to engage previously marginalized local communities in the processes of conservation monitoring. Stander[34] and Liebenberg[35] independently addressed and attested to the conservation monitoring skills and value of including these groups.

Future developments in FIT capability for cheetah are ongoing, and include field-trials for validation with free-ranging cheetah, building age-class algorithms (including changes in foot morphology of individuals over time) and substrate controls. The authors are also investigating computer vision image segmentation techniques to optimize accuracy and consistency in marking landmark points.

Since footprints are one of the most ubiquitous animal signs, and generally much easier to find than the animals themselves, the wider adoption of footprint identification could be game-changing in conservation monitoring. The world's main protected terrestrial areas receive an estimated eight billion recreational visits per annum[36]. A majority of visitors now carry smartphones. Using an app. being developed for WildTrack the collection of footprint data will be simple and quick and could potentially effect a data set of unprecedented sample size and spatial scale. With a cost-effective data collection protocol, FIT readily adapts to mesh into any conservation toolbox. As an image classification system its robust model may also have application in the medical, forensic, and law-enforcement fields (e.g. anti-poaching).

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DISCLOSURES:

The authors have nothing to disclose.

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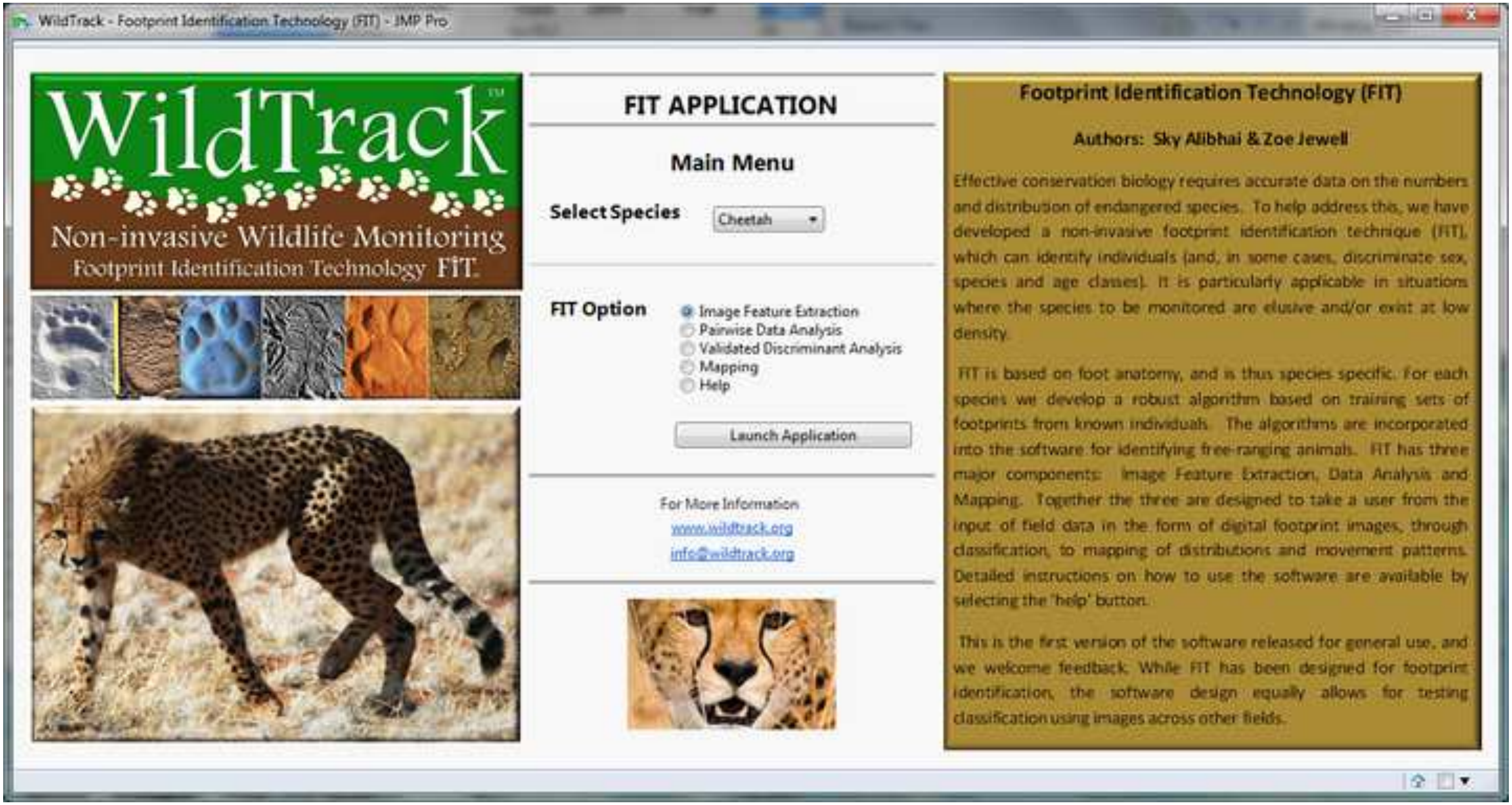

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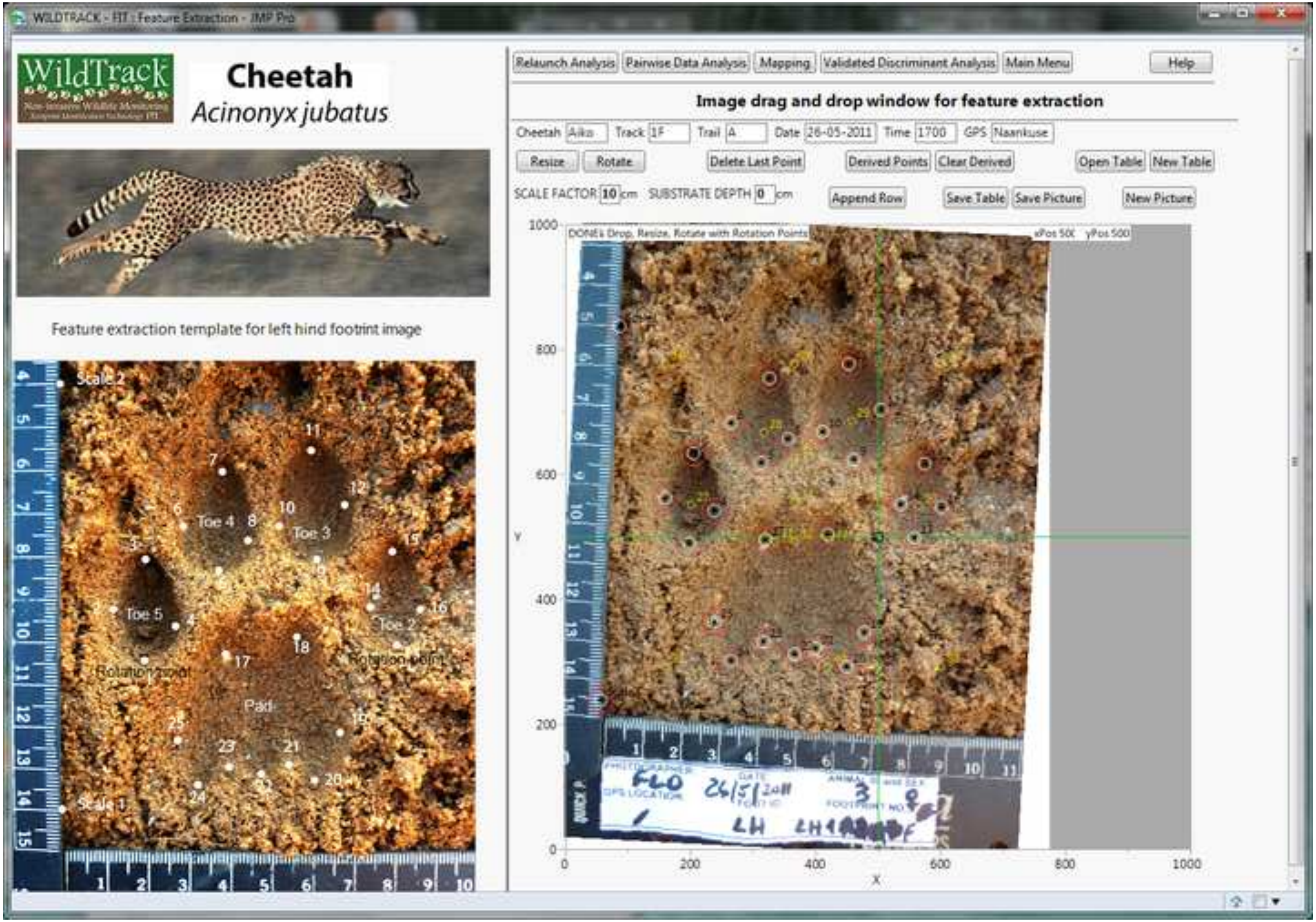

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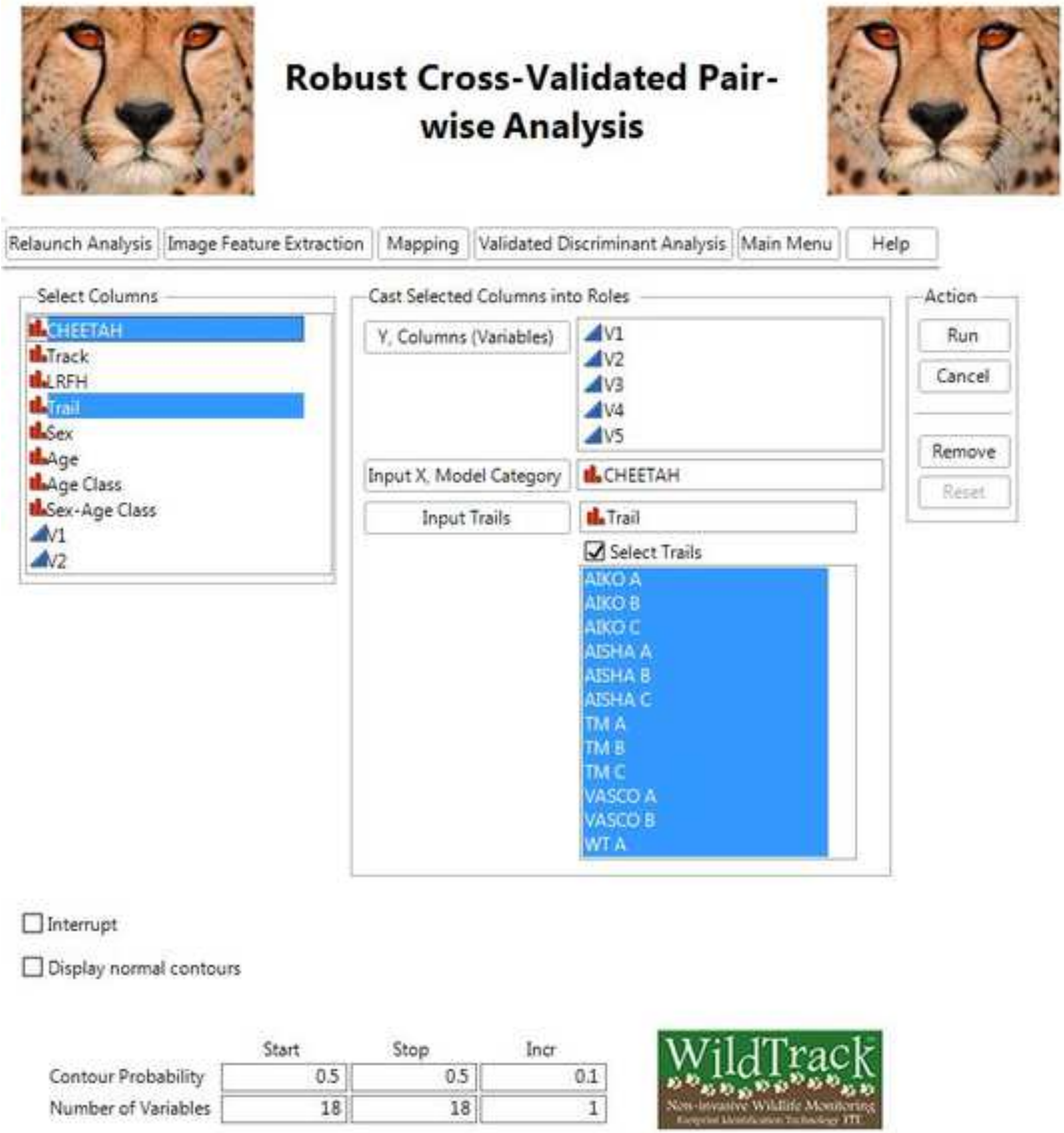

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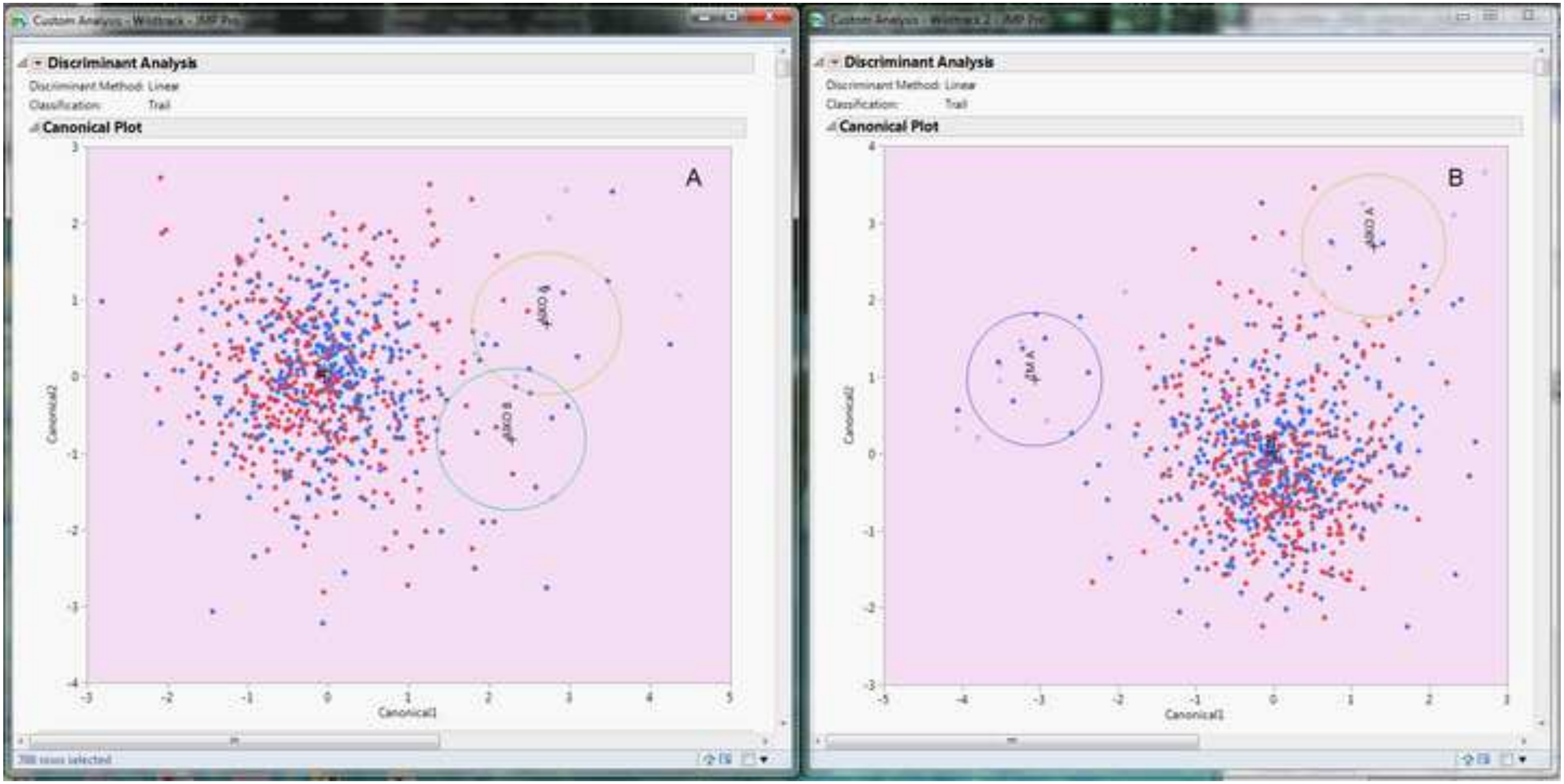

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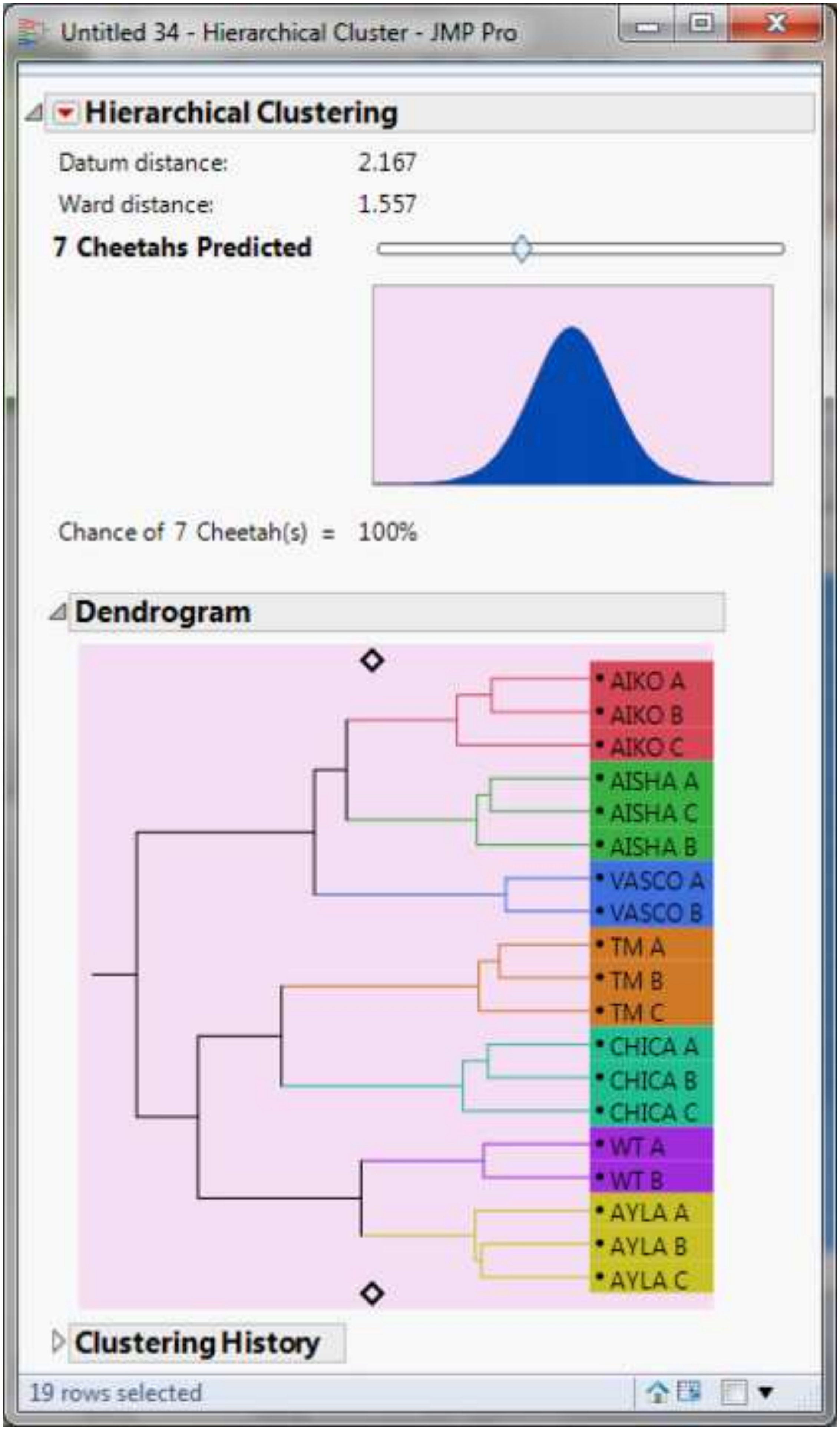

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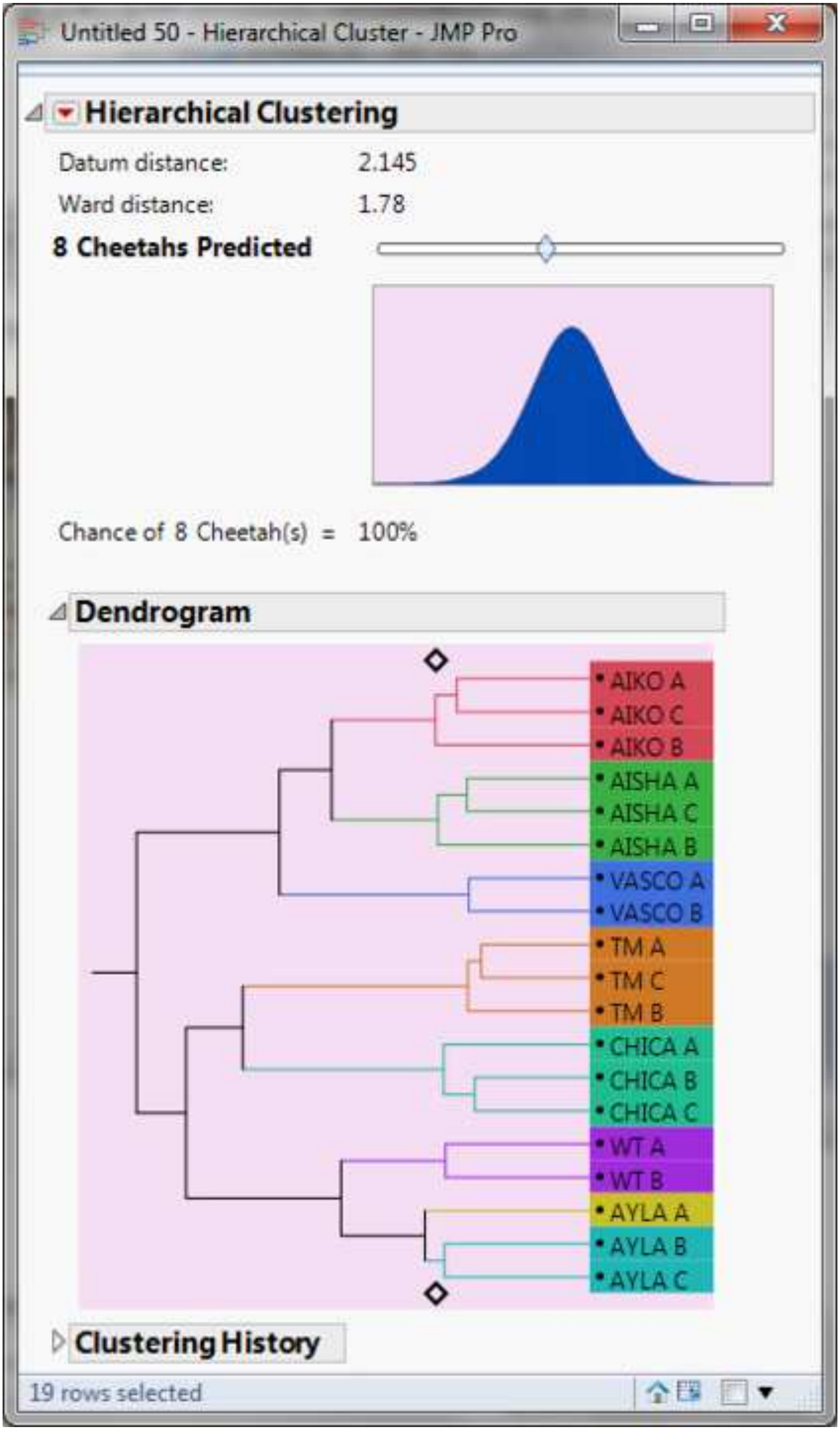

Figure 5c

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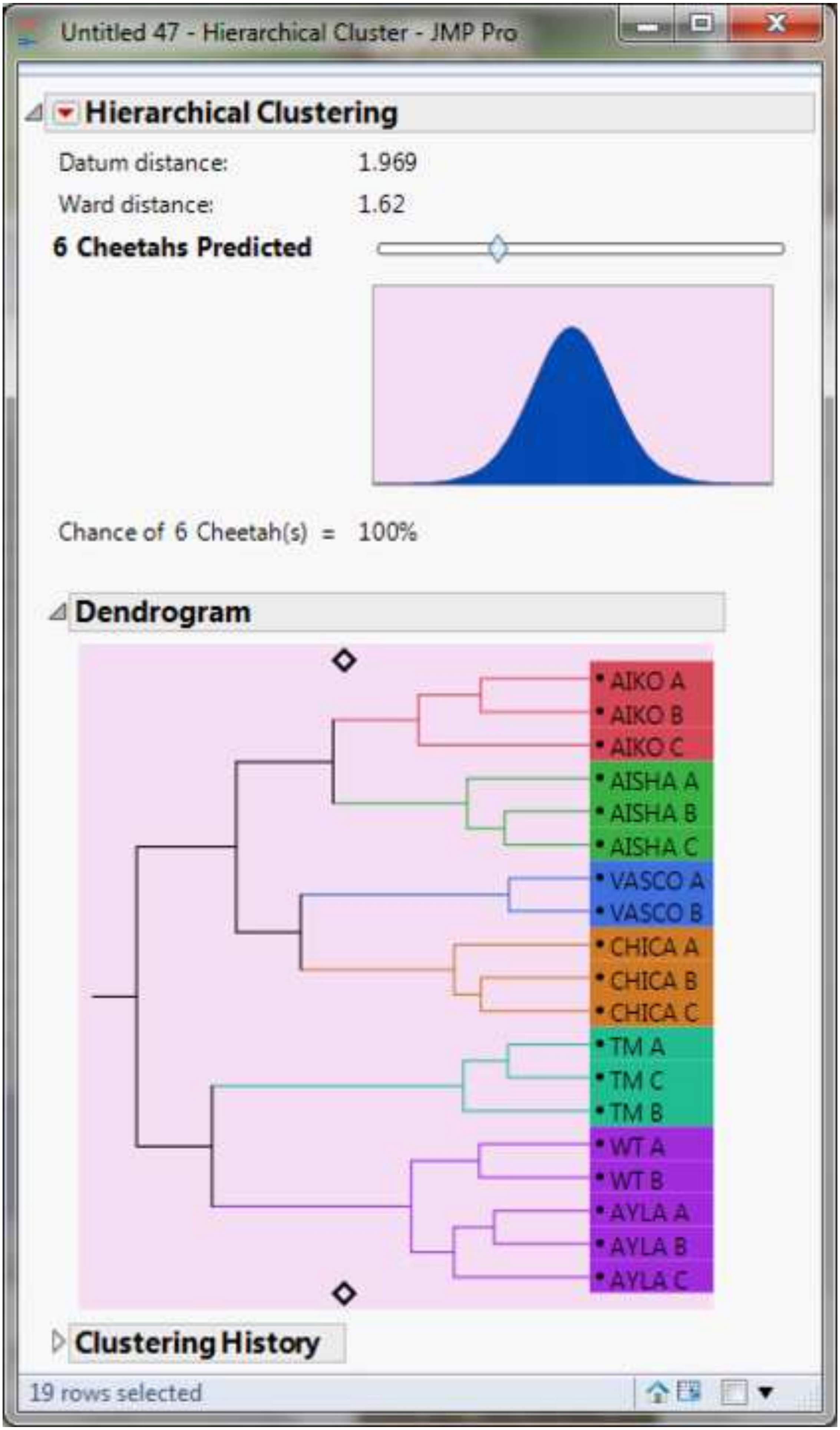

Figure 6

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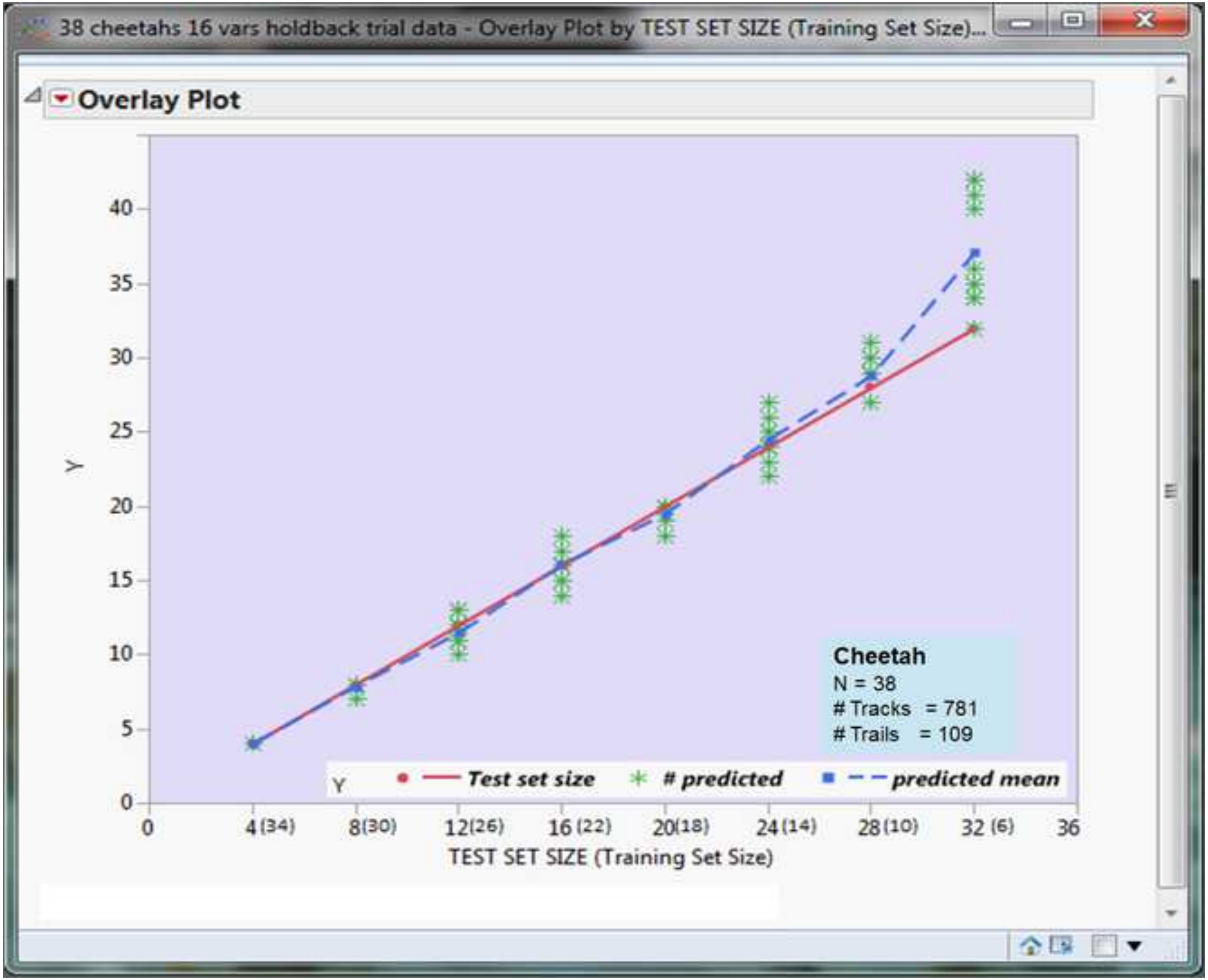

Figure 7a

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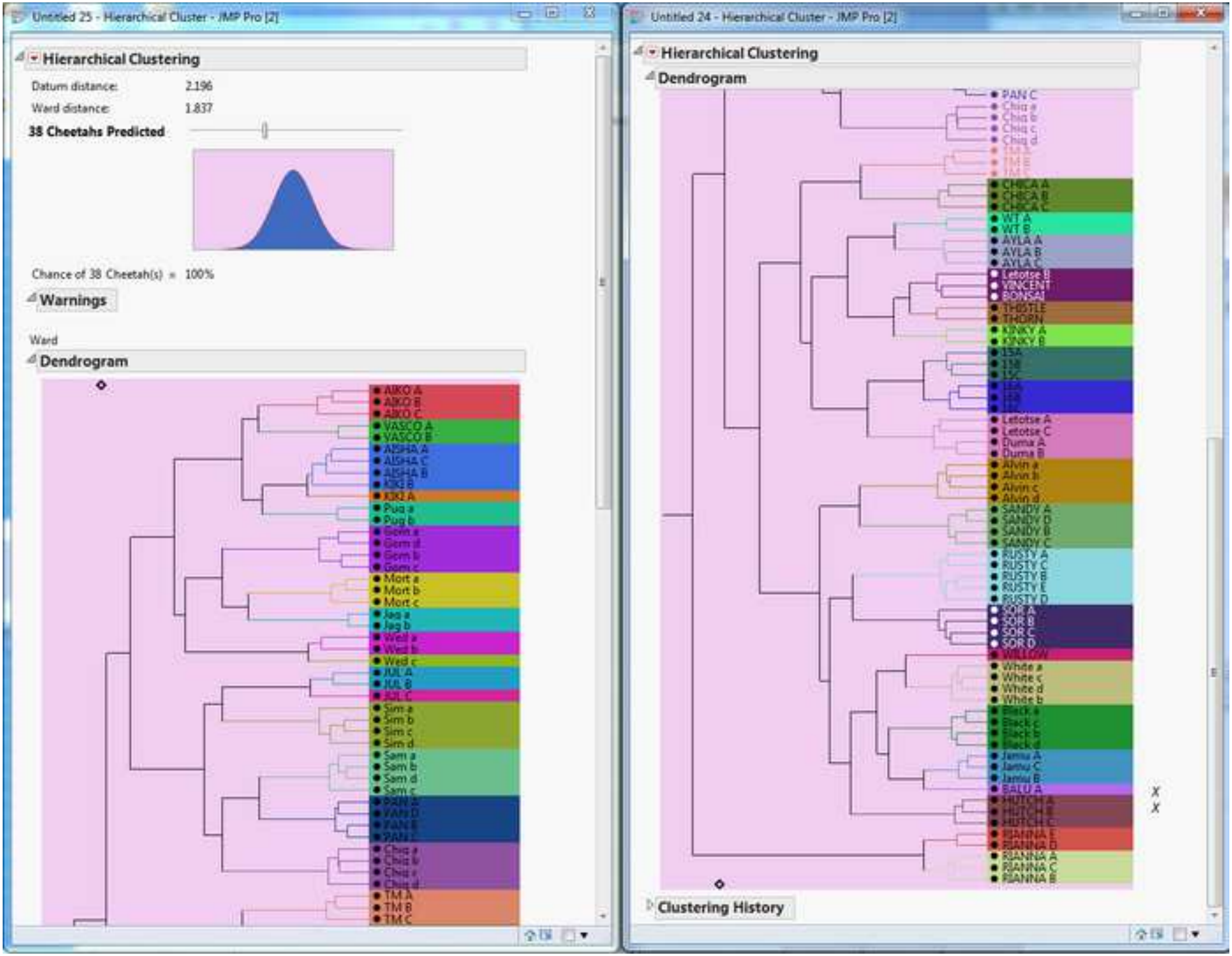

Figure 7b

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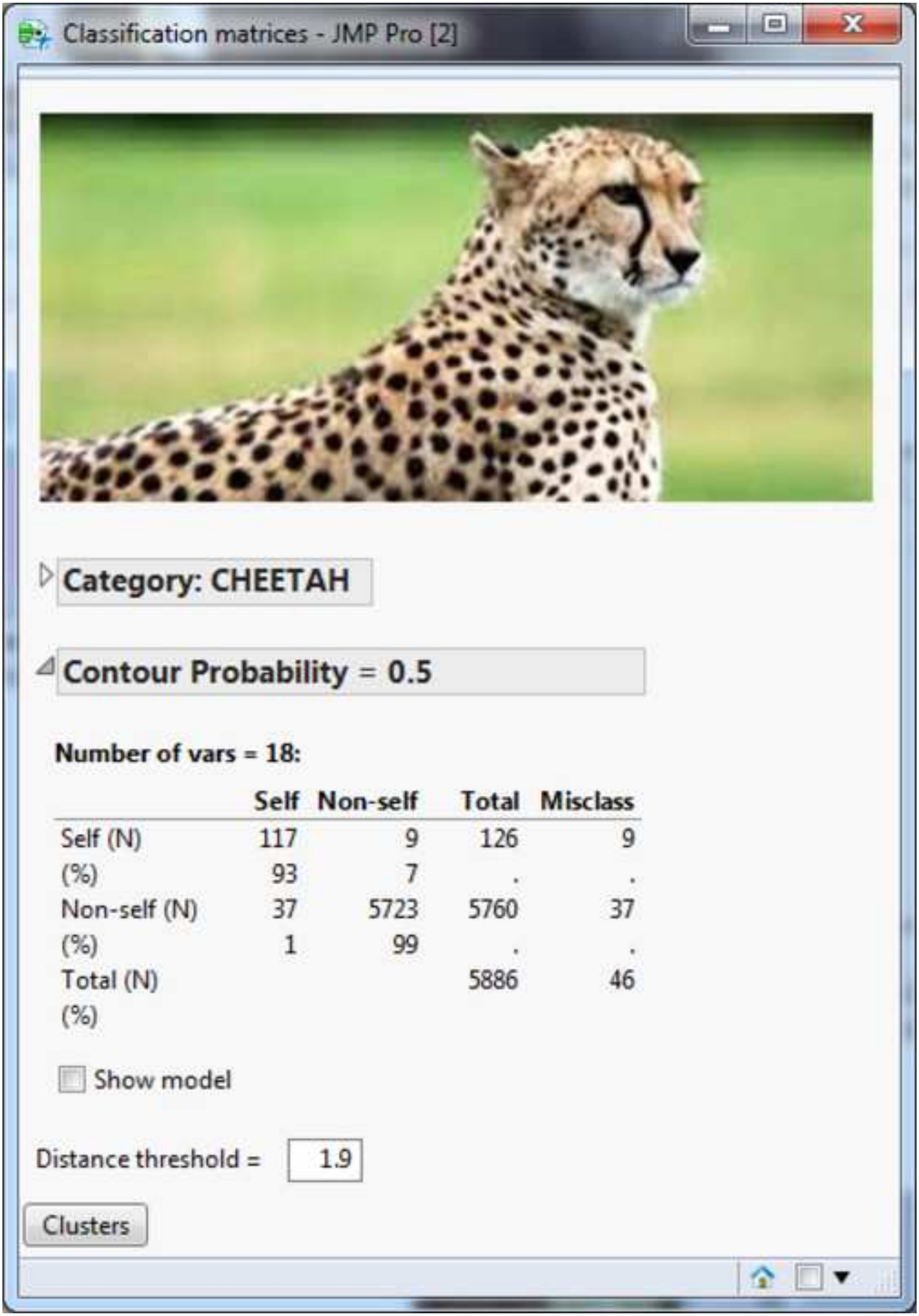

Figure captions for jove

Fig. 1. The opening main menu window in FIT. FIT is an addin in JMP data visualization software from SAS designed to identify individulas, sex, age-class etc. from morphometric measurements. It also has a mapping capability which enables the tracking of animal movement patterns in time and space. A seamless integration allows the navigation between the different options.

Fig. 2. The feature extraction window in FIT deals with images. Capabilities include drag and drop images, automatic resizing to fit window, rotation of images for standardization, substrate depth factoring etc. Pre-assigned landmark points are placed which will generate a series of scripted derived points to enable the extraction of metrics in the form of distances, angles and areas. The output is in the form of a row of data providing the xy co-ordinates and the metrics.

Fig. 3. Pairwise data analysis window in FIT. Once a database of measurements has been created, the pair-wise analysis window is designed to help validate the data and/or test for data from unknown populations. The analysis is based on a customized model incorporating a constant which compares pairs of trails sequentially. The final ouput is in the form of a cluster dendrogram which provides a prediction for the number of individuals and the relationship between the trails.

Fig. 4. The figure shows the outcome of a pair-wise comparison of trails from the same individual (A) and two different individuals (B) based on a customized model developed in JMP. The classifier incorporated into the model is based on the presence or absence of overlap between the ellipses.

Fig. 5. A dendrogram of a sample of trails from seven cheetahs showing the correct prediction when the algorithm is optimized (A) and when the algorithm is suboptimal (B & C). The algorithm is based on three adjustable entities, the number of measurements used, the ellipse size (confidence interval used) and finally, the threshold value which determines the cut-off value for the clusters.

Fig. 6. Dendrogram showing the predicted outcome when all 109 trails from 38 cheetah are included in the analysis. The important thing here is to not the fidelity of the trails forming the clusters. With the misclassifications it was interesting to note that many of them occurred between littermates e.g. cheetahs Letotse /Duma and Vincent/Bonsai.

Fig. 7. A holdback trial carried out sequentially by varying the proportion of cheetahs in the test and training sets. Rather than apportioning cheetahs to training and test sets arbitrarily, an analyses was performed sequentially increasing the test set size. For each test set, 10 iterations were performed with cheetahs being selected randomly for each iteration. For each test set, this allowed a mean value to be calculated. The figure shows the varying test size plotted against itself (red), and on the y axis the predicted value for each test size iteration (green) and the mean predicted value for each test size (blue). It can be seen that even when the test set size is increased considerably (28) compared with the training set size (10), the mean predicted value is similar to the expected value.

	# of cheetahs	# of footprint images	Range of footprints per cheetah	# of trails	Range of trails per cheetah	Age range (yrs)
Females	16	386	12 - 36	55	2 - 5	2.5 – 8.5
Males	22	395	7 - 32	54	1 - 4	1 - 11
Total	38	781	7 - 36	109	1 - 5	1 - 11

Table 1. Summary of data

Excel Spreadsheet- Table of Materials/Equipment

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Table of Materials/Equipment

ITEM
Garden shovel
Garden rake
Substrate tamper
River or builders sand
Buckets
Watering can or sprayer
Digital camera
Paper for Photo ID slips
Carpenters' cm folding rule
Laptop or desktop computer
JMP software
FIT add-in to JMP software

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Author(s): JEWELL, Z.C; ALIBHAI, S.K.; WEISE, F. VAN VUUREN, M; VAN VUUREN, R; & MUNRO, S.

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