The Rufford Foundation
Final Report

Congratulations on the completion of your project that was supported by The Rufford Foundation.

We ask all grant recipients to complete a Final Report Form that helps us to gauge the success of our grant giving. The Final Report must be sent in **word format** and not PDF format or any other format. We understand that projects often do not follow the predicted course but knowledge of your experiences is valuable to us and others who may be undertaking similar work. Please be as honest as you can in answering the questions – remember that negative experiences are just as valuable as positive ones if they help others to learn from them.

Please complete the form in English and be as clear and concise as you can. Please note that the information may be edited for clarity. We will ask for further information if required. If you have any other materials produced by the project, particularly a few relevant photographs, please send these to us separately.

Please submit your final report to jane@rufford.org.

Thank you for your help.

Josh Cole, Grants Director

Grant Recipient Details	
Your name	Antoine Marchal
Project title	3D Tracking : An Innovative Non-invasive Method for Wildlife Monitoring
RSG reference	18780-1
Reporting period	November 2015 - May 2017
Amount of grant	£4977
Your email address	marchal.ant@gmail.com
Date of this report	12 July 2017

1. Please indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
Develop a field technique to create digital 3D models of paws and tracks using photogrammetry.				This technique is based on the following article: Marchal, A. F. J., Lejeune, P., & Bruyn, P. J. N. (2016). Virtual plaster cast: digital 3D modelling of lion paws and tracks using close-range photogrammetry. *Journal of Zoology*, *300*(2), 111-119.
Build a reference database including 3D tracks and paws from the targeted species.				Our reference database contains thousands of tracks from the targeted species. In addition to cheetahs, leopards and lions, we also sampled tracks from African wild dogs, domestic dogs and spotted hyenas. The database also contains hundreds of lion paws.
Feature extraction from 3D tracks and paws.				We successfully applied an advanced morphometric technique, namely geometric morphometrics, to extract the information from tracks and paws by means of fixed landmarks with curve and surface sliders.
Identification algorithms at species, age, sex and/or at individual level.				Using lion tracks and paws, we analysed the differences in size and shape between various age-sex categories (i.e. juvenile female, juvenile male, sub-adult female, sub-adult male, adult female and adult male) and according to the antero-posterior (front or hind) and medio-lateral (right or left) position. We also studied the possibility of identifying individual lions from their tracks and gaits. For the other species, we worked on different identification algorithms to identify the species from their tracks.
Photogrammetry versus				Due to high costs and practicability

lasergrammetry.				in the field, we eventually decided not to work with laser scanners anymore. Rather we focused on photogrammetry that represents a cheap alternative to create digital 3D models using a normal digital camera. The ultimate goal is to develop a method that can be used widely.
Substrate and manipulator bias.				We tested the manipulator repeatability in terms of landmark positioning. We built a reference object that consists of a 3D printed lion paw and track. This reference object will enable us to test different cameras, measure the manipulator bias during data acquisition and assess the influence of the substrate on tracks.
Review of the current use of animal tracks.				This review is part of the first chapter of the main applicant's PhD Thesis.
International community of '3D Trackers'.				We created two non-profit organisations, one in Belgium and one in South Africa. Both organisations are named 'Wildlife 3D Tracking'. The two organisations have a common website (www.wildlife3dtracking.org). In the near future, this website will host a platform named 'eTrack'. Anyone in the world will be able to upload track pictures onto the platform where they will be automatically transformed into digital 3D models.

2. Please explain any unforeseen difficulties that arose during the project and how these were tackled (if relevant).

Working with wild animals always takes time, especially when it comes to animals that are potentially dangerous to humans such as lions. We could have worked with captive animals but we would have been dealing with other disadvantages: captive animals can be overfed and may not display their natural gaits, and the substrate from captive animal facilities can be very different from natural substrate. Furthermore, some captive animal facilities do not always follow acceptable animal ethics. Therefore we have only done work with wild animals and their tracks were sampled following direct observations (either after a sighting, or by using telemetry)

or in front of camera traps. In some instances, tracks were identified through the use of tracking books.

Two of our study sites, Hluhluwe-iMfolozi Park and Tembe Elephant Park, were provincial parks and one of them, Kgalagadi Transfrontier Park, was a national park. Doing research in protected areas that are managed by the government always takes time due to administrative procedures. But now that this project research has already taken place, future work in these study sites or with the same conservation agencies will be easier to implement.

The capture of wild lions is always difficult due to logistical reasons. When the lions are sedated, there is a limited amount of time that can be used to collar, brand, draw blood and insert a micro-chip into the individuals before they wake-up. Therefore, conducting any additional manipulation, such as 3D sampling the paws, represented quite a challenge. To do this, we had to design a sampling protocol that was as simple and as quick as possible. With our technique, we only required 15 pictures per paw to reconstruct the digital 3D model using a normal digital camera. The manipulation takes less than 5 minutes per lion.

3. Briefly describe the three most important outcomes of your project.

We developed and tested a reliable, objective, practical, cost- and time-effective field technique to sample animal tracks in 3D by using a normal digital camera. This technique, which requires low logistical supports, will enable long-term longitudinal data sampling in remote and resource-limited areas. Local community members, traditional trackers and citizen scientists from around the world will be able to use this easy-to-use technique.

After spending much time out in the field, we built a significant reference database that contains 3D tracks from six different species: cheetah, leopard, lion, African wild dog, domestic dog and spotted hyaena. The information extracted from the tracks enables us to develop several identification algorithms at the species, age, sex and/or at individual level. These algorithms can now be used to monitor wild populations and to gain a better understanding of the human-wildlife conflict.

During the project we had the opportunity to spend time with two traditional San trackers (also known as Bushmen) in the Kalahari Desert. The trackers were very interested by our 3D sampling technique and by its potential applications in wildlife studies. They even agreed to try the technique themselves on a lion track.

4. Briefly describe the involvement of local communities and how they have benefitted from the project (if relevant).

In each study site, we had to be accompanied by a local armed field guard to insure our security when walking out of sight of our research vehicle. All the guards were really enthusiastic about working on tracks. They were also intrigued by the recording technique that was neither drawing nor making a plaster cast, but rather about creating a 'virtual plaster cast'.

In the community lands surrounding Hluhluwe-iMfolozi Park, we had to collaborate with community members in order to sample tracks from their domestic dogs. Local farmers were interested to know that we were developing a method to assist them in the conflict between humans and wildlife. In fact, it is not uncommon for them to lose livestock to African wild dogs or spotted hyaenas that are wandering out of the park. In the case of Hluhluwe-iMfolozi Park, surrounding farmers can receive compensation from the park management whenever they can prove that African wild dogs were responsible of the killing of their livestock.

Meeting the San trackers was one of the most important outcomes of this project. The San people are the indigenous hunter-gatherers of southern Africa and they are master trackers. Unfortunately, their lifestyle and skills are disappearing. We believe that reviving the ancestral art of tracking using current technologies would help to preserve their culture and tradition. Modern science still has much to learn from indigenous knowledge and the synergy between the two can be used to empower the trackers. The two trackers that we met were very keen to learn about our project and they are looking forward to future collaborations.

5. Are there any plans to continue this work?

Yes, work will continue through the two non-profit organisations that we have created as part of this project. Both organisations are named 'Wildlife 3D Tracking' or 'W3DT', one is registered in Belgium and one in South Africa.

The vision of W3DT is:

'Reviving the Ancestral Art of Tracking using Current Technologies for the Benefit of Nature & Indigenous Trackers'.

The goals of W3DT can be organised as following:

1. Wildlife Monitoring
    - To set up an online platform named eTrack where people from around the world will be able to upload pictures of tracks and their relevant information. Track sampling will follow a simple protocol so that pictures will be automatically converted into digital 3D models using computer vision and photogrammetry.
    - To develop identification algorithms for species, age, sex and/or at individual level using the information extracted from tracks.
    - To apply the identification algorithms in non-invasive monitoring of wild populations.
    - To use the identification algorithms for a better understanding of the human-wildlife conflict.
2. Indigenous Trackers
    - To locate the remaining indigenous trackers and train future generations in the art of tracking.
    - To empower indigenous trackers and get them involved in nature conservation.

- To preserve indigenous knowledge, and facilitate the synergy between art of tracking and science.

3. Anti-Poaching
   - To use the recording technique on human tracks in support of the on-going fight against poaching.

6. How do you plan to share the results of your work with others?

The results on lion tracks and paws are available in the main applicant's PhD Thesis that is entitled 'Monitoring lions (*Panthera leo*) using digital 3D models of their tracks'. The results comparing tracks from African wild dogs and domestic dogs are available in the Master Thesis of Maude Vandenabeele.

The work on spotted hyena tracks will be available in the Master Thesis of Nicolas Deflandre in September 2017.

A scientific article entitled 'Identification of the anteroposterior and mediolateral position of lion paws and tracks using 3D geometric morphometrics' has been accepted for publication in 'African Journal of Wildlife Research' (Impact Factor: 1.143). The article will be published in October 2017.

We are still working on additional scientific articles. We also wish to share the results of our work through soft publications to reach the general public. Such an article entitled '*Modélisation 3D de pattes et de traces de lions*' ('3D modelling of lion paws and tracks') has been published in French in the Newsletter of Gembloux Agro-Bio Tech (University of Liège, Belgium):

http://www.gembloux.ulg.ac.be/blog/modelisation-3d-de-pattes-et-de-traces-de-lions/

The website of W3DT (www.wildlife3dtracking.org) and associate social media accounts will also be used to share the results of our work.

7. Timescale: Over what period was The Rufford Foundation grant used? How does this compare to the anticipated or actual length of the project?

The Rufford Foundation grant was used over a period of 19 months (from November 2015 to May 2017) (see section 8 of this report for details). The funds were received on 21 January 2016 but we had the authorisation from Jane Raymond to incorporate our research expenses from November and December 2015 in the budget.

The actual length of the project was longer than expected due to logistical reasons, administrative procedures (for the set up of the two non-profit organisations) and mainly due to the completion of the main applicant's PhD degree (writing up, submitting a scientific article, and preparation for both a private and public PhD defence).

8. Budget: Please provide a breakdown of budgeted versus actual expenditure and the reasons for any differences. All figures should be in £ sterling, indicating the local exchange rate used. (ZAR1= £0.052/53)

Item	Budgeted Amount	Actual Amount	Difference	Comments
Accommodation	518	-652	-134	We were originally not planning to conduct any fieldwork in Kgalagadi Transfrontier Park when we did the budget. Accommodation fees are more expensive in that study site than in Hluhluwe-iMfolozi and Tembe Elephant parks.
Travel costs	2486	-2357	129	The difference may be explained by the fact that the program has changed due to the addition of a third study site.
Field ranger	864	-432	432	We did not have to pay for the field ranger in the third study site that was added after submission of our grant application. Furthermore we also had a special authorisation to check our camera traps in the vicinity of the research vehicle without the presence of an armed guard in both Hluhluwe-iMfolozi Park and Tembe Elephant Park.
Website	74	-291	-217	We decided to buy additional options/services for our website (such as a premium account, and personalised domain and mailbox).
Registration of non-profit organisations	298	-209	89	Registering the two non-profit organisations in Belgium and South Africa was less expensive than expected.
DSLR camera	273	-216.9	56.1	We managed to find a better price on the digital camera than expected.
Camera lens (+ SD card)	96	-239.2	-143.2	Unfortunately the price of the lens in South Africa was much more expensive than expected.

				We also bought a SD card with the lens.
Binoculars	157	-141.7	15.3	We managed to find a better price on the binoculars than expected.
Handheld GPS	173	-82.5	90.5	We managed to find a better price on the handheld GPS than expected.
3D printing for reference object	0	-24.2	-24.2	This expense was necessary but not anticipated.
Base for reference object	0	-19.1	-19.1	This expense was necessary but not anticipated.
Broom for sweeping camera trap stations	0	-6.6	-6.6	This expense was necessary but not anticipated.
Universal charger for GPS's batteries	0	-32	-32	This expense was necessary but not anticipated.
Square rulers	0	-4.2	-4.2	This expense was necessary but not anticipated.
Telemetry antenna	0	-189.4		This expense was necessary but not anticipated. The antenna that we were supposed to borrow from the ecologists was not available anymore.
Rhinoceros software for 3D processing	0	-92.8	-92.8	This expense was necessary but not anticipated.
Compact digital camera	38	0	38	Finally we did not have the need for a compact digital camera.
TOTAL	4977	-4989.6	-12.6	The balance was paid out with our own fund.

9. Looking ahead, what do you feel are the important next steps?

The important next steps will be:

- To set up the eTrack platform;
- To sample more tracks from different species and/or from different locations;
- To keep improving the method that we have developed (in terms of recording technique, feature extraction and statistical analyses);
- To facilitate collaborations and particularly the involvement of local communities and indigenous trackers in the work of W3DT;
- To constantly share the results of our work, raise awareness and increase the exposure of W3DT to the general public.

Although our long-term goal is for W3DT to be financially stable and supported by other larger-scale funders, we wish to apply for a second Rufford Small Grant to help us fulfil the next important steps of our project.

10. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did The Rufford Foundation receive any publicity during the course of your work?

The Rufford Foundation logo was displayed during the following talks that were part of scientific conferences and/or meetings:

- Age and sex identification from digital 3D models of lion tracks using geometric morphometrics. 15th Savanna Science Network Meeting (SSNM), Skukuza, Kruger National Park, South Africa (March 2016).
- Age and sex identification from digital 3D models of lion paws using geometric morphometrics. Southern African Wildlife Management Association (SAWMA) Symposium, Tzaneen, South Africa (September 2016).
- Species discrimination between African wild dog (*Lycaon pictus*) and domestic dog (*Canis lupus familiaris*) tracks. Wild Dog Advisory Group of South Africa (WAG-SA), Tzaneen, South Africa (September 2016).
- Foot identification from digital 3D models of lion tracks and paws. 14th Savanna Science Network Meeting (SSNM), Skukuza, Kruger National Park, South Africa (March 2016).

The logo was also placed on the following posters that were presented during a scientific conference and a congress:

- Using photogrammetry for age, sex and individual identification from lion trails. International Long-Term Ecological Research Network (ILTER) Open Science Meeting, Skukuza, Kruger National Park, South Africa (October 2016).
- Back on Track… in 3D. International Union for Conservation of Nature (IUCN) World Conservation Congress, Honolulu, Hawaii State, USA (September 2016). This e-poster is available online: https://portals.iucn.org/congress/session/10098

The logo is displayed in the article '*Modélisation 3D de pattes et de traces de lions*' ('3D modelling of lion paws and tracks') that has been published in the Newsletter of Gembloux Agro-Bio Tech (University of Liège, Belgium). The article is available online: http://www.gembloux.ulg.ac.be/blog/modelisation-3d-de-pattes-et-de-traces-de-lions/

The Rufford Foundation was mentioned in the acknowledgements of the article entitled 'Identification of the anteroposterior and mediolateral position of lion paws and tracks using 3D geometric morphometrics' that has already been accepted and that will be published in October 2017 in 'African Journal of Wildlife Research' (Impact Factor: 1.143).

The Rufford Foundation was acknowledged in the PhD Thesis of Antoine Marchal and the Master Thesis of Maude Vandenabeele. The logo was displayed during the defences of both degrees.

Finally, the logo is displayed on W3DT website (www.wildlife3dtracking.org).

11. Please provide a full list of all the members of your team and briefly what was their role in the project.

Nico de Bruyn and Philippe Lejeune were the two co-supervisors of the principal applicant's PhD research. They brought valuable input into the project, especially in terms of academic and scientific aspects. Both of them will still be involved in W3DT. They also provide a useful link with their respective universities, namely the University of Liège (Belgium) and the University of Pretoria (South Africa).

Dave Druce and Catheriné Hanekom are the ecologists of Hluhluwe-iMfolozi Park and Tembe Elephant Park respectively. Their role was mainly about providing field expertise and facilitating the access to their protected areas. Both of them work for the provincial conservation agency named Ezemvelo KZN Wildlife with who we wish to further our collaborations through W3DT.

Maude Vandenabeele and Nicolas Deflandre were two master students from the University of Liège who helped us with the data collection and analysis.

12. Any other comments?

We would like to sincerely thank the Rufford Foundation for their precious support. We are confident that this project will have long-lasting impact in terms of nature conservation and local community empowerment through W3DT. We wish to re-apply for additional funding from Rufford Foundation, and hope that our application will be successful.