What We Can Learn from CyberTracking: Applications of an International Tracker Evaluation System for Professional and Citizen Science, and the Theory of Original Wisdom

Kersey Lawrence

Ph.D., University of Connecticut, 2020

Abstract

Wildlife tracking is an old skill, one that belonged to and was formative to every culture on Earth. Today, few cultures retain the traditional ecological knowledge of their oldest skills, and many pieces of this knowledge have been lost to modernization. Wildlife tracking is different, however, not because there are only a few cultures today that still use tracking to find food and for safety, but because there has been a resurgence of interest among people who do not consider themselves indigenous to the place where they track, and did not learn the skills directly from their ancestors. Among all trackers, indigenous or not, some are better than others. Their degree of skill is based on what captures their interest and how much time they spend practicing. The word "indigenous," however, has become synonymous with "expert" when it comes to collecting track-based data for science, regardless of evidence of experience or expertise. Furthermore, identification and interpretation of wildlife tracks and signs are commonly required skills in modern biological science to locate and determine the presence of animal species, count populations, and identify individual animals, yet most research conducted with track-based data does not include a metric of the skill and reliability of the person collecting the data. Track-based data collected by unskilled and untrained people can result in unreliable conclusions, which can negatively impact wildlife and land management.

This research includes an in-depth quantitative and qualitative analysis of trackers evaluated by and certified through *CyberTracker Conservation's Tracker Certification System*. The research goals were to: 1) review how track-based data is being collected for scientific research, and provide guidelines for reporting the skill level of trackers in future research, 2) test the reliability of the system for evaluating trackers' skills, 3) provide guidelines for determining when an expert tracker is needed to collect track-based data, 4) to examine the human dimensions around what it takes to become an expert tracker, and 5) determine whether or not the modernization of an indigenous tracking is resulting in a net loss of traditional ecological knowledge.

What We Can Learn from CyberTracking: Applications of an International Tracker Evaluation System for Professional and Citizen Science, and the Theory of Original Wisdom

Kersey Lawrence

B.S., 1999, Natural Resources Management & Engineering, University of Connecticut

M.S., 2009, Natural Resources & the Environment, University of Connecticut

A Dissertation

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

at the

University of Connecticut

2020

ISBN 978-0-620-90235-9

APPROVAL PAGE

Doctor of Philosophy Dissertation

What We Can Learn from CyberTracking: Applications of an International Tracker Evaluation System for Professional and Citizen Science, and the Theory of Original Wisdom

Presented by

Kersey Lawrence, M.S.

Major Advisor________________________

Thomas H. Meyer

Associate Advisor________________________

Tracy A. G. Rittenhouse

Associate Advisor________________________

Robert M. Ricard

Associate Advisor________________________

Howard J. Kilpatrick

Acknowledgements

To Lee and Manoa, for (mostly) quietly enduring the time away from each other that this journey has taken.

To my parents, John and Donna Grott, for always giving me the trust and freedom to wander off and explore the wild spaces around me as a child, and for loving and supporting me unconditionally throughout my life.

This work would not have been possible without the guidance and patience of my advisor, Professor Thomas H. Meyer. It's been a joy to work with such an incredibly talented and caring individual.

In addition to my advisor, the other committee members who participated in this process deserve my appreciation for their role in "getting this done, and done well." They are Dr. Tracy Rittenhouse, Dr. Howard Kilpatrick, and Dr. Robert Ricard. Dr. Chadwick Rittenhouse and Dr. L. Mark Elbroch also provided some wonderfully insightful and constructive feedback to incorporate into publications.

Thanks to all the quantitative experts I've consulted with over the years, including Dr. Patrick Joyce, Brian Bader, and Professor Ming-Hui Chen, all from the Center for Applied Statistics at UCONN, and Sartaj Singh at Codementor. I also owe a great deal to Dr. Robert Ricard at UCONN for introducing me to the rich environment of qualitative analysis and the human dimensions of scientific work.

Funding for various aspects of this research came from Nature Guide Training PTY LTD, the Norcross Wildlife Foundation Inc., the Ellen Bishop Carder Scholarship, the Center for Environmental Sciences and Engineering at UCONN, the New England Outdoor Writers Association and the James V. Spignesi Jr. Memorial Scholarship, the Connecticut Agricultural Experiment Station and the French Foundation.

This work is dedicated to all the trackers who I worked with and studied alongside, across the world, during this adventure, and the many lodges and reserves who support those in South Africa, and especially to Louis Liebenberg, who developed the CyberTracker Tracker Certification System and continues to refine it and to travel to remote places and identify and uplift talented trackers. Together, with Master Trackers Adriaan Louw and Dr. L. Mark Elbroch, they brought it to the rest of the modern world.

And finally, to the animals who make the tracks that trackers identify, interpret, and follow, in order to find them.

"Famba landza nkonzo" (Xitsonga, the Shangaan language of South Africa)

"Let's go tracking" (English).

Table of Contents

Chapter 1 – Introduction and Synopsis of Chapters

Abstract

Wildlife tracking is an old skill, one that belonged to and was formative to every culture on Earth. Today, few cultures retain the traditional ecological knowledge of their oldest skills, and many pieces of this knowledge have been lost to modernization. Wildlife tracking is different, however, not because there are only a few cultures today that still use tracking to find food and for safety, but because there has been a resurgence of interest among people who do not consider themselves indigenous to the place where they track, and did not learn the skills directly from their ancestors. Among all trackers, indigenous or not, some are better than others, just like in every traditional village some people were better at making clothing than others, or making pottery, or baskets. Their degree of skill was based on what captured their interest and how much time they spent practicing. The word "indigenous," however, has become synonymous with "expert" when it comes to collecting track-based data for science, regardless of evidence of experience or expertise. Furthermore, identification and interpretation of wildlife tracks and signs are commonly required skills in modern biological science to locate and determine the presence of animal species, count populations, and identify individual animals, yet most research conducted with track-based data does not include a metric of the skill and reliability of the person collecting the data. Track-based data collected by unskilled and untrained people can result in unreliable conclusions, which can negatively impact wildlife and land management.

CyberTracker Tracker Certifications were developed in South Africa in the 1990's to measure the accuracy of trackers, and have become the "gold-standard" for evaluating the skill of trackers across the world. Participants spend two days being evaluated, in-the-field, and

receive a score that reflects their skill level. Evaluations have been conducted for many, non-literate, indigenous San groups of people, as well as for other indigenous African trackers, western scientists, and tracking enthusiasts around the world.

This research includes an in-depth quantitative and qualitative analysis of trackers evaluated by and certified through CyberTracker. The research goals were to: 1) review how track-based data is being collected for scientific research, and provide guidelines for reporting the skill level of trackers in future research, 2) test the reliability of the CyberTracker Tracker Certification System for evaluating trackers' skills, 3) provide guidelines for determining when an expert tracker is needed to collect track-based data, 4) to examine the human dimensions and develop a theory of what it takes to become an expert tracker, and 5) determine whether or not the modernization of an indigenous tracking is resulting in a net loss of traditional ecological knowledge.

Chapters included in this dissertation reflect those goals. Chapter two is a content-analysis of peer-reviewed, published scientific journal articles on how track-based data is collected for wildlife research. It provides guidelines for determining when a certified tracker is necessary. Chapter three is a quantitative analysis on the accuracy of trackers certified at different levels of skill in CyberTracker tracker evaluations. Chapter three also includes a qualitative component derived from questions answered by participants in survey instruments, and a validation of the process with camera trapping data. Chapter four is a qualitative analysis from interviews with trackers, some employed, full-time, as trackers in ecotourism in South Africa, and others engaged in tracking recreationally or as a partial aspect of their work. I describe how trackers in the Greater Kruger region of South Africa might reflect a global transition away from tracking as isolated pockets of traditional ecological knowledge within small subgroups of indigenous people to a revival and growth among a much broader demographic of people that spans continents and cultures. I propose the culture of tracking as opposed to cultures that track, in a constructivist grounded theory where tracking is Original Wisdom.

Introduction

Wildlife tracking includes two distinctly different but complementary activities: the first activity is where people identify and interpret tracks (footprints) and signs (broken branches, browsed vegetation, beds, kill sites, feathers, bones, scats, etc.), and the second activity is where people follow a series of fresh tracks and signs – a human's or animal's trail - to find the trail's maker. Either of these two activities, tracks and signs identification and interpretation (T&S), or trailing, are colloquially called tracking, and people who conduct both, or either, of these two activities are called trackers (Liebenberg 1990*a*, *b*, Liebenberg et al. 2010). Comprehensive knowledge of T&S has been described as a fundamental building block to becoming a good tracker, similarly to learning the A, B, C's of the English language before beginning to put together words and sentences. Trailing is further described as similar to when those words and sentences become paragraphs and form an actual story. Trailing well is not possible without knowing T&S, and trackers are not actually tracking, they aren't trackers, until they are reading the story of the animal they are following. That story includes reading how the animal interacts with the landscape, with other creatures on that landscape, and then finding the animal without it becoming aware that it is being observed (Liebenberg 1990*a*, Liebenberg et al. 2010, Logie 2010, Du Plessis 2010, 2018, Ijäs 2017).

Some trackers follow and find humans for search and rescue or fugitive purposes, but this research focuses on wildlife tracking. In this research I use the term tracking (and variations of that term) to mean the identification, interpretation, and following of tracks and signs to find animals. I am not referring to the use of scent dogs, spatial and temporal data associated with telemetry, including Global Positioning Systems (GPS), genetic markers, or other technologies or laboratory procedures used to find animals.

In order to study and conserve animals, we must know where they are located and how many there are (Wilson and Delahay 2001). Surveying animals is a foundational activity in wildlife research and conservation, where wildlife tracks and signs are classified as indirect-signs. Identifying tracks and signs of target species is a non-invasive survey technique that does not require the observer to capture, handle, or otherwise impact animals' lives or behaviors (Beier and Cunningham 1996, Gompper et al. 2006, Gruber et al. 2008). Observers are required to identify suitable habitat for, and indicators of (tracks and signs) the target species' presence where the species are not directly observed (Wilson and Delahay 2001, Gusset and Burgener 2005, Gompper et al. 2006, Gruber et al. 2008).

Citizen science projects include biologists, volunteers, and members of the general public. Citizen scientists sometimes collect track-based data for science and conservation. These projects often have multiple goals and results. Evidence shows that citizen science projects educate people about the targeted natural organisms and can increase awareness and concern for the environment and for participants' local communities (Cohn 2008, Jordan et al. 2011, Crall et al. 2012, Haywood 2014). A debatable result is that citizen science projects also allow people with no scientific background to learn about how to "conduct science" through their hands-on experiences (Brossard et al. 2005, Jordan et al. 2011).

Citizen scientists are often unpaid volunteers or low paid participants. Project managers can therefore hire large numbers of people to collect large datasets while keeping employment costs low and focus their funding on other project aspects instead of on equipment purchase and laboratory procedures (Hart et al. 2012). Scientists overseeing citizen science projects have noted, however, the need for some kind of quality control on data collected by observers with a wide variety of skill and knowledge levels (Jordan et al. 2011, Kremen et al. 2011, Hunter et al. 2012, Havens and Henderson 2013). The variety results in considerations of citizen science data as much less rigorous than professionally collected data (Mueller et al. 2012). This brings up a further question regarding who is considered a professional, and whether or not science professionals actually collect more reliable data in all instances (Lewandowski and Specht 2015). The majority of citizen scientists and professional scientists collecting track-based data do so with little or no training, and their skill level is unknown, resulting in the similarly unknown accuracy and reliability of the data collected (Evans et al. 2009).

The Audubon Society's Christmas Bird Counts are the longest running citizen science project. Christmas Bird Counts illustrate this dichotomy between rejecting the results as scientific work and emphasizing the value of teaching and learning (Mueller et al. 2012). Differences among observers, both professionals and volunteers, in bird counts are a well-documented source of potential error (Diefenbach et al. 2003, Alldredge et al. 2006, 2007). Researchers collecting presence-absence information in breeding bird surveys have documented bias's due to observer experience or skill level. They note that these variables should be included in data collection, reporting, and modeling (Sauer et al. 1994, Alldredge et al. 2006, 2007, McClintock et al. 2017).

None-the-less, researchers of terrestrial wildlife use tracks and signs as a measure of many responses with little or no attention to measuring observer bias. T&S is used to measure species: presence (Van Dyke et al. 1986, Zielinski and Kucera 1995, Zielinski and Stauffer 1996, Carroll et al. 1999, Crooks and Soulé 1999, Gusset and Burgener 2005, Stanley and Royle 2005, Gompper et al. 2006, Barnum et al. 2007, Crooks et al. 2008, Jeffress et al. 2011, Pirie et al. 2016); relative and absolute abundance (Skalski 1991, Allen et al. 1996, Edwards et al. 2000, Wilson and Delahay 2001, Silveira et al. 2003, Karanth et al. 2004, Gusset and Burgener 2005, Stanley and Royle 2005, Harrington et al. 2008, Funston et al. 2010, Keeping 2014); population sizes and densities (Becker 1991, Smallwood et al. 1995, Beier and Cunningham 1996, Zielinski and Stauffer 1996, Stander 1998, Hayward et al. 2002, Karanth et al. 2003, 2011, Stephens et al. 2006, Engeman and Evangilista 2007, Linnell et al. 2007, Balme et al. 2009, Golden et al. 2009, Keeping and Pelletier 2014); behaviors and habitats (Carroll et al. 1999, Alexander et al. 2005, Barnum et al. 2007, Elbroch and Wittmer 2013*a*, McHenry et al. 2016); and individual animal identities (Lewison et al. n.d., Fitzhugh and Gorenzel 1985, Smallwood and Fitzhugh 1993, Stander et al. 1997, Jewell et al. 2001, 2016, Wilson and Delahay 2001, Karanth et al. 2004, Herzog et al. 2007, Kerley and Salkina 2007, Alibhai et al. 2008, 2017, Harrington et al. 2008, Crowley et al. 2012, Wong et al. 2012, Elbroch and Wittmer 2013*a*, Marchal et al. 2016, Marchal 2017).

In wildlife research, non-detection of a species does not prove the absence of a species in an area (MacKenzie and Royle 2005, Stanley and Royle 2005). The probability of detecting a species includes the probability of finding it given it is present and the probability that the observer(s) correctly identify it. The second probability is seldom considered in research using track-based data (Evans 2007, Evans et al. 2009). Observers can bias data in two ways. First, false reports of non-target species that are mistakenly identified as the target species. This creates false-positives in data. Second, false-negatives occur when observers misidentify the target species as another species (Weidong and Swihart 2004, Evans 2007, Evans et al. 2009).

When track-based data are collected for science, identification and interpretation is considered so simple that anyone can do it, without training, experience, or expertise. Methods go undescribed or unreported, and, in many instances, no external verification of the data occurs (DNA, camera traps, etc.) (Alibhai et al. 2008, Louw, A., 2013, pers. comm.). For example, scientists assume that technicians will be able to differentiate the tracks and signs of different carnivores in varying substrates with little training and/or by consulting drawings or pictures in a published field guide (Crooks et al. 2008, Pirie et al. 2016). The unspoken assumption is that the data they collect will be unbiased and external verification is unnecessary.

When observer bias is not considered, negative effects can have real consequences. For example, Evans et al. (2009) documented observer bias by biologists and volunteers using tracks to identify river otter (*Lontra canadensis*) presence in an ongoing study in Texas that began in 1995. Results of their research showed both false-positives and false-negatives. River otter tracks were commonly confused with other species, and other species tracks were also commonly confused with river otter tracks. These errors occurred with both biologists and volunteers who returned, year after year, to collect data. It resulted in invalidating the results of the Texas otter-monitoring project (Evans 2007, Evans et al. 2009). Similarly, Karanth et al. (2003) and Sharma et al (2001) documented three decades of unreliable data collected by park rangers and wildlife managers on Asian tigers (*Panthera tigris*) in India's "pugmark census method" (Choudhury 1970, 1972, Sharma et al. 2001, Karanth et al. 2003).

Even though such research indicates that collecting reliable track-based data requires experience and/or verification, and that biased data can have profound impacts on management decisions (Smallwood and Fitzhugh 1993, Karanth et al. 2003, Silveira et al. 2003, Evans et al. 2009), the trend is still to hire persons with no experience in tracking, or to provide minimal or no training or evaluation of their tracking skills, before allowing them to collect track-based data (Evans et al. 2009).

To confirm the identification of track-based data, some scientists use comparative verification in the form of technology, mention, or describe the experience of their observers. Comparative verification is especially used when scientists attempt to interpret advanced questions, such as age, sex, specific behaviors, or individual animals from tracks and signs (Smallwood and Fitzhugh 1993, Grigione et al. 1999, Lewison et al. 2001, Purchase 2007).

Comparative technologies include comparison of the observer's identification with: computer modeling and statistical analysis of measurements taken from tracks, drawings, photos, plates, or track casts (Alibhai et al. 2008, Jewell and Alibhai 2012, Marchal et al. 2016), photos from remotely triggered camera traps (Wilson and Delahay 2001, Silveira et al. 2003, Gompper et al. 2006), positions in time and space from telemetry (Lawrence-Apfel et al. 2012), and genetic analysis from hair or scat (McKelvey et al. 2006) (sometimes combined further with identification from scat-detection dogs). These types of verification require theoretical and practical training for the practitioner to use them skillfully and are desirable when research budgets can include them (Pimm et al. 2015). In some instances, measurements and models derived from computer software are very accurate in analyzing photographs of clear tracks to determine species and even individual animals – but variations between observer measurements must be accounted for, tracks must be perfect and repeated, and the software does not work with signs. Using software to identify tracks also requires carrying equipment into the field and detailed computer analysis back in camp or in-office (Jewell et al. 2001, Alibhai et al. 2008) only to reach the same conclusions that have been proven possible with an experienced tracker (Stander et al. 1997, Elbroch et al. 2011, Wong et al. 2012). Scientists using technological tools recognize the need to have sufficient training in their skilled implementation, allowing them to move beyond a tool to a skill, but the assumption remains that tracking is so easy that anyone can do it without the training that allows it to be skillfully implemented (A. Louw, pers. comm. 2013). It too often remains an unskilled tool from the proverbial toolbox without evolving into the dynamic skill it actually is.

This brings us to the overall research question; what kind of experience does a tracker need to collect reliable data? Comparative verification with track-based data is more common and more economical with oversight from an experienced supervisor than with technology. Project leaders and species biologists often review information collected in the field to assist with identification. Project or biological experience, however, whether at a broad or a specific taxonomic grouping, infrequently includes experience with the T&S of the target animals or with other T&S that they could be commonly confused with (De Angelo et al. 2010). In studies where technology and experience were combined, Harrington et al (2010) conducted DNA analysis of scats collected by experienced observers and the scats were verified to not be from their target species. Zuercher et al. (2003), on the other hand, conducted the same type of comparison resulting in 100% agreement of scat identification between DNA and indigenous and local observers.

Some research suggests that people from indigenous cultures may be local experts, perhaps because they still live in a way that provides them with the prerequisite experience (Rutina et al. 2017). Stander et al (1997) showed that Ju/'Hoan San trackers who were raised in a hunting and gathering culture were able to correctly interpret complex scenarios and even to identify individual animals from their tracks and signs. Conversely, Rutina et al (2017) found that indigenous herder's in Botswana could not reliably identify the tracks and kill characteristics of different carnivore species preying on their livestock. Somewhere in the middle, Wong et al. (2012) showed that Inuit hunters were capable of identifying individual animals from tracks and signs, but that there were degrees of accuracy among hunters based on the quality and duration of their experience. These types of conflicting results are not isolated or rare, making it difficult to develop consistent guidelines for collecting and reporting of track-based information, with or without technology. Such guidelines should include what experience an observer needs to collect track-based data, and how that experience should be verified and/or reported.

This research is on people who describe themselves as trackers and have been evaluated in the *CyberTracker Tracker Certification System*, described below. Background information has been repeated and expanded, as needed, in each subsequent chapter for the chapter to be understood without the context of the other chapters. Similarly, enough of the methodology (research design), data analysis, results, and conclusions of each subsequent chapter have been repeated here to enable the reader to understand the major points of chapter on its own. The research questions for each chapter are different, but related, so the methods, data analysis, results, and conclusions are also different but together form an argument for ensuring that scientists provide evidence of the skill level of observers who collect track-based data. It’s not enough to state that a tracker comes from an indigenous background. Skill is based on training and experience, which are variable because skill and experience depend on the amount of time and the quality of effort spent by individuals.

Background

This research focuses on participants in an international tracker certification system, CyberTracker Tracker Evaluations. CyberTracker evaluations provide participants with a metric of their current tracking expertise in a field evaluation format (Liebenberg et al. 2017). The field evaluation also serves as an instructional workshop, in which participants gain experience in how to differentiate tracks and signs of different species, including those with similar size and foot morphology that are easily confused. Field evaluations also improve the accuracy and reliability of participants' skills by utilizing an immediate feedback testing system that facilitates learning (Dihoff et al. 2003, Liebenberg et al. 2017).

In much of Africa, the term, tracker, connotes a specific occupation. Trackers in Africa are black-skinned persons of tribal descent, frequently non-literate, and have historically participated in cultures that live close to the land in hunting, gathering, agrarian, or pastoral lifestyles by which they obtained profound naturalist or ecological knowledge about the landscape and the organisms that live on it (Carruthers 1995, 2003, Zips and Zips- Mairitsch 2007). This traditional-ecological knowledge (Rutina et al. 2017) assists trackers in identifying and interpreting what they see on the land (T&S), and in the pursuit of animals (trailing, for hunting and ecotourism). Knowledge of the land and of the animals living there allows trackers to speculate and intuit where a specific animal will be found, in what season, during what moon phase or weather episode, at what time of the day or night, how the animal typically interacts with others of its own species and with other species, where the animal will go to find the best foods and sheltering locations, how often the animal needs to drink, and where the water sources are located (Liebenberg 1990*a*, 2006, 2008, 2013, Liebenberg et al. 1999, 2010, Elbroch et al. 2011).

In 2007, Louis Liebenberg and Dr. L. Mark Elbroch introduced the CyberTracker system of evaluation in the USA, and it has subsequently been implemented across Africa and Europe, Taiwan, and in Canada (http://www.cybertracker.org, http://www.trackercertification.com). Outside of Africa's guiding industry, mostly hobbyists use CyberTracker evaluations to test their own levels of knowledge and to improve their skill. Even in Africa, the evaluation system has been disregarded in many management and scientific circles as either unnecessary (tracking is easy and needs no verification) or as untrustworthy (some believe that it's impossible to differentiate, for example, a male female lion's (*Panthera leo*) track from a male's (or even from a male leopard (*Pathera pardus*) (Louw A. 2011, pers. comm.).

CyberTracker is the only internationally used system for certifying trackers. Prior to 2013 it was the only system in the world. In 2013 another system was introduced in South Africa. The new system was created by one of the CyberTracker evaluators and is a replicate system based on the principles and methodology of the CyberTracker system. This research does not include data from the replicate system.

This research focuses on the CyberTracker system of certifying trackers, which is a field evaluation. Specifically, it focuses on the people who participate in the evaluations, both on how the information they provide can be reliably used in data collection for conservation purposes, and on how the skill is learned by the indigenous and non-indigenous people under study.

The History of CyberTracker[1]

Louis Liebenberg originally developed CyberTracker in 1994 as icon-based software. The software ran on a hand-held, electronic, data-collection device that also included time and location information (positions) provided by GPS. The San of the Kalahari, a people with an established indigenous culture that included tracking, used CyberTracker with their tracking skills to geo-locate animals for national park services in paid conservation employment. This

[1] For more details about CyberTracker Conservation, the software, and the tracker evaluations, go to www.cybertracker.org, www.trackercertification.com, and see the subsequent chapters of this dissertation.

accomplished several things: CyberTracker allowed park managers and biologists to know more about the presence or absence of animal species, their numbers and behaviors, and provided them with valuable data to base their management decisions upon; CyberTracker allowed the San trackers to make use of their traditional ecological knowledge; and CyberTracker allowed the San trackers to provide a small income to their families for food, clothing and shelter – helping to replace the hunting and gathering lifestyle that the San were no longer legally able to do in the park. The name CyberTracker describes the interface between technology and the traditional culture surrounding the original skill of tracking (L. Liebenberg, pers. comm. 2013; http://www.cybertracker.org).

The tracker evaluation side of CyberTracker developed after the original software because some data collected were noticeably erroneous (e.g. solitary species in large groups, and *vise versa*). Even in a traditional culture best known for its tracking skill, like the San, some skills were lost to the younger generations because they were becoming unnecessary in the modernizing world, and amongst those in the older generations some trackers were better than others. The tracker evaluation system, a practical field evaluation of trackers' ability to identify and interpret tracks and signs without technology or assistance, ensured that persons collecting track-based data in any scenario, with or without technology, achieved a known standard of reliability in the data collected (Liebenberg, L., 2013, pers. comm.)

This research does not use or analyze data collected with the technology described above (software and GPS enabled, hand-held device). This research examines the results of tracker evaluations as a hands-on, in-the-field component designed to measure the accuracy of people who collect track-based data.

CyberTracker Certification: Tracks & Signs, Trailing, and Tracker Evaluations[2]

CyberTracker Tracker Evaluations are comprised of two separate components: the *Tracks and Signs identification and interpretation evaluation* (T&S evaluation), and the *trailing evaluation*. Each T&S and Trailing evaluation is further divided into separate *secondary* (formerly called lower band) and *tertiary* (formerly called *specialist* evaluations) levels (Figure 1). The tertiary evaluation contains more difficult questions in both quantity and quality for T&S, and participants progress from following hard-footed animals, like a white or black rhinoceros (*Ceratotherium simum* or *Diceros bicornis*) or a large ungulate, to following soft-footed animals, like a lion (*Panthera leo* or *Puma concolor*) or a bear (genus *Ursus*), in a trailing evaluation. In the secondary evaluations, participants can achieve the following levels of certification in T&S, or in trailing: 70-79% = *level 1*, 80-89% = *level 2*, 90-99% = *level 3*, 100% = *professional*. Professional level is considered the desired industry standard in South Africa for an employed tracker.

After achieving professional level in a secondary evaluation, participants are automatically invited to a tertiary evaluation. Tertiary evaluations are designed to produce the next generation of true experts who are not only competent to reliably identify, interpret, and follow tracks and signs to find animals, but also to instruct others in how to accurately and reliably track animals, and to evaluate the skill level of other people in the CyberTracker system. Tertiary evaluations are conducted on a pass/fail basis where a participant needs to achieve 100%

---

[2] Information described comes from my experiences and field notes, meetings with members of the CyberTracker Evaluation Standards Committee, and the CyberTracker website. My experiences are relevant because I have spent over a decade studying tracking in Africa, North America, and Europe and my skill-level has been certified to be at the highest standard in the international CyberTracker Tracker Certification System, as described in this and subsequent chapters of this dissertation. I am also an accredited evaluator on this system in North America and South Africa.

to pass and become a T&S specialist or a trailing specialist. Any score less than 100% results in the participant rated as *not-yet-competent* at the specialist level. Achieving 100% in both the T&S and the trailing evaluations at the tertiary levels, combined, makes a participant a *senior tracker*. Senior tracker is the highest level that can be earned (Figure 1). Senior trackers can be awarded the right to be called *master tracker* after spending at least 10 years contributing significantly to the field of tracking, upon review by the *CyberTracker Evaluation Standards Committee***.**

After achieving the specialist level, and by invitation from a CyberTracker *evaluator* (a person qualified to give evaluations by this same process), and with acceptance by the CyberTracker evaluation standards committee, a specialist can undertake a rigorous peer-review process running evaluations under the tutelage of at least two different *external evaluators* to become an evaluator in the area in which they have achieved their specialization.

Secondary evaluations are run by one evaluator. Tertiary evaluations require two evaluators, where one is an external evaluator. This process ensures a peer-review (evaluator agreement) of the more complex questions required. T&S evaluations test up to ten participants at a time over an average period lasting from 1 to 3 days, depending on the number of participants and whether the evaluation is a secondary or a more complex tertiary evaluation. An evaluation cannot be held without at least 2 participants. This requirement is to avoid ethical questions regarding familiarity with participants. In addition, an evaluator may not evaluate his or her own students that they have recently mentored, at tertiary evaluations.

After the initial training through peer-review, and appointment as a regional evaluator, evaluators are then required to run, assist, or attend, two out of three events, in a two-year cycle to retain their evaluator status and maintain common standards. These three events include: a secondary evaluation with another evaluator, a tertiary evaluation with other evaluators, or the *CyberTracker Evaluators Workshop*, including the practical field sessions. All three of these events allow evaluators to calibrate their thoughts with other evaluators, in the field, about how to select, phrase, and score unambiguous questions.

A participant can only earn the rank of *Tracker* by earning levels in both T&S and Trailing, and will only earn the rank associated with the lower score. For example, a participant who earns T&S level 3 without also participating in a Trailing evaluation earns only the rank of T&S 3. If that participant also earns a Trailing level 3 they earn the rank of Tracker 3. If, instead, a participant earns a T&S level 3 and a Trailing level 2, then they earn the rank of Tracker 2 in association with their lower score of the two evaluations (Table 1).

Tracks & Signs Evaluations: A Brief Overview of the Process

During T&S evaluations, a qualified evaluator finds tracks and signs in the field and circles or marks each track or sign as a question with sticks, stones, numbers, or flags, to make them obvious to participants. Tracks and signs made by mammals, birds, invertebrates, reptiles, or amphibians are all potential questions, as are marks made by humans, vehicles, and natural acts (eg. lightning strikes, frost cracks). Sign questions can include: beds, dens, scats (feces), pellets (regurgitations), urine, scent markings (including territorial markings and anal pastings), scratching or rubbings, nipped twigs, opened nuts, feathers, nests, galls and casings, webs, exoskeletons and other body parts, skulls and bones, gaits and track patterns, kill site analysis, behavioral interpretations, and more. Participants look at each question, without time limits, and privately convey to the evaluator (whispering, or by writing it down and showing the evaluator what they have written) what they think each question is. The evaluator writes their answers down on the evaluation score sheet next to their name, under the appropriate questions (Figure 2). Books, rulers, phones, conversations, and other resources are not allowed at the questions.

Evaluators assign a *point rating* to each question, and write each question and its associated point rating on the score sheet for the evaluation, before asking the questions. A 1-point question is considered of simple complexity, a 2-point question is of medium complexity, and a 3-point question is very complex. Getting a 1-point question correct results in 1-point, but getting it incorrect results in a penalty of minus 3; Getting a 2-point question correct results in 2-points, but getting it incorrect results in a penalty of minus 2-points; Getting a 3-point question correct results in 3-points, but getting it incorrect results in a penalty of minus 1-point. Therefore, participants are penalized heavily for getting a simple question wrong, and awarded minimally for getting it right, and penalized minimally for getting a very complex question wrong or awarded more points for correctly answering. Unreasonably complex questions should not be asked.

In secondary T&S evaluations, 50 questions are asked in the following proportions: ten 1-point questions, thirty 2-point questions, and ten 3-point questions.[3] In tertiary evaluations 50 questions are asked, all of which are very complex (3-points), and, additionally, seven bonus level questions are asked. Getting three bonus level questions correct in a tertiary evaluation will cancel one incorrect 3-point question (a participant can recover from getting up to two regular questions wrong by getting six bonus questions correct).

Bonus level questions are extremely complex, but not unreasonable, and are often partial tracks, unusual signs, or recent discoveries. If they are recent discoveries, they must be published

[3] At the time of this publication, in North America and Europe, the point rating system in T&S evaluations is skewed towards more difficult questions, and there is no published master list of questions and their point ratings.

or well-documented, and used as teaching-moments or learning opportunities for several years before being asked as questions. A question that starts out as a recent discovery can decrease in complexity over a period of years, beginning as a teaching moment, progressing to a bonus level question as trackers begin to become familiar with seeing the question, and as that familiarity increases the question might decrease further in complexity to a 3-point question, then to a 2-point or even a 1-point question. An example of this is an ant lion larval pitfall trap (family *Myrmeleontidae*), which was a new invertebrate discovery to trackers who predominately and historically recognized large mammal tracks and signs, Ant lion pitfall traps were introduced to the evaluation process at the bonus level and over a period of years have now become so commonly recognized that the question is rated at 1-point, or simple complexity, today. Currently, bonus point questions are only asked in tertiary T&S evaluations, although they have been included in secondary evaluations in the past when formulating and testing the best procedures for evaluations.

At the time of this research, evaluators did not ask the same question twice in an evaluation. For example, if a 2-point impala (*Aepyceros melampus*) track is asked as a species identification question, there will be no other 2-point impala tracks asked as a species identification question. The evaluator may ask the gait or track pattern of an impala at a 2-point rating, or some other sign or behavior, or the evaluator may ask a more or less complex impala track, such as a 3-point impala track in deep mud or soft sand, or a 1-point impala track in an entire track pattern among a herd. Current protocol (2018) allows some repetition of questions.

At the end of an evaluation (secondary or tertiary), scores are tallied by adding the number of points gained (correct) and dividing by the number points gained plus the number points lost (incorrect), as shown below in Formula 1.1.

$$\text{Score} = \frac{\text{(Number of points correct)}}{\text{(Number of points gained + number of points lost)}}$$

Formula 1.1. Score calculation for T&S evaluations.

Trailing Evaluations: A Brief Overview of the Process

Trailing evaluations are also divided into secondary and tertiary levels, where a participant must achieve their professional status in a secondary evaluation before being invited to attend the more difficult tertiary level. At both the secondary and tertiary levels, participants might choose their own trail or it might be selected for them by the evaluator(s). Following fresh trails generally gives participants more opportunity to gain momentum and find an animal, while following old trails is much more difficult and finding the animal is generally unlikely. A participant choosing his or her own trail can indicate aspects of confidence, knowledge of animal behaviour, and that they can identify when a trail is fresh enough to follow and find the animal. Having a trail chosen by the evaluators might not negate the previous statement, but might instead be for efficiency purposes. Allowing each participant the time to choose their trail takes more time than choosing one for them. Participants might overlook a fresh trail, however, or misidentify it as older, or, an evaluator might want to see how a participant is able to work an older trail in a difficult area. Track aging is a particularly difficult aspect of advanced tracking, and is generally not penalized heavily unless there are glaringly repeated errors.

On a secondary evaluation, participants are asked to follow a hard-footed species. In South Africa this is often rhinoceros, but can also include Cape buffalo bulls (*Syncerus caffer*) or even greater kudu bulls (*Tragelaphus strepsiceros*). Sometimes an opportunity arises for participants to follow lion or leopard (*Panthera pardus*) trails, or elephant trails (*Loxodonta*

Africana), so these species are not excluded as an option, but soft-footed cat trails are more often reserved for the more difficult tertiary level. Elephant trails can be used at both levels, but the right set of circumstances must be available because, in some areas, there are so many elephants that remaining on one trail can be next to impossible, in grasses for example where the pattern of the feet is not visible and the grasses are pushed down in every direction from the trails of many elephants. In North America, species trailed in secondary evaluations include various species of feral hog, deer, elk, and moose (family *Cervidae*).

On tertiary evaluations, evaluators must see the candidates trail a soft-footed species. In South Africa, this is usually lion, and sometimes leopard. In North America, this is usually bears, or sometimes mountain lions. Depending on species abundance, and how long it takes to find a suitable trail, candidates are also asked to trail other species, which gives the evaluators a more well-rounded idea of the candidate's skill, and gives the candidate more opportunities to show the evaluator an animal. For example, in South Africa, a candidate might be asked to trail a kudu bull. After seeing that candidate trail for an unspecified amount of time, the evaluators might decide to rotate the tracker to another candidate, and watch how the new candidate does on the same species. There are usually four candidates present, and each candidate might get some time on the same animal's trail. If, a lion's or a rhino's trail were crossed while a candidate was trailing the kudu, the evaluators might decide to leave the kudu and pursue the lion or the rhino. In this way, every participant gets an opportunity to demonstrate their skill in following and finding on multiple species while looking for the required soft-footed animals. The time each participant gets is unspecified because it might only take as short as 30 minutes for an evaluator to observe and confirm the level of a tracker's repeated errors. Typically, the more skilled a tracker is, the more time evaluator(s) generally need to identify where those repeated errors occur and whether or not those errors are above or below the threshold of the standard under different trailing conditions.

Participants are scored at both secondary and tertiary levels of evaluation according to the same five aspects: spoor recognition, spoor anticipation, awareness of dangerous situations, alertness, and stealth. Each of the five aspects also have five, more specific criteria that describe what the evaluator(s) are watching for, totaling 25 criteria that a participant can be scored on (Figure 3).

Each criterion observed is scored between 5 and 10 points each, for a total possible score out of 250 points. Participants do not need to be scored in all the criteria. In a secondary evaluation, 16 of the 25 criteria must be scored, and in a tertiary evaluation, 23 of 25 criteria must be scored. The most infrequent criteria to observe are usually the ones involving an approach on an animal, and these are the ones that are often left unscored; however, a candidate must have shown an evaluator a successful approach during at least one evaluation before they can be awarded the professional level. Then, that approach's score can be factored into the specialist level scoring if no animal is encountered. Thus, the participant must demonstrate proficiency in both following an animal's trail, and finding the animal to achieve the highest standard.

Evaluators score participants on how they observe their performance in these criteria on varying terrains. The animal's trail, in each of these varying substrates is also given a score in terms of how complex it is. The candidate, therefore, receives a score for each criterion in the most difficult terrain that they were observed working the trail. Similar to the point ratings for a T&S evaluation, sections of each trail are assigned a point rating according to their level of complexity. For example, a one-point trail would be considered of simple complexity, a two-point trail of intermediate complexity, and a three-point trail as complex. Anything above a three-point trail is considered on a gradient from very complex to extremely complex to unreasonably complex. Unreasonably complex trails are not scored and are considered to be above the level of the standard.

It's not unusual for a trail to switch back and forth between the different levels of complexity depending on the behaviour of the species being followed, the terrain it crosses, and other environmental factors (light, wind, interference from other animals). If a candidate follows a simple trail easily, scoring well in all the criteria, the evaluator knows they are above level 1 standard, whereas if the trail becomes intermediately complex and the candidate struggles to follow it, then the candidate is somewhere in the second level of the standard for certification in trailing. Then, a candidate's score is a matter of the evaluator refining their observations of the candidate on the trail according to the criteria – did the candidate notice things like wind direction and alarm calls, did they move quietly, *etc*.? If the candidate follows an intermediately complex trail well, and only begins to have difficulty in a very complex trail, then the evaluator knows they are somewhere in the third level scoring of the standard. Thus, the candidates are always scored by using the criteria in conjunction with the complexity of the trail.

Research Problem

Observer bias is a critical element of many research methodologies and it logically follows that observer bias would also be important to understand with this methodology. The reference standard for CyberTracker T&S evaluations is A Field Guide to the Animal Tracks of Southern Africa (Liebenberg 1990*b*). As the developer of the system, and of the reference standard, Liebenberg was never tested (Liebenberg, L., 2012, pers. comm.). Based on interviews with evaluators and participants who have participated in the CyberTracker system for over 20 years, they believe that the system and reference standard are accurate and reliable, and that the following can be described accurately: species, numbers of animals, age of the track, sex and identity of individuals (in some species), and behaviors. However, in areas where ranges of species with very similar foot morphology and size overlap, trackers, scientists and land managers debate the ability to differentiate species. A common example is the difficulty in differentiating the following continuum of antelope species from each other: Sharpe's grysbok (*Raphicerus sharpei*), steenbok (*Raphicerus campestris*), common duiker (*Sylvicapra grimmia*), bushbuck (*Tragelaphus scriptus*), nyala (*Tragelaphus angasii*) and the greater kudu - where foot sizes and shapes of the largest individuals of one species overlap considerably with the smallest individuals of the next species (Liebenberg, L., and A. Louw 2012, pers. comm.).

Research Statement

This research identifies a need within wildlife and conservation research to provide evidence for the skill level of people collecting track-based data.

Research Questions

Chapter 2 answers the questions:

- How has track-based data been used in science?
- Was there a measure of observer bias or external validation of the data?
- What is the general reliability of the track-based data previously collected for science?
- How can the reliability of track-based data be improved?

Chapter 3 answers the questions:

- What is the reliability of data collected by participants evaluated by the CyberTracker T&S evaluations?
- Are there differences in the accuracy of participants who achieve different levels of certification in the CyberTracker T&S evaluations?
- What differences are there among questions asked in the CyberTracker T&S evaluations that contribute to the ability of certified participants to answer them correctly?
- Are the CyberTracker T&S evaluations accurate? Are CyberTracker evaluators testing people on the animals that they think they are testing them on, especially with species that have similar foot size and morphology?
- Are there other demographic or qualitative variables that produce more accurate and reliable trackers, such as the community a tracker comes from, whether or not the person is male or female, indigenous or non-indigenous, or years of experience?
- What guidelines should project managers follow to ensure that track-based data is reliable enough to be used for science and for management decisions?

Chapter 4 answers the questions:

- What differences are there in the ways trackers from different cultures learn tracking, and how are these changing with time?
- Do indigenous Shangaan trackers retain traditional ecological knowledge around tracking?
- How do CyberTracker certified trackers become experts?
- What does it mean to be an expert tracker?

Participation of Human Subjects and Animal Welfare Protocols

This research was approved by the UCONN Institutional Review Board (IRB) for Research with Human Subjects (Protocol H10-127). Evaluation data was historical. Participants in evaluations were either self-selecting, part of an entry level guide training course, or employees of lodges involved in providing their employees with increasing levels of training and certification. Participants were only identified by their first names on datasheets and remain anonymous. Participants in the camera-trapping study, including those who participated in surveys and interviews, were self-selecting volunteers at participating reserves. Before any data was collected, participants verbally consented to participation, with the additional agreement that their name, place of employment, or any identifying information would not be revealed unless they specifically asked to be identified in a quote or personal story. This research was exempt from the requirement for an Institutional Animal Care and Use Committee (IACUC) protocol and approval (Exemption E13-007). No animals were harmed, captured, or manipulated in any way.

Chapter 2 Synopsis

A Content-Analysis of How Wildlife Tracking is Used in Science and Guidelines for Evidentiary Standards when Using Track-Based Data

Research Design

I conducted a content-analysis of publications, looking for how tracking has been and is currently used in wildlife science and conservation. Specifically, I looked for peer-reviewed journal articles where observers collected track-based data, and how they validated the reliability of their data by providing evidence of their observer's skill or through concurrent use of technology. Between 2016 and 2019, I routinely conducted literature and internet searches for studies and researchers that collected track-based data. For each publication, I compiled data on what type of track, sign, or behavior was studied, species, location, year of study, the objective of the research, the outcome of the research, and whether or not the data were independently collected concurrently with another measure of accuracy (such as: camera-traps, radiotelemetry, DNA, or expert witness). If an expert witness was used, I noted what field the expertise was in and whether or not their experience applied directly to tracking (Figure 4). I refined my search strategy over time, eliminating non-relevant publications and including newly published material.

Data Analysis

I followed a decision-making process for searching for and selecting papers, extracting, interpreting, and categorizing information (Figure 4). I reviewed 421 peer-reviewed publications for at least one of the following features: a) Articles that purposefully describe how to identify tracks and/or signs of wildlife. b) Articles that use tracks and/or signs as data about the location and/or ecology of a species. c) Articles that use tracks and/or signs to differentiate individuals within a species, and/or their age, gender, or size of animals. d) Articles that contribute to what we know about a species through observers watching animals and describing the tracks and signs related to specific behaviors. These could be older papers based on original observations of animal behaviors, often resulting in the documentation of the "natural-history" or ecology of a species. Many of these older papers could result in modern observers recognizing these previously described tracks and signs as related to those behaviors.

After determining whether or not a paper should be included in the analysis, I reviewed each publication and categorized the papers in an Excel spreadsheet and using NVivo 12, according to: year, topic (tracks, signs, behaviors, etc.), potential method of validation (observer reliability by expert with concurrent GPS, DNA, camera-traps, etc.), location, and species. I also included brief notes on the purpose of each study, the methods used, and the results, modeled after Aubry and Houston (1992).

There were three major categories indicating measures of data reliability that emerged: a) publications where data reliability is based on the observer's or mentor's skill, b) publications where data reliability is based on independent, verifiable occurrence records, c) publications where data reliability is not required, or inherently built into the study. An example of this is where the animals under study are captive or from a closed population. Each category is broken down into several sub-categories that explain possible criteria for inclusion (Table 2).

Categories and scoring

A full table with scores for each of the 421 papers is in the Appendices of Chapter 2. There are three categories, A, B and C, and multiple subcategories (Table 2). The highest possible combined score a paper can receive is +3, while the lowest score possible is -1. A description follows, below, with an example of the categories and how the scoring works. A paper does not need to receive a score from all categories and only one score is assigned per category even though it's possible that a paper could use a technology that qualifies it in more than one subcategory per category.

Category A

Scoring in one of the many subcategories of category A range from -1 if the publication lacks evidence or +1 if the publication describes evidence of observer reliability in collecting track-based data. I make no assumptions about observer reliability, meaning that, even if I personally know the observer to have verifiable experience, if it is not explicitly stated and described in the paper then it is scored with a -1, accordingly.

Category B

Category B has multiple subcategories, placement in any of these subcategories results in a +1 and there are no negative scores. These papers include concurrent validation between observers and some kind of technology or methodology. While these papers are the "easiest" to assume observer reliability through concurrent validation, there are noted problems throughout the literature for each and I do not account for the assumptions of these techniques or methods, and note that, in some cases, there might be technical failures and methodological inconsistencies, gaps, and flaws. Half of the subcategories in category B describe concurrent use of technology such as camera or video trapping, radio-telemetry or GPS, or DNA analysis. Each of these technologies have their pros and cons, and can be used improperly or malfunction. Some descriptions are both methodological and technological, e.g. DNA analysis uses not only technology, but also requires a methodological procedure. Other, methodological subcategories in category B include using mark-recapture surveys, scat- or scent-detection dogs, or the collection of some artifact in the field representing tracks: measurements, photographs, sooted-track plates, track casts, tracings, which can then be analyzed statistically or used in computer modeling or simulations. B category publications can have evidence for more than one subcategory but will not receive a score greater than +1 for collecting track-based data concurrently with more than one technology or method.

Category C

A publication in category C can score 0, 0.5, or 1 in either one of two subcategories, C1 or C2. Papers in C1 are scored a zero because they are descriptive papers or reviews in a natural history style where direct observations allowed the discovery and publication of track-based information that we take for granted today. Most C1 papers do not get scored additionally in categories A or B due to their historical observational style (48 out of 56 papers are in only C1). If, however, it is a more recent paper, and there is information regarding how the data were collected and/or technology used, it can also be scored in category A and/or B.

Subcategory C2 papers can receive a score of +1 or +0.5. Papers scoring +1 contain data that was collected under conditions that do not require external validation, such as in a laboratory, or a captive population, conditions where the animal's tracks were followed and the animal was found, or conditions where the tracks are so considered so easy that no skill is needed to identify them. Most C2 publications receive a score of +1, but some receive only a +0.5 when collected in snow conditions because, while snow is described as an easy substrate in the scientific literature, it has been documented as challenging across tracking books and field guides. Snow can make seeing tracks and signs easier, but snow can also make identifying tracks and signs more difficult. Snow must be the correct depth for tracks to register clearly. If snow depth is too shallow, tracks can melt quickly, distorting or erasing detail. If snow depth is too deep, the tracker can't see into the bottom of the hole to identify the features of the track. The angle of the sun on snow can also make tracks challenging to see, which can be especially problematic when scientists are attempting to identify tracks from a moving vehicle or aircraft. Therefore, in instances where there is potential for misinterpretation in snow, or confusion with other species, the paper is assigned a score of 0.5 instead of +1. Conversely, a paper can receive a full +1 in snow, such as when the animal is followed and found without interference from other animals of the same or different species, or when only the simplest identification or interpretations are necessary.

An Example of Scoring:

In "Evaluating Methods for Counting Cryptic Carnivores," Balme et al (2009), received the following scores:

- A1e - Observers are described as experienced at identifying wildlife tracks and signs, but no evidence of that experience is given.
  - A Category score = -1
- B1b - Track-based data is collected at sites concurrently with photos or videos from camera traps.
- B1c - Track-based data is collected at sites concurrently with telemetry: radiotelemetry (UHF, VHF, etc.) or GPS location positions.
  - B Category score = +1
- C2 - No experience in track and sign identification or interpretation is required, in-the-field, for the conditions or the questions asked. Examples include:
  - Track-based data is simple in complexity and unmistakable by a novice (classic).
  - Track-based data is collected in an area where there are no other species present that have similar tracks and/or signs.
  - Track-based data is from a closed or captive population or from a controlled laboratory setting.
  - Track-based data is collected by following the animal's trail and finding the animal.
  - Track-based data is collected by following a clear animal trail in snow or sand. Tracks and signs are abundant and easily interpretable due to the substrate. The observers follow an animal's indisputable trail, step-by-step, and collect multiple sources of classic evidence (tracks, scats, behavioral signs, odors particular to a species, etc.).
    - C category score = +1

Totaling the marks from the three categories, the paper received an overall score of 1. In category A, A1e subcategory, classification results in a mark of -1, while in category, subcategories B1b and B1c result in a single score of +1, and because the population of leopards under study was described as completely known, photographed, GPS-collared, and enumerated, concurrent with track-based data-collection, resulting in an additional +1 in category C subcategory C2.

Total paper score: -1 +1 +1 = 1

Note that authors were not contacted, so scores are based on information mentioned solely in each publication. Papers can be roughly compared by their overall scores. A paper receiving a score of 2 is not necessarily more reliable in terms of the way that track-based data was collected than one scoring a 1. A paper receiving an overall score of +1 because the paper had a certified expert tracker collecting the data can be as reliable as another paper using DNA analysis to confirm the species identity of every scat collected by an untrained observer (both would score +1), but if that observer were also a trained expert or had expert mentorship, the score of that paper would increase to +2. All of the above are reliable. The overall trend, though, is that the lowest scoring papers will have some potential pitfall identified with the observers collecting the data, and scores and reliability for papers will increase with increasing score. Table 2, therefore, is less critical of the existing literature than the table is meant to provide an example and a guideline for future researchers collecting track-based data, suggesting protocol that should be followed and explicitly described to ensure reliability.

The majority of papers are scored ≤0 (267 out of 421). Fifty-six of those received a zero score by default, not by penalty, because they were in category C1, leaving 211 (58% of 365 papers) that lacked evidence of observer reliability. Papers scoring above zero totaled 154 (42% of 365 papers), the above zero score indicating that evidence of observer reliability was included (Figure 5).

Results

The data extracted from peer-reviewed publications spanned 88 years, from 1931 to 2019. Publications came from 56 different countries. Top research producing countries were: USA (n=117), Canada (n=28), and South Africa (n=23). Most research was conducted in the field with wild animals, but 190 papers were not. The publications included 153 species and several taxonomic groupings (wildlife, large carnivores, large mammals, small mammals, game animals (ungulates), mesocarnivores, macropods, rodents, etc.). The three most studied species included: *Puma concolor* (n=35), *Vulpes vulpes* (n=31), and *Martes martes* (n=22). Humans are included in the analysis, not because of inclusion of search and rescue, anti-poaching, or fugitive tracking research, but because those 10 papers actively included an aspect of research directly on the observer bias of the persons collecting track-based data. 199 articles described research requiring the identification of wildlife signs, 154 used wildlife tracks, and 68 used a combination of wildlife tracks and signs. Articles using signs (including tracks and signs) totaled 267, and articles using tracks (including tracks and signs) totaled 222.

I attempted to determine what technique, if any, the scientists used to validate the accuracy and reliability of their data. I was unable, however, to differentiate between truly unvalidated methods and unreported methods. Because methods went unreported, I assumed the scientists did not validate them. Four articles were not scored for observer reliability because they did not describe the observers as certified trackers, even though I personally know the observers to be so (Taylor et al. 2015, Marchal et al. 2016, Marchal 2017, Romani et al. 2018).

The predominant use of signs, 63%, reflects that signs can be found in almost any substrate, particularly in substrates that do not yield easily to tracks, such as gravel and rock surfaces. Signs also persist longer than tracks in the environment. I further divided signs into feces, urine, scent-marking, and other signs. Feces, urine, and scent marking behaviours are some of the most commonly studied animal signs.

Out of the 267 articles containing sign-based information, 182 (68%) used data collected from feces, urine, or scent-marking. Of the 182 articles collecting data from feces, urine, and scent-marking, only four publications corroborated their identification using scat-detection dogs and DNA analysis, and in an additional 28 publications with only DNA analysis. These corroborations might not be good assessments of the validation of the actual data collected, however, because the sample and the evidence were not always collected at the same time or location. Forty-six articles included seeing the animals as an accuracy measurement (captive studies or finding the animal); some form of concurrent telemetry (GPS, VHF, etc.) was used in sixteen studies, and remotely triggered camera or video traps were used in twenty-one. Eighteen studies were conducted in snow, and eight attempted to identify individuals, gender or age class of specific animals.

The remaining 85 articles using other signs as data, used: birth sites, winter beds, summer beds, fawn beds, generalized beds (Kusler et al. 2017), sleeping and resting sites, hunting beds, antlers, horns, hooves (Mccullough 1965), alarm calls and vocalizations (audible communication), teeth, tooth marks (Murmann et al. 2006), skeletal remains, skulls (Kobryczuk et al. 2008*a*, *b*), kill sites, caching, age and decomposition rate of signs, locomotion, hair (McKelvey et al. 2006), substrate, dens, burrows, wallowing sites, nests and nest predation, tree cavities, scrapes, pedal gland marking, bite marks on trees (Clapham et al. 2013), roosts, and specific attributes of habitats used for different activities (Wolf and Ale 2009), feeding signs and other behaviors.

In the 154 track-based articles, 28 attempted identification of wildlife beyond species to the individual level, gender, or age class. Large carnivores and rare species were particularly investigated due to their relative importance due to their IUCN status, or their cryptic and nocturnal behaviours that made them difficult to observe and count, or from conflicts with humans and domesticated animals.

In fifty-seven articles, observers collected track-based data in snow (31 articles including purely track-based data and 26 articles using tracks and signs data in snow). In these articles, snow was frequently described an easy substrate for tracks and signs recognition. Even so, track deterioration due to weather and poor quality of substrate were frequently noted as challenges to identification and interpretation (Liebenberg 1990*a*, *b*, Funston et al. 2010). Some researchers described the presence of potentially confounding species present in the same area, but not how observers accounted for differentiating confounding species with their target species.

Forty-one articles required the persons collecting the data to use tracings, impressions, etc., and/or to measure, draw, and/or photograph animal tracks in order to determine the species or individual. Some observers also checked with a mentor or with reference material (a field guide to tracks and signs, a reference collection or key, etc.). In other articles observers photographed feet and/or tracks and brought them back to an office or laboratory for processing and modeling with some kind of discriminatory statistics or with software.

In total, 90 articles mentioned some aspect of the observer's or mentor's skill or the training provided. Thus, the remaining 331 articles made no mention of skill or training for their observers. In some instances, authors discussed a need for skilled observers in order to reduce bias and increase accuracy, but they did not provide a description or measure of it. Many of the 90 articles contained claims about observer competency by making the following types of statements about their observers: experienced, expert, or trained. Yet, only twelve articles provided evidence for the training observers received or a measure of their skill.

Skilled identification and interpretation of animal tracks and signs was considered sufficient by the authors in ten articles where persons collecting the data were described as biologists and pilot-biologists (where data was collected mostly from low flying aircraft) (Becker 1991, Smallwood et al. 1995, Zielinski and Kucera 1995, Becker et al. 1998, Gompper et al. 2006, Magoun et al. 2007, McBride et al. 2008), biologists and houndsmen-biologist teams (Smallwood et al. 1995, McBride et al. 2008), and biological-technicians under supervision of biologists (Zielinski and Kucera 1995, Zielinski and Schlexer 2009). One article described using experts at a jaguar conference to differentiate big cat tracks from large dog tracks using photographs; they did not describe the criteria for being considered an expert (De Angelo et al. 2010). De Angelo et al. (2010) conclude that 67% of tracks were correctly identified by >50% of their observers, and speculate that this is due to variation in previous experience, merely noting that "several authors have mentioned the relevance of field expertise in sign identification."

In six articles, the observers were competent enough to follow tracks and find the animals. Since Stander et al (1997) verified that his small team of Ju/'Hoan San trackers accurately interpreted 98% of track reconstructions after visual observations of the animals by the author, it is assumed that all indigenous people will achieve the same levels of accuracy. Skill was assumed high in seventeen articles where persons collecting the data were described as indigenous or local expert trackers. In twelve of these articles, evidence of the tracker's skill was not provided. In these articles, low numbers of trackers were used to collect data, so if the trackers' skills were high then the accuracy of the subsequent data would also consistently be high. The opposite could also be true.

CyberTracker evaluated observers were described in only eleven of 421 papers, primarily coming from one scientist and his team, L. M. Elbroch, who is himself a tracker and evaluator for CyberTracker. Many of the papers where he is included as an author and where observers collected track-based data describe data-collectors as, "CyberTracker certified," and qualify that statement further with, "at least a level 3 in the CyberTracker system."

One of these articles, Elbroch et al (2011), defines a local expert as a community member with extensive local knowledge but no scientific training. They collect track-based data using a senior tracker in the CyberTracker system of evaluations, the highest certification that can be earned. Notably, these authors develop and recommend using a knowledge gradient to help scientists employing community members in citizen science research to differentiate experts from unskilled observers (Elbroch et al. 2011). In only one other article, the author (from outside the Elbroch lab) describes himself as having one year of tracking experience and additionally having a mentor with a CyberTracker level 3 track and sign certification actively assisting him (Duffie et al. 2019).

Conclusion

Among the 421 individual papers analyzed, the highest percentage (25%) were scored in the combined (sub)categories of A1 + B. A1 means that the observer's skill or experience was not described, but B1 adds that some technology or methodology was concurrently used, which could make the data more reliable. By itself, the A1 subcategory contained the second highest number of paper scores with 19%. Subcategories C1 and C2 contained 11 and 15% respectively (26%). C1 papers were descriptive and did not require validation. C2 papers were on captive or closed populations, or otherwise not needing external validation. Next, A1 + B + C contained 10% of papers scored by combining, for example, an observer with unverified skill, camera-traps and snow conditions (Gompper et al. 2006). All other categories contained less than 10% of papers scored. It is notable that subcategory A2 (papers that provide evidence for observer skill or experience) is not among categories containing more than 10%. In fact, only 7% of papers gave evidence for observer skill at all.

In wildlife management, conservation, and research, scientists need to monitor wildlife quickly, efficiently, and accurately. Some scientists use tracks and signs to identify where animals are, what they need in terms of habitats and resources, what influences they have on their environment, describe why it vanished from certain areas, and to help determine their futures in other areas. Yet, in 421 papers spanning 88 years, 56 countries, and 154 species, only 7% of papers gave evidence for observer skill or experience with collecting track-based data. Table 3 indicates major topics explored in this research, and the problems noted by the assumptions made by researchers for each topic are described next.

Snow-tracking

The degree of difficulty in snow-tracking is highly debatable. Identification of tracks in snow conditions is often considered so simple that a novice observer can do it well. A fresh, shallow, snowfall can hold new tracks perfectly for long distances. On the other hand, extreme weather events, such as snow-storms can wipe out a trail completely. In deep snow, details that determine identity can become obscured in the bottom of a vertical tunnel created by an animal’s leg, and direction of travel of the animal can also become difficult to discern. Trackers might need to follow a trail for some time to figure out the direction and species. Along the trail, trackers can use other tracks and signs, such as the smell of urine, scat, scent-marking behaviors, gaits and track-patterns, and beds, to determine the identity of the animal (Forrest 1988, Golden et al. 2009, Gu et al. 2014, McCann et al. 2017). From simple to complex trails, the longer a trail is followed, the more information can be gleaned from the tracks and signs observed, and the more confident an observer can be about the identity and behaviors of the animal (Golden et al. 2009, Liebenberg et al. 2010, Gu et al. 2014, McCann et al. 2017) Golden et al. 2009, Liebenberg et al. 2010, Gu et al. 2014, McCann et al. 2017).

Tracking basics

Scientists often assume that technicians will be able to differentiate the tracks and signs of different species in varying substrates with little training and/or by consulting drawings or pictures in a published field guide (Crooks et al. 2008, Pirie et al. 2016) – the unspoken assumption is that the data they collect will be unbiased and external verification is unnecessary. Other observers compare or supplement the information provided from tracks and signs with information provided by modern methods, such as GPS or radiotelemetry, camera-traps, and scat-detection dogs with or without complementary DNA analyses. This makes the data provided by each method more rigorous, or provides a measure of the accuracy and reliability of each method against the other, as long as it is comprehensive.

Both T&S and trailing can be easy when a trail is fresh, the substrate is soft and holds the track impressions clearly and continuously, the lighting is favorable, there are few or no confusing species, and the animal is behaving predictably. Animal trails can also be quite difficult, or impossible, to follow. Lighting, or lack of it, can wash out tracks from detection. Older tracks are more difficult to see because time and weather soften the edges, making them less crisp and clear. Even a fresh trail can look old with a little bit of wind or rain on it (Liebenberg 1990*a*, Liebenberg et al. 2010, Gutteridge and Liebenberg 2013). Tracks and signs are more difficult to detect from a moving vehicle, such as from a tracker seat mounted to the front of a safari or research vehicle, especially when the angles from the sun are not favorable in the direction of overall travel. The faster the vehicle moves, the more difficult track detection is. Speed creates an additional degree of difficulty from flying aircraft due to the distance from the ground and glare off of snow and ice.

Most species have “classic” tracks or sign that are produced by their baseline behaviors. Classic tracks or signs are those that are easy to differentiate from other species when in their most typical, most common appearance. These classic tracks and signs are usually the ones that become well documented in the literature. Other tracks and signs are more difficult to identify. Research on bear signs, such as hair, tooth, and claw marks left on trees (Clapham et al. 2013) or power poles (Karamanlidis et al. 2007) or on habitual marking trails (Taylor et al. 2015), require less training and experience to identify than differences between tracks of different mesocarnivores species (Zielinski and Kucera 1995, Foresman and Pearson 1998), or different individuals of the same species (Herzog et al. 2007). Additionally, tracks in some substrates are more difficult to identify in than in other substrates. Sand (Bothma and Le Riche 1984) and snow have a reputation for being easier than more solid surfaces and more vegetative ground cover (Bothma and Le Riche 1984, Patterson et al. 2004), but some researchers recognize that snow or sand can distort classic features in tracks and are easily confused with similarly sized species in the same areas. They advise caution and the need for training and skill (Forrest 1988, Patterson et al. 2004, Gu et al. 2014, McCann et al. 2017).

Identification of individuals (or sex and age class)

On some occasions, age (Rumble et al. 1996, Purchase 2007), sex (Rumble et al. 1996, Zalewski 1999, García et al. 2010, Gu et al. 2014), or even the individual identity (Smallwood and Fitzhugh 1993, Grigione et al. 1999, Jones et al. 2004, Herzog et al. 2007) of an animal can be determined from tracking. Different species of animal have different morphometric (Chame 2003) and scent characteristics (Kerley and Salkina 2007) to their scats, as well as different genetic profiles (Kohn and Wayne 1997, Zuercher et al. 2003). Some animals have deformities or injuries that make their tracks unique and recognizable. Animals like elephants (Dudley et al. 1992) and rhinoceros (Jewell et al. 2001, Alibhai et al. 2008) have unique wear patterns on the bottoms of their feet. Carnivores tend to be territorial, and exclude others of the same species from the area they claim (Allen et al. 2015), but this does not exclude occasional trespassers or attempted takeovers of territories. Male animals are usually much larger than females in many species. Overlap in track size occurs, though, between species, such as between male leopards and female lions, which then requires the observer to have more experience differentiating the tracks by small differences in foot morphology, and by social structure – lions form prides or coalitions, while leopards are solitary. A tracker who is familiar with the landscape and its territorial residents will have an advantage over a tracker that does not (Liebenberg 1990*a*, Liebenberg et al. 2010).

Feces, urine, and scent-marking

Of all the signs, scats (feces, fecal or feacal droppings, pellets, etc.) are widely collected and examined. Through them, observers attempt to determine animal diets or changes in diet, territoriality and marking behaviors, species identity, individual identity, and numbers of a species (Skalski 1991, Lanszki et al. 2006, 2008, Skalski and Wierzbowska 2008, Murdoch and Buyandelger 2010, Sidorovich et al. 2010, 2011, Lanszki and Heltai 2011). Observers collect scats, and/or scent or scat-detection dogs are sometimes used to find scats of particular species, and/or these are tested by DNA analysis (Kerley and Salkina 2007, Long et al. 2007*a*, *b*, Harrington et al. 2010).

Both classic and atypical scats are easily confused with those of multiple other species. Examples of this include the dog (family *Canidae*), cat (family *Felidae*), or weasel (family *Mustelidae*) families' scats. Long et al (2007*a*, *b*) describe coyote (*Canis latrans*) and bobcat (*Lynx rufus*) scats as visually indistinguishable and raccoon (*Procyon lotor*) scats as easily confused with bears. Davison et al (2002) found that expert marten surveyors failed to differentiate pine marten (*Martes martes*) scats from those of red foxes (*Vulpes vulpes*). Harrington et al (Harrington et al. 2010) found through DNA validation that none of the scats collected by their observers were of mink (*Neovison vison*), their target species. Depending on an animal's seasonal diet, individual state of health, or the outside forces of weathering and aging acting upon the scats, scats from species within each family will present considerable confusion to even expert trackers (Davison et al. 2002, Long et al. 2007*a*, *b*). On such occasions, it's necessary to have more conclusive, additional sign, such as clear tracks made at the same time, to make a determination (Zielinski and Kucera 1995). Some observers only report their observations or results, while others give additional information on species whose tracks or signs might be present in the same areas and confused with the animals they study.

Scent-detection dogs

Some scent-detection dogs are better than others at their job (Long et al. 2007*a*, DeMatteo et al. 2018). Accuracy rates on how many times hounds attempt *vs.* find actual animals for telemetry collaring or other mark-recapture methods in research programs are not usually reported, but, in-the-end, they yield telemetry-based, camera-trap data and behavioral data (Elbroch and Wittmer 2013*b*, *a*, Elbroch et al. 2012, 2014, Elbroch and Kusler 2018) on specifics such as beds (Kusler et al. 2017) kill-sites (O'Malley et al. 2018) and den site characteristics (Bleich et al. 1996), anyway. Can we, therefore, assume some degree of accuracy in hounds being able to follow and find animals? Some papers note complications in scat-detection dogs with differences in dog performance due to variability in handler training, indifference or loss of interest in scents by individual dogs making them poor performers at the task, and potential bias introduced by counter-marking of other animals (DeMatteo et al. 2018).

Technologies

There has been a considerable amount of success with two- and three-dimensional photography and casting to model and differentiate the tracks of individual captive and closed samples of mountain lions (Alibhai et al. 2017), African lions (Marchal et al. 2016, 2017, Marchal 2017), black (Jewell et al. 2001) and white (Alibhai et al. 2008) rhinoceros, cheetahs (Jewell et al. 2016), Amur tigers (Gu et al. 2014), tapirs (Moreira et al. 2018), and giant pandas (Li et al. 2018). These smaller captive and closed samples are used to test the models before using them to enumerate wild populations. These techniques require clear tracks of specific feet (usually hind tracks) in good substrate, for the observer to carry photographic supplies equipment into the field and use it in a systematic way, and standardized placement of points on reproductions within custom software to differentiate individuals with a high degree of accuracy.

Expert trackers

Including subject matter experts, such as biologists of a species or a suite of species, e.g. furbearers, should not automatically qualify these people as observers to identify and interpret tracks and signs of their focal species. In fact, it has been shown to be otherwise as tracking is a specific skill that requires specific training and practice (Liebenberg 1990*a*, 2013, Zielinski and

Kucera 1995, Liebenberg et al. 2010). Likewise, native, indigenous, or local people are often cited as expert track-based data collectors in scientific publications, as if the historical aspect of their culture to a landscape alone should validate their skills (Elbroch et al. 2011). When observers are native, indigenous, or local and spend their time on the landscape tracking they might be experts (Elbroch et al. 2011), but these people might not be experts if they haven't yet spent the time gaining the necessary experience (Wong et al. 2012). Since Stander et al (1997) showed that five Ju'Hoan San hunters collectively interpreted 569 known tracking scenarios with an accuracy of 98%, his paper is frequently cited as justification for using native, indigenous, or local trackers, especially San, in track-based data collection, without further description of the experience level of the persons collecting the data. Yet, when observers are tested, interobserver variation occurs where some individuals are better observers and more reliable than others (Zuercher et al. 2003, Elbroch et al. 2011, Wong et al. 2012, Rutina et al. 2017).

When track-based data are collected, identification and interpretation are considered so simple that anyone can do it, without training, experience, or expertise. On-the-other-hand, track-based data are considered so impossible or unreliable that they shouldn't be used in science and conservation. The fact is that both of the above statements are true or false at different times, but this depends on the observer, not the data. Some tracks and signs are easier to identify and interpret than others, especially with experience. A more experienced observer will be able to identify and interpret more, and more difficult, tracks and signs than a less experienced observer. Even if an observer works as a professional tracker in Africa, there is a range of ability within the occupation based on experience. Unless someone is a clearly demonstratable expert, or working under circumstances without difficulty or variation, we can't know the reliability of their track-based data unless we have a means to measure it.

Chapter 3 Synopsis

Evaluating the Evaluation: A Mixed-Methods Analysis of CyberTracker Evaluated Wildlife Trackers and Suggested Guidelines for Collecting Track-Based Data for Science

Study Area

This study took place in South Africa. There were two phases of data collection. Phase one included data collected from CyberTracker track and sign evaluations (eval data) across South Africa. Phase two included data collected from camera-trap studies (photo data) conducted in two different regions. The first region was a 23,000-hectare private game reserve in the bushveld habitat of the Waterberg Biosphere Reserve in the Limpopo Province. The second region included five different game reserves in the lowveld habitat of the Greater Kruger National Park in the Mpumalanga Province (Figure 6). Additional, qualitative components included the results from survey instruments administered to trackers during phase two and a comparison of the eval and photo datasets (all data).

Research Design

Phase one – eval data

Eval data were collected from previously completed evaluation score sheets provided by CyberTracker evaluators in South Africa. When possible, I attended evaluations as an observer and collected copies of the score sheets directly after the evaluations were completed. Personal communications with each of the five different evaluators indicated that the data spanned approximately a decade of evaluations administered in South Africa.

Phase two – photo data

I collected photo data in the winter seasons (May through August) of 2010, 2011, and 2012. I set remotely-triggered camera-traps on sand roads and game trails. Sand roads and game trails are considered track-traps, which are areas of soft sand or soil that will record a track if an animal walks through it. Cameras photographed animals making tracks (the questions) and then evaluated trackers identified the track makers to the species level. At each camera trap station, all trackers answered the same question, "what do you see here?" I recorded the identify, certification level, and observations of the trackers in a field notebook and compared it with the information in the photos (the answers) from the camera-traps. I determined whether the answer given by the tracker was correct or incorrect, and recorded any answers (species, etc.) that were incorrectly given.

Track-traps were approximately four meters long by four meters wide. I swept each plot daily, after checking it with trackers and recording their data. Sweeping erased the previous 24 hours of tracks and signs and smoothed out the surface of the track-trap for optimum recording substrate. Tracks and signs from the camera-trapping phase were not assigned a point rating, because I was not yet a trained evaluator in the system and therefore not yet qualified to do so.

I attached Cuddeback, Reconyx, or Bushnell camera-traps to small trees at the side of the road or along the game trails at each track-trap. I used two cameras per site, to: provide redundancy, ensure identifiable photographs of all species if one camera malfunctioned, and to identify individual animals (such as individual leopards by spot pattern) and their sex where possible. Cameras varied in their settings by manufacturer, but were set to take multiple photos at the shortest time lag or highest sensitivity. Cuddeback cameras were the slowest, taking a set of three photos with a lag of three seconds between sets, upon triggering by motion. Reconyx cameras were the fastest, taking almost continuous photos upon triggering, without lag before taking subsequent photos.

I also administered voluntary survey instruments (Appendix A) to 141 trackers that worked with me at the camera-trapping locations and were interviewed for the qualitative analysis of this research exploring the demographic qualities of trackers. Variables from survey instruments included the amount of experience a participant had, their gender, whether or not they self-identified as an indigenous person, and what major community they self-identified from.

Comparison of the Eval and Photo datasets (All Data)

The two models, evaluation and photo, could not be compared statistically because they did not share enough independent variables. They were qualitatively compared using descriptive statistics and graphical summaries of tracker level performance on getting questions correct and through comparisons of example questions.

Data Analysis

I transcribed data from scoresheets (eval) and field notebooks (photo) into Microsoft Excel spreadsheets, which were then imported into a Microsoft Access database. Survey instrument data provided by participating trackers were also transcribed and included in the same Access database. I used Access to create queries, explore the data, and to generate initial descriptive statistics. The data were unstacked according to their method of collection (eval or photo) into two different datasets. Text string variables were converted to integer variables for analysis and visualization.

The data met the following assumptions: a binary dependent variable, independent observations, little or no multicollinearity among independent variables, linearity of independent variables and log odds of the response variable, and a large sample size. I used Pearson's coefficient to test for correlations and then binary logistic regression in Minitab 19 and Python 3.6 for null hypothesis testing and prediction. Results were considered significant at $p < 0.05$.

The binary, dependent variable in the logistic regression model for the evaluation data was *match*. When an answer given by a participant in an evaluation matched the question asked, the question was answered correctly and the value recorded for that question/participant combination was either match = correct or if the participant's answer did not match the question, the answer was match = incorrect. The independent, categorical variables recorded from the evaluation score sheets were:

- *Tracker level* achieved (0, 1, 2, 3, and 4 in secondary evaluations, and 5 and 6 in tertiary evaluations). Note, it's important to clarify the differences between actual tracker levels achievable in each type of evaluation, and the coding terms used in this analysis. In the evaluation model, the analysis includes terms for tracker levels 0 through 6, while in the photo model the analysis omits level 5 because it does not exist in a non-evaluation situation. Level 5 are participants who have achieved 100%, or Professional level, in the secondary evaluation, and then attempted the more rigorous Specialist level evaluations but not yet passed the Specialist level with 100%.
- *point rating* for each question asked (1, 2, 3, 4, where a point rating of 4 is considered a bonus question of extreme complexity), and
- *band* (secondary or tertiary, formerly known as lower and upper band, or standard and specialist, respectively).

For each question, I also created ten additional descriptive, categorical variables to try to determine if one or more made significant contributions to predicting that participants of different tracker levels answered more questions correctly. These were:

- *Taxon* (amphibia, aves, invertebrates, mammalia, none, plantae, reptilia, variable (alarm call varies with species)),
- *group* (bird, herp, pad, hoof, human, invert, mega, vehicle, or other (natural, number, body part, age, alarm)),
- *type* (interpretation (sex, foot, gait, etc.), other (wind, stone, vegetation), scat, sign, track, trail)
- number of legs (*num legs* = 0, 1, 2, 4, 6, 8, 16, 30 or 80),
- number of toes on the front foot (*num toes front* = 0, 1, 2, 3, 4, or 5),
- number of toes on the hind foot (numb toes hind = 0, 1, 2, 3, 4, or 5),
- *foot complexity* (based on number of pads/angles or distinct identifying features always present: complex, medium, none, simple, variable),
- size of track or sign (*TorS size* = large, medium, small, variable, very large, very small),
- social structure (*spp social structure* = groups, none, pairs, solitary, variable), and
- common (*TorS common* = yes or no, if a track or sign is commonly found).

I performed the same logistic regression analyses with the photo data as with the eval data, above, where the dependent, binary, variable was *match* (correct or incorrect), based on whether or not the participant identified the tracks or sign of the species in the photo correctly. The independent variables were the same as in the eval data, except that there were no point ratings for photo data because I was not yet an evaluator and there were no other evaluators present to assign point ratings. Four qualitative variables were also added from the survey instruments. These were:

- *Indigenous* (yes or no, based on South Africa tribal affiliation (Shangaan)),
- *gender* (female or male),
- *community* (European, Indian, North American, Shangaan, South African), and
- *experience* with tracking (months experience, converted to *years experience*, ranging from 1 to 18 years as a continuous variable).

Results

Total number of questions

In total, participants were asked 365 unique questions about tracks and signs during evaluations and camera-trapping. There were 462 unique answers given because a participant could give any possible answer for a question. There were 78 questions that were asked in both the evaluations and the camera-trapping. Example questions are: aardvark (tracks) (*Orycteropus afer*), white rhinoceros dung, lion gait correct, and leopard sex correct (gait and sex questions, respectively, were pooled and matched as correct or incorrect. For example, a lion trotting was coded as lion gait correct just as a lion in an overstep walk would be lion gait correct and the corresponding answers could either be lion gait correct as a correct answer, or lion gait incorrect if the participant answered incorrectly.

Eval data

I analyzed data from 147 different evaluations (139 secondary and eight tertiary). 1027 different participants took those evaluations (985 secondary and 42 tertiary). There were 323 unique questions asked during evaluations (314 secondary and 160 tertiary), and 419 unique answers given (408 secondary and 190 tertiary).

For each tracker level, as the point rating increases, trackers get fewer questions correct (Table 4). For example, at tracker level 1, questions at point rating 1 were answered correctly 91% of the time (*n*=2269), questions at point rating 2 were answered correctly 73% of the time (*n*=6527), questions at point rating 3 were answered correctly 48% of the time (*n*=2440), and the 35 questions asked at the bonus level (point rating 4) were answered correctly 9% of the time. Note: bonus level questions are not typically asked at the secondary level. This trend is seen throughout the data, from a robust sample size of 49,000 questions asked.

Results show that questions with simple complexity (point rating 1) are answered correctly 82% of the time (*n*=1454) by participants that are rated as not-yet-competent, 91% by level 1 trackers (*n*=2269), 95% by level 2 trackers (*n*= 3221), 98% by level 3 trackers (*n*=2499), and 99% by professional trackers (*n*=89). Questions with simple complexity are not asked in tertiary evaluations, so there is no data for specialist level trackers or trackers that attempted but did not achieve specialist.

Complex questions (point rating 3) are answered correctly only 40% of the time (*n*=1603) by participants that are rated as not yet competent, 48% by level 1 trackers (*n*=2440), 65% by level 2 trackers (*n*=3498), 76% by level 3 trackers (*n*=2738), and 95% by professional trackers (*n*=95). In tertiary evaluations, 86% of complex questions are answered correctly (*n*=1720) by trackers who are technically still professional trackers who attempt but are not yet competent at the specialist level, and 94% of these more numerous and difficult questions are answered correctly by specialists (n=181).

I found that higher-level trackers are able to answer more, and more complex, questions correctly (Figure 7). In Figure 7, the plot on the left includes the dummy code for level 5 at the tertiary evaluations, which shows those participants scoring lower than professional level and even some level 3 participants from secondary evaluations, but they are doing so in a much more difficult evaluation. The plot on the right groups level 5 in with professional level, which makes the 3-D graph less discontinuous at that point. Neither plot is incorrect, they each merely depict different ways the data were analyzed, removing and including level 5 as a dummy variable because it was not an official CyberTracker level but was distinct from professional level and specialist level.

Significance and coefficients for logistic regression

After removing correlated variables with Pearson correlation tests, the explanatory variables that were significant, contributed and remained in the final eval model at $p \leq 0.05$ (Wald test, n=49,000) were tracker level, and point rating. Other coefficients reported extensively in Chapter 3 include the variance inflation factors (VIF), coefficients (Coef), the standard errors of the coefficients (SE coef), Z-values, and 95% confidence intervals (95% CI). All VIF values are all between 1 and 5, indicating little or no multicollinearity. The coefficients for tracker level are all positive, indicating that a participant answering a question correctly at each increasing tracker level is more likely than at the reference level (0). The standard errors of the coefficients (SE coef) for tracker level are all small (near 0), indicating that they are precise. Z-values for the 95% confidence intervals (95% CI) are large enough (absolute value >2) to also indicate a statistical difference from zero. Conversely, the coefficients for point rating are all negative, indicating that a participant answering a question correctly at each increasingly complex point rating is less likely than at the reference event (point rating 1, or simple complexity). VIF, SE Coef, 95% CI, and Z-values are similar to those described above. Using these same reference coefficients, there is also evidence described in Chapter 3 that the variables for: other, scat, sign; track questions are were likely to be correct than interpretation and trail questions; larger tracks are identified correctly more frequently than smaller tracks, across all size ranges; species that are normally solitary are less likely to be answered correctly than a question about a species with a group social structure; and when a species is common a participant is more likely to answer questions about it correctly than if it is uncommon.

Odds-ratios for logistic regression

The odds-ratios reported in chapter 3 illustrate the within-groups relationships with greater detail. Odds-ratios compare each event in each variable with the other events in that variable. For example, tracker levels where A=1 and B=0, we interpret this as the odds of a tracker level 1 getting a question correct are almost 2 (1.7787) times more likely than a tracker level 0. This trend continues throughout increasing tracker levels, with smaller odds-ratios between levels that are close together than in ones that are further apart. For example, the odds of a tracker level 4 (professional) getting a question correct are almost 40 times (39.7721) more likely than a tracker level 0 (not-yet-competent), odds of a tracker level 4 getting a question correct are over 22 times (22.3607) more likely than a tracker level 1, odds of a tracker level 4 getting a question correct are over 12 times (12.4853) more likely than a tracker level 2, and the odds of a tracker level 4 getting a question correct are almost 6 times (5.7553) more likely than a tracker level 3. At the tertiary evaluation level, the odds of a tracker level 6 (specialist) getting a question correct are only 0.7 times (0.7045) more likely than a professional level tracker. It’s important to remember though, that participants are being asked only complex and very complex questions at that level, whereas professional level trackers are being asked questions with a mix of complexity levels in a secondary evaluation. Within the tertiary evaluation itself, the odds of a specialist level tracker getting a question correct are approximately 3 times (2.6549) more likely than a non-specialist, level 5. Odds-ratios for point rating are all small but <1, indicating that the questions are more likely to be correct at level B. Therefore, as point rating increases, the likelihood of a participant getting a question correct decreases slightly with the question's increasing complexity. The odds-ratios for the other variables are described extensively in chapter 3.

Model fit and predictive ability for logistic regression

The predictive ability of the binary logistic regression model including the two variables that contributed the most, tracker level and point rating, was low. The fit for the evaluation model was: r-sq = 0.130, r-sq (adj) = 0.1299 (df model = 5, df residuals = 49993). The low fit and predictive ability could be for many reasons, and will be addressed in the discussion section.

Camera-trapping data

I camera-trapped over three field seasons (May – Aug, 2010, 2011, 2012), testing 111 previously evaluated participants (Table 5). Eighty-two days (1968 hours) of camera-trapping were conducted (Table 6). There were 120 different species photographed/questions asked during camera-trapping, and 133 different answers given.

All participants in the camera-trapping study were certified at some level of competency. In Table 4, the light grey columns on the right show both the number of trackers participating at each tracker level and their mean percentage of correct answers. There are two zeros in two different cells, for level 0 (not-yet-competent), and also for level 5 (not yet a specialist). There were no level 0 participants and level 5 trackers are at the professional level because this study was not actually conducted within an evaluation. Therefore, data from trackers that were not yet specialist but had attempted at least one tertiary evaluation are recorded under the professional level. Tracker level 1 mean percent correct was 71% (*n*=547), tracker level 2 mean percent correct was 80% (*n*=1622), tracker level 3 mean percent correct was 88% (*n*=1550), professional level mean percent correct was 94% (*n*=888), and specialist level mean percent correct was 98% (*n*=2713).

Many of the same variables from the evaluation model were also included in the photo model. Band and point rating were not included because the photo data was not collected during evaluations. Camera-trapping data included additional demographic variables taken from survey instruments, such as the community a tracker comes from, whether a participant was male or female (gender), whether or not the participant considered themselves indigenous to that land, and their estimated months of experience with tracking.

Significance and coefficients for logistic regression

After removing correlated variables with Pearson correlation tests, the explanatory variables that were significant, contributed and remained in the final photo model at $p \leq 0.05$ (Wald test, *n*=7320) were years experience, tracker level, TorS size, TorS common, and indigenous. The two significant variables that contributed most to the photo model were tracker level and years experience. Other coefficients reported extensively in Chapter 3 include the variance inflation factors (VIF), coefficients (Coef), the standard errors of the coefficients (SE coef), Z-values, and 95% confidence intervals (95% CI). All VIF values are all between 1 and 5, indicating little or no multicollinearity. The coefficients for tracker level are all positive, indicating that a participant answering a question correctly at each increasing tracker level is more likely than at the reference level (1). The standard errors of the coefficients (SE coef) for tracker level are all small (near 0), indicating that they are precise. Z-values for the 95% confidence intervals (95% CI) are large enough (absolute value >2) to also indicate a statistical difference from zero. The reference event for TorS size = large, and all the coefficients of the other events (except veryLarge) are negative. This result is interpreted as larger tracks are correct more frequently than smaller tracks, across all size ranges. The variable for TorS common has a positive coefficient, indicating that when a species is common (yes) a participant is more likely to answer questions about the species correctly than if it is an uncommon species (no). Interestingly, indigenous is significant in the model, with a small negative coefficient, meaning that questions are more likely to be answered correctly by non-indigenous participants (see discussion, and chapter 4).

Odds-ratios for logistic regression

The odds-ratios reported in Chapter 3 illustrate the within-groups relationships for the photo model in greater detail. Odds-ratios compare each event in each variable with the other events in that variable. For example, years experience is positive and >1 (1.1). This result indicates that as experience accumulates trackers are increasingly likely to answer questions correctly. Tracker levels A=2 and B=1, indicates that the odds of a tracker level 2 getting a question correct are 2.1 times more likely than a tracker level 1. This trend continues throughout increasing tracker levels, with smaller odds-ratios between levels that are close together than in ones that are further apart. For example, the odds of a professional tracker (level 4) getting a question correct are 5.9 times more likely than a tracker level 1, odds of a professional tracker getting a question correct are 2.8 times more likely than a tracker level 2, odds of a professional tracker getting a question correct are 1.9 times more likely than a tracker level 3. Between the tertiary and secondary levels, the odds of a specialist tracker getting a question correct are 2.4 times more likely than a professional level tracker, odds of a specialist tracker getting a question correct are 4.4 times more likely than a tracker level 3, odds of a specialist tracker getting a question correct are 6.7 times more likely than a tracker level 2, and the odds of a specialist tracker getting a question correct are 14.2 times more likely than a tracker level 1. For the variable TorS size, there are odds-ratios of <1 and >1, indicating that questions are more likely to be correct when the track or sign is larger, rather than smaller. The odds-ratio for TorS common indicates that the odds of getting a common track or sign question correct are approximately 4 times more likely than an uncommon one, and indigenous trackers are slightly less than 1 time (0.7) less likely to answer a question correctly than non-indigenous trackers (see discussion, and chapter 4).

Model fit and predictive ability for logistic regression

The predictive ability of the binary logistic regression model including the two variables that contributed the most, tracker level and years experience, was low. The fit for the photo model was: r-sq = 0.1426, r-sq (adj) = 0.140 (df model = 4, df residuals = 7315). The low fit and predictive ability could be for many reasons, and will be addressed in the discussion section.

All data

Evaluation participants answered 38960 question correctly (78%) and 11039 incorrectly, and photo participants answered 6542 questions correctly (89%) and 778 questions incorrectly. The percentages of correct answers are high, suggesting that identifying tracks and signs correctly might be accomplished by unskilled observers. However, only 17 out of 365 questions were always answered correctly, and those questions were generally less complex in their point ratings. In the evaluation study, the number of correct answers given by participants in evaluations clearly increases with tracker level and decreases with point rating, and in the camera-trapping study, the number of correct answers also increases with tracker level and years experience (Table 4.). Tracker level was the only variable that was shared, significant, and contributed much to the predictive value of both models. All other significant explanatory variables appear to have only small effects on the outcome of a participant getting a question correct. Figure 8 shows a side-by-side line plot comparing the percentage of questions answered correctly by trackers of increasing levels of certification in evaluations and in the camera-trapping study. The dip in tracker level 5 is caused by trackers not obtaining 100% in the more difficult tertiary evaluations, and it corresponds to a gap in the photo data where that level does not exist because those trackers remain officially certified as professional level.

Conclusion

Descriptive statistics indicate that people hired to collect track-based data will, on average, be correct 82% of the time when answering questions of simple complexity. These percentages indicate what level of skill is necessary to accurately collect track-based data, on average. But, some species/questions are more complex than others, and therefore more difficult to answer and require a higher level of expertise. The average score of specialist trackers is 97.94% in T&S evaluations, with respect to the mean number of questions answered correctly in evaluations, and bonus questions were answered correctly less than 50% of the times answered by specialist level candidates (both those that passed and those that did not).

Evaluation data corroborated by camera-trap data also showed that trackers certified by CyberTracker evaluations in South Africa accurately identified and interpreted wildlife tracks and signs, and differentiated the tracks and signs of similar species. Unqualified or low-level participants in CyberTracker evaluations in South Africa were able to answer some questions correctly, but the percentage of questions answered correctly increased as participants achieved higher levels. Some questions of simple complexity, such as fresh elephant tracks were almost always answered correctly by all levels of participants, whereas other questions of higher complexity, such as fresh caracal tracks (*Caracal caracal*) required higher scoring participants to answer them correctly.

Results from the evaluation model indicated that the main variables of tracker level and point rating are significant and contribute the most to the model. Results from the camera-trapping model indicated that years of experience and tracker level are significant and contribute most to the model. In both models, the likelihood of answering questions increased with T&S size, and with how common a T&S was. In the evaluation model, track questions were the most likely to be answered correctly, and scats, other signs and interpretations were less likely to be answered correctly. Questions where the species had a recognizable social structure were correct more frequently than questions without a recognizable social structure in the evaluation model but this variable was not significant in photo model. This result could be due to low sample size in the photo data collected.

The predictive values of getting a question correct with any of the variables included on was low for both models. This result could be because of confounding effects of substrate, weather, size of tracks, and scarcity of particular species. The number of different questions asked (n = 323 eval, n = 120 photo, with 78 similar questions in both) at different levels of complexity (n = 4), where some questions were always answered correctly and some questions were always answered incorrectly, and with many other combinations of correct and incorrect questions by trackers of seven different levels of quantifiable skill in the evaluations could result in extremely high variability. Alternatively, there could be some, as of yet un-named variable(s), that would contribute to the predictive ability of the model, such as the local knowledge of participants on the number of different species present in the area where the evaluation question was asked and even where particular animals are habitually seen. Point rating captures some of this variability, but point rating limited to 4 selections: simple complexity (1), complex (2), very complex (3), extremely complex but not impossible (4). While the complexity of a question does increase and is reflected in the point rating, these ratings might not account for all of the exact variables that made the question more complex, including the potential number of species it could be confused with. Thus, questions reach a threshold of complexity that might not encapsulate the true complexity of the question.

The amount of experience a tracker has could be refined as a predictive variable in the future. As the variable is currently used, specialist level trackers range from having 3 years to 18 years of experience. Perhaps a more useful, or additional, measure would be how long the tracker has been a specialist for. Similarly, most tracker levels contain a range of scores. Participants at level 0 that are not-yet-competent achieve scores between zero and 69%; level 1 at 70-79%, level 2 at 80-89%, level 3 at 90-99%, only level 4 (professional level) in secondary evaluations is strictly 100%. In the more challenging tertiary evaluations, where no questions of simple complexity are asked, the only passing score is 100% (specialist level), with scores seen as low as 87% in this data, which would result in those participants remaining at the previously achieved professional level (they are not demoted to level 3). Yet, when the model is run using the participants’ actual scores as the dependent variable instead of their tracker levels achieved, the predictive power of the model changes little. Separating the analysis into two models, one for secondary evaluations and one for tertiary evaluations also does not change the predictive value of the model for secondary evaluations, and decreases the predictive value of the tertiary evaluations (probably due to the reduced sample size).

There are a large number of unusual observations in both models, but careful review of these provides no justification for removing them. The observations are unusual, but sometimes novice trackers get lucky in an evaluation by guessing a question correctly, just as sometimes high-level trackers get questions wrong. While this provides evidence for independence of observations, it also increases variance around the means of the explanatory variables.

Explanatory variables that might be missing from the analysis include how many years a question has been asked, and at what point rating. In my observations, the question of a single rhinoceros's single toe (not the entire track) was very difficult for participants to recognize when it was a new question. But, as participants were increasingly exposed to the question and participants taught each other about the potential question, they learned to study what a single rhinoceros' toe looked like very carefully under different conditions to increase the likelihood of recognizing it in an evaluation. This learning process is slowly transferring itself to other animal's tracks, like hippopotamus, or even hyenas, where recognizing a single toe of many different species is becoming something that trackers practice.

This variable, recognizing partial tracks, might need further refinement to encapsulate the statistical nature of the process, because someone who is employed every day to follow and find rhinoceros might have already seen thousands of variations of a rhino's single toe in many different substrates, behaviors and weather conditions. So that might be a simple question to them. But trackers are not usually asked to follow and find things like hyenas, so a single toe of a hyena might be an extremely complex question to the same tracker. Additionally, as a new question is introduced to the system, e.g. rhino toe, it begins at a bonus level rating, and over the course of years becomes less complex in rating because – once you learn to see it, it's almost unmistakable, and trackers who get it wrong to begin with rarely do so again. So, what then is the true complexity of a rhino's single toe?

Other possibly important explanatory variables include differences among the evaluators. The length of time an evaluator has been qualified or how many evaluations they have completed, and the number of additional evaluations they have attended as a peer-reviewer, or the number of times they have been peer-reviewed by another evaluator, are all variables not considered here.

The experience of evaluators and the peer review component of this system is critical to establishing and maintaining a standard. Even with rigorous training to become an evaluator, I have observed that new evaluators are not as clear in the way they ask some questions, or what an allowable question is, as more seasoned evaluators are. Conversely, more seasoned evaluators have more experience, which leads to more skill, and they are constantly exposed to new information from participants wherever they travel to conducting evaluations. This exposure can lead to a situation where a seasoned evaluator has seen a question enough, with enough variation, that s/he thinks a question is of simple complexity, and it might be to him or her, but in reality, it's a very complex question for the majority of participants attempting an evaluation. If evaluators don't meet regularly to share information and compare how they are currently wording and rating questions, there can be migration of complexity from the standard in both directions – where some questions become more difficult and others too easy.

Finally, the explanatory variable indigenous was significant in the photo model. Odds-ratios showed that indigenous trackers are slightly less than 1 time (0.7078) less likely to answer a question correctly than non-indigenous trackers. This variable contributed minimally to the model overall, but is still intriguing because I expected indigenous trackers to be more likely to answer questions correctly than non-indigenous trackers.

The indigenous culture studied in this dissertation are the Shangaan people living around the Kruger National Park. People from indigenous cultures purportedly retain some amount of traditional ecological knowledge from living in close association with the land. Traditional ecological knowledge usually revolves around culturally specific ways of obtaining or creating food, medicine, shelter, or some characteristic that improved a group of people's qualities of life. Since the end of the apartheid era in South Africa, indigenous peoples have moved, largely *en masse*, towards towns and cities where children can be educated by western systems and jobs can be obtained. Trackers are aging, and no longer passing on these skills to the younger generation, who all claim to want to become engineers, lawyers, and doctors. The relationship with land is no longer noticeable. At the same time, there is a shift, towards non-indigenous people, from all over the world, to learn tracking out of a simple interest to know what is living and moving around them. This is discussed further in chapter 4.

Chapter 4 Synopsis
Tracking is Original Wisdom & the Culture of Trackers, A Constructivist Grounded Theory

Research Design

I used constructivist grounded theory (CGT), to understand how trackers characterize themselves, tracking, and their tracking skill. I looked further into how they learned tracking and obtained mastery in it, and how the traditional ecological knowledge of trackers is changing. Steps in CGT include data collection; conducting iterative comparative analysis with initial-coding and recoding; creating memos that describe, sort, and link ideas; identifying gaps, limitations, and future research (theoretical sampling) and attaining a saturation point whereby no new categories/stages emerge, developing a theoretical outline; and finally, consulting any existing literature (Molinari and Vander Linden 2019). CGT precludes conducting a literature review prior to the data collection and analysis to avoid fitting data into an existing idea or theory instead of allowing a theory to emerge from the data (Glaser 1998).

The study took place in person in South Africa and the USA during 2010 – 2012, with additional data collected via telephone and through the internet (e-mail, Facebook). The sample included 38 trackers, eight in a pilot study, and 30 additional. Of the 38 trackers, there were twenty-eight South Africans (fourteen of which were Shangaan), and ten Americans. Five participants were women (zero Shangaans, two South Africans, and three Americans). All participants were certified trackers (both T&S and trailing) within the CyberTracker system. Most participants were highly certified within CyberTracker, having earned a level 3 or higher. Trackers were coded into full-time trackers (FTTs) and part-time trackers (PTTs) and assigned a number corresponding with their identifying information.

As a tracker myself, and as someone who has achieved the highest CyberTracker certification achievable, *senior tracker*, I counted a self-interview among the American women trackers and added my interview and field observations for coding and analyzation (Charmaz 2014, 2017, Garratt 2018). My interview and field observations added more individual data points to the already existing coded categories but were consistent with the other participant's data and did not add new information (Glaser 1998, Garratt 2018). This result supported my strong effort to bring my experience to the research while remaining unbiased in my data collection and analysis (Garratt 2018), and to co-construct a theory with the other trackers explaining how to become an expert tracker in an international system (Charmaz 2014).

In most cases where trackers are quoted, their words are left in the order, grammar, and overall voice in which they were spoken. In some cases, repeated words or phrases were omitted. Word order or tense has only been modified when necessary for understanding, and my clarifications are provided in parentheses. At the onset of interviews, all participating trackers gave their informed consent for any information they provided to be used in publications. This informed consent was contingent upon my guarantee that they would not be identified. This was important for some of them to feel that they could speak freely about their stories, especially to the employed, lodge-based, Shangaan trackers. All names have been changed or removed, and specific references to other people or places have been generalized to protect the privacy of the individuals providing information.

Data collection and analysis began with a semi-structured interview (Appendix B) with the first tracker, one employed at a lodge in KNP. Every concept in the interview was recorded, transcribed, and coded according to CGT (Glaser 1992, 2014, Anselm and Corbin 1998, Charmaz 2014, Glaser and Strauss 2017). As more data was added from subsequent interviews, more categories were identified and refined, until no new categories were discovered. I wrote memos as ideas occurred to me, and for connections, contrasts, and comparisons between codes throughout the research.

Interviews typically lasted one to two hours and were recorded on a Zoom handheld recording device. Thereafter, I spent several days with some trackers, sometimes with more than one tracker at once, walking the landscapes where they lived or worked, and tracking with them. Conversations that occurred during those times were spontaneous, and they tested me on my tracking knowledge as I asked them questions about what they knew and how they knew it. This was as much a conversation as it was a trust-building period. Conversations that occurred in the field were recorded in a field notebook as they occurred, or as soon as possible after they occurred, and also coded as data. Trackers recommended other trackers for me to interview. One interview occurred over the phone, and another in a written, question and answer format.

During one of my first interviews in South Africa, we heard on the lodge's private-network radio that there were lions in a dry, overgrown riverbed, so we drove to the area. The trackers jumped off the vehicle, and one, the senior tracker in the group (FTT11), said to me, "The lions, their tracks are right down there. They went down the river. You stay here and we will find them." I nodded, then jumped off the vehicle and followed them. They looked around at me, surprised, and I said, "Where you go, I go." They admitted later that they had never tracked with a woman, and their instinct was to protect me by leaving me safely behind in the vehicle. Not only were there lions somewhere in the riverbed, but also hippos and buffalos, or any other dangerous animal, could be hiding in the reeds. Even so, they were happy to see me with them and testing myself. Unintentionally, in this way, I became an active participant in their lives instead of an outside observer, and we built trust and rapport between us all. I say unintentionally, because my intent had not been to participate to build trust, but simply because I wanted to track, too, and would not be left behind just because I was a woman or a guest. Many of these trackers knew me a little bit prior to the interviews, too, which also helped. They had seen me and spoken with me at previous CyberTracker evaluations, where I had been going through the same stressful process of being tested on my tracking knowledge and skill as they were, at the same time (Lawrence 2012, unpublished field notes).

Word by word, line by line, concept by concept, initial coding became focused coding as I identified the most pertinent codes through memos and began to ask trackers additional questions related to those codes, and to look deeper into information given, identify gaps, and to integrate a theory (Glaser 1998, Charmaz 2014, Molinari and vander Linden 2019). This was an iterative process of constant comparison that continued until there were no new codes or variation provided in the data from interviewing and observing additional trackers (Glaser 1992, 1998, 2018, Charmaz 2014, Molinari and vander Linden 2019). Codes merged into core categories that encompassed the collected data into a new theory (Charmaz 2014, Singh and Estefan 2018).

During coding, I attempted to eliminate (or minimize) my preconceptions of what I would find (Charmaz 2014, Glaser 2014), because I wanted to understand the tracker's viewpoints, first and foremost (Charmaz 2014). However, because I am an expert on this subject, I agree with Charmaz's (2014) constructivist grounded theory methodology, as emphasized in her quote, below, and believe that my own knowledge and opinions could influence the questions I ask and my interpretation of tracker's answers.

> … fundamentally, the empirical world does not appear to us in some natural state apart from human experience. Instead we know the empirical world through language and the actions we take toward it. In this sense, no researcher is neutral because language confers form and meaning on observed realities. Specific use of language reflects views and values (Charmaz 2014).

Charmaz's constructivist grounded theory promotes the idea that informed researchers can co-construct a useful theory by using inductive (the researcher collects data, identifies patterns, and develops a theory), deductive (the researcher makes an informed hypothesis, collects and analyzes data, and shows that the results support or fail to support the hypothesis), and abductive (the researcher uses their own expertise to intuit ideas that explain unanswered observations) approaches (Charmaz 2014, Singh and Estefan 2018). Instead of simply engaged observation and emergent codes, categories, and theory (Glaser 2014), the questions and answers we asked each other became an ongoing conversation where trackers told their stories and revealed their concerns as we co-constructed the major categories of supporting data and the theory of original wisdom, according to our experience and expertise (Charmaz 2014, Singh and Estefan 2018).

Results

Consistent with the research objective pursued, the grounded theory analysis led to four categories of interest where data support a theory of a culture belonging to all trackers, that of tracking is Original Wisdom. The four categories supporting the theory are 1) what it means to be a tracker, 2) developing the skill, 3) CyberTracker and certification of expertise, and 4) obtaining mastery.

These categories are summarized and then illustrated in chapter 4 with representative quotes from a tracker or multiple trackers from the different cultures studied. These quotes are mostly in agreement between different trackers, but opposing opinions are pointed out, even where they are not shared by others in their community, because these were interesting digressions that led to further exploration of the concepts and categories.

Category 1) What it means to be a tracker.

Trackers that spent more time doing T&S initially described aspects of T&S as tracking, and trackers that spent more time trailing initially described aspects of trailing as tracking but, the more they spoke, the more their focal point merged into the other by explaining the details that they needed to know to be a good tracker. Those details included so much more than T&S recognition. Characteristics of good trackers were that they were always aware of their surroundings, including stopping to look around and ahead, to listen, and to engage all of their senses. Knowledge of animal behavior and animal communication was critical, as well as track aging. Track aging, is, in fact, one of the most complex aspects of good tracking to learn, and probably takes the longest because it is so variable from area to area, species to species, substrate to substrate, and dependent on local and regional weather conditions. Trackers also noted that they developed a connection, a relationship with the land, that they practiced on, even if they were not indigenous to that land and their own culture had not been close to a land for many generations.

Category 2) Developing the skill.

Trackers all had some formative experience with time spent in nature as children, where they developed a fondness for being outside and a curiosity about what they saw. They learned tracking for three reasons, traditional, economic, and/or recreational. FTTs employed during the Apartheid era came from a traditional background where, as children they learned from their families how to track in order to find food and to keep themselves safe, and to follow their livestock and keep them safe. After the abolishment of Apartheid, the family focus shifted from a traditional view of having children follow the herds and spending time outside, to one of indoor education and its promise of better paying, more prestigious jobs (economics). For the most part, children of FTTs have stopped becoming trackers, and when they do, they are trained on the job by older, unrelated trackers, a CyberTracker trained guide (a PTT), or by an outside trainer, such as a CyberTracker evaluator being brought in by the lodge where they are employed. Conversely, PTTs, including women, cannot get a job as a tracker because the job market does not exist for them, so they either track as one facet of their job, or recreationally. Both FTTs and PTTs have achieved the highest levels of certification in CyberTracker, but for different reasons – one does it because it's their job, and the other because it's their passion.

Trackers unanimously stated that the most important thing to do to become a good tracker was to spend time doing it. Beyond the physical aspects of tracking well, trackers also cited patience, persistence, humility and curiosity as qualities of a good trackers. There are many varied obstacles and opportunities for the cultures studies in becoming a good tracker, but, beyond simple practice, the only shortcut to becoming a good tracker mentioned was the presence of a mentor, and in some instances, the CyberTracker evaluations took the place of a mentor.

Category 3) CyberTracker and Certification of Expertise

Overall, trackers enjoyed the learning provided by CyberTracker Evaluations and felt that they provided them with valuable information about how to improve their skills. When trackers had issues with how evaluations were being run, the CyberTracker Evaluation Standards Committee stepped in to clarify or change the protocol to make it more transparent. The residual dissatisfaction stemmed not from the evaluations themselves, but from lodge management not providing enough training, or time to prepare, for an evaluation, or from personal ego when a tracker expected to receive a better score than they actually ended up getting.

Category 4) Obtaining mastery.

CyberTracker is a system whereby a tracker can identify their current level of skill, and how to improve. It's likely that there are many excellent trackers who have not been evaluated and should not be excluded from employment, especially in research. A good tracker can recognize when another person is also a good tracker, because they know what to look for. To recognize if someone has obtained mastery, trackers look for the ability to recognize tracks and signs, and also the humility to recognize when they are wrong, or don't know an answer. They at what a tracker does on a trail, right and wrong, and how s/he fixes mistakes – not that they never make them.

Conclusion

Original Wisdom is a blend of TEK and Western science that encompasses the culture of all trackers, no matter what culture or community that they were born into. It's old, and knowledge and skill are gained from family and friends through ancestral relationships to land. But in both recently modernizing and in already modern societies, tracking also includes new knowledge and skill being discovered by observation, research, technology, and publications. The foundational concepts of the theory are summarized in Table 5.

Discussion

In Chapter 2 of this dissertation, I reviewed 421 peer-reviewed, published journal articles, from 56 different countries, spanning 88 years, and studying 153 different species, where some form of track or sign identification was used in the research. Only seven percent of those publications gave evidence of observer skill or experience level from the tracker collecting track-based data. In Chapter 3 of this dissertation, I presented an accuracy assessment on the CyberTracker track and sign evaluation for evaluating trackers. Results indicated that trackers who scored higher in the evaluations were more accurate in identifying wildlife tracks and signs than those with low scores. Furthermore, in a comparison between tracker identification of tracks and signs with camera trapping photos, trackers who scored higher in the evaluations were more accurate in identifying wildlife tracks and signs than those who scored lower. The CyberTracker evaluations are, therefore, a quick and suitable way to determine which level trackers to hire, especially, when background information on tracker experience is variable, questionable, or unavailable.

Measurable training or experience matters when observers collect track-based data. On average, higher certified trackers will perform better than lower certified trackers, and lower certified trackers perform better than non-trackers. Experience and effort matter most to expertise in tracking, but one way that we can know the quality of a tracker's experience and effort is if they have demonstrated their skills through evaluation and meeting the CyberTracker standard. More experienced trackers are more reliable in the questions that they can answer, especially when those questions are complex. The CyberTracker evaluations form a good baseline for determining the reliability of observers collecting track-based data for science. When questions are simple in complexity (unmistakable, even by a novice, with no confusing species present and in areas with good substrate), an unrated or low-level tracker will suffice. In other areas and with other, more complex questions, a minimum of a level 3 tracker should be hired to expect data to be reliable approximately 75% of the time. Under extremely difficult conditions, hiring a specialist, or having a specialist mentor available to the research team, is advised. Complexity can include such characteristics as old, weathered, partial, easily confused with other species, uncommon, small, and no obvious social structure. Moreover, scats, signs, and interpretations can be more difficult than tracks to identify.

Chapter 4 is based on interviews with CyberTracker certified trackers from three cultures, the Shangaan Tribe of South Africans located near Kruger National Park, European descended South Africans, and North Americans. Trackers were interviewed, and discussions continued while in the field tracking. The focus of the inquiry was to (a) understand patterns of people's behavior (what they do), (b) understand how they interpret their experiences, and (c) develop theory that calls forth rather than suppresses or obscures participants' voices.

Using constructivist grounded theory, trackers were separated into FTTs and PTTs, based on their experiences. Shangaan trackers were all FTTs, because they were employed in full time positions as trackers for lodges in the ecotourism industry. Full-time tracking was both an opportunity for them and an obstacle. It was an opportunity as employment that could support a family, but also an obstacle because it was no longer a sought-after occupation within their culture. All other trackers were PTTs. Table 5 summarizes and illustrates the foundational concepts described in this research for the trackers studied, and how they achieve mastery at tracking.

Chapter 4 summarizes that Tracking is Original Wisdom in the sense that it is a fundamental, old knowledge to all cultures. It was once practiced during hunting for food, and for knowledge of and safety from dangerous animals. Tracking is also Original Wisdom in the sense that it is new knowledge that comes from curiosity and passion to observe animals and use modern resources and technologies to dive into deeper explorations of the smaller details of tracking. This pushes the frontier of tracking knowledge and skill forward with new discoveries and with publications that are not related to food, shelter, or quality of life. The culture of trackers, therefore, seems not to be composed of an either/or culture, but of many, all of which can lead to holistic expertise. When hiring a tracker for research, a more important consideration than whether or not someone comes from an indigenous culture, should be whether or not they have mastered the skills required.

Figures and Tables

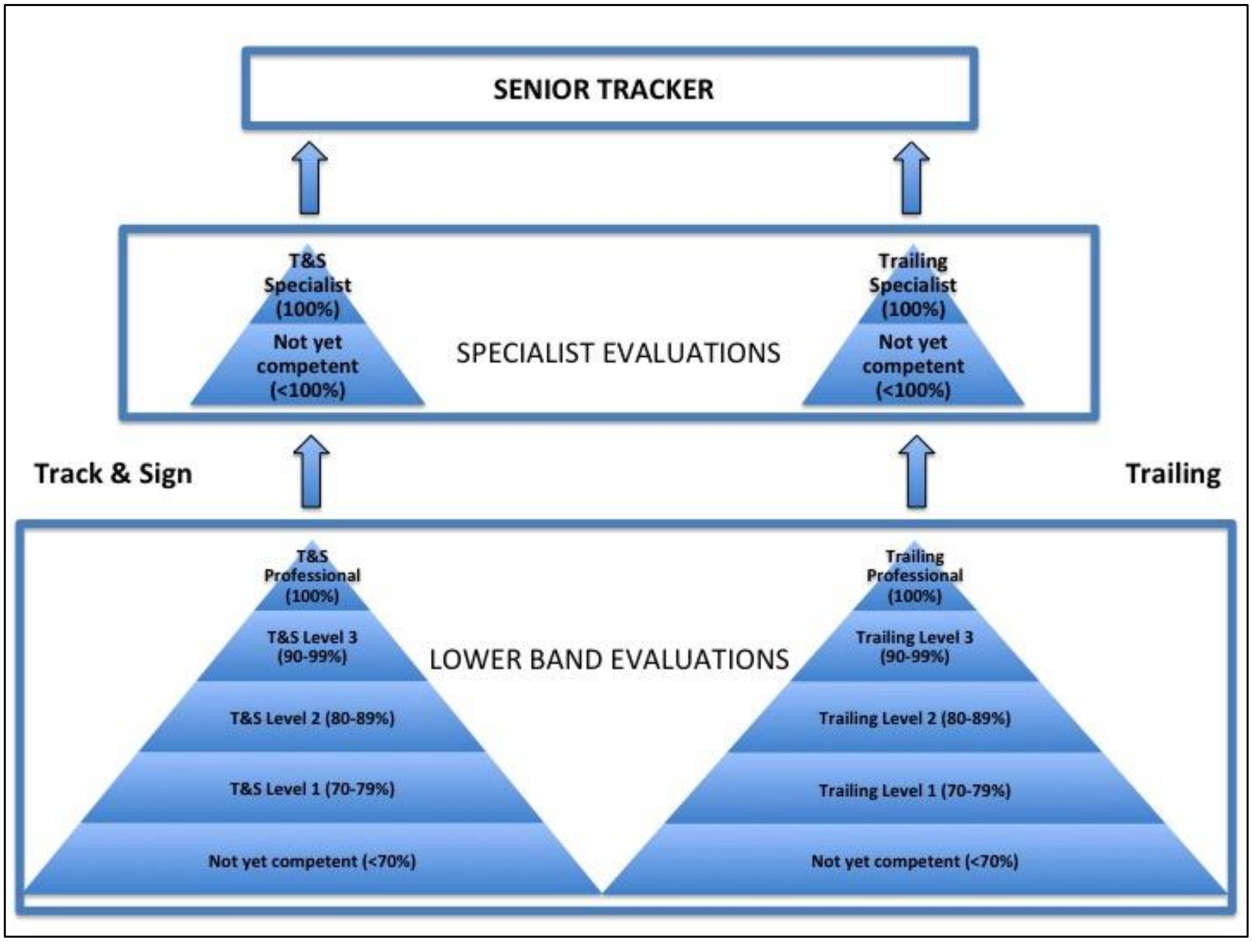
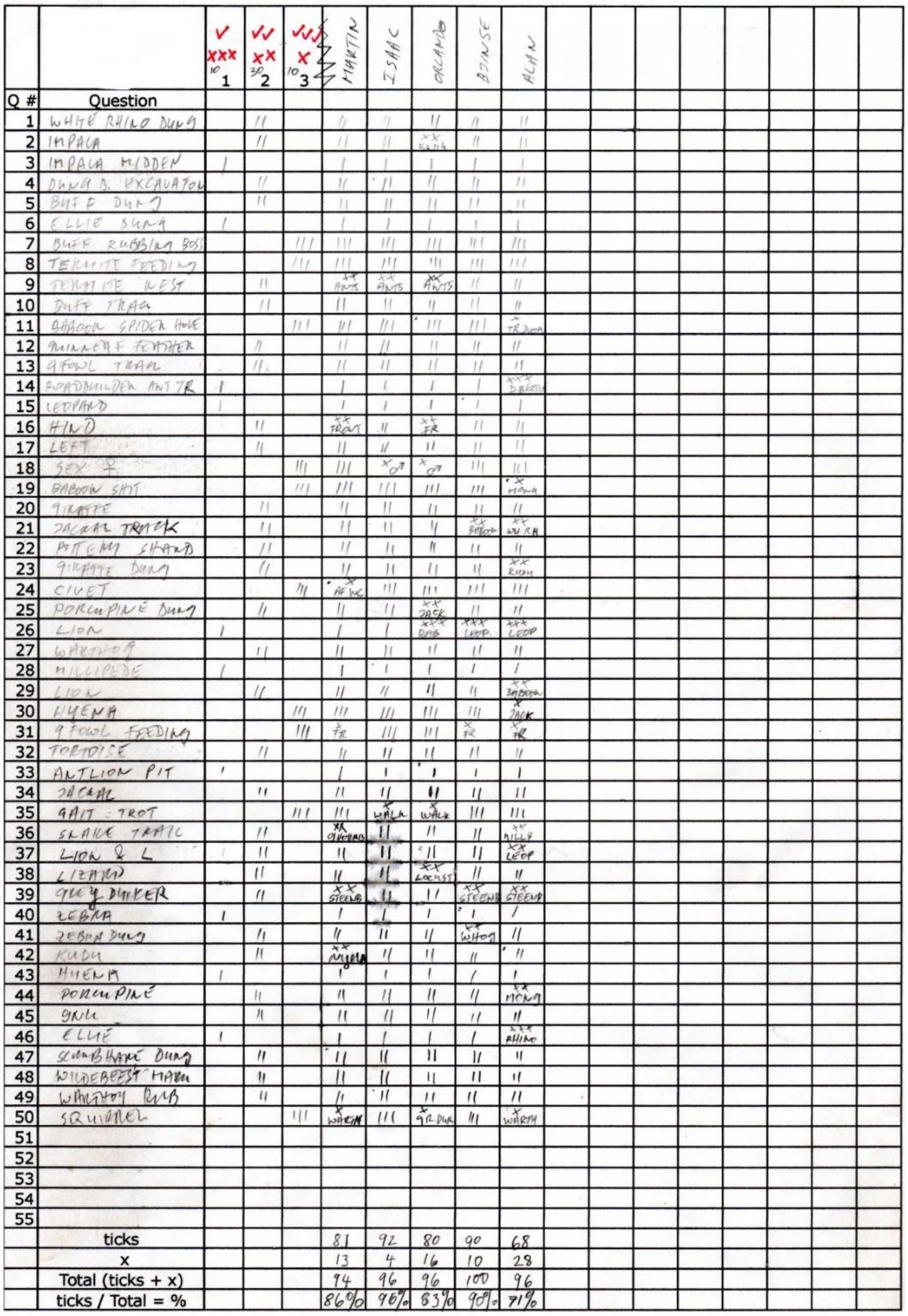


Figure 1. A diagram of the potential progression of a tracker from unqualified to expert in the CyberTracker Tracker Certification System.

Working from bottom to top in either T&S identification and interpretation (left), or in trailing (right), from not-yet-competent (bottom) to specialist (top), or even senior tracker (top of figure, the highest level that can be earned). As the pyramids suggest, there are fewer participants are able to achieve higher levels than lower ones. Note, the name of the lower band evaluation has been changed to the secondary evaluation and the name of the specialist evaluation is used interchangeably with tertiary evaluation.



Q #	Question	1 (✓ xxx, 10)	2 (✓✓ xx, 30)	3 (✓✓✓ x, 10)	MARTIN	ISAAC	ORLANDO	BONSE	ALAN
1	WHITE RHINO DUNG		//		//	//	//	//	//
2	IMPALA		//		//	//	xx KUDU	//	//
3	IMPALA MIDDEN	/			/	/	/	/	/
4	DUNG B. EXCAVATOR		//		//	//	//	//	//
5	BUFF DUNG		//		//	//	//	//	//
6	ELLIE DUNG	/			/	/	/	/	/
7	BUFF RUBBING BOSS			///	///	///	///	///	///
8	TERMITE FEEDING			///	///	///	///	///	///
9	TERMITE NEST		//		xx ANTS	xx ANTS	xx ANTS	//	//
10	BUFF TRAIL		//		//	//	//	//	//
11	BABOON SPIDER HOLE			///	///	///	///	///	x TR BOON
12	GUINEAFOWL FEATHER		//		//	//	//	//	//
13	GFOWL TRAIL		//		//	//	//	//	//
14	ROADBUILDER ANT TR	/			/	/	/	/	xxx DBEETL
15	LEOPARD	/			/	/	/	/	/
16	HIND		//		xx FRONT	//	xx FR	//	//
17	LEFT		//		//	//	//	//	//
18	SEX ♀			///	///	x ♂	x ♂	///	///
19	BABOON SHIT			///	///	///	///	///	x MONG
20	GIRAFFE		//		//	//	//	//	//
21	JACKAL TRACK		//		//	//	//	xx BABOON	xx WH RH
22	PATTERN SHAPED		//		//	//	//	//	//
23	GIRAFFE DUNG		//		//	//	//	//	xx KUDU
24	CIVET			///	x AFWC	///	///	///	///
25	PORCUPINE DUNG		//		//	//	xx JACK	//	//
26	LION	/			/	/	xxx BAB	xxx LEOP.	xxx LEOP
27	WARTHOG		//		//	//	//	//	//
28	MILLIPEDE	/			/	/	/	/	/
29	LION		//		//	//	//	//	xx BABOON
30	HYENA			///	///	///	///	///	x JACK
31	GFOWL FEEDING			///	x FR	///	///	x FR	x FR
32	TORTOISE		//		//	//	//	//	//
33	ANTLION PIT	/			/	/	/	/	/
34	JACKAL		//		//	//	//	//	//
35	GAIT : TROT			///	///	x WALK	x WALK	///	///
36	SNAKE TRAIL		//		xx [illegible]	//	//	//	xx MILLIP
37	LION & L		//		//	//	//	//	xx LEOP
38	LIZARD		//		//	//	xx LOCUST	//	//
39	GREY DUIKER		//		xx STEENB	//	//	xx STEENB	xx STEENB
40	ZEBRA	/			/	/	/	/	/
41	ZEBRA DUNG		//		//	//	//	xx WHOG	//
42	KUDU		//		xx NYALA	//	//	//	//
43	HYENA	/			/	/	/	/	/
44	PORCUPINE		//		//	//	//	//	xx MONG
45	GNU		//		//	//	//	//	//
46	ELLIE	/			/	/	/	/	xxx RHINO
47	SCRUBHARE DUNG		//		//	//	//	//	//
48	WILDEBEEST MARK		//		//	//	//	//	//
49	WARTHOG RUB		//		//	//	//	//	//
50	SQUIRREL			///	x WARTH	///	x GR DUIK	///	x WARTH
51									
52									
53									
54									
55									
	ticks				81	92	80	90	68
	x				13	4	16	10	28
	Total (ticks + x)				94	96	96	100	96
	ticks / Total = %				86%	96%	83%	90%	71%

Figure 2. An example of a track and sign score sheet.

Questions are described in the rows, Point rating alongside each question under columns 1, 2, and 3, and participant names go across the additional columns at the top. Then, each participant is given a score for each question they answer correctly. Incorrect answers given are recorded.

Tracking Evaluation Sheet

Tracker:	Specie:
Evaluators:	Group Size:
Location:	Group Composition:
Date:	Wet/Dry
Time Started:	Windy: Yes/No
Time Completed:	Cloudy: Yes/No
Time Duration:	Animal Found: Yes/No

(1) Spoor recognition

- [ ] Not looking down in front of feet, but looking for signs five to ten metres ahead.
- [ ] Moving at a steady rate, not in stop-start manner.
- [ ] Recognising signs in grass or hard substrate.
- [ ] Recognising when there are no signs when no longer on trail.
- [ ] Ability to recognise signs after losing spoor.

(2) Spoor anticipation

- [ ] Looking well ahead, reading the terrain to look for most probable route.
- [ ] Interpret behaviour from tracks.
- [ ] Using knowledge of terrain (water, dongas, clearings) to predict movements of animal.
- [ ] Not over cautious (too slow), but not too confident (too fast).
- [ ] Anticipate where to find tracks after losing spoor.

(3) Anticipation of dangerous situations

- [ ] Awareness of wind direction.
- [ ] Knowledge of behaviour, e.g. animals resting at mid-day.
- [ ] Animal behaviour indicating danger.
- [ ] Avoid danger by leaving the spoor and picking it up further ahead, but not over cautious.
- [ ] Determine the position of dangerous animals without putting him or herself at risk.

(4) Alertness

- [ ] Looking well ahead for signs of danger.
- [ ] Stop to listen when necessary.
- [ ] Warning signs, alarm calls and smells.
- [ ] Signs of other animals.
- [ ] Seeing an animal before it sees the tracker.

(5) Stealth

- [ ] Minimise noise levels (walking, talking vs hand signals, etc.).
- [ ] Low impact on other animals.
- [ ] Use of cover to approach animal and exit route.
- [ ] Appropriate proximity to animal (close enough to observe, but not too close).
- [ ] Animal unaware of tracker

Comments:

Figure 3. The score sheet for a Trailing Evaluation showing the five major aspects observed, each with five scoring criteria. Each criterion observed is scored between 5 and 10 points each, for a total possible score out of 250 points.

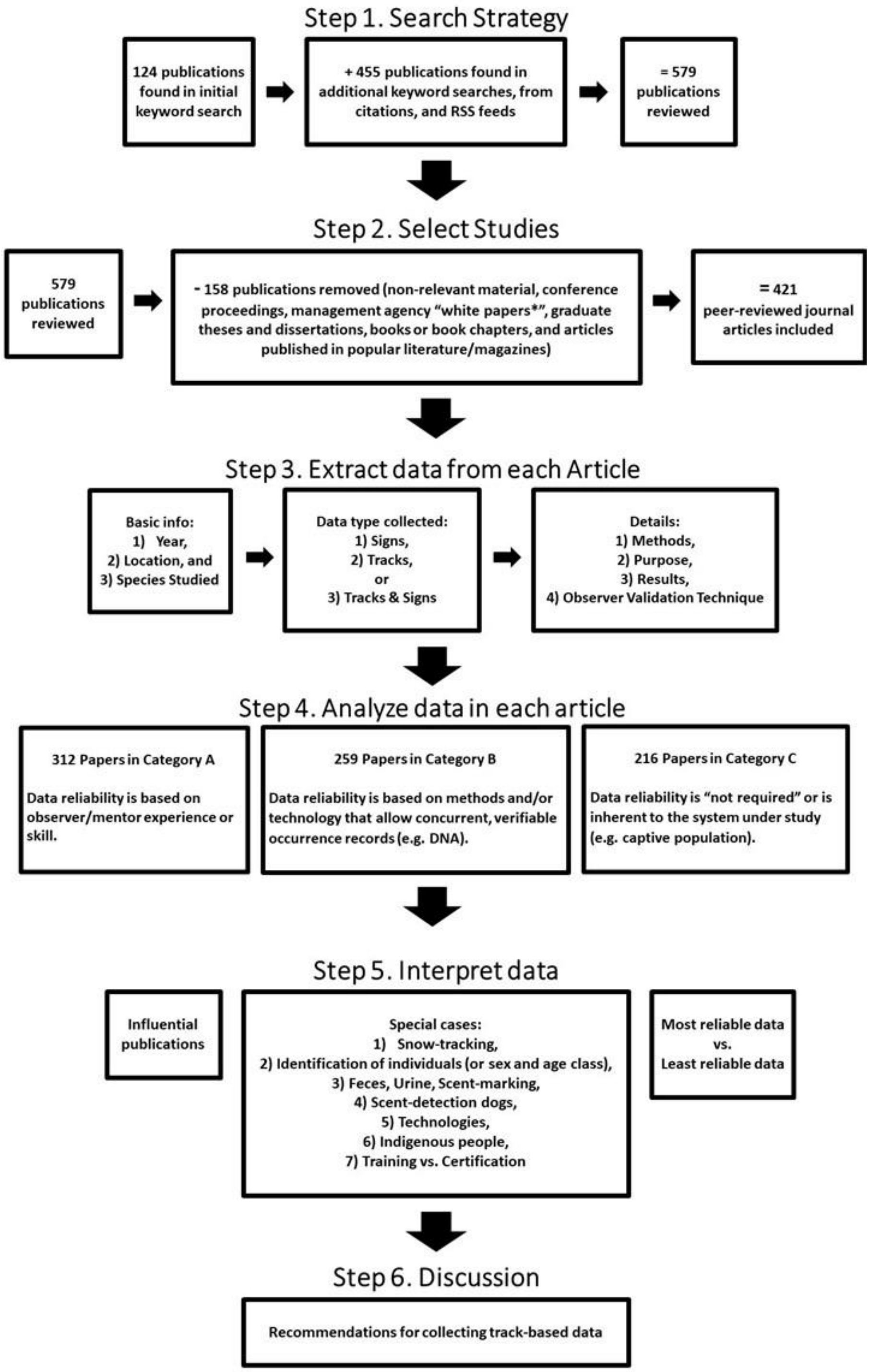


Figure 4. A flow chart of the steps taken in Chapter 2 for a content-analysis of peer-reviewed, published journal articles where observers collected track-based data.

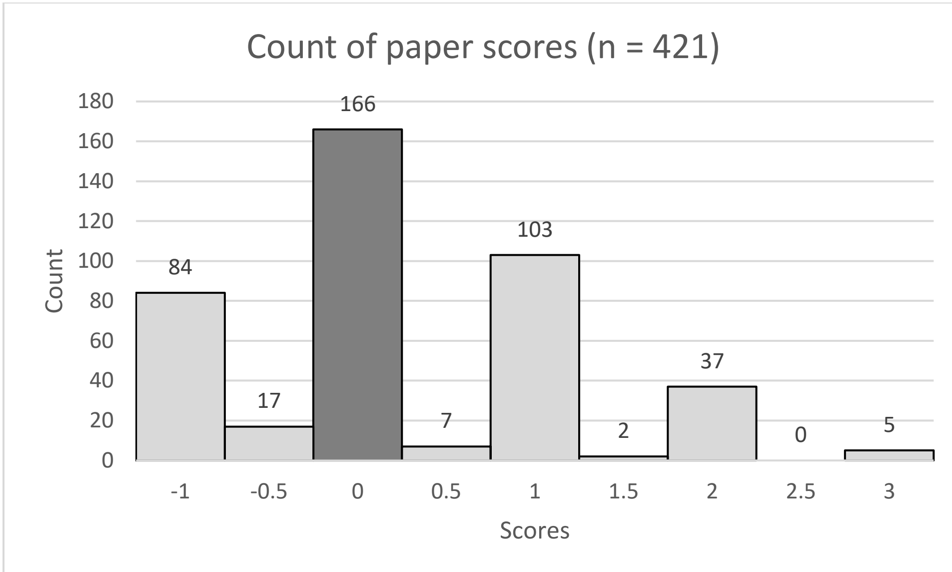


Figure 5. Final count of 421 paper scores.

In general, papers scoring ≤ 0 can be considered weaker in observer reliability than those scoring ≥ 0. Also, higher scoring papers generally have more additive positive factors contributing to their observer reliability. The majority of papers score less than zero because they lack evidence of observer reliability.

Figure 6. A map of the major study areas where camera trapping and surveys were conducted with CyberTracker certified trackers in South Africa. Map created by Elaine Linden.

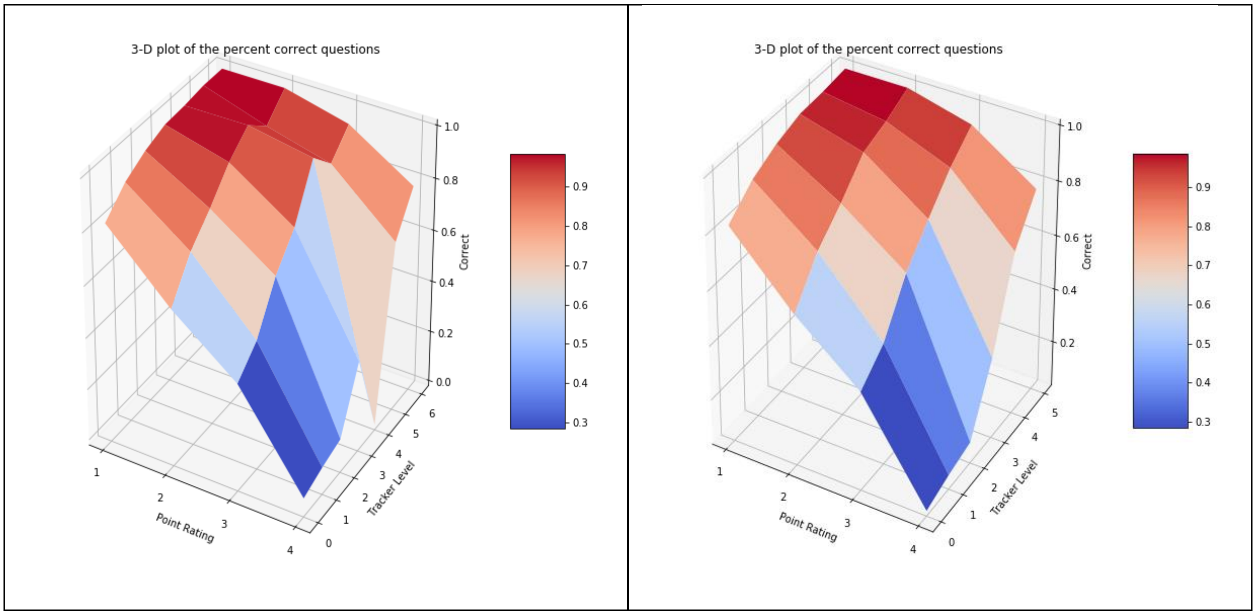


Figure 7. Three-dimensional plots showing the impact of tracker level and point rating on getting a question correct.

The plot on the left separates out participants that do not obtain specialist from those that do in the more difficult tertiary evaluations, whereas the plot on the right combines non-specialists with professional level trackers.

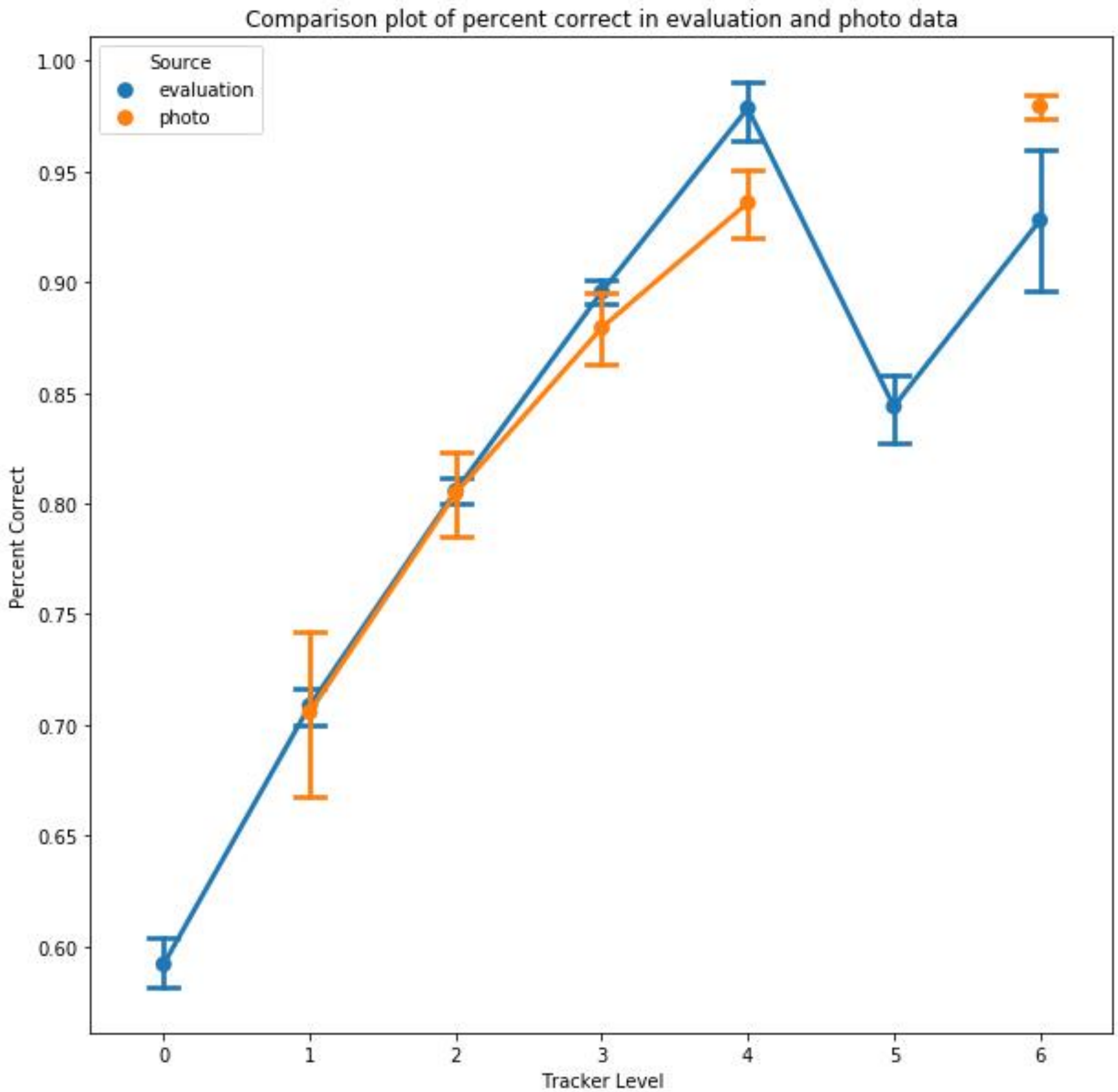


Figure 8. Line plots comparing the performance of different levels of trackers in getting questions correct from evaluations with the camera-trapping data.

Table 1. Examples of how a track and sign certification plus a trailing certification combined result in a tracker certification.

Participants can only earn the rank of Tracker if they have earned a level in both T&S and Trailing evaluations. Their Tracker level will correspond to the lower level achieved between the two separate evaluations. This table is read from left to right, reading across row 1: a participant who earns a Level 1 T&S plus a Level 3 Trailing will earn the right to call themselves a Tracker 1 (Tracker Level 1), etc.

	T&S	**+**	**TRAILING**	**=**	**TRACKER**
1	Level 1	+	Level 3	=	Tracker 1
2	Level 3	+	Level 2	=	Tracker 2
3	Level 3	+	Level 3	=	Tracker 3
4	Professional	+	Not-yet-competent	=	Not-yet-competent
5	Specialist	+	Professional	=	Professional Tracker
6	Specialist	+	Specialist	=	Senior Tracker

Table 2. Data reliability categories for peer-reviewed publications using track-based data used in wildlife-science.

Publication placement in a category does not imply an assessment of the inherent assumptions, practical strengths and weaknesses, or standardization of the methods or technologies used, only that they were used. Categories are not in any order of importance, and publications might fit in one or more categories, and into more than one subcategory in Category B, but they are not scored more than once in each category.

Category	Description	Score
A.	**Data reliability is based on observer/mentor experience or skill.**	
	Note: Examples of "evidence of experience or skill" include: they found tracks and followed them to the animal and were able to correctly identify the animal's behavior on the trail; a detailed field test; or a CyberTracker or other rigorous tracking certification.	
A1.	**Data reliability is based on unknown, assumed, or undefined observer experience or skill.**	-1
	A1a). Observer experience with identifying wildlife tracks and signs is not described.	
	A1b). Observers measure track-based data and use field guides, manuals, keys, or collections to identify it. However, evidence of experience with identifying wildlife tracks and signs is not described.	
	A1c). Observers are described as biologists or technicians with significant in-the-field experience, such as, at minimum, a 4-year degree in some field of ecology, biology, or natural resources, up to a professor or research associate at a college or university. Or at least 4+ years working for a state, provincial, national, or international wildlife agency or NGO, working with a species or a group of species, ex. bears, or fur-bearers. However, evidence of experience with identifying wildlife tracks and signs is not described.	

Category	Description	Score
	A1d). Observers are described as local or native people (or similar) with track and sign identification and interpretation experience, and/or traditional ecological knowledge in tracking. However, evidence of experience with identifying wildlife tracks and signs is not described.	
	A1e). Observers are described as experienced at identifying wildlife tracks and signs, but no evidence of that experience is given.	
	A1f). (Formerly A3a) Observers have regular access, in-the-field, to a supervisor or mentor (similar to A1c in this table), who may have expertise in a species or group of species (ex. bears, or furbearers) but no evidence of the mentor's experience is given for identifying or interpreting the tracks and signs of those or other animals.	
	A1g). (Formerly A3b) Observers take a tangible representation as evidence of the track or sign from the field (e.g. a photo, tracing, track cast, plates from sooted track-plates, skeletal remains, etc.,) for assistance with identification by a supervisor or mentor, but no evidence is given for the mentor's experience with track and sign identification and interpretation.	
A2.	**Data reliability is based on evidence of observer/mentor experience or skill.**	+1
	Data reliability is based on known observer skill from reputable and representative quantitative or qualitative demonstration and/or certification.	
	A2a). Observers are described as local, native, indigenous (or similar) people with track and sign identification and interpretation experience, and/or traditional ecological knowledge in tracking, and evidence is cited of their experience.	
	A2b). Observers are described as experienced at identifying wildlife tracks and signs and evidence is cited of their experience.	

Category	Description	Score
	A2c). Observers participate in a workshop, taught by a tracker with documented and described skill (evidence), on how to identify and interpret the tracks and signs of their target species and how to differentiate them from any confounding species. Workshop duration and format is described, e.g. < 1 day, 1-2 days, >2 days, in-the-field vs lecture, etc. (Caution – workshops and trainings are not investigated for quality and content.	
	A2d). (Formerly A4a) Observers have regular access, in-the-field, to a supervisor or mentor (similar to A1c in this table), who is described as experienced at identifying wildlife tracks and signs and evidence is cited of their experience.	
	A2e). (Formerly A4b) Observers take a tangible representation as evidence of the track or sign from the field (examples of ex-situ evidence include: a photo, tracing, track cast, plates from sooted track-plates, skeletal remains, etc.,) for assistance with identification by a supervisor or mentor. The evidence of the mentor's experience with identifying and interpreting tracks and signs is described.	
B.	**Data reliability is based on concurrent, verifiable occurrence records.**	
B1.	**Data reliability is based on methods and/or technology that allow independent, concurrent, verification of the identity and/or interpretation of tracks and signs. Methods are not always used across all sites and samples (e.g. cameras not placed at all track traps, DNA analysis not done on all samples, etc.).**	+1
	B1a). Track-based data is collected using tracings, impressions, photos, etc. (taken by the observer, on-site), which are measured and often post-processed using some form of discriminatory statistics and/or modeling.	
	B1b). Track-based data is collected at sites concurrently with photos or videos from camera traps.	
	B1c). Track-based data is collected at sites concurrently with telemetry: radiotelemetry (UHF, VHF, etc.) or GPS location positions.	

Category	Description	Score
	B1d). Track-based data is collected concurrently with mark-recapture methods (other than cameras or telemetry).	
	B1e). Track-based data is collected concurrently with scat-detection dogs or scent-detection dogs.	
	B1f). Track-based data is collected concurrently with scat-detection dogs or scent-detection dogs AND DNA analysis for species, individual, or sex identification.	
	B1g). Track-based data is collected concurrently with DNA analysis for species, individual, or sex identification; or, micro or gross diet analysis of scats or pellets.	
	B1h). Track-based data is collected concurrently with visual or audible surveys (line or point counts, etc.) of animals.	
C.	**Data reliability is "not required" or inherent to the system under study.**	
	Note: A "classic" track or sign is defined as representative of the species, and therefore distinct in appearance from other species. The track or sign is from a normal adult representative of its species (not very young, or injured). It is clear, entire, and not degraded from significant weather or age. Feces are from a healthy animal eating a normal diet. Usually there are no other confounding species presenting similar tracks and signs in the same area (not always noted).	
C1)	Data is in the form of: a literature review; a methods paper; or a descriptive paper (or similar). A paper documenting the characteristics of classic tracks or signs (including behaviors that are determined from the presence of specific tracks and signs). A paper in the "Natural History" style of observation and report, that becomes "classic" information.	0

Category	Description	Score
C2.	No experience in track and sign identification or interpretation is required, in-the-field, for the conditions or the questions asked. Examples include: • Track-based data is simple in complexity and unmistakable by a novice (classic). • Track-based data is collected in an area where there are no other species present that have similar tracks and/or signs. • Track-based data is from specimens, a closed or captive population, visual observations of the animal, or from a controlled laboratory setting. • Track-based data is collected by following the animal's trail and finding the animal. • Track-based data is collected by following a clear animal trail in snow (or continuous soft sand). Tracks and signs are abundant and easily interpretable due to the substrate. The observers follow an animal's indisputable trail, step-by-step, and collect multiple sources of classic evidence (tracks, scats, behavioral signs, odors particular to a species, etc.). *Note: Only 0.5, not +1, when track-based data is collected by following an animal trail in snow or sand when methods are not described or conditions are variable enough that track identification is questionable.*	+1 +0.5

Table 3. Counts of specialty types of data collected in 421 articles

Data Type Collected	Signs	Tracks	Both Tracks and Signs	Feces, Urine, and Scent Marking	Other Signs (not feces, etc.)
Paper Count	199	154	68	183	84
with scat-detection dogs and DNA analysis	4	0	0	4	0
by DNA analysis (without dogs)	34	2	8	32	2
seeing the animals	53	19	1	25	28
telemetry	29	18	7	9	20
remotely triggered camera or video traps	17	11	6	16	1
in snow	28	31	26	17	11
review or description	14	21	5	14	9
individuals, gender, or age	3	28	5	1	2
Evidence of observer skill	34	43	16	34	5

Table 4. The percent of questions answered correctly at each combination of track and sign level achieved and question point rating (level of complexity) in evaluations and camera-trapping.

	Evaluation Data	Point Rating				(nE) Eval Sample Size	Photo Data	(nP) Photo Sample Size	(nE + nP) Total Sample Size
		1	2	3	(4) Bonus				
Secondary Track & Sign Levels	(0) Not Yet Competent (<70% Secondary Eval)	82.39% n=1454	58.8% n=4129	39.7%4 n=1603	5.2% n=19*	**7205**	0	**0**	**7205**
Secondary Track & Sign Levels	(1) Level 1 (70-79% Secondary Eval)	90.52% n=2269	72.85% n=6527	48.16% n=2440	8.57% n=35*	**11271**	70.57%	**547**	**11818**
Secondary Track & Sign Levels	(2) Level 2 (80-89% Secondary Eval)	95.28% n=3221	81.71% n=9353	64.84% n=3498	11.11% n=45*	**16117**	80.46%	**1622**	**17739**
Secondary Track & Sign Levels	(3) Level 3 (90-99% Secondary Eval)	98.36% n=2499	92.03% n=7287	75.75% n=2738	33.33% n=39*	**12563**	87.94%	**1550**	**14113**
Secondary Track & Sign Levels	(4) Professional (100% Secondary Eval)	98.88% n=89	99.15% n=234	94.74% n=95	0% n=1*	**419**	93.58%	**888**	**1307**
Tertiary Track & Sign Levels	(5) Not yet a Specialist but still Professional (<100% Tertiary Eval)****	0*	92.16% n=268	85.70% n=1720	64.02% n=214	**2202**	0****	**0**	**2202**
Tertiary Track & Sign Levels	(6) Specialist (100% Tertiary Eval)	0**	100% n=18***	93.92% n=181	78.26% n=23	**222**	97.94%	**2713**	**2935**
	(n) Sample Size	**9532**	**27816**	**12275**	**376**	**49999**		**7320**	**57319**

Special character explanations:

* Sample size is small for Bonus Level questions in Secondary Evaluations because they were generally not asked and reserved for Tertiary Evaluations.

** Questions rated as Simple in complexity (Point Rating 1) were not asked in Tertiary Evaluations.

*** A small number of Complex questions (Point Rating 2) are allowed in Tertiary Evaluations when conditions are too difficult to find a sufficient number of more complex questions.

**** A participant is not demoted from Professional Level Track & Sign if they do not achieve Specialist on a Tertiary Evaluation, regardless of score because this is a more complex evaluation. In the Photo dataset these participants are Professional Level (4).

Table 5. Foundational concepts of the theory, Tracking is Original Wisdom.

TRACKING IS ORIGINAL WISDOM - FOUNDATIONAL CONCEPTS

1. Part-time trackers tend to have more opportunities to maintain or re-establish tracking skills.
2. Full-time trackers tend to have more obstructions to learning and are either cut off from learning tracking skills, or learn them to fulfill their basic needs.
3. An existing relationship with a land is not necessary to develop expert tracking skills, but it helps, and one often develops from being on the land frequently and learning what's living and moving, and interacting, in the environment that one lives in.
4. Tracking is an **Original Wisdom.** It's **Original** in that **it's old**, and was **Wisdom** practiced by all first peoples relating to food and safety, some of this information might be exclusive to a land or a culture based on regional species and substrates, but the concepts and processes for learning are universal.
5. Tracking is an **Original Wisdom.** It's **Original** in that **it's new**, and is **Wisdom** practiced by modern peoples for recreational uses that include resources and technologies that push the boundaries of what's possible to know much further than for food and safety.
6. There is a lot of overlap in the information provided by both first peoples and modern peoples, yet each group has "areas of expertise" based on why and how they learn tracking, and what they spend their time focusing on.
7. The primary mechanisms for developing expert tracking skills are time and practice, thereafter, having a teacher or a mentor helps to accelerate the process.
8. CyberTracker includes mentoring aspects through its evaluations, by its evaluators, and builds a community of trackers among participants.
9. The best trackers have spent more time doing it, no matter their background.
10. An attitude of humility and patience is important to learning and to becoming an expert. Whether this is causal to a person becoming a tracker, or a result of becoming a tracker, is uncertain. It might come from the fact that even expert trackers will sometimes be wrong in an identification or interpretation, or will lose the trail of an animal or mess-up an approach.

Appendices
Appendix A. Survey Instrument

Please print clearly and return to Kersey Lawrence, contact info: 071.325.2325 South Africa/ 860.334.4092 USA

Tracking Questionnaire

Name____

Date____________________Venue_____________________Evaluator_______________

Section 1. Demographic information:

1. I am: Male Female (please circle one).

2. My age is: _________.

3. I am: white black (please circle one), or other: _________________ (please provide "other").

4. My cultural group is:____(please provide description, for example: American Indian/Cherokee, Chinese, Hawaiian, Shangaan, Zulu, etc.)

5. The highest grade level I have completed in school is ____ (please fill in grade level).

6. I grew up in an area that can mostly be described as: (please circle one choice, in the table below)

City	Small Town	Large Town	Village	Farming	Natural Area (forest, desert, bush)

7. I currently live in an area that can mostly be described as: (please circle one choice in the table below)

City	Large Town	Small Town	Village	Farming	Natural Area (forest, desert, bush, etc.)

Section 2. Previous Tracking Experience:

8. Please put an X next to the most appropriate statement below:

- I have no previous tracking experience_______
- I have only the tracking experience provided by this course/evaluation_______

• I have practiced tracking before as part of a class, an occupation, or as an interest_______

9. I have approximately ________ years tracking experience (please write number of years).

• During that time my tracking experience was: (please circle one)

Occasional (1-3 times a month)	Frequent (4-10 times a month)	Intensive (10-19 times a month)	Occupational (20 or more times a month)

10. In the past two (2) years my tracking experience was: (please circle one)

Occasional (1-3 times a month)	Frequent (4-10 times a month)	Intensive (10-19 times a month)	Occupational (20 or more times a month)

Section 3. Previous CyberTracker Evaluations:

11. The number of CyberTracker Track and Sign Evaluations I have participated in is:

1-2	3-4	5-6	6-7	8-9	10 or more

12. My highest score on a CyberTracker Track and Sign Evaluation so far is ________ (percent %).

13. The number of CyberTracker Trailing Evaluations I have participated in is:

1-2	3-4	5-6	6-7	8-9	10 or more

14. My highest score on a CyberTracker Trailing Evaluation so far is ________ (percent %).

Section 4. Current CyberTracker Evaluation:

15. This evaluation is part of a course: YES NO (please circle one).

• In this course we spent ________ days focused on tracking (please fill in number).

16. My level of enjoyment with this evaluation was: Low Medium High (please circle one).

17. The amount I learned during this evaluation was: Low Medium High (please circle one).

18. For today's evaluation, I expect to receive a certification level of: (please circle one)

No Level (less than 70%)	Level 1 (70-79%)	Level 2 (80-89%)	Level 3 (90-99%)	Level 4 (100%)	Specialist (100% on Specialist evaluation)	Senior (100% on both Track and Sign and Trailing evaluations)

Appendix B. Semi-Structured Interview Questions (examples)

Today's date:

What is your name?

What level tracker are you in the CyberTracker system? Track and Sign? Trailing?

Where do you work as a tracker?

How old are you?

What is the highest grade that you completed in school?

Can you tell me about your family that lives with you at home?

What was your childhood like? How did you learn tracking?

What is childhood like for your children, today, and how does this differ from how it was for you?

What is your culture and where are you from?

What is tracking?

How do you use tracking?

How else could tracking be used that would be helpful in some way?

How do you say "tracking" or "to go tracking" or "Let's go tracking" in your language?

Who becomes a tracker in your culture? Outside of your culture?

How did you learn tracking?

Who does your salary support, besides yourself?

Are your children, or the children in your village, interested in learning tracking?

Do you try to teach tracking? To who?

Tell me a story about when you first learned to track – a story from when you were learning that taught you something important?

Describe your day as a tracker.

Did you learn anything from books or television or the internet about tracking? How did you learn?

Tell me about where you have worked as a tracker: Where did you start, how long ago was that, how long were you there for, where did you go next, how long were you there for, when did you first take a CyberTracker evaluation, how did you do, how long did it take you to achieve the level you are now at

Does your employer help or support your advancement as a tracker, and do you get rewarded for becoming a better tracker?

Describe the CyberTracker evaluation system, what's good and bad about it for you?

Does becoming a more qualified tracker in the CyberTracker system help you to be a better tracker?

Does being a qualified tracker with CyberTracker help you in your job?

Are there other evaluation systems? Other ways to learn tracking?

Describe how you felt when you were new to tracking, how was your confidence then, and how does it compare to now – to what do you attribute that to?

How many T&S evaluations have you taken? When was the first one? What was your first score? When was the second one and what was your score… How did you improve your score?

How many Trailing evaluations have you taken? When was the first one? What was your first score? When was the second one and what was your score… How did you improve your score?

Besides how to identify a track or sign, what is important to know in tracking?

What role can trackers have in managing wildlife or land, or in research?

Would you travel to other parts of the world to be involved in tracking research?

How do you become a good tracker? How do you tell if someone is a good tracker, or is improving in their tracking ability?

What advice would you give to someone who wants to become a good tracker?

Are there any shortcuts to learning to be a good tracker?

Who do you know that is becoming a tracker?

Who do you suggest that I also interview?

Given the following defintition of Traditional Ecological Knowledge (TEK): "The evolving knowledge acquired by indigenous and local peoples over hundreds or thousands of years through direct contact with the environment". (https://www.fws.gov/nativeamerican/pdf/tek-fact-sheet.pdf)

What role have/do trackers play in traditional ecological knowledge?

What have you learned from other trackers that you would consider traditional ecological knowledge?

Literature Cited

Alexander, S. M., P. C. Paquet, Travis B. Logan, and D. J. Saher. 2005. Snow-tracking versus radiotelemetry for predicting wolf-environment relationships in the Rocky Mountains of Canada. Wildlife Society Bulletin 33(4):1216–1224.

Alibhai, S. K., Z. C. Jewell, and J. W. Evans. 2017. The challenge of monitoring elusive large carnivores: an accurate and cost-effective tool to identify and sex pumas (Puma concolor) from footprints. PloS One 12(3):e0172065. https://doi:10.1371/journal. pone.0172065

Alldredge, M. W., K. H. Pollock, and T. R. Simons. 2006. Estimating detection probabilities from multiple-observer point counts. The Auk 123(4):1172–1182.

Alldredge, M. W., T. R. Simons, and K. H. Pollock. 2007. Factors affecting aural detections of songbirds. Ecological Applications 17(3):948–955.

Allen, L., R. Engeman, and H. Krupa. 1996. Evaluation of three relative abundance indices for assessing dingo populations. Wildlife Research 23(2):197–205.

Allen, M. L., L. M. Elbroch, C. C. Wilmers, and H. U. Wittmer. 2015. The comparative effects of large carnivores on the acquisition of carrion by scavengers. The American Naturalist 185:822-833. http://dx.doi.org/10.5061/dryad.dh2vr.

Anselm, S., and J. Corbin. 1998. Basics of qualitative research: techniques and procedures for developing grounded theory. Sage Publications, Thousand Oaks, CA.: 431.

Aubry, K. B., and D. B. Houston. 1992. Distribution and status of the fisher (*Martes pennanti*) in Washington. Northwestern Naturalist 73(3):69–79.

Balme, G. A., L. T. B. Hunter, and R. Slotow. 2009. Evaluating methods for counting cryptic carnivores. Journal of Wildlife Management 73(3):433–441.

Barnum, S., K. Rinehart, and L. M. Elbroch. 2007. Habitat, highway features, and animal-vehicle collision locations as indicators of wildlife crossing hotspots. Road Ecology Center, John Muir Institute of the Environment, UC Davis, Davis. http://escholarship.org/uc/item/3d35b16n

Becker, E. F. 1991. A terrestrial furbearer estimator based on probability sampling. Journal of Wildlife Management 55(4):730–737.

Becker, E. F., M. A. Spindler, and T. O. Osborne. 1998. A Population Estimator Based on Network Sampling of Tracks in the Snow. Journal of Wildlife Management 62(2):968.

Beier, P., and S. C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. Wildlife Society Bulletin 24(3):540–546.

Bleich, V. C., B. M. Pierce, J. L. Davis, and V. L. Davis. 1996. Thermal characteristics of mountain lion dens. The Great Basin Naturalist 56(3):276–278.

Bothma, J. D. P., and E. A. N. le Riche. 1984. Aspects of the ecology and the behaviour of the leopard *Panthera pardus* in the Kalahari desert. Koedoe-African Protected Area Conservation and Science 27:259–279.

Brossard, D., B. Lewenstein, and R. Bonney. 2005. Scientific knowledge and attitude change: the impact of a citizen science project. International Journal of Science Education 27(9):1099–1121.

Carroll, C., W. J. Zielinski, and R. F. Noss. 1999. Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath region, USA. Conservation Biology 13(6):1344–1359.

Carruthers, J., 1995. The Kruger National Park: A Social and Political History. University of Natal Press. Pietermaritzburg, South Africa: 170.

Caruthers, J., 2006. Tracking in game trails: looking afresh at the politics of environmental history in South Africa. Environmental History 11:804-829.

Chame, M. 2003. Terrestrial mammal feces: a morphometric summary and description. Memórias do Instituto Oswaldo Cruz 98:71–94.

Charmaz, K. 2014. Constructing Grounded Theory. Sage Publications, Los Angeles, CA.: 416.

Charmaz, K. 2017. The power of constructivist grounded theory for critical inquiry. Qualitative Inquiry 23:34–45.

Choudhury, S. R. 1970. Let us count our tigers. Cheetal 14(2):41–51.

Choudhury, S. R. 1972. Tiger census in India. Cheetal 15:67–84.

Clapham, M., O. T. Nevin, A. D. Ramsey, and F. Rosell. 2013. The function of strategic tree selectivity in the chemical signalling of brown bears. Animal Behaviour 85(6):1351-1357.

Cohn, J. P. 2008. Citizen science: can volunteers do real research? Bioscience 58(3):192–197.

Crall, A. W., R. Jordan, K. Holfelder, G. J. Newman, J. Graham, and D. M. Waller. 2012. The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. Public Understanding of Science 22(6):745–764.

Crooks, K. R., and M. E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400(6744):563–566.

Crooks, K. R., M. Grigione, A. Scoville, and G. Scoville. 2008. Exploratory use of track and camera surveys of mammalian carnivores in the Peloncillo and Chiricahua mountains of Southeastern Arizona. The Southwestern Naturalist 53(4):510–517.

Crowley, S. M., C. J. Johnson, and D. Hodder. 2012. The role of demographic and environmental variables on the presence of snow tracks by river otters *Lontra canadensis*. Wildlife Biology 18:105–112.

Davison, A., J. D. S. S. Birks, R. C. Brookes, T. C. Braithwaite, and J. E. Messenger. 2002. On the origin of faeces: morphological versus molecular methods for surveying rare carnivores from their scats. Journal of Zoology 257(2):141–143.

De Angelo, C., A. Paviolo, and M. S. Di Bitetti. 2010. Traditional versus multivariate methods for identifying jaguar, puma, and large canid tracks. Journal of Wildlife Management 74(5):1141–1151.

DeMatteo, K. E., L. W. Blake, J. K. Young, and B. Davenport. 2018. How behavior of nontarget species affects perceived accuracy of scat detection dog surveys. Nature: Scientific Reports 8:e13830. https://doi.org/10.1038/s41598-018-32244-1

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. Variability in grassland bird counts related to observer differences and species detection rates. The Auk 120(4):1168–1179.

Du Plessis, P. 2010. Tracking knowledge: science, tracking and technology. Master of Social Science, University of Cape Town, RSA.: 83.

Du Plessis, P. 2018. Gathering the Kalahari: tracking landscapes in motion. Doctoral Dissertation, Anthropolgy, University of Santa Crus, CA.: 331.

Dudley, J. P., A. Y. Mensah-Ntiamoah, D. G. Kpelle, A. Y. Mensah-Ntiamoah, and D. G. Kpelle. 1992. Forest elephants in a rainforest fragment: preliminary findings from a wildlife conservation project in southern Ghana. African Journal of Ecology 30(2):116–126.

Duffie, D. R., R. A. Gitzen, N. W. Sharp, and A. J. Turner. 2019. Effectiveness and accuracy of track tubes for detecting small-mammal species occupancy in southeastern herbaceous wetlands and meadows. Southeastern Naturalist 18:130–146.

Edwards, G. P., N. D. de Preu, B. J. Shakeshaft, I. v. Crealy, N. D. de Preu, B. J. Shakeshaft, and I. V. Crealy. 2000. An evaluation of two methods of assessing feral cat and dingo abundance in central Australia. Wildlife Research 27(2):143–149.

Eiseman, C., N. Charney, and J. Carlson. 2010. Tracks & Sign of Insects & Other Invertebrates: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 592.

Elbroch, L. M., and A. Kusler. 2018. Are pumas subordinate carnivores, and does it matter? PeerJ 6:e4293. http://dx.doi.org/10.7717/peerj.4293

Elbroch, L. M., and H. U. Wittmer. 2012. Table scraps: inter-trophic food provisioning by pumas. Biology Letters 8(5):776–779.

Elbroch, L. M., and H. U. Wittmer. 2013a. The effects of puma prey selection and specialization on less abundant prey in Patagonia. Journal of Mammalogy 94(2):259–268.

Elbroch, L. M., and H. U. Wittmer. 2013*b*. Nuisance ecology: do scavenging condors exact foraging costs on pumas in Patagonia? PLoS One 8:e53595. http://dx.doi.org/10.1371/journal.pone.0053595

Elbroch, L. M., M. L. Allen, B. H. Lowrey, and H. U. Wittmer. 2014. The difference between killing and eating: ecological shortcomings of puma energetic models. Ecosphere 5(5):1–16. http://dx.doi.org/10.1890/ES13-00373.1

Elbroch, L. M., T. H. Mwampamba, M. J. Santos, M. Zylberberg, L. Liebenberg, J. Minye, C. Mosser, and E. Reddy. 2011. The value, limitations, and challenges of employing local experts in conservation research. Conservation Biology 25:1195–1202.

Engeman, R. M., and P. Evangilista. 2007. Investigating the feasibility of a passive tracking index for monitoring wildlife in the Lower Omo Valley, Ethiopia. African Journal of Ecology 45(2):184–188.

Evans, J. W. 2007. Observer error in identifying species using indirect sigs: analysis of a river otter track survey technique. Master of Science, Wildlife and Fisheries Science, Texas A&M University: 63.

Evans, J. W., C. A. Evans, J. M. Packard, G. Calkins, and L. M. Elbroch. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management 73(3):426–432.

Fitzhugh, E. L., and W. P. Gorenzel. 1985. Design and analysis of mountain lion track surveys. Cal-Nevada Wildlife:78–87.

Foresman, K. R., and D. E. Pearson. 1998. Comparison of proposed survey procedures for detection of forest carnivores. Journal of Wildlife Management 62(4):1217–1226.

Forrest, L. R. 1988. Field Guide to Tracking Animals in Snow. Stackpole Books, Mechanicsville, PA.: 181.

Funston, P. J., L. Frank, T. Stephens, Z. Davidson, A. Loveridge, D. M. Macdonald, S. Durant, C. Packer, A. Mosser, and S. M. Ferreira. 2010. Substrate and species constraints on the use of track incidences to estimate African large carnivore abundance. Journal of Zoology 281:56–65.

García, K. P., J. Carlos Ortiz, M. Vidal, and J. R. Rau. 2010. Morphometrics of the tracks of Puma concolor: is it possible to differentiate the sexes using measurements from captive animals? Zoological Studies 49(4):577–582.

Garratt, D. 2018. Reflections on being an expert. Grounded Theory Review 17:86–89.

Glaser, B. G. 1992. Basics of Grounded Theory Analysis. Sociology Press, Mill Valley, CA.: 128.

Glaser, B. G. 1998. Doing Grounded Theory: Issues and Discussions. Sociology Press, Mill Valley, CA.: 254.

Glaser, B. G. 2014. Choosing grounded theory. The Grounded Theory Review 13(2):3–19.

Glaser, B. G. 2018. Getting started. Grounded Theory Review 17(1):3–6.

Glaser, B. G., and A. L. Strauss. 2017. Discovery of Grounded Theory: Strategies for Qualitative Research. First edition. Transaction Publishers, New York, N.Y.: 270.

Golden, H. N., J. David Henry, E. F. Becker, M. I. Goldstein, J. M. Morton, D. Frost, A. J. Poe Golden, P. Canada, N. Yukon, and A. J. Poe. 2007. Estimating wolverine *Gulo gulo* population size using quadrat sampling of tracks in snow. Wildlife Biology 13(2):52-61.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D. Lapoint, D. A. Bogan, and J. R. Cryan. 2006. A comparison of noninvasive techniques to survey carnivore communities in Northeastern North America. Wildlife Society Bulletin 34(4):1142–1151.

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.

Gruber, B., B. Reineking, J. M. Calabrese, A. Kranz, K. Poledníková, L. Poledník, R. Klenke, A. Valentin, and K. Henle. 2008. A new method for estimating visitation rates of cryptic animals via repeated surveys of indirect signs. Journal of Applied Ecology 45(2):728–735.

Gu, J., S. K. Alibhai, Z. C. Jewell, G. Jiang, and J. Ma. 2014. Sex determination of Amur tigers (*Panthera tigris altaica*) from footprints in snow. Wildlife Society Bulletin 38(3):495–502.

Gu, W., and R. K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biological Conservation 116(2):195–203.

Gusset, M., and N. Burgener. 2005. Estimating larger carnivore numbers from track counts and measurements. African Journal of Ecology 43(4):320–324.

Gutteridge, L., and L. Liebenberg. 2013. Mammals of Southern Africa and their Tracks and Signs. Jacana Media, Auckland Park, RSA.: 291.

Harrington, L.A., A. L. Harrington, and D. W. Macdonald. 2008. Estimating the relative abundance of American mink (*Mustela vison*) on lowland rivers: evaluation and comparison of two techniques. European Journal of Wildlife Research 54(1):79-87.

Harrington, L. A., A. L. Harrington, J. Hughes, D. Stirling, and D. W. Macdonald. 2010. The accuracy of scat identification in distribution surveys: American mink, *Neovison vison*, in the northern highlands of Scotland. European Journal of Wildlife Research 56(3):377–384.

Hart, A., R. Stafford, A. Goodenough, and S. Morgan. 2012. The role of citizen science and volunteer data collection in zoological research. International Journal of Zoology 2012(105345):1–3. http://dx.doi.org/10.1155/2012/105345

Havens, K., and S. Henderson. 2013. Citizen science takes root. American Scientist 101:378–385.

Hayward, G. D., D. G. Miquelle, E. N. Smirnov, and C. Nations. 2002. Monitoring Amur tiger populations: characteristics of track surveys in snow. Wildlife Society Bulletin 30:1150–1159.

Herzog, C. J., R. W. Kays, J. C. Ray, M. E. Gompper, W. J. Zielinski, R. Higgins, and M. Tymeson. 2007. Using patterns in track-plate footprints to identify individual fishers. Journal of Wildlife Management 71(3):955–963.

Hunter, J., A. Alabri, and C. Ingen. 2012. Assessing the quality and trustworthiness of citizen science data. Concurrency and Computation: Practice and Experience 25:454-466.

Ijäs, M. 2017. Fragments of the hunt. Persistence hunting, tracking and prehistoric art. Doctoral Dissertation, Department of Art, Aalto University, Helsinki, Finland: 228.

Jewell, Z. C., S. K. Alibhai, F. Weise, S. Munro, M van Vuuren, and R van Vuuren. 2016. Spotting cheetahs: identifying individuals by their footprints. Journal of Visualized Experiments (JOVE) 111:e10.3791/54034. http://dx.doi.org/10.3791/54034

Jewell, Z., and S. K. Alibhai. 2012. Identifying endangered species from footprints. The International Society for Optics and Photonics (SPIE). http://dx.doi.org/10.1117/2.1201212.004636

Jewell, Z. C., S. K. Alibhai, and P.R. Law. 2001. Censusing and monitoring black rhino (*Diceros bicornis*) using an objective spoor (footprint) identification technique. Journal of Zoology 254:1-16.

Jones, C., H. Moller, and W. Hamilton. 2004. A review of potential techniques for identifying individual stoats (*Mustela erminea*) visiting control or monitoring stations. New Zealand Journal of Zoology 31(3):193-203.

Jordan, R. C., S. A. Gray, D. v Howe, W. R. Brooks, and J. G. Ehrenfeld. 2011. Knowledge Gain and Behavioral Change in Citizen-Science Programs. Conservation Biology 25(6):1148–1154.

Karamanlidis, A., D. Youlatos, S. Sgardelis, and Z. Scouras. 2007. Using sign at power poles to document presence of bears in Greece. Ursus 18:54–61.

Karanth, K. U., A. M. Gopalaswamy, N. S. Kumar, S. Vaidyanathan, J. D. Nichols, and D. I. MacKenzie. 2011. Monitoring carnivore populations at the landscape scale: occupancy modelling of tigers from sign surveys. Journal of Applied Ecology 48(4):1048–1056.

Karanth, K. U., J. D. Nichols, J. Seidenstricker, E. Dinerstein, J. L. D. Smith, C. McDougal, A. J. T. Johnsingh, R. S. Chundawat, and V. Thapar. 2003. Science deficiency in conservation practice: the monitoring of tiger populations in India. Animal Conservation 6(2):141–146.

Karanth, K. U., J. D. Nichols, N. Kumar, W. A. Link, and J. E. Hines. 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences (PNAS) 101(14):4854–4858.

Keeping, D. 2014. Rapid assessment of wildlife abundance: estimating animal density with track counts using body mass–day range scaling rules. Animal Conservation 17(5):486–497.

Keeping, D., and R. Pelletier. 2014. Animal density and track counts: Understanding the nature of observations based on animal movements. PLoS ONE 9(5): e96598. http://dx.doi.org/10.1371/journal.pone.0096598

Kerley, L. L., and G. P. Salkina. 2007. Using scent-matching dogs to identify individual Amur tigers from scats. Journal of Wildlife Management 71(4):1349–1356.

Kobryńczuk, F., M. Krasińska, and T. Szara. 2008*a*. Sexual Dimorphism in Skulls of the Lowland European Bison, *Bison Bonasus Bonasus*. Annales Zoologici Fennici. 45(4):335–340.

Kobryńczuk, F., M. Krasińska, and T. Szara. 2008*b*. Polarization of Skull Shapes in Adult Lowland European Bison, *Bison Bonasus Bonasus*. Annales Zoologici Fennici. 45(4):341–346.

Kohn, M. M. H., and R. K. Wayne. 1997. Facts from feces revisited. Trends in Ecology & Evolution. 12(6):223–227.

Kremen, C., K. S. Ullman, and R. W. Thorp. 2011. Evaluating the quality of citizen-scientist data on pollinator communities. Conservation Biology 25(3):607–617.

Kusler, A., L. M. Elbroch, H. Quigley, and M. Grigione. 2017. Bed site selection by a subordinate predator: An example with the cougar (*Puma concolor*) in the Greater Yellowstone Ecosystem. PeerJ 5:e4010; http://dx.doi.org/10.7717/peerj.4010

Lanszki, J., and M. Heltai. 2011. Feeding habits of sympatric mustelids in an agricultural area of Hungary. Acta Zoologica Academiae Scientiarum Hungaricae 57(3):291–304.

Lanszki, J., M. Heltai, and L. Szabó. 2006. Feeding habits and trophic niche overlap between sympatric golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*) in the Pannonian ecoregion (Hungary). Canadian Journal of Zoology - Revue Canadienne de Zoologie 84(11):1647-1656.

Lawrence-Apfel, K., K. Arifuzzaman, and T. H. Meyer. 2012. An accuracy assessment of global navigation satellite system wildlife-tracking collars in the southern Chilean Patagonia. Anales Instituto Patagonia 40:105–113.

Lewandowski, E., and H. Specht. 2015. Influence of volunteer and project characteristics on data quality of biological surveys. Conservation Biology 29(3):713–723.

Lewison, R., E. L. Fitzhugh, and S. P. Galentine. 2001. Validation of a rigorous track classification technique: identifying individual mountain lions by their tracks. Biological Conservation 99(3):313–321.

Li, B. v., S. K. Alibhai, Z. C. Jewell, D. Li, and H. Zhang. 2018. Using footprints to identify and sex giant pandas. Biological Conservation 218:83–90.

Liebenberg, L. 1990. The Art of Tracking: The Origin of Science. David Philip Publishers, Cape, RSA.: 187.

Liebenberg, L. 2006. Persistence hunting by modern hunter-gatherers. Current Anthropology 47(6):1017–1026.

Liebenberg, L. 2008. The relevance of persistence hunting to human evolution. Journal of Human Evolution 55(6):1156–1159.

Liebenberg, L. 2013. The Origin of Science. CyberTracker Books. www.cybertracker.org/science/books, Cape Town, RSA.: 265.

Liebenberg, L., A. Louw, and L. M. Elbroch. 2010. Practical Tracking: A Guide to Following Footprints and Finding Animals. Stackpole Books, Mechanicsburg, PA., USA.: 352.

Liebenberg, L., J. Steventon, N. Brahman, K. Benadie, J. Minye, H. K. (Karoha) Langwane, and Q. (Uase) Xhukwe. 2017. Smartphone icon user interface design for non-literate trackers and its implications for an inclusive citizen science. Biological Conservation 208:155–162. http://dx.doi.org/10.1016/j.biocon.2016.04.033

Liebenberg, L., J. Steventon, K. Benadie, and J. Minye. 1999. Rhino Tracking with the CyberTracker Field Computer. Pachyderm 27:59–61.

Liebenberg, L. 1990. A Field Guide to the Animal Tracks of Southern Africa. David Philip Publishers, Cape Town, RSA.: 306.

Linnell, J. D., P. Fiske, I. Herfindal, J. Odden, H. Brøseth, and R. Andersen. 2007. An evaluation of structured snow-track surveys to monitor Eurasian lynx *Lynx lynx* populations. Wildlife Biology 13: 456-466.

Logie, C. 2010. The literacy of tracking: a comparative analysis of tracking within two Bushman post-hunter communities. Master of Arts in Culture, Communication and Media Studies, University of KwaZulu-Natal, Howard College, Durban, RSA.: 108

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007*a*. Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management 71(6):2018–2025.

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007*b*. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Management 71(6):2007–2017.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42(6):1105–1114.

Magoun, A. J., J. C. Ray, D. S. Johnson, P. Valkenburg, F. N. Dawson, and J. Bowman. 2007. Modeling wolverine occurrence using aerial surveys of tracks in snow. Journal of Wildlife Management 71(7):2221–2229.

Marchal, A. F. J. 2017. Monitoring lions (*Panthera leo*) using digital 3D models of their tracks. Doctoral Dissertation, Zoology and Agricultural Sciences & Bio-engineering, University of Pretoria, Pretoria, RSA.: 151.

Marchal, A. F. J., J. P. Lejeune, and P. J. N. de Bruyn. 2017. Identification of the anteroposterior and mediolateral position of lion paws and tracks using 3D geometric morphometrics. South African Journal of Wildlife Research 47(2):106–113.

Marchal, A. F. J., J. P. Lejeune, and P. J. N. de Bruyn. 2016. Virtual plaster cast: digital 3D modelling of lion paws and tracks using close-range photogrammetry. Journal of Zoology 300(2):111–119.

Mcbride, R. T, R. T. Mcbride, R. M. McBride, and C. E. McBride. 2008. Counting pumas by categorizing physical evidence. Southeastern Naturalist 7(3):381–400.

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2017. Classifying carnivore tracks using dimensions that control for snow conditions. Wildlife Society Bulletin 41(2):278–285.

McClintock, B. T., L. L. Bailey, K. H. Pollock, and T. R. Simons. 2010. Unmodeled observation error induces bias when inferring patterns and dynamics of species occurrence via aural detections. Ecology 91(8):2446–2454.

McCullough, D. R. 1965. Sex characteristics of black-tailed deer hooves. Journal of Wildlife Management 29:210–212.

McHenry, E., C. O'Reilly, E. Sheerin, K. Kortland, and X. Lambin. 2016. Strong inference from transect sign surveys: combining spatial autocorrelation and misclassification occupancy models to quantify the detectability of a recovering carnivore. Wildlife Biology 22(5):209–216.

McKelvey, K. S., J. von Kienast, K. B. Aubry, G. M. Koehler, B. T. Maletzke, J. R. Squires, E. L. Lindquist, S. Loch, and M. K. Schwartz. 2006. DNA analysis of hair and scat collected along snow tracks to document the presence of Canada lynx. Wildlife Society Bulletin 34(2):451–455.

Molinari, M. P., and K. Vander Linden. 2019. Value-based mavericking. Grounded Theory Review 18(1):83–98.

Moreira, D. O., S. K. Alibhai, Z. C. Jewell, C. J. da Cunha, J. B. Seibert, and A. Gatti. 2018. Determining the numbers of a landscape architect species (*Tapirus terrestris*), using footprints. PeerJ 6(3):e4591. https://doi.org/10.7717/peerj.4591

Mueller, M. P., D. Tippins, and L. Bryan. 2012. The Future of Citizen Science. Democracy and Education 20(1):1-12.

Murdoch, J. D., and S. Buyandelger. 2010. An account of badger diet in an arid steppe region of Mongolia. Journal of Arid Environments 74(10):1348–1350.

Murmann, D. C., P. C. Brumit, B. A. Schrader, and D. R. Senn. 2006. A comparison of animal jaws and bite mark patterns. Journal of Forensic Sciences 51(4):846–860.

Neter, J., M. H. Kutner, and C. Nachtsheim. 1996. Applied Linear Statistical Models. 4th ed. Irwin Publishers, Chicago, IL., USA:1408.

O'Malley, C., L. M. Elbroch, P. E. Lendrum, and H. B. Quigley. 2018.. Motion-triggered video cameras reveal spatial and temporal patterns of red fox foraging on carrion provided by mountain lions. PeerJ 6:e5324. https://doi.org/10.7717/peerj.5324

Patterson, B. R., N. W. S. Quinn, E. F. Becker, and D. B. Meier. 2004. Estimating wolf densities in forested areas using network sampling of tracks in snow. Wildlife Society Bulletin 32(3):938–947.

Pimm, S. L., S. K. Alibhai, R. Bergl, A. Dehgan, C. Giri, Z. C. Jewell, L. Joppa, R. Kays, and S. Loarie. 2015. Emerging technologies to conserve biodiversity. Trends in Ecology & Evolution 30(11):685–696. Elsevier Ltd.

Pirie, T. J., R. L. Thomas, and M. D. E. E. Fellowes. 2016. Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology 22:13–21.

Purchase, D. 2007. Using spoor to determine the age and weight of subadult black rhinoceroses (*Diceros bicornis L.*). South African Journal of Wildlife Research 37:96–100.

Romani, T., C. Giannone, E. Mori, and S. Filacorda. 2018. Use of track counts and camera traps to estimate the abundance of roe deer in North-Eastern Italy: are they effective methods? Mammal Research 63(4):477–484.

Rumble, M. A., T. R. Mills, B. F. Wakeling, and R. W. Hoffman. 1996. Age and gender classification of Merriam’s turkeys from foot measurements. Proceedings of the National Turkey Symposium 7:129–134.

Rutina, L. P., K. M. Mogwera, S. Elford, C. Mpofu, and D. Ntloyathuto. 2017. Herders’ ecological knowledge and carnivore predation on livestock investigations in Makgadikgadi and Nxai national parks, Botswana. Koedoe - African Protected Area Conservation and Science 52(2):1–9.

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American breeding bird survey. The Auk 11(1): 50–62.

Sharma, S. 2001. Evaluation of pugmark census technique. Thesis, Saurashtra University, Gujarat and Wildlife Institute of India, Dehra Dun, Uttaranchal, India.

Sidorovich, V. E., A. A. Sidorovich, and D. A. Krasko. 2010. Effect of felling on red fox (*Vulpes vulpes*) and pine marten (*Martes martes*) diets in transitional mixed forest in Belarus. Mammalian biology Zeitschrift für Säugetierkunde. 75(5):399–411.

Sidorovich, V. E., I. I. Rotenko, and D. A. Krasko. 2011. Badger *Meles meles* spatial structure and diet in an area of low earthworm biomass and high predation risk. Annales Zoologici Fennici 48(1):1-16.

Silveira, L., A. T. A. Jácomo, and J. A. F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114(3):351–355.

Singh, S., and A. Estefan. 2018. Selecting a grounded theory approach for nursing research. Global Qualitative Nursing Research 5:1-9. https://doi.org/10.1177/2333393618799571

Skalski, J. R. 1991. Using sign counts to quantify animal abundance. Journal of Wildlife Management 55(4):705–715.

Skalski, T., and I. Wierzbowska. 2008. Variation of insect assemblages in fox and marten faeces collected in southern Poland. Annales Zoologici Fennici 45(4):308–316.

Smallwood, K. S., and E. L. Fitzhugh. 1995. A track count for estimating mountain lion *Felis concolor californica* population trend. Biological Conservation 71(3):251–259.

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

Stander, P. E. 1998. Spoor counts as indices of large carnivore populations: the relationship between spoor frequency, sampling effort and true density. Journal of Applied Ecology 35(3):378–385.

Stander, P. E., //. Ghau, D. Tsisaba, //. ≠Oma, and and //. Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Stanley, T. R., and J. A. Royle. 2005. Estimating site occupancy and abundance using indirect detection indices. The Journal of Wildlife Management 69(3):874–883.

Stephens, P. A., O. Y. Zaumyslova, D. G. Miquelle, A. I. Myslenkov, and G. D. Hayward. 2006. Estimating population density from indirect sign: track counts and the Formozov–Malyshev–Pereleshin formula. Animal Conservation 9(3):339–348.

Taylor, A. P., M. S. Gunther, and M. L. Allen. 2015. Black bear marking behaviour at rub trees during the breeding season in northern California. Behaviour 152(7-8):1097–1111.

Taylor, C. A., and M. G. Raphael. 1988. Identification of mammal tracks from sooted track stations in the Pacific Northwest. California Fish and Game 74(1):4–15.

Taylor, M. E. 1970. Locomotion in some East African viverrids. Journal of Mammalogy 51(1):42–51.

Van Dyke, F. G. van, R. H. Brocke, and H. G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102–109.

Wilson, G. J., and R. J. Delahay. 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. Wildlife Research 28(2):151–164.

Wolf, M., and S. Ale. 2009. Signs at the top: habitat features influencing snow leopard *Uncia uncia* activity in Sagarmatha National Park, Nepal. Journal of Mammalogy 90(3):604–611.

Wong, P. B. Y., P. Van Coeverden de Groot, C. Fekken, H. Smith, M. Pagès, and P. T. Boag. 2012. Interpretations of polar bear (*Ursus maritimus*) tracks by Inuit hunters: inter-rater reliability and inferences concerning accuracy. The Canadian Field-Naturalist 125(2):140–153.

Zalewski, A. 1999. Identifying sex and individuals of pine marten using snow track measurements. Wildlife Society Bulletin 27:28-31.

Zielinski, W. J., and F. V. Schlexer. 2009. Inter-observer variation in identifying mammals from their tracks at enclosed track plate stations. Northwest Science 83(4):299–307.

Zielinski, W. J., and H. B. Stauffer. 1996. Monitoring Martes populations in California: survey design and power analysis. Ecological Applications 6(4):1254–1267.

Zielinski, W. J., and T. E. Kucera. 1995. American marten, fisher, lynx, and wolverine: survey methods for their detection. General Technical Report PSW GTR-157. US Department of Agriculture, Forest Service, Pacific Southwest Research Station: 172.

Zips, W., and Zips-M Mairitsch. 2007. Lost in Transition? The Politics of Conservation, Indigenous Land Rights and Community-Based Resource Management in Southern Africa. The Journal of Legal Pluralism and Unofficial Law 39(55):37-71.

Zuercher, G. L., P. S. Gipson, and G. C. Stewart. 2003. Identification of carnivore feces by local peoples and molecular analyses. Wildlife Society Bulletin 31(4):961–970.

Chapter 2. A Content-Analysis Of How Wildlife Tracking Is Used In Science And Guidelines For Evidentiary Standards When Using Track-Based Data

Abstract

Wildlife research results are only as good as the data collected. Many wildlife scientists collect track-based data in their wildlife research programs. Track-based data include tracks and other indirect field signs of an animal's presence or of its classic behaviors in a habitat. We use these data to identify the species that made them, and in some instances the ages, sexes, sizes, or individuals within a species. We also use them to count animals and monitor trends in their numbers, to determine the areas they inhabit and the resources they need to live, and to interpret behaviors. Wildlife management, research, and conservation are fundamentally based on the following questions: "who is here?", "how many of them are there?", and "how do they live?". Track-based data can help scientists answer these questions and provide decision makers with information relevant for maintaining sustainable wildlife populations, managing endangered or invasive species, avoiding human-wildlife conflicts, and making wise-use decisions for developing human infrastructures while improving ecological relationships.

There is a persistent doubt that wildlife tracks and signs themselves are not inherently accurate and reliable, and a plethora of peer-reviewed journal articles have been published that either support or refute this. The one thing that many of these papers have in common is the failure to report an objective measurement of the skill of the person collecting track-based data, even though these data (quietly, in the background) form the foundation of many higher-level questions asked and in developing technologies used in research programs and conservation initiatives. Due to the nature of the questions being asked and the decisions being made from the information provided, track-based data need to be as accurate and reliable as possible, otherwise, all that follows is fundamentally flawed.

I present here a content-analysis of how track-based data have been used in peer-reviewed scientific research for wildlife. I searched publications for where/how/when track-based data has been used to answer ecological questions about wildlife. Then, I evaluated how the data were collected, and I created a table that applies scores to criteria authors' report as an objective measurement of independent verification of observer bias for the data. In conclusion, I suggest a system for introducing and maintaining the concepts of accuracy and reliability to scientists collecting track-based data for wildlife research, conservation, and management.

Background

What is track-based data?

In wildlife research, track-based data include the identification of tracks and indirect signs of wildlife (Stander et al. 1997, Wilson and Delahay 2001, Evans et al. 2009). Tracks are also known as footprints, spoor, or pugmarks, depending on the region of the world they are in (Panwar 1979, Stander 1998). Indirect field signs, or signs, include but are not limited to feces (scats, pellets, or dung), urinations, visual marking and scent-marking, kill-sites and browse evidence, body parts and skeletal remains, feathers, eggs, nests, webs, beds, dens, burrows, gaits and track patterns (ways of moving), and even particular smells, and vocalizations and alarm calls (Wilson and Delahay 2001, Terry et al. 2005, Elbroch and McFarland 2019). Many different species have tracks and signs that appear similar to the untrained observer, so an observer must practice to acquire the skill needed to distinguish tracks and signs (Liebenberg 1990*a*, Elbroch 2003).

Tracks and signs interpretation requires more skill than basic tracks and signs identification (Liebenberg 1990*b*). For example, kill-site analysis is often an interpretation of who killed who, based on the tracks and signs present (Larivière 1999, Elbroch and Wittmer 2012, Elbroch and McFarland 2019). A short sequence of ungulate tracks leading to and stopping at clipped vegetation is an interpretation of browsing (Elbroch and McFarland 2019). A running gait is not an animal's baseline behavior, so this gait is interpreted as the animal chasing something, fleeing from something, or perhaps playing, just as a particular pattern of footprints can be interpreted as a stop of forward locomotion (Muybridge 1957, Hildebrand 1962, 1977, Elbroch and McFarland 2019). Ways of moving can be particularly important in substrates that don't hold track morphology, such as in leaf litter or snow where the pattern, size of the tracks, and distance between the tracks can be interpreted to help identify the species that made them (Forrest 1988, Liebenberg et al. 2010).

How are track-based data used?

Track-based data are fundamentally used to determine whether or not a species is present in an area. Wildlife researchers know that their non-detection of a species does not mean that a species is absent, only that no evidence was found for its presence (Carroll et al. 1999, Weidong and Swihart 2004, MacKenzie 2005, Evans et al. 2009). A species could be present, but perhaps the observer didn't cover enough ground to find evidence, and sampling intensity will vary from species to species, habitat to habitat, budget to budget. To detect tracks and signs of a species, an observer needs to be able to develop a search image of what to look for, find it, and not misidentify the tracks and signs of a species as something else (false-negatives), and not identify another species as their target (false-positives) (Evans et al. 2009). Some species are common and easy to detect, others are more difficult. Carnivores typically fall into the more difficult category, especially when they are rare, shy, secretive, solitary, and/or nocturnal (Van Dyke et al. 1986, Zielinski and Kucera 1995, Zielinski and Stauffer 1996, Carroll et al. 1999, Crooks and

Soulé 1999, Gusset and Burgener 2005, Stanley and Royle 2005, Gompper et al. 2006, Barnum et al. 2007, Crooks et al. 2008, Jeffress et al. 2011, Pirie et al. 2016).

Track-based data are also used in more complex measures, including but not limited to biodiversity assessments (Pimm et al. 2015) and determining species richness (Silveira et al. 2003). Examples of these include inventories of small mammal species using track-plates, tubes, or tunnels (Zielinski and Kucera 1995, Zielinski and Stauffer 1996, Clapperton et al. 1999, Blackwell et al. 2002, Zielinski et al. 2004, Crooks et al. 2008, Zielinski and Schlexer 2009, Ellison and Swanson 2016), or, on a larger scale, identifying what species use wildlife crossing structures to safely cross roads. These take the form of underpasses or overpasses of varying size, from a few feet in diameter to accommodate small animals like turtles and foxes, to enormous bridge-like structures made for accommodating large animals from bears to elephants (Silveira et al. 2003, Blaum et al. 2008, Ford et al. 2009, Bellis et al. 2013).

Track-based data are also used in determining environmental relationships. Questions asked include how continuously or discontinuously a species is distributed across and landscape (Aubry and Houston 1992, Aubry and Lewis 2003, Aubry and Jagger 2006), what are the general habitats that species uses (e.g. coniferous forest, deciduous forest, prairie, mountain, etc.), and specific habitat requirements (e.g. open areas, cliffy refugia, snags, blow downs and areas of thick cover) (Anderson 1998, Purcell et al. 2009, Trudeau et al. 2011). Many species use seasonally different habitats, moving between them as the weather changes (Armstrong et al. 1983, Lang et al. 1985, Messier and Barrette 1985, D'Eon 2001, Grovenburg et al. 2010). Surveying those areas when the animal is absent might cause a disregard for the importance of that habitat to the species. Carnivores usually have particular areas, called home ranges, that they live in. Within those home ranges are areas that are defended against other members of the same species, called territories, and within those areas are specific sites used for bedding and denning (Macdonald 1980, Kusler et al. 2017). These areas are often heavily marked, visually, audibly, and with scent, to deter unwanted interactions or to advertise sexual receptiveness (e.g. many of the felids) (Maximilian L. Allen et al. 2015), or convey foraging information (e.g. hyenas) (Mills 1984, Woodmansee et al. 1991). Different stages of life might require different micro-habitats, such as differences in needs between birthing sites and sites used as bedding areas (Carroll et al. 1999, Alexander et al. 2005, Barnum et al. 2007, L. M. Elbroch et al. 2015, McHenry et al. 2016).

Species are often managed for sustainable numbers in an ecosystem. Track-based data are one possible data source for estimating population size. Additionally, observers calculate indices of abundance (Skalski 1991, Allen et al. 1996, Edwards et al. 2000, Wilson and Delahay 2001, Silveira et al. 2003, Karanth et al. 2004, Gusset and Burgener 2005, Stanley and Royle 2005, Harrington et al. 2008, Funston et al. 2010, Keeping 2014) and baseline measures to estimate a population and to monitor if it is increasing or decreasing (Becker 1991, Smallwood et al. 1995, Beier and Cunningham 1996, Zielinski and Stauffer 1996, Stander 1998, Hayward et al. 2002, Karanth et al. 2003, 2011, Stephens et al. 2006, Engeman and Evangilista 2007, Golden et al. 2007, Linnell et al. 2007, Balme et al. 2009, Keeping and Pelletier 2014).

For many species of concern, especially carnivores, or large, charismatic megafauna, observers have explored how to measure and model tracks and signs to determine sex, gender, weight, or individuals. The prevailing thought among wildlife scientists is that if we can identify and enumerate all of the individuals, we will know the population density and be able to monitor it efficiently (Fitzhugh and Gorenzel 1985, Smallwood and Fitzhugh 1993, Stander et al. 1997, Jewell et al. 2001, Lewison et al. 2001, Wilson and Delahay 2001, Karanth et al. 2003, Herzog et al. 2007, Kerley and Salkina 2007).

Why are track-based data used?

Track-based data are non-invasive, meaning that handling, manipulation, or disturbance of animals is not needed. Invasive methods tend to require capture and handling of individual animals, and can be risky for the animals (Jewell et al. 2001, Jewell and Alibhai 2012). Common invasive methods include mark-recapture or using a form of attached radiotelemetry and/or global positioning systems (GPS). Common non-invasive survey methods include camera-trapping; track-plates, tubes, or tunnels, snow-tracking; and photographic and photogrammetric analysis of coat patterns or recognition of injuries, tracks, or other individually identifiable features; scent dogs finding scats; DNA material gathered through hair snares or scats; and other visual and auditory counts of the actual animals in their natural habitats. Methods used depend on the species under study, the questions asked, and the budget available (Wilson and Delahay 2001).

Data reliability

Some track-based data are inherently reliable, without a need to validate with a measure of observer reliability or with concurrent technologies and methods. Circumstances for inherently reliable track-based data includes descriptive papers, laboratory experiments, captive populations, and fully known or enumerated populations, although these can and do provide perfect opportunities to study observer reliability and to develop new technologies and methods to assist with collecting valid data (Jewell et al. 2001, 2016, Alibhai et al. 2008, 2017, Li et al. 2018).

When data are not inherently reliable, scientists should include a measure of validation, either of the persons collecting the data, or with concurrent use of technologies and methods, such as camera-traps or standardized measuring and modeling procedures. Most scientists, however, fail to mention any evidence of skill level or training completed by the observers collecting their track-based data, only that data were collected. Others mention that trained or experienced observers were used, or experts collected the data, but offer no evidence of training, experience, or expertise. Similarly, a mentor with undescribed but real experience sometimes trains new observers and is only known by their professional reputation in that field, or with a particular species (Lewison et al. 2001) Lewison et al. 2001), which may or may not be readily apparent in their publications to an outsider of those subjects. Conversely, supervisors or mentors with extensive training in management or biology but with no experience with tracking sometimes oversee the data collected by observers (Panwar 1979). This has been notably problematic over first 30 years of tiger census in India, where field rangers with unexplained tracking experience brought tracings of tiger tracks back from the field for office-based supervisors with no tracking experience to identify and differentiate from one another (Choudhury 1970, Panwar 1979, Singh 2000*a*, Karanth et al. 2003). When training information is described it varies widely from just, “trained,” to a few hours in a day (Jeffress et al. 2011), weeks (Jhala et al. 2010), and upwards to a few years (Houser et al. 2009, Zielinski and Schlexer 2009).

Observers collecting the track-based data are also not always scientists and their technicians. Citizen scientists include volunteers and people who are hired to collect data for scientific research. These people might have no experience with the scientific method, the experimental process, or tracking (Elbroch et al. 2011, Johnston et al. 2018). They often just have a passion to be outdoors, and to do something for their community and environment. Pros and cons of research on citizen science has shown that these volunteers develop stronger understandings of “how to do science” and interest in their local area and policies, but they need substantial guidance and training in order to collect accurate and meaningful data, which is not often in the scope of the project’s budget (Davis and Wagner 2003, Diefenbach et al 2003, Cohn 2008, Crall et al. 2011, 2012, Johnston et al. 2018).

I was unable to find, in the scientific literature, the following information: what a good, proficient, or expert track-based observer should know, and no guidelines for how much experience that takes (Evans et al. 2009, Elbroch et al. 2011). Due to budget limitations many studies can’t DNA test every scat, or put camera-traps at every track-plot, or capture and collar all animals in an area for complete telemetry coverage, and so they rely on observers collecting track-based data for the remainder of their samples. Scientists conducting track-based identifications concurrently with scat-based DNA identification go to great lengths to include descriptions of how they collected, processed, and tested scats for DNA analysis, including describing which kits and chemicals they used, but there often isn’t even a single sentence describing how the people collecting the scats from the field for DNA analysis know that the scat they are collecting is from their target species. This trend continues with research using camera-traps, telemetry, and other mark-recapture and modeling techniques, where those methods are described in full, but not for observer accuracy with track-based data. These all have a component of interpretation that require an educated observer. When these studies use DNA, camera-traps, telemetry, etc., directly as concurrent validation techniques for track-based data, the omission of observer credentials is not as problematic as when there are no concurrent validation techniques. There are modeling techniques to account for discrepancies in sampling with technologies, but when they are not taking observer error into account then the fundamental accuracy of the data they are modeling is uncertain.

Methods

I conducted a content-analysis of publications on how tracking is used in wildlife science and conservation. Specifically, I looked for peer-reviewed journal articles where observers collected track-based data, and how they validated the reliability of their data through observer skill or through concurrent use of technology. Between 2016 and 2019, I routinely conducted literature and internet searches for studies and researchers that collected track-based data(see Search Strategy in the next section). For each publication, I compiled data on what type of track, sign, or behavior was studied, species, location, year of study, the objective of the research, the outcome of the research, and whether or not the data were independently collected concurrently with another measure of accuracy (such as: camera-traps, radiotelemetry, DNA, or expert witness). If an expert witness was used, I noted what field the expertise was in and whether or not their experience applied directly to tracking. I refined my search strategy over time, eliminating non-relevant papers and including newly published material.

Tracks are more narrowly definable than signs, they are footprints. They can be measured and collected in tracings, photographs, plaster casts, and on "sooted" surfaces of track-plates, tubes, or tunnels (Zielinski and Kucera 1995). They can be represented individually (one track), or in a trail of continuous tracks, and in varied substrates, such as snow or sand.

Defining signs becomes a more complex endeavor. Signs include scats, dung, urine, scrapes, visual markings (rubbings, scratching, or bites on vegetation) or scent-marks, anal pastings, middens or latrines, feathers, skulls, long bones and other skeletal remains, beds, dens, burrows, webs, nests, feeding sign (kill sites, browse, grazing, debarking, or rooting), locomotion (gaits and track patterns), and animal communication (vocalizations and body language). Many of these tracks and signs combine to become behavioral interpretations instead of merely an identification of a species. So, if track-based data include behavioral interpretations then almost all natural-history, ecology, biology, and ethology research can be included in a comprehensive review with other genres describing how people differentiate the tracks and signs of wildlife, including forensics, taphonomy, anthropology, and ichnology.

The field of natural history in particular includes the deliberate observation of animals in their environment and the description of their behaviors, which includes their tracks and signs. Wildlife research and many of the -ologies (ecology, biology, ethology, mammalogy, ornithology, herpetology, entomology, etc.) go beyond observation and seek to conduct experiments and test hypotheses, but are rooted in natural history. Results of all of the above fields include describing new species and documenting new behaviors (Schmidly 2005, Tewksbury et al. 2014). Tracking is both a subset of, and supersedes, the field of natural history. Trackers must broadly and deeply know about the morphology and behaviors of animals to identify and interpret tracks and signs, which is also considered naturalist knowledge. Knowing these things requires time spent practicing, and researching books, papers, the internet, etc. Where T&S differs from natural history is that trackers specialize on differentiating footprints, in great detail (Liebenberg 1990*b*, 2013, Elbroch et al. 2001, 2012, Elbroch 2003, 2006, Liebenberg et al. 2010, Elbroch and Rinehart 2011, Gutteridge 2012, 2017, 2020, Gutteridge and Liebenberg 2013, Elbroch and McFarland 2019).

Search strategy

I searched Google Scholar, Research Gate, and the University of Connecticut’s electronic library system, which included Web of Science and Scopus, for the keywords: “wildlife track*

AND sign*", "wildlife track*", "animal track* AND sign*", "animal track*", "track* surveys", "tracker*", "scat*", "sign* surveys", "indirect sign*", and "non-invasive survey methods + wildlife".

Initially, I reviewed 124 articles for information pertaining to track-based data collection, looking specifically for descriptions of how the data were collected, whether the data would require identification of a species or individual from T&S, and whether or not the authors mentioned the observer's experience, training, or cited a measure of bias, accuracy, or reliability of the person(s) collecting the data (the tracker's skill). These 124 articles were from 33 different countries where people collected track-based data on 80 different species, as well as on larger groupings of taxa, such as: carnivores, canids, felids, mesocarnivores, small mammals, predators, or ungulates. These articles spanned 52 years, from 1965 through 2017.

Using a word cloud of keywords in the 124 publications (Figure 1), I expanded my search to include new keywords that frequently appeared. I adding the following terms to my search: "spoor", "footprint*", "snow + track*", "track* + trap*", "track* + counts", "carnivore* + track*", "lynx + track*", "panthera + track*", "tigris + track*", "canis + track*", "martes* + track*", "otter* + track*", and other frequently occurring words combined with the stemmed word "track*". I selected the number of keywords to display in the word cloud based on word counts and increments of 10, where both "track*" and "sign*" appeared. For example, generating 30 most frequently used keywords did not include "signs*", but generating 40, did, so the word cloud contained the 40 most frequently used words.

I regularly updated my literature collection using RSS feeds from Research Gate and Google Scholar on the aforementioned keywords with alerts sent to my Google e-mail address, and with repeated manual searches. I also reviewed the literature cited in the downloaded articles for additional relevant articles, which I searched for, obtained, and reviewed.

I found and reviewed an additional 455 publications for a total of 579 publications. This brought the total publications reviewed to 579. The decision-making process that I followed for searching and selecting papers, extracting, categorizing, and interpreting data, is illustrated in Figure 2. I do not consider this an exhaustive review, because there was no asymptote reached in the number of new papers that could be gleaned from following up on the literature cited in published, peer-reviewed articles. However, the most commonly cited articles are in this analysis. I consider this analysis to be representative of the myriad ways that track-based information is collected and used in the ecological sciences, with many varied species and from across the world.

Select studies

Upon review of 579 publications found, I read and removed 158 papers from further analysis. The 421 remaining papers used in this analysis can be found in Appendix A. Removed publications included: a) non-peer reviewed publications: conference proceedings, management agency “white papers”, graduate theses and dissertations, books or book chapters, and articles published in popular literature/magazines; b) Peer-reviewed publications that were purely conceptual or theoretical or that modeled synthesized data, unless they included a measure of the tracker’s skill from the original data collected; and c) most peer-reviewed publications from paleoanthropology, anthropology, taphonomy, forensics, or ichnology, if they did not contribute to the accuracy and reliability of wildlife-tracking or wildlife-trackers/observers using track-based data in science. I included a few exceptions, such as the USDA Forest Service technical report on American Marten, Fisher, Lynx, and Wolverine: Survey Methods for Their Detection

(Zielinski and Kucera 1995) because it is a well-documented field reference for tracks and signs identification methodology of those species, which is referenced by almost any papers conducting research with fisher *(Pekania pennanti*, formerly *Martes)*, marten (*Martes martes*), lynx (Lynx canadensis) and their relatives (Aubry and Lewis 2003, Aubry and Jagger 2006).

I reviewed the remaining 421 peer-reviewed publications for at least one of the following features: a) Journal articles that purposefully describe how to identify tracks and/or signs of wildlife. b) Journal articles that use tracks and/or signs as data about the location and/or ecology of a species. c) Journal articles that use tracks and/or signs to differentiate individuals within a species, and/or their age, gender, or size of animals. d) Journal articles that contribute to what we know about a species through observers watching animals and describing the tracks and signs related to specific behaviors. These could be older papers based on original observations of animal behaviors, often resulting in the documentation of the natural-history or ecology of a species. Many of these older papers could result in modern observers recognizing these previously described tracks and signs as related to those behaviors.

After determining whether or not a paper should be included in the analysis, I reviewed each publication and categorized them in an Excel spreadsheet and using NVivo 12, according to: year, topic (tracks, signs, behaviors, etc.), potential method of validation (observer reliability), location, and species. I also included brief notes on the purpose of each study, the methods used, and the results (Aubry and Houston 1992).

Results

Extract data

The data extracted from peer-reviewed publications spanned 88 years, from 1931 to 2019. After 1979, at least one paper per year was included in the analysis, the number of publications reaching a peak in 2008, as publications became more frequent per year. Publication rate averaged 0.70 papers per year from 1931 up to 1979 (n = 33 papers over 47 years), 7.21 from 1979 up to 2008 (n = 209 papers over 29 years), and 14.92 from 2008 up to 2019 (n = 179 papers over 12 years) (Figure 3). These increases could be due to increased: interest in the field; number of scientific fields, scientists and journals; online availability; use of field technologies; or other reasons that I did not investigate.

Publications in this review come from 56 different countries (Figure 4). Top research producing countries were: USA (n=117), Canada (n=28), South Africa (n=23), Spain (n=22), India (n=17), Botswana (n=16), Namibia (n=14), Poland (n=12) and Australia (n=10). The other countries all had less than 10 published papers each. I used search engines while I was based in the USA and South Africa during this research, however, and thus the search engines might be a cause for location bias. Most publications describe field research, but 190 papers used captive or closed populations, direct observations, collections and specimens, descriptive papers, or laboratory experiments and models, some with undescribed lab locations, or locations in more than one country.

The publications included one-hundred and fifty-three species and several taxonomic groupings (wildlife, large carnivores, large mammals, small mammals, game animals (ungulates), mesocarnivores, macropods, rodents, etc.). In some cases, I grouped subspecies into one generalized species, for example, different subspecies of brown bears were grouped as *Ursus arctos*. Many scientists studied more than one subject at a time, for example, while Evans et al (2009) gathered data on river otters, they also collected data and reported on other wildlife. In some research, animals were grouped due to the difficulty in distinguishing their tracks and signs from one another, as is the case within many *Martes* species (Posłuszny et al. 2007, Rosellini et al. 2008*a*), between *Martes spp.* and foxes (*Vulpes spp.*) (Davison et al. 2002, Rosellini et al. 2008*a*) and within the *Cervidea* family (D'Eon 2001).

The most studied species using tracks and signs included: *Puma concolor* (n=35), *Vulpes vulpes* (n=31), *Martes martes* (n=22), *Panthera tigris* (n=19), *Pekania (Martes) pennanti* (n=18), *Odocoileus spp.* (n=17), *Canis lupus* (n=15), *Canis latrans* (n=14), *Panthera leo* (n=12), *Lontra canadensis* (n=11), *Panthera pardus* (n=11), *Ursus arctos* (n=11), *Capreolus capreolus* (n=10), *Cervus elaphus* (n=10), *Homo sapiens* (n=10), and *Lynx canadensis* (n=10). All other species had less than 10 published papers in the analysis. Humans are included in the analysis, not because of inclusion of search and rescue, anti-poaching, or fugitive tracking research, but because those 10 papers actively included an aspect of research on observer bias in collecting track-based data.

Methods of concurrent validation

Out of 421 articles reviewed, 199 articles described research requiring the identification of wildlife signs, 154 used wildlife tracks, and 68 used a combination of wildlife tracks and signs. Articles using signs (including tracks and signs) totaled 267, and articles using tracks (including tracks and signs) totaled 222 (Table 1). I attempted to determine what technique, if any, the scientists used to validate the accuracy and reliability of their data. I was unable, however, to differentiate between truly unvalidated methods and unreported methods. Because methods went unreported, I assumed the scientists did not validate them. Four articles were not scored for observer reliability because they did not describe the observers as certified trackers, even though I personally know the observers to be so (Taylor et al. 2015, Marchal et al. 2016, Marchal 2017, Romani et al. 2018).

Articles where sign-based data were collected

The predominant use of signs, 63% (Table 1), reflects that signs can be found in almost any substrate, particularly those that do not yield easily to tracks, such as gravel and rock surfaces, and signs persist longer than tracks in the environment. I've further divided signs into: "feces, urine, and scent-marking," and "other signs" based on their use, and methods of data reliability.

Feces, Urine, and Scent-Marking

Feces, urine, and scent marking behaviours are some of the most commonly studied animal signs. Out of the 267 articles containing sign-based information, 182 (68%) (Table 2) used data collected from feces, urine, or scent-marking. Feces (scats, pellets, dung, etc.) are used to determine species identification and occurrence (Thompson et al. 1989, Beauvais and Buskirk 1999, Trites and Joy 2005, Aubry and Jagger 2006, Thorn et al. 2011), to count animals based on number and age of feces found age (Kelly and Garton 1997, Heise-Pavlov and Meade 2012), and to define trends in numbers of animals, and identify individual animals. Other uses of fecal material include diet analysis (Miotto et al. 2007, Zhang et al. 2009). Diet analysis is performed using reference collections, books, and keys (Forman 2005). I group these three types of specialized signs together because it's not uncommon for animals to use both feces and urine as scent marking material, and thus differentiating can be difficult when these activities are purely elimination of waste vs some communicative action, and most are concurrent and multi-functional (Johnson 1973).

Of the 182 articles collecting data from feces, urine, and scent-marking, only four publications corroborated their identification using scat-detection dogs and DNA analysis, and in an additional 28 publications with only DNA analysis. These were not comprehensive corroborations, however, because camera trap placement along transects or in plots were assumed to capture the animal producing the signs in other locations of the sampling area. Forty-six articles included seeing the animals as an accuracy measurement (captive studies or finding the animal); some form of concurrent telemetry (GPS, VHF, etc.) was used in sixteen studies, and remotely triggered camera or video traps were used in twenty-one. Eighteen studies were conducted in snow, and eight attempted to identify individuals, gender or age class of specific animals.

Other Signs

The remaining 85 articles (Table 2) using other signs as data, used birth sites, winter beds, summer beds, fawn beds, generalized beds (Kusler et al. 2017), sleeping and resting sites, hunting beds, antlers, horn, hooves (Mccullough 1965), alarm calls and vocalizations (audible communication), teeth, tooth marks (Murmann et al. 2006), skeletal remains, skulls (Kobryczuk et al. 2008, Kobryńczuk et al. 2008), kill sites, caching, age and decomposition rate of signs, locomotion, hair (McKelvey et al. 2006), substrate, dens, burrows, wallowing sites, nests and nest predation, tree cavities, scrapes, pedal gland marking, bite marks on trees (Larivière 1999), roosts, and specific attributes of habitats used for different activities (Wolf and Ale 2009), feeding signs and other behaviors.

Articles where track-based data were collected

Tracks

In the 154 track-based articles (Table 2), 28 attempted identification of wildlife beyond species to the individual level, gender, or age class. Large carnivores and rare species were particularly investigated due to their relative importance due to their IUCN status, or their cryptic and nocturnal behaviours that made them difficult to observe and count, or from conflicts with humans and domesticated animals.

In fifty-seven articles (31 purely tracks and 26 tracks and signs), observers collected track-based data in snow, many of them citing snow as an easy substrate for tracks and signs recognition. Even so, track deterioration due to weather and poor quality of substrate were frequently noted as challenges to identification and interpretation (Liebenberg 1990*b, a*). Observers infrequently described potential confounding species present in the same area.

Forty-one articles required the persons collecting the data to use tracings, impressions, etc., and/or to measure, draw, and/or photograph animal tracks in order to determine the species or individual. Some observers also checked with a mentor or with reference material (a field guide to tracks and signs, a reference collection or key, etc.). In other articles observers photographed feet and/or tracks and brought them back to an office or laboratory for processing and modeling with some kind of discriminatory statistics or with software.

Description of tracker's skill

In total, 90 articles mentioned some aspect of the observer's or mentor's skill or the training provided. Thus, the remaining 331 articles made no mention of skill or training for their observers. In some instances, authors discussed a need for skilled observers in order to reduce bias and increase accuracy, but they did not provide a description or measure of it. Many of the 90 articles contained claims about observer competency by making the following types of statements about their observers: experienced, expert, or trained. Only twelve articles provided evidence for the training observers received or a measure of their skill.

Skilled identification and interpretation of animal tracks and signs was considered sufficient by the authors in ten articles where persons collecting the data were described as biologists and pilot-biologists (where data was collected mostly from low flying aircraft) (Becker 1991, Smallwood and Fitzhugh 1993, Zielinski and Kucera 1995, Becker et al. 1998, Gompper et al. 2006, Magoun et al. 2007, Mcbride et al. 2008), biologists and houndsmen-biologists (Smallwood and Fitzhugh 1993, Mcbride et al. 2008), and biological-technicians under supervision of biologists (Zielinski and Kucera 1995, Zielinski and Schlexer 2009). One article described using experts at a jaguar conference to differentiate big cat tracks from large dog tracks using photographs; they did not describe the criteria for being considered an expert (De Angelo et al. 2010). De Angelo et al. (2010) conclude that 67% of tracks were correctly identified by >50% of their observers, and speculate that this is due to variation in previous experience, merely noting that “several authors have mentioned the relevance of field expertise in sign identification.”

In only six research publications, the observers were competent enough to follow tracks and find the animals. Since (Stander et al. 1997) verified that his small team of Ju/’Hoan San trackers accurately interpreted 98% of track reconstructions after visual observations of the animals by the author, it is assumed that all indigenous people will achieve the same levels of accuracy. Skill was assumed high in seventeen articles where persons collecting the data were described as ‘indigenous’ or local ‘expert’ trackers. In twelve of these, evidence of the tracker’s skill was not provided. In these articles, low numbers of trackers were used to collect data, so if the trackers’ skills were high then the accuracy of the subsequent data would also consistently be high. The opposite could also be true.

In effort to be consistent and only score papers for information reported in their content, four articles were not scored for observer reliability because they did not describe the observers as certified trackers, even though I personally know the observers to be so (Taylor et al. 2015, Marchal et al. 2016, Marchal 2017, Romani et al. 2018). Observers certified in an international tracker certification system, called the CyberTracker Tracker Certification System, were described in eleven of 421 papers, primarily coming from one scientist and his team, L. M. Elbroch, who is himself a tracker and evaluator for CyberTracker. Many of the papers where he is included as an author and where observers collected track-based data describe data-collectors as, "CyberTracker certified," and qualify that further with, "at least a level 3 in the CyberTracker system." One of those articles describes a local expert (a community member with extensive local knowledge but no scientific training) as a Senior Tracker in the CyberTracker system of evaluations, the highest certification that can be earned. Notably, these authors develop and recommend using a knowledge gradient to help scientists employing community members in citizen science research to differentiate experts from unskilled observers (Elbroch et al. 2011). In only one other article, the author (from outside the Elbroch lab) describes himself as having one year of tracking experience and additionally having a mentor with a CyberTracker level 3 track and sign certification actively assisting him (Duffie et al. 2019).

Analyze data

I classified publications based on three major categories indicating measures of data reliability: a) publications where data reliability is based on the observer's or mentor's skill, b) publications where data reliability is based on independent, verifiable occurrence records, c) publications where data reliability is not required, or inherently built into the study. An example of C is where the animals under study are captive or from a closed population. Each category is broken down into several sub-categories that explain possible criteria for inclusion. They are described in detail in Table 3, in no particular order of importance.

Categories and scoring

A table with scores for each of the 421 papers is in Appendix A. There are three categories, A, B and C, and multiple subcategories in Table 3. The highest possible combined score a paper can receive is +3, while the lowest score possible is -1. A description follows, below, with an example, of the categories and how the scoring works. A paper does not need to receive a score from all categories and only one score is assigned per category even though it's possible that a paper could use a technology that qualifies it in more than one subcategory per category.

Category A

Scoring in one of the many subcategories of category A range from -1 if the publication does not describe evidence, or +1 if the publication describes evidence of observer reliability in collecting track-based data. I make no assumptions about observer reliability, meaning that, even if I personally know the observer to have verifiable experience, if it is not explicitly stated and described in the paper then it is scored with a -1, accordingly.

Category B

Category B has multiple subcategories, placement in any of these results in a +1 and there are no negative scores. These papers include concurrent validation between observers and some kind of technology or methodology. While these papers are the easiest to assume observer reliability through concurrent validation, there are noted problems throughout the literature for each and I do not account for the assumptions of these techniques or methods, and note that, in some cases, there might be technical failures and methodological inconsistencies, gaps, and flaws. Half of the subcategories in category B describe concurrent use of near-irrefutable technology such as camera or video trapping, radio-telemetry or GPS, or DNA analysis. I call these near-irrefutable because each of these technologies have their pros and cons, and can be used improperly or malfunction. Some descriptions are both methodological and technological, e.g. DNA analysis uses not only technology, but also requires a methodological procedure. Other, methodological subcategories in category B include using mark-recapture surveys, scat- or scent-detection dogs, or the collection of some artifact in the field representing tracks: measurements, photographs, sooted-track plates, track casts, or tracings, which can then be analyzed statistically or used in computer modeling or simulations. B category publications can have evidence for more than one subcategory but will not receive a score greater than +1 for collecting track-based data concurrently with more than one technology or method.

Category C

In category C, a publication can score 0, 0.5, or 1 in either one of two subcategories, C1 or C2. Papers in C1 are scored a zero because they are descriptive papers or reviews in a natural history style where direct observations allowed the discovery and publication of track-based information that we take for granted today. Most C1 papers do not get scored additionally in categories A or B due to their historical observational style (48 out of 56 papers are in only C1). If, however, a publication is a more recent, and there is information regarding how the data were collected and/or technology used, the paper can also be scored in category A and/or B.

Subcategory C2 papers can receive a score of +1 or +0.5. Papers scoring +1 contain data that was collected under conditions that do not require external validation, such as in a laboratory, or a captive population, conditions where the animal's tracks were followed and it was found, or conditions where the tracks are so considered so easy that no skill is needed to identify them. Most C2 publications receive a score of +1, but some papers receive only a +0.5 when collected in snow conditions because, while snow is described as an easy substrate in the scientific literature, it has been documented as challenging across tracking books, field guides, and by experienced trackers like myself.

Snow can make seeing tracks and signs easier, but snow can also make it difficult. Snow must be the correct depth for tracks to register clearly. If snow depth is too shallow, tracks melt. If snow is too deep, the tracker can't see into the bottom of the hole to identify the features of the track. The angle of the sun on snow can also make tracks challenging to see, which can be especially problematic when scientists are attempting to identify tracks from a moving vehicle or aircraft. Therefore, in instances with potential for misinterpretation in snow, or confusion with other species, the paper is assigned a score of 0.5 instead of +1. Conversely, a paper can receive a full +1 in snow, such as when the animal is followed and found without interference from other animals of the same or different species, or when only the simplest identification or interpretations are necessary.

An Example of Scoring:

In "Evaluating Methods for Counting Cryptic Carnivores," Balme et. al. (2009), received the following scores:

- A1e - Observers are described as experienced at identifying wildlife tracks and signs, but no evidence of that experience is given.

    - A Category score = -1

- B1b - Track-based data is collected at sites concurrently with photos or videos from camera traps.
- B1c - Track-based data is collected at sites concurrently with telemetry: radiotelemetry (UHF, VHF, etc.) or GPS location positions.
    - B Category score = +1

- C2 - No experience in track and sign identification or interpretation is required, in-the-field, for the conditions or the questions asked. Examples include:
    - Track-based data is simple in complexity and unmistakable by a novice (classic).
    - Track-based data is collected in an area where there are no other species present that have similar tracks and/or signs.
    - Track-based data is from a closed or captive population or from a controlled laboratory setting.
    - Track-based data is collected by following the animal's trail and finding the animal.
    - Track-based data is collected by following a clear animal trail in snow or sand. Tracks and signs are abundant and easily interpretable due to the substrate. The observers follow an animal's indisputable trail, step-by-step, and collect multiple sources of classic evidence (tracks, scats, behavioral signs, odors particular to a species, etc.).
        - C category score = +1

Totaling the marks from the three categories, the paper received an overall score of 1. In category A, A1e subcategory, classification results in a mark of -1, while in category, subcategories B1b and B1c result in a single score of +1, and because the population of leopards under study was described as completely known, photographed, GPS-collared, and enumerated, concurrent with track-based data-collection, resulting in an additional +1 in category C subcategory C2.

Total paper score: -1 +1 +1 = 1

Papers can roughly be compared by their overall scores, but note that authors were not contacted. Scores are based on information mentioned solely in each publication. A paper receiving a score of 2 is not necessarily more reliable in terms of the way that track-based data was collected than a paper scoring a 1. A paper receiving an overall score of +1 because it had a certified expert tracker collecting the data can be as reliable as another paper using DNA analysis to confirm the species identity of every scat collected by an untrained observer (both would score +1), but if that observer were also a trained expert or had expert mentorship, the score of that paper would increase to +2. All of the above methods are reliable. The overall trend, though, is that the lowest scoring papers will have some potential pitfall identified with the observers collecting the data, and scores and reliability will go up from there. Table 3, therefore, is less critical of the existing literature than it is meant to provide an example and a guideline for future researchers collecting track-based data, suggesting protocol that should be followed and explicitly described to ensure reliability.

A full list of each paper and its score is in Appendix A. The majority of papers are scored ≤0 (267 out of 421). Fifty-six of those received a zero score by default, not by penalty, because they were in category C1, leaving 211 (58% of 365 papers) that lacked evidence of observer reliability. Papers scoring above zero totaled 154 (42% of 365 papers), the above zero score indicating that evidence of observer reliability was included (Figure 5).

Due to the focus of this summary on papers where observers collect track-based data, the majority of papers were scored in category A (312 scores of observer reliability), followed by category B (259 scores of concurrent technology and methodology), and then in category C (217 scores of observer reliability not required) (Figure 6). Papers scored in multiple categories resulted in 788 individual scores in combined categories. A breakdown of how many papers received scores in each subcategory can be found in Figure 7, and a count of those scores is seen in Figure 8.

Among the 421 individual papers analyzed, the highest percentage (25%) were scored in the combined (sub)categories of A1 + B (Table 4). A1 means that the observer's skill or experience was not described, but B1 adds that some technology or methodology was concurrently used, which could make the data more reliable. By itself, the A1 subcategory, contained the second highest number of paper scores with 19%. Subcategories C1 and C2 contained 11 and 15% respectively (26%). C1 papers were descriptive and did not require validation. C2 papers were on captive or closed populations, or otherwise not needing external validation. Next, A1 + B + C contained 10% of papers scored by combining, for example, an observer with unverified skill, camera-traps and snow conditions (Gompper et al. 2006). All other categories contained less than 10% of papers scored.

Note that in subcategory A2 (papers that provide evidence for observer skill or experience) is not among categories containing more than 10%. Only 7% of papers provided evidence of observer skill.

The Case for Observer Reliability

Case Study – Fishers in the Pacific Northwest, USA

Even though fisher (*Martes pennanti*) were becoming increasingly rare due to habitat loss from logging operations in the pacific-northwest region of the USA (Aubry and Houston 1992, Carroll et al. 1999, McKelvey et al. 2008), this species was denied listing under the Endangered Species Act (ESA) in the 1990's due to evidence indicating that fisher were still widely distributed across their historical range. The evidence submitted included tracks and signs or visual or auditory observations, photos or videos or recordings, and/or specimens from roadkills and trapping records. While specimens provided unequivocal evidence, much of the photo, audio and recorded evidence lacked diagnostic information, and track and sign evidence collected was provided by unverified observers with unknown skill levels in habitats with many known confusing species and challenging substrates. The evidence collected resulted in overestimation of their diminishing distribution (Aubry and Houston 1992, McKelvey et al. 2008). Shortly thereafter, (Zielinski and Kucera 1995), developed rigorous guidelines for collecting track-based data on fisher, marten (*Martes martes*), Wolverine (*Gulo gulo*), and lynx (*Lynx candadensis*). They used camera-traps, track-plates, and snow tracking to develop protocol, but prefaced their protocol with a need for training and practice with identification and interpretation of tracks and signs. At the same time, Zielinski and Truex (1995) successfully developed a discriminant analysis to differentiate the tracks of captive fisher and marten collected from sooted track-plates. This development led to a re-evaluation and invalidation of the anecdotal data earlier collected that had resulted in overestimation of fisher abundance and failure to list with the ESA (Aubry and Lewis 2003, Aubry and Jagger 2006, McKelvey et al. 2008). Re-evaluation included the development of a gradient of evidentiary standards, where the reliability of evidence was scaled according to taxa, with rarer species requiring more rigorous evidence (McKelvey et al. 2008). Even with documentation that tracks and signs collected could be identified and differentiated among species with similar morphology (Zielinski and Truex 1995, Herzog et al. 2007, McKelvey et al. 2008), they were considered among the least reliable evidence gathered because of the lack of observer training, skill, and reliability (Aubry and Lewis 2003, Aubry and Jagger 2006, McKelvey et al. 2008). More recently, Herzog et al. (2007) noted that some biologists have more aptitude than others at spatial and pattern recognition, and Zielinski and Schlexer (2009) specifically tested inter-observer variating in identifying tracks from track-plates, finding agreement and accuracy was high when training and experience were provided. McKelvey et al (2008) estimate that mistaken emphasis on unreliable evidence provided by unskilled observers delayed conservation efforts for the fisher by at least a decade.

Case Study – River Otters in Texas, USA

Across the world, river otters are thought to have easily identifiable tracks and signs that make their presence easily identifiable. Evans et al (2009) tested the observer reliability of biologists and volunteers from long-term surveys of river otters (*Lontra canadensis*) in Texas. They found that experienced biologists misidentified otter tracks as from other species, and misidentified other species tracks as otter tracks. Their research and evaluation bring into question the quality of the data from over 20 years of otter track surveys conducted by Texas Parks and Wildlife. Evans et al. (2009) showed that participant scores increased between a first and a second track and sign evaluation by a qualified evaluator from the CyberTracker Tracker Certification System, indicating an improved and measurable ability to identify otter tracks and signs. Classically presented otter signs, such as scats, spraints, latrines and rolls, on-the-other-hand, are less easily confused with other species (Depue and Ben-David 2010, Barocas et al. 2016).

Case Study – Tigers in India

Steadily declining, tigers (*Panthera tigris*) were listed as endangered in the IUCN Red List (International Union for the Conservation of Nature, https://www.iucnredlist.org/) in

1986, and their numbers have continued to decline. Beginning in the 1972, Indian tigers were surveyed using the now infamous pugmark census technique (Choudhury 1970, 1972) whereby thousands of forestry personnel across 300,000 km^2 of potential tiger habitat in India used measurements and a glass plate called a tiger tracer to measure and trace the rear track of every individual tiger over one or two weeks (some also took plaster casts). While evidence of tracking was not described, personnel were described as "experienced" and as generally knowledgeable about the movements and territories of individual tigers in their areas due to repeated visual observations of the actual animals, which are individually recognizable by their unique markings. Tracings were brought back to supervisors, who compared them for similarities and differences and determined identity on their comparisons and their personnel's knowledge of tiger territories. These censuses determined the overall status (decreasing, stable, or increasing) of tigers across India and individual reserve management plans for tigers (Choudhury 1970, 1972, Panwar 1979, Karanth et al. 2003). Assumptions of the technique include that thousands of personnel will be able to find and identify pugmarks from all tiger tracks in their areas, differentiate them from other species, figure out which foot is the hind foot, measure and draw it without variation, know that the tiger's track they are recording is different (or mistakenly identify it as the same) from the next block over being simultaneously surveyed and/or know that it is the individual's tracks that they regularly see in that area and not a transient tiger (risks from inaccurate identification of individuals, overcounting and undercounting). Further assumptions include that supervisors can identify and differentiate the pugmarks of different tigers from the tracings and information provided by forestry personnel (Karanth et al. 2003). Research with captive tigers indicates that experienced personnel performed poorly at identifying individual tigers by their tracks (Karanth 1987), but improved when captive tigers were studies in small numbers with standardized substrates (Riordan 1998). Even still, the technique has led to incorrect reporting of tiger numbers and inadequate conservation measures across tiger range in India (Karanth et al. 2003).

The case studies above are not unique. Track-based data can be accurate and useful, but only when observers have measurable experience or the data are collected concurrently with another method, such as camera-traps or DNA, which provide independent data validation.

Discussion and Conclusion

In wildlife management, conservation, and research, scientists need to monitor wildlife quickly, efficiently, and accurately. Some scientists use tracks and signs to identify where animals are, what they need in terms of habitats and resources, what influences they have on their environment, describe why it vanished from certain areas, and to help determine their futures in other areas. Yet, in 421 papers spanning 88 years, 56 countries, and 154 species, only 7% of papers gave evidence for observer skill or experience with collecting track-based data.

Snow-tracking

Of concern in papers where observer skill was not required, one of the conditions described was observers who collect track-based data with snow-tracking, which was often considered so simple that a novice observer could do it well. The degree of difficulty in snow-tracking, however, is highly debatable, and I urge caution in assuming it to be easy. Extreme weather events, such as snow-storms, can wipe out a trail completely. On the other hand, a fresh, shallow, snowfall can hold new tracks perfectly for long distances. Once snow becomes deeper, though, it can be difficult to make out any detail in the bottom of a vertical tunnel from a footfall, and it can be difficult to determine direction of travel of the animal, and trackers might need to follow for some time to figure that out. Along the trail they can use other tracks and signs, such as the smell of urine, scat, scent-marking behaviors, gaits and track-patterns, and beds, to determine the identity of the animal (Forrest 1988, Golden et al. 2007, Gu et al. 2014). From simple to complex trails, the longer a trail is followed, the more information can be gleaned from the tracks and signs observed, and the more confident an observer can be about the identity and behaviors of the animal (Golden et al. 2007, Liebenberg et al. 2010, Gu et al. 2014, McCann et al. 2017).

Tracking basics

Scientists either do not report observer skill, or assume that observers will be able to differentiate the tracks and signs of different species in varying substrates with little training and/or by consulting drawings or pictures in a published field guide (Crooks et al. 2008, Pirie et al. 2016) – the unspoken assumption is that the data they collect will be unbiased and external verification is unnecessary. I was unable to find evidence in the literature that observer bias and observer training was validated. Therefore, I must conclude that validation was either not reported or that validation did not happen. Reporting validated methods in data collection is crucial to the reliability of projects that use these methods to produce high quality science.

Other scientists compare or supplement the information provided from tracks and signs with information provided by modern methods, such as GPS or radiotelemetry, camera-traps, and scat-detection dogs with or without complementary DNA analyses. This makes the data provided by each method more rigorous, or provides a measure of the accuracy and reliability of each method against the other.

Both T&S identification and interpretation, and following and finding animals, or trailing**,** can be easy when a trail is fresh, the substrate is soft and holds the track impressions clearly and continuously, the lighting is favorable, there are few or no confusing species, and the animal is behaving predictably. Animal trails can also be quite difficult, or impossible, to follow. Lighting, or lack of it, can wash out tracks from detection. Older tracks are more difficult to see because time and weather soften the edges, making them less crisp and clear. Even a fresh trail can look old with a little bit of wind or rain on it (Liebenberg 1990*b*, *a*, Gutteridge 2012). Tracks and signs are more difficult to detect from a moving vehicle, such as from a tracker seat mounted to the front of a safari or research vehicle, especially when the angles from the sun are not favorable in the direction of overall travel. The faster the vehicle moves, the more difficult track detection is. I can only assume an additional degree of difficulty is present from flying aircraft due to the distance from the ground and glare off of snow and ice.

Note that most species have classic tracks or sign that are produced by their baseline behaviors. Classic tracks or signs are those that are easy to differentiate from other species when in their most typical, most common appearance. These are usually the ones that become well documented in the literature. Some tracks and signs are more difficult than others to identify. Research on bear signs, such as hair, tooth, and claw marks left on trees (Clapham et al. 2013) or power poles (Karamanlidis et al. 2007) or on habitual marking trails (Taylor et al. 2015), require less training and experience to identify than differences between tracks of different mesocarnivores species (Zielinski and Kucera 1995, Foresman and Pearson 1998), or different individuals of the same species (Herzog et al. 2007). Additionally, tracks in some substrates are more difficult to identify in than in other substrates. Sand (Bothma and le Riche 1984) and snow have a reputation for being easier than more solid surfaces and more vegetative ground cover

(Bothma and le Riche 1984, Patterson et al. 2004), but some researchers recognize that snow can distort classic features in tracks and are easily confused with similarly sized species in the same areas. They advise caution and the need for training and skill (Forrest 1988, Patterson et al. 2004, Gu et al. 2014, Weise et al. 2017).

Identification of individuals (or sex and age class)

On some occasions, age (Rumble et al. 1996, Purchase 2007), sex (Rumble et al. 1996, Zalewski 1999, García et al. 2010, Gu et al. 2014), or even the individual identity (Smallwood and Fitzhugh 1993, Grigione et al. 1999, Jones et al. 2004, Herzog et al. 2007) of an animal can be determined from tracking. Different species of animal have different morphometric (Chame 2003) and scent characteristics (Kerley and Salkina 2007) to their scats, as well as different genetic profiles (Kohn and Wayne 1997, Zuercher et al. 2003). Some animals have deformities or injuries that make their tracks unique and recognizable. Animals like elephants (*Loxodonta Africana*) (Dudley et al. 1992) and rhinoceros (Jewell et al. 2001, Alibhai et al. 2008) have unique wear patterns on the bottoms of their feet. Carnivores tend to be territorial, and exclude others of the same species from the area they claim (M L Allen et al. 2015). Male animals are usually much larger than females in many species. Overlap in track size occurs, though, between species, such as between male leopard and female lions (*Panthera leo*), which then requires the observer to have more experience differentiating the tracks by small differences in foot morphology, and by behavior or social structure – lions form prides or coalitions, while leopards are generally solitary (Liebenberg 1990*b*, *a*).

Feces, urine, and scent-marking

Of all the signs, scats (feces, fecal or feacal droppings, pellets, etc.) are widely collected and examined. Through them, observers attempt to determine animal diets or changes in diet, territoriality and marking behaviors, species identity, individual identity, and numbers of a species (Skalski 1991, Lanszki et al. 2006, Skalski and Wierzbowska 2008, Murdoch and Buyandelger 2010, Sidorovich et al. 2010, 2011, Lanszki and Heltai 2011). Observers collect scats, and/or scent or scat-detection dogs are sometimes used to find scats of particular species, and/or these are tested by DNA analysis (Kerley and Salkina 2007, Long et al. 2007*a*, *b*, Harrington et al. 2010).

Both classic and atypical scats are easily confused with those of multiple other species. Examples of this include the dog (family *Canidae*), cat (family *Felidae*), or weasel (family *Mustelidae*) families' scats. Long et al (2007*a*, *b*) describe coyote (*Canis latrans*) and bobcat (*Lynx rufus*) scats as visually indistinguishable and raccoon (*Procyon lotor*) scats as easily confused with bears. Davison et al (2002) found that expert marten surveyors failed to differentiate pine marten (*Martes martes*) scats from those of red foxes (*Vulpes vulpes*). Harrington et al (Harrington et al. 2010) found through DNA validation that none of the scats collected by their observers were of mink (*Neovison vison*), their target species. Depending on their seasonal diet, individual state of health, or the outside forces of weathering and aging acting upon the scats, scats from species within each family will present considerable confusion to even expert trackers (Davison et al. 2002, Long et al. 2007*a*, *b*). On such occasions, it's necessary to have more conclusive, additional sign, such as clear tracks made at the same time, to make a determination (Zielinski and Kucera 1995). Some observers only report their observations or results, while others give additional information on species whose tracks or signs might be present in the same areas and confused with the animals they study.

Scent-detection dogs

Some scent-detection dogs are better than others at their job (Long et al. 2007*b*, DeMatteo et al. 2018). Accuracy rates on how many times hounds attempt *vs.* find actual animals for telemetry collaring or other mark-recapture methods in research programs are not usually reported, but, in-the-end, they yield telemetry-based, camera-trap data and behavioral data (Elbroch and Wittmer 2012, 2013*a*, Elbroch et al. 2014, Elbroch and Kusler 2018) on specifics such as beds (Kusler et al. 2017) kill-sites (O'Malley et al. 2018) and den site characteristics (Bleich et al. 1996), anyway. Can we, therefore, assume some degree of accuracy in hounds being able to follow and find animals? Some papers note complications in scat-detection dogs with differences in dog performance due to variability in handler training, indifference or loss of interest in scents by individual dogs making them poor performers at the task, and potential bias introduced by counter-marking of other animals (Long et al. 2007*b*, DeMatteo et al. 2018).

Technologies

There has been a considerable amount of success with two- and three-dimensional photography and casting to model and differentiate the tracks of individual captive and closed samples of mountain lions (Alibhai et al. 2017), African lions (Marchal et al. 2016, 2017, Marchal 2017), black (Jewell et al. 2001) and white (Alibhai et al. 2008) rhinoceros, cheetahs (Jewell et al. 2016), Amur tigers (Gu et al. 2014), tapirs (Moreira et al. 2018), and giant pandas (Li et al. 2018). These smaller captive and closed samples are used to test the models before using them to enumerate wild populations. These techniques require clear tracks of specific feet (usually hind tracks) in good substrate, for the observer to carry photographic supplies equipment into the field and use it in a systematic way, and standardized placement of points on reproductions within custom software to differentiate individuals with a high degree of accuracy.

Expert trackers

Subject matter experts, such as biologists of a species or a suite of species, e.g. furbearers, does not automatically qualify observers to identify and interpret tracks and signs of their focal species. In fact, it has been shown to be otherwise as tracking is a specific skill that requires specific training and practice (Liebenberg 1990*b*, 2013, Zielinski and Kucera 1995, Liebenberg et al. 2010). Likewise, native, indigenous, or local people are often cited as expert track-based data collectors in scientific publications, as if the historical aspect of their culture to a landscape alone should validate their skills (Elbroch et al. 2011). When observers are native, indigenous, or local and spend their time on the landscape tracking they might be experts (Elbroch et al. 2011), but they might not if they haven't spent the time yet gaining the experience necessary(Wong et al. 2011). Since (Stander et al. 1997) showed that five Ju'Hoan San hunters collectively interpreted 569 known tracking scenarios with an accuracy of 98%, his paper is frequently cited as justification for using native, indigenous, or local trackers, especially San, in track-based data collection, without further description of the experience level of the persons collecting the data. Yet, when observers are tested, interobserver variation occurs where some individuals are better observers and more reliable than others (Zuercher et al. 2003, Elbroch et al. 2011, Wong et al. 2011, Rutina et al. 2017).

When track-based data are collected, identification and interpretation are considered so simple that anyone can do it, without training, experience, or expertise. On-the-other-hand, track-based data are considered so impossible or unreliable that they shouldn't be used in science and conservation. The fact is that both of the above statements are true or false at different times, but this depends on the observer's experience, not the data. Some tracks and signs are easier to identify and interpret than others, especially with experience. A more experienced observer will be able to consistently identify and interpret more, and more difficult, tracks and signs than a less experienced observer, and under more difficult conditions. Even if an observer works as a professional tracker in Africa, there is a range of ability within the occupation based on experience. Unless someone is a clearly demonstratable expert, or working under circumstances without difficulty or variation, we can't know the reliability of their track-based data unless we have a means to measure it.

Figures and Tables

Figure 1. A word cloud indicating larger words appear more frequently in the keywords of peer-reviewed journal articles.

This word cloud generated the top 40 most frequently used, stemmed, keywords in 124 papers initially reviewed.

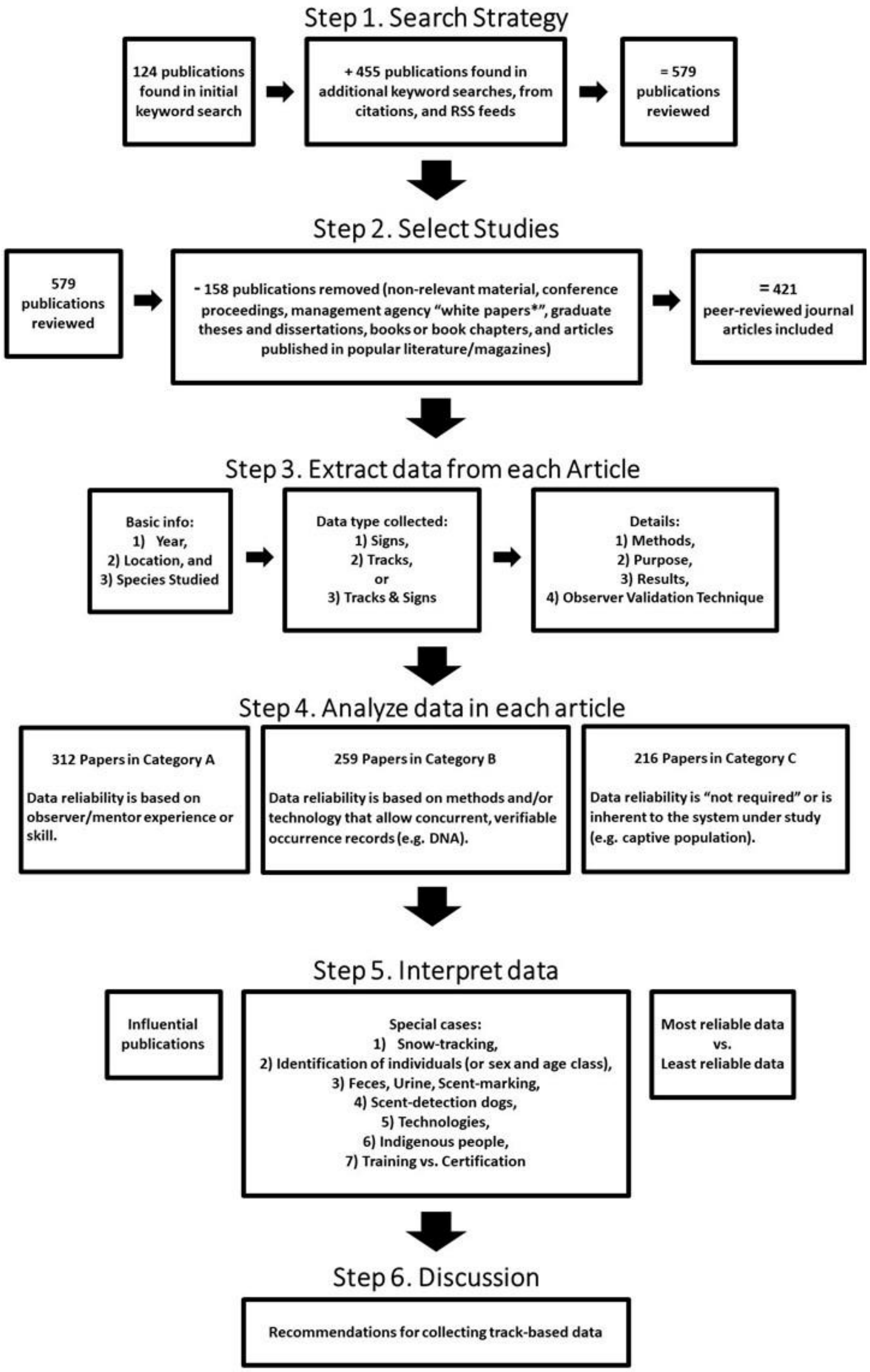


Figure 2. The process used for searching, selecting, and analyzing information for interpretation and discussion in a content-analysis of how track-based data has been used in science.

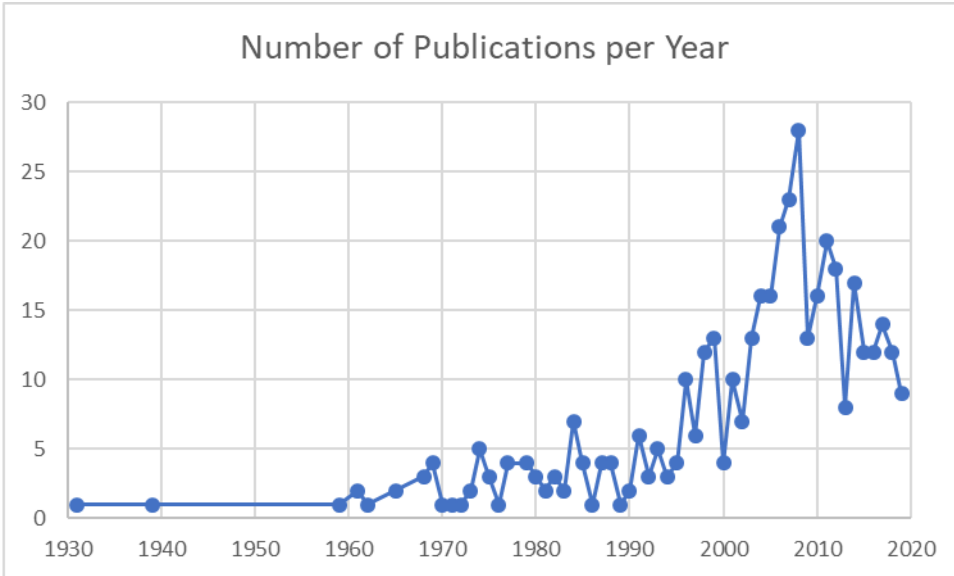


Figure 3. A graph of how many papers using track-based data were published per year.

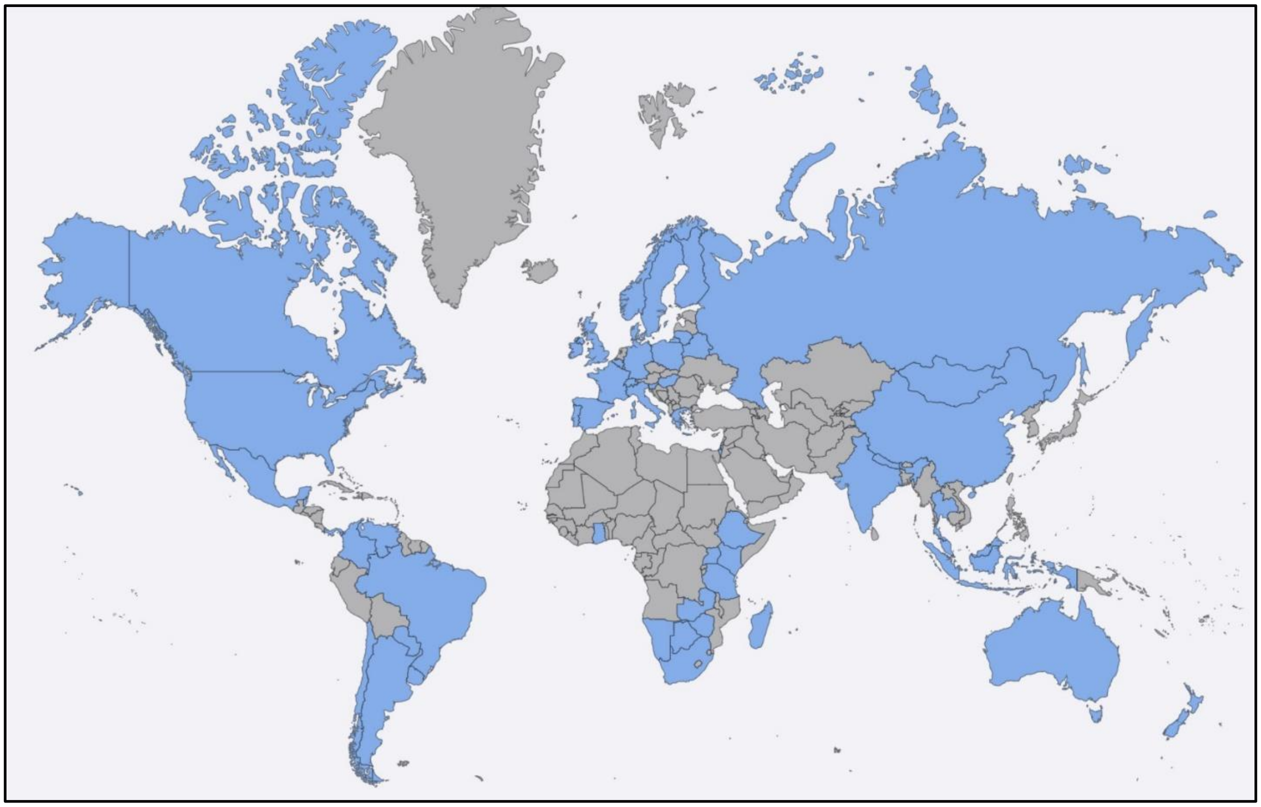


Figure 4. Locations of publication – scientists collected data in 56 different countries.

Graphic from www.amcharts.com/visited_countries/

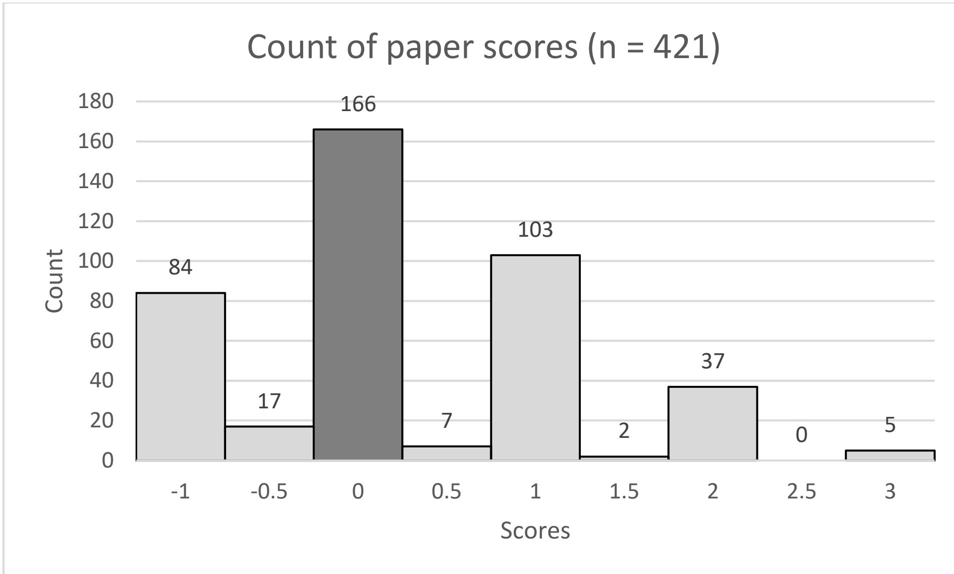


Figure 5. Final count of 421 paper scores.

In general, papers scoring ≤ 0 can be considered weaker in observer reliability than those scoring ≥ 0. Also, higher scoring papers generally have more additive positive factors contributing to their observer reliability. The majority of papers score less than zero because they lack evidence of observer reliability.

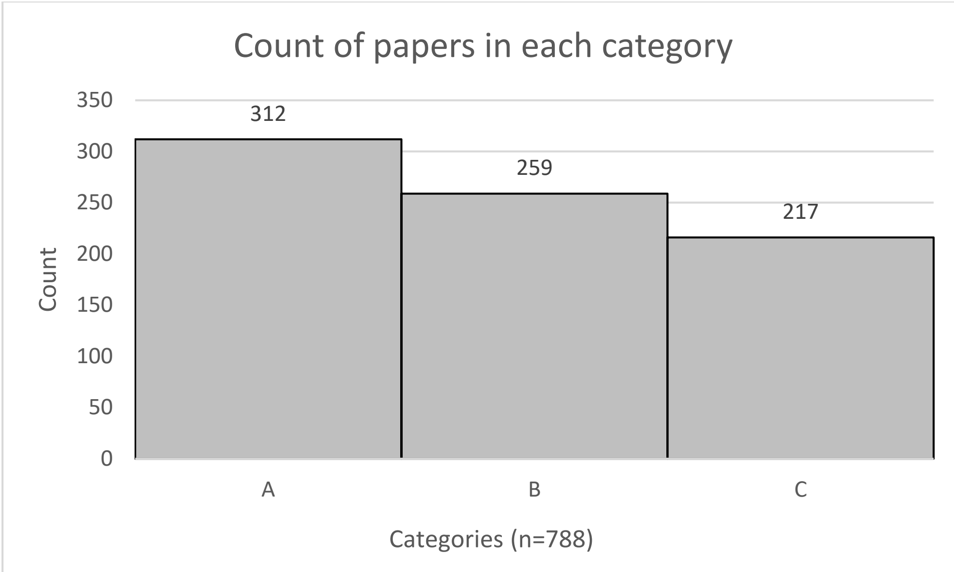


Figure 6. Count of papers in each category.

The sample size is 788, not 421 because papers can be scored in multiple categories.

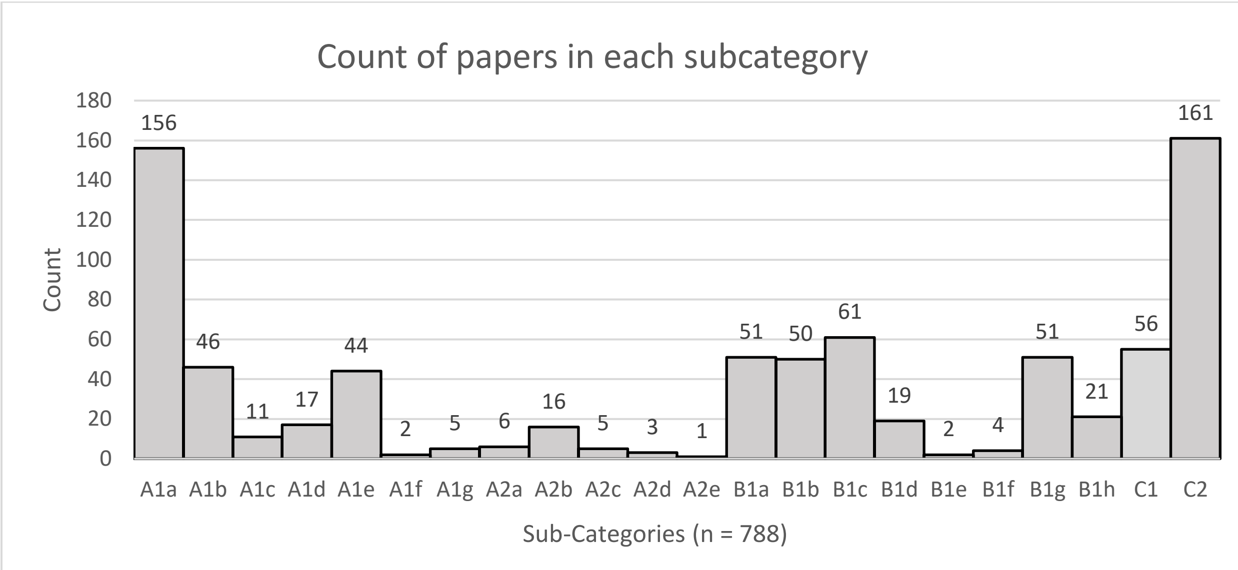


Figure 7. Count of papers in each subcategory.

A1, A2, and B papers can have more than one subcategory but are only scored once for A and/or B. C category papers are either in subcategory C1 or C2, and can also receive a score for A and/or B.

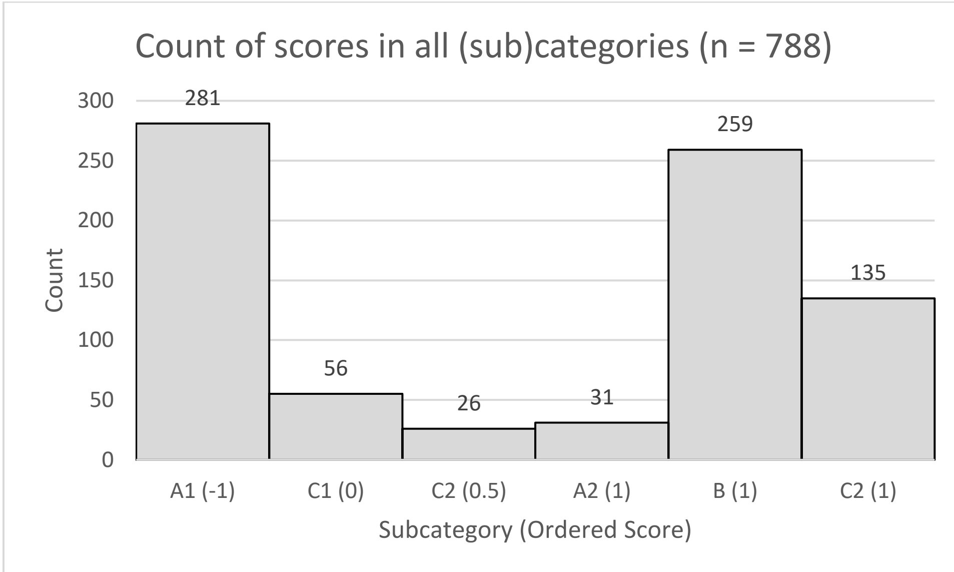


Figure 8. Count of scores in all subcategories.

Papers were counted multiple times due to scoring in more than one category. Papers are ordered on the X-axis from -1 to +1, instead of by A, B, C.

Table 1. Counts and percents of major data types collected in 421 articles.

Research where observers used signs as data are most numerous, especially when combining papers from the data types, Signs (47%), and Tracks & Signs (16%), combined = 267 papers, or 63%. Researchers using Tracks, at 37%, when combined with Tracks & Signs, authored 222 papers, or 53%.

Data Type Collected	# Articles using Signs	# Articles using Tracks
Signs Only	199 (47%)	N/A
Tracks Only	N/A	154 (37%)
Both Tracks and Signs	68 (16%)	68 (16%)
TOTAL #	267 (63%)	222 (53%)

Table 2. Counts of specialty types of data collected in 421 articles

Data Type Collected	Signs	Tracks	Both Tracks and Signs	Feces, Urine, and Scent Marking	Other Signs (not feces, etc.)
Paper Count	199	154	68	183	84
with scat-detection dogs and DNA analysis	4	0	0	4	0
by DNA analysis (without dogs)	34	2	8	32	2
seeing the animals	53	19	1	25	28
telemetry	29	18	7	9	20
remotely triggered camera or video traps	17	11	6	16	1
in snow	28	31	26	17	11
review or description	14	21	5	14	9
individuals, gender, or age	3	28	5	1	2
Evidence of observer skill	34	43	16	34	5

Table 3. Data reliability categories for peer-reviewed publications using track-based data used in wildlife-science

Publication placement in a category does not imply an assessment of the inherent assumptions, practical strengths and weaknesses, or standardization of the methods or technologies used, only that they were used. Categories are not in any order of importance, and publications might fit in one or more categories, and into more than one subcategory in Category B, but they are not scored more than once in each category.

Category	Description	Score
A.	**Data reliability is based on observer/mentor experience or skill.**	
	Note: Examples of "evidence of experience or skill" include: they found tracks and followed them to the animal and were able to correctly identify the animal's behavior on the trail; a detailed field test; or a CyberTracker or other rigorous tracking certification.	
A1.	**Data reliability is based on unknown, assumed, or undefined observer experience or skill.**	-1
	A1a). Observer experience with identifying wildlife tracks and signs is not described.	
	A1b). Observers measure track-based data and use field guides, manuals, keys, or collections to identify it. However, evidence of experience with identifying wildlife tracks and signs is not described.	
	A1c). Observers are described as biologists or technicians with significant in-the-field experience, such as, at minimum, a 4-year degree in some field of ecology, biology, or natural resources, up to a professor or research associate at a college or university. Or at least 4+ years working for a state, provincial, national, or international wildlife agency or NGO, working with a species or a group of species, ex. bears, or fur-bearers. However, evidence of experience with identifying wildlife tracks and signs is not described.	
	A1d). Observers are described as local or native people (or similar) with track and sign identification and interpretation experience, and/or traditional ecological knowledge in tracking. However, evidence of experience with identifying wildlife tracks and signs is not described.	

Category	Description	Score
	A1e). Observers are described as experienced at identifying wildlife tracks and signs, but no evidence of that experience is given.	
	A1f). (Formerly A3a) Observers have regular access, in-the-field, to a supervisor or mentor (similar to A1c in this table), who may have expertise in a species or group of species (ex. bears, or furbearers) but no evidence of the mentor's experience is given for identifying or interpreting the tracks and signs of those or other animals.	
	A1g). (Formerly A3b) Observers take a tangible representation as evidence of the track or sign from the field (e.g. a photo, tracing, track cast, plates from sooted track-plates, skeletal remains, etc.,) for assistance with identification by a supervisor or mentor, but no evidence is given for the mentor's experience with track and sign identification and interpretation.	
A2.	**Data reliability is based on evidence of observer/mentor experience or skill.**	+1
	Data reliability is based on known observer skill from reputable and representative quantitative or qualitative demonstration and/or certification.	
	A2a). Observers are described as local, native, indigenous (or similar) people with track and sign identification and interpretation experience, and/or traditional ecological knowledge in tracking, and evidence is cited of their experience.	
	A2b). Observers are described as experienced at identifying wildlife tracks and signs and evidence is cited of their experience.	
	A2c). Observers participate in a workshop, taught by a tracker with documented and described skill (evidence), on how to identify and interpret the tracks and signs of their target species and how to differentiate them from any confounding species. Workshop duration and format is described, e.g. < 1 day, 1-2 days, >2 days, in-the-field vs lecture, etc. (Caution – workshops and trainings are not investigated for quality and content.	
	A2d). (Formerly A4a) Observers have regular access, in-the-field, to a supervisor or mentor (similar to A1c in this table), who is described as experienced at identifying wildlife tracks and signs and evidence is cited of their experience.	

Category	Description	Score
	A2e). (Formerly A4b) Observers take a tangible representation as evidence of the track or sign from the field (examples of ex-situ evidence include: a photo, tracing, track cast, plates from sooted track-plates, skeletal remains, etc.,) for assistance with identification by a supervisor or mentor. The evidence of the mentor's experience with identifying and interpreting tracks and signs is described.	
B.	**Data reliability is based on concurrent, verifiable occurrence records.**	
B1.	**Data reliability is based on methods and/or technology that allow independent, concurrent, verification of the identity and/or interpretation of tracks and signs. Methods are not always used across all sites and samples (e.g. cameras not placed at all track traps, DNA analysis not done on all samples, etc.).**	+1
	B1a). Track-based data is collected using tracings, impressions, photos, etc. (taken by the observer, on-site), which are measured and often post-processed using some form of discriminatory statistics and/or modeling.	
	B1b). Track-based data is collected at sites concurrently with photos or videos from camera traps.	
	B1c). Track-based data is collected at sites concurrently with telemetry: radiotelemetry (UHF, VHF, etc.) or GPS location positions.	
	B1d). Track-based data is collected concurrently with mark-recapture methods (other than cameras or telemetry).	
	B1e). Track-based data is collected concurrently with scat-detection dogs or scent-detection dogs.	
	B1f). Track-based data is collected concurrently with scat-detection dogs or scent-detection dogs AND DNA analysis for species, individual, or sex identification.	
	B1g). Track-based data is collected concurrently with DNA analysis for species, individual, or sex identification; or, micro or gross diet analysis of scats or pellets.	
	B1h). Track-based data is collected concurrently with visual or audible surveys (line or point counts, etc.) of animals.	

Category	Description	Score
C.	**Data reliability is "not required" or inherent to the system under study.**	
	Note: A "classic" track or sign is defined as representative of the species, and therefore distinct in appearance from other species. The track or sign is from a normal adult representative of its species (not very young, or injured). It is clear, entire, and not degraded from significant weather or age. Feces are from a healthy animal eating a normal diet. Usually there are no other confounding species presenting similar tracks and signs in the same area (not always noted).	
C1)	Data is in the form of: a literature review; a methods paper; or a descriptive paper (or similar). A paper documenting the characteristics of classic tracks or signs (including behaviors that are determined from the presence of specific tracks and signs). A paper in the "Natural History" style of observation and report, that becomes "classic" information.	0
C2.	No experience in track and sign identification or interpretation is required, in-the-field, for the conditions or the questions asked. Examples include: • Track-based data is simple in complexity and unmistakable by a novice (classic). • Track-based data is collected in an area where there are no other species present that have similar tracks and/or signs. • Track-based data is from specimens, a closed or captive population, visual observations of the animal, or from a controlled laboratory setting. • Track-based data is collected by following the animal's trail and finding the animal. • Track-based data is collected by following a clear animal trail in snow (or continuous soft sand). Tracks and signs are abundant and easily interpretable due to the substrate. The observers follow an animal's indisputable trail, step-by-step, and collect multiple sources of classic evidence (tracks, scats, behavioral signs, odors particular to a species, etc.). *Note: Only 0.5, not +1, when track-based data is collected by following an animal trail in snow or sand when methods are not described or conditions are variable enough that track identification is questionable.*	+1 +0.5

Table 4. Count and percent of papers.

Papers are grouped into categories and major subcategories by themes of how the track-based data were validated.

Part 1. Categories and major subcategories	**Count of papers**	**Percent of papers**
A1	81	19
A2	9	2
A1 + B	105	25
A2 + B	8	2
A1 + B + C	42	10
A2 + B + C	5	1
A1 + C	29	7
A2 + C	6	1
B + C	26	6
C	110	26
Total	**421**	**100**

Appendices

Appendix A. List of publications reviewed and their data reliability scores for track-based data.

The table is arranged alphabetic citation of the last name of the first author.

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
1	Ahlswede et al. 2019	A	A1d	-1					-1
2	Aing et al. 2011	A, C	A1a	-1			C2	0.5	-0.5
3	Alcala-Galvan and Krausman 2012	A	A1a	-1					-1
4	Alcalay et al. 2014	C					C2	1	1
5	Alexander et al. 2005	A, B, C	A1a	-1	B1c	1	C2	1	1
6	Alibhai et al. 2017	A, C	A2b	1			C2	1	2
7	Alibhai et al. 2008	A, C	A2b	1			C2	1	2
8	Alldredge et al. 1991	A, B	A1a	-1	B1d	1			0
9	Allen et al. 1996	A	A1a	-1					-1
10	Allen et al. 2014	A, B	A1b	-1	B1c	1			0
11	Allen et al. 2015	A, B	A1a	-1	B1b, B1c	1			0
12	Allen et al. 2016	A, B	A1a	-1	B1b, B1c	1			0
13	Allen et al. 2017	A	A1a	-1					-1
14	Altmann 1974	C					C1	0	0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
15	Anderson and Medin 1969	A, C	A1a	-1			C2	1	0
16	Anderson 1998	C					C1	0	0
17	Armstrong et al. 1983	A, C	A1a	-1			C2	0.5	-0.5
18	Aschemeier and Maher 2011	A	A1a	-1					-1
19	Aubry and Houston 1992	C					C1	0	0
20	Aubry and Jagger 2006	C					C1	0	0
21	Aubry and Lewis 2003	C					C1	0	0
22	Azorit et al. 2004	C					C2	1	1
23	Balčiauskas et al. 2011	A	A1b	-1					-1
24	Balestrieri et al. 2005	A	A1b	-1					-1
25	Balme et al. 2009	A, B, C	A1e	-1	B1b, B1c	1	C2	1	1
26	Barja et al. 2004	A	A1a	-1					-1
27	Barja 2005	A	A1a	-1					-1
28	Barocas et al. 2016	A, B	A1a	-1	B1b, B1d	1			0
29	Barrett 1981	A, B	A1a	-1	B1c, B1d	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
30	Barrientos and Virgós 2006	A	A1a	-1					-1
31	Barry et al. 2018	A	A2b	1					1
32	Bauer et al. 2014	A	A2a	1					1
33	Beauvais and Buskirk 1999)	C					C 2	1	1
34	Becker et al. 1998	A, C	A1c	-1			C 2	1	0
35	Becker 1991	A, C	A1c	-1			C 2	0.5	-0.5
36	Beier and Cunningham 1996	A	A1a	-1					-1
37	Belant et al. 2016	A, B	A1e	-1	B1h	1			0
38	Belant et al. 2019	A, B	A1e	-1	B1h	1			0
39	Bellis et al. 2013	A, B, C	A1a, A1b	-1	B1b	1	C 2	0.5	0.5
40	Berg and Gese 2010	C					C 2	1	1
41	Bider et al. 1968	A	A1e	-1					-1
42	Blackwell et al. 2002	A	A1a	-1					-1
43	Blaum et al. 2008	A	A1d	-1					-1
44	Bleich et al. 1996	B, C			B1c , B1e	1	C 2	1	2
45	Boast and Houser 2012	A	A1d	-1					-1
46	Bonesi and Macdonald 2004	A	A1e	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
47	Bothma and le Riche 1984	C					C 2	1	1
48	Bothma and le Riche 1993	C					C 2	1	1
49	Boutros et al. 2007	B, C			B1c	1	C 2	1	2
50	Boydston et al. 2006	B, C			B1c	1	C 2	1	2
51	Brodie and Brockelman 2009	A	A1b	-1					-1
52	Brodie 2006	A	A1a	-1					-1
53	Brown et al. 1996	A, B	A1a	-1	B1d	1			0
54	Bulinski and McArthur 2000	A, C	A1a, A1e	-1			C 2	1	-1
55	Burton et al. 2011	A	A1a	-1					-1
56	Cagnacci et al. 2004	A	A1a	-1					-1
57	Canon and Bryant 1997	A, B	A1a	-1	B1d	1			0
58	Carroll et al. 1999	A	A1a	-1					-1
59	Cavallini 1994	A	A1b	-1					-1
60	Chame 2003	C					C 1	0	0
61	Chen et al. 1999	A, C	A1e	-1			C 2	0.5	-0.5
62	Choudhury 1972	A, C	A1f	-1			C 1	0	-1
63	Clapham et al. 2012	B, C			B1b	1	C 2	1	2
64	Clapham et al. 2013	B, C			B1b	1	C 2	1	2

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
65	Clapperton et al. 1999	A	A1b	-1					-1
66	Clevenger and Purroy 1996	A	A1e	-1					-1
67	Crête and Larivière 2003	C					C 2	0.5	0.5
68	Crooks and Soulé 1999	A	A1e	-1					-1
69	Crooks et al. 2008	A	A1b	-1					-1
70	Croose et al. 2019	A	A1e	-1					-1
71	Crowley et al. 2012	B, C			B1c	1	C 2	1	2
72	Dagg 1973	C					C 1	0	0
73	Darden et al. 2008	A, B	A1e	-1	B1b , B1c	1			0
74	Davison et al. 2002	A, B	A1e	-1	B1g	1			0
75	Day et al. 2016	A, B	A1a	-1	B1b , B1c	1			0
76	De Angelo et al. 2010	A	A1c, A1e,	-1					-1
77	Dearborn 1939	C					C 1	0	0
78	Delibes-Mateos et al. 2008	A	A1a	-1					-1
79	Dell’Arte et al. 2007	A	A1a	-1					-1
80	DeMatteo et al. 2018	B, C			B1f	1	C 2	1	2

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
81	D'eon 2001	A, C	A1b	-1			C2	0.5	-0.5
82	Depue and Ben-David 2010	A	A1a	-1					-1
83	Devetak and Arnett 2015	C					C2	1	1
84	D'hondt et al. 2011	A	A1a	-1					-1
85	Domínguez-Rodrigo and Piqueras 2003	C					C2	1	1
86	Dor et al. 2014	C					C2	1	1
87	Drennan et al. 1998	A	A1b	-1					-1
88	Dudley et al. 1992	A	A1a	-1					-1
89	Duffie et al. 2019	A, B	A2b, A2d, A2e	1	B1b	1			2
90	Dzięciołowski 1976	A	A1a	-1					-1
91	Edwards et al. 2000	A	A1a	-1					-1
92	Elbroch et al. 2012	A, B	A1a	-1	B1b, B1c	1			0
93	Elbroch and Wittmer 2013*a*	A, B, C	A2b	1	B1c	1	C2	1	3
94	Elbroch and Wittmer 2013*b*	A, B, C	A2b	1	B1b, B1c	1	C2	1	3
95	Elbroch et al. 2011	A	A2b	1					1
96	Elbroch et al. 2014	A, B, C	A2b	1	B1b, B1c	1	C2	1	3

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
97	Elbroch et al. 2015*a*	A, B, C	A1a	-1	B1b	1	C2	1	1
98	Elbroch et al. 2015*b*	A, B	A2b	1	B1b, B1c	1			2
99	Elbroch et al. 2015*c*	A, B, C	A1a	-1	B1c	1	C2	1	1
100	Elbroch et al. 2017*a*	A, B	A1a	-1	B1c	1			0
101	Elbroch et al. 2017*b*	A, B	A2b	1	B1c	1			2
102	Ellison and Swanson 2016	A	A1a	-1					-1
103	Engeman and Evangilista 2007	A	A1d	-1					-1
104	Engeman et al. 2001	A	A1a	-1					-1
105	Engeman et al. 2002	A	A1a	-1					-1
106	Eppley et al. 2016	B, C			B1c	1	C2	1	2
107	Evans et al. 2009	A	A2c	1					1
108	Ewer and Wemmer 1974	C					C2	1	1
109	Ferkin and Pierce 2007	C					C1	0	0
110	Fitzhugh and Gorenzel 1985	C					C1	0	0
111	Flower et al. 2014	C					C2	1	1
112	Foelix et al. 2017	C					C2	1	1
113	Ford et al. 2009	A, B	A1a	-1	B1c	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
114	Foresman and Pearson 1998	A, B	A1b	-1	B1b	1			0
115	Forman 2005	A	A1b	-1					-1
116	Freilich and LaRue 1998	A, C	A1e	-1			C2	1	0
117	Fröhlich et al. 2012	A, B	A1a	-1	B1c	1			0
118	Funston et al. 2010	A	A1d, A1e	-1					-1
119	Gallant et al. 2007	A, C	A1a	-1			C2	1	0
120	Gallant et al. 2008	A, C	A1a	-1			C2	1	0
121	Gamberg and Atkinson 1988	C					C2	1	1
122	García et al. 2010	C					C2	1	1
123	Gardner et al. 2010	A, C	A2b	1			C2	0.5	1.5
124	Glen and Dickman 2003	A, B	A1a	-1	B1b	1			0
125	Godbois et al. 2005	C					C2	1	1
126	Golden et al. 2007	A, C	A1e	-1			C2	0.5	-0.5
127	Goldyn et al. 2003	A	A1a	-1					-1
128	Gompper et al. 2006	A, B, C	A1e	-1	B1b, B1g	1	C2	1	1
129	Gore et al. 1993	A, B	A1a	-1	B1a	1			0
130	Gosling and Roberts 2001	C					C1	0	0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
131	Gosling 1982	C					C1	0	0
132	Gosselin et al. 2017	B, C			B1g	1	C2	1	2
133	Gossow et al. 1974	C					C2	1	1
134	Goszczyński 1990	A, C	A1a	-1			C2	0.5	-0.5
135	Granatosky et al. 2018	C					C2	1	1
136	Graves et al. 2011	A, B	A1a	-1	B1g	1			0
137	Green and Mattson 2003	A, B	A1a	-1	B1c	1			0
138	Grigione et al. 1999	A, B	A1a	-1	B1a, B1c	1			0
139	Grovenburg et al. 2010	A, B	A1a	-1	B1c	1			0
140	Gruber et al. 2008	A	A1a	-1					-1
141	Gryz et al. 2008	A	A1b	-1					-1
142	Gu et al. 2014	B, C			B1a	1	C2	1	2
143	Guillera-Arroita et al. 2011	C					C2	1	1
144	Gusset and Burgener 2005	A, B	A1a	-1	B1a	1			0
145	Halpin and Bissonette 1988	A, C	A1a	-1			C2	0.5	-0.5
146	Hamilton 1982	C					C1	0	0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
147	Hansen and Jacobsen 1999	A, B	A1a	-1	B1g	1			0
148	Harihar and Pandav 2012	A	A1c	-1					-1
149	Härkönen and Heikkilä 1999	A	A1a	-1					-1
150	Harmsen et al. 2010	A, B	A1a	-1	B1b, B1g	1			0
151	Harrington et al. 2007	C					C2	1	1
152	Harrington et al. 2010	A, B	A1e	-1	B1g	1			0
153	Harrington et al. 2008	A, B	A1a	-1	B1g	1			0
154	Harrison et al. 2002	A, B	A1a	-1	B1b, B1g	1			0
155	Harrow et al. 2018	A, B	A1b	-1	B1a, B1d	1			0
156	Haynes 1983	C					C2	1	1
157	Hayward et al. 2002	A, C	A1a, A1e	-1			C2	0.5	-0.5
158	Hayward et al. 2005	A, B	A1a	-1	B1d	1			0
159	Hebblewhite et al. 2005	A, B, C	A1a	-1	B1c	1	C2	1	1
160	Heise-Pavlov and Meade 2012	C					C2	1	1
161	Helldin and Danielsson 2007	A	A1b	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
162	Hemming 1969	C					C 2	1	1
163	Henry 1977	C					C 2	1	1
164	Herzog et al. 2007	A, B	A1a, A1g	-1	B1a	1			0
165	Hildebrand 1959	C					C 1	0	0
166	Hildebrand 1961	C					C 1	0	0
167	Hildebrand 1962	C					C 1	0	0
168	Hildebrand 1968	C					C 1	0	0
169	Hildebrand 1977	C					C 1	0	0
170	Hildebrand 1980	C					C 1	0	0
171	Hines et al. 2010	A	A1e	-1					-1
172	Hooper and Rea 2009	A, C	A2b, A2d	1			C 2	1	2
173	Hornocker 1969	B, C			B1d	1	C 2	1	2
174	Houser et al. 2009	A, B	A2d	1	B1c, B1d, B1h	1			2
175	Hüner and Peter 2012	B, C			B1b	1	C 2	1	2
176	Janečka et al. 2008	A, B	A1a	-1	B1g	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
177	Jankowiak et al. 2008	A, B	A1a	-1	B1g	1			0
178	Jeffress et al. 2011	A	A2c	1					1
179	Jewell and Alibhai 2012	B, C			B1a	1	C 1	0	1
180	Jewell et al. 2001	B, C			B1a	1	C 2	1	2
181	Jewell et al. 2016	A, B	A1a	-1	B1a	1			0
182	Jhala et al. 2010	A, B	A2c	1	B1b	1			2
183	Johnson and Aldred 1982	B, C			B1g	1	C 2	1	2
184	Johnson et al. 1984	A, B	A1c	-1	B1g	1			0
185	Johnson 1931	C					C 1	0	0
186	Johnson 1973	C					C 1	0	0
187	Jones et al. 2004	C					C 1	0	0
188	Jordan et al. 2014	C					C 2	1	1
189	Jordan et al. 2011	C					C 2	1	1
190	Karamanlidis et al. 2007	A, B	A1a	-1	B1a	1			0
191	Karanth et al. 2011	A, C	A1e, A1g	-1					-1
192	Karanth et al. 2003	C					C 1	0	0
193	Keeping et al. 2019	A	A1e	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
194	Keeping and Pelletier 2014	A, C	A2a	1			C 1	0	1
195	Keeping 2014	A	A2a	1					1
196	Keeping et al. 2018	A	A2a	1					1
197	Kelly and Garton 1997	C					C 2	1	1
198	Kendall et al. 1992	A	A2c	1					1
199	Kent and Hill 2013	A, B	A1d	-1	B1b	1			0
200	Kerley and Salkina 2007	B, C			B1e	1	C 2	0.5	1.5
201	Khan and Goyal 1993	C					C 2	1	1
202	King and Edgar 1977	C					C 1	0	0
203	King et al. 2007	A, B	A1b	-1	B1b	1			0
204	Kiseleva and Sorokin 2013	A, B	A1b	-1	B1b, B1g	1			0
205	Kleiman 1974	C					C 2	1	1
206	Kobryczuk et al. 2008	C					C 2	1	1
207	Kobryńczuk et al. 2008	C					C 2	1	1
208	Kohn and Wayne 1997	C					C 1	0	0
209	Kojola et al. 2014	A, B, C	A1a	-1	B1h	1	C 2	1	1
210	Kolbe et al. 2007	A, B, C	A1a	-1	B1c	1	C 2	1	1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
211	Krofel et al. 2017	A, B, C	A1a	-1	B1c, B1g	1	C2	0.5	0.5
212	Kurek 2015	C					C1	0	0
213	Kusler et al. 2017	A, B, C	A2b	1	B1c	1	C2	1	3
214	Lang et al. 1985	A, C	A1a	-1			C2	0.5	-0.5
215	Lanszki and Heltai 2011	A	A1b	-1					-1
216	Lanszki et al. 2006	A	A1b	-1					-1
217	Larivière 1999	C					C1	0	0
218	Law et al. 2013	B, C			B1a	1	C2	1	2
219	Leach et al. 1984	C					C1	0	0
220	Leberg et al. 2004	A, B, C	A1c	-1	B1g	1	C2	1	1
221	Leoniak et al. 2012	A, C	A2b	1			C2	1	2
222	Lewison et al. 2001	A, B, C	A1f	-1	B1a	1	C2	1	1
223	Li et al. 2018	B, C			B1a	1	C2	1	2
224	Liebenberg et al. 1999	C					C1	0	0
225	Liebenberg et al. 2017	C					C1	0	0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
226	Liebenberg 2006	C					C 1	0	0
227	Liebenberg 2008	C					C 1	0	0
228	Lieberman et al. 2007	C					C 1	0	0
229	Linkie et al. 2006	A	A1e	-1					-1
230	Linnell et al. 1999	B, C			B1c	1	C 2	1	2
231	Linnell et al. 2004	B, C			B1c	1	C 2	1	2
232	Linnell et al. 2007	A, B, C	A1a	-1	B1c	1	C 2	1	1
233	Litvaitis et al. 1985	A, C	A1a	-1			C 2	0.5	-0.5
234	Livingston et al. 2005	A	A1a	-1					-1
235	Lokare et al. 2014	A, C	A1b	-1			C 2	1	0
236	Long et al. 2011	A, B	A1a	-1	B1b, B1f	1			0
237	Long et al. 2007*b*	A, B	A1a	-1	B1f	1			0
238	Long et al. 2007*a*	A, B	A1a	-1	B1b, B1f	1			0
239	Lovei et al. 1996	C					C 1	0	0
240	Loveridge et al. 2006	A	A1a	-1					-1
241	Lozano et al. 2003	A	A1a	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
242	Lozano 2010	A	A1a	-1					-1
243	Lurz 1998	A, C	A1a	-1			C2	1	0
244	Lyra-Jorge et al. 2008	A, B	A1e	-1	B1b	1			0
245	Macdonald et al. 1987	A	A1b	-1					-1
246	Macdonald 1979	C					C2	1	1
247	Macdonald 1980	C					C1	0	0
248	Magoun et al. 2007	A, C	A1b, A1c	-1			C2	0.5	-0.5
249	Maletzke et al. 2008	C					C2	1	1
250	Malo et al. 2004	A, B	A1a	-1	B1g	1			0
251	Marchal 2017	A, B	A1a	-1	B1a, B1b, B1h	1			0
252	Marchal et al. 2016	A, B	A1a	-1	B1a, B1b, B1h	1			0
253	Marchetti et al. 2019	C					C1	0	0
254	Marler 1961	C					C1	0	0
255	Marneweck et al. 2018	C					C2	1	1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
256	Martins et al. 2006	C					C2	1	1
257	Marzluff et al. 1996	B, C			B1d, B1h	1	C2	1	2
258	Mason and Macdonald 1987	A	A1a	-1					-1
259	Mason 1984	C					C2	1	1
260	Massei et al. 1998	C					C2	1	1
261	Matsuda et al. 2010	C					C2	1	1
262	Mcbride et al. 2008	A, B	A2b	1	B1a, B1b, B1c, B1d	1			2
263	McCann et al. 2017	B, C			B1a, B1c	1	C2	1	2
264	Mccord 1974	A, B, C	A1a	-1	B1g	1	C2	0.5	0.5
265	Mccullough 1965	B, C			B1a	1	C2	1	2
266	McHenry et al. 2016	A, B	A1a	-1	B1g	1			0
267	McKelvey et al. 2006	A, B, C	A1a	-1	B1c, B1g	1	C2	1	1
268	McKelvey et al. 2008	A, B, C	A1a	-1	B1a	1	C1	0	0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
269	McLellan et al. 2018	A, B, C	A1a	-1	B1c	1	C 2	1	1
270	Melville and Bothma 2006	A	A2a	1					1
271	Melville et al. 2004	A, B	A1d	-1	B1g	1			0
272	Messier and Barrette 1985	A, C	A1a	-1			C 2	0.5	-0.5
273	Midgley et al. 2012	A, C	A1b	-1			C 2	1	0
274	Midlane et al. 2014	A	A1a	-1					-1
275	Midlane et al. 2015	A	A1a, A1d	-1					-1
276	Miller et al. 2003	C					C 2	1	1
277	Mills 1984	C					C 2	1	1
278	Millspaugh et al. 1998	B, C			B1c	1	C 2	1	2
279	Miotto et al. 2007	A, B	A1a	-1	B1g	1			0
280	Molteno et al. 1998	B, C			B1c	1	C 2	1	2
281	Monclús et al. 2009	A	A1a	-1					-1
282	Monterroso et al. 2013	A, B	A1e	-1	B1g	1			0
283	Mooty et al. 1984	A	A1a	-1					-1
284	Morden et al. 2011	C					C 2	1	1
285	Moreira et al. 2018	A, B	A1a	-1	B1a	1			0
286	Mullins et al. 2010	C					C 2	1	1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
287	Murdoch and Buyandelger 2010	A, B	A1b	-1	B1c	1			0
288	Murmann et al. 2006	C					C2	1	1
289	Murray and Boutin 1991	C					C2	0.5	0.5
290	Mysterud and Østbye 1995	A, C	A1a	-1			C2	0.5	-0.5
291	Mysterud and Østbye 2006	C					C2	1	1
292	Mysterud and Østbye 1995	A, B	A1a	-1	B1c	1			0
293	Neff 1968	C					C1	0	0
294	Ng et al. 2004	A, B	A1a	-1	B1b	1			0
295	Nie et al. 2012	A	A1a	-1					-1
296	Nieminen 1990	C					C2	1	1
297	Norris et al. 2008	A	A1b, A1d	-1					-1
298	O'Mahony et al. 2012	A, B	A1a	-1	B1g	1			0
299	O'Malley et al. 2018	A, B	A2b	1	B1c	1			2
300	Owen-Smith and Chafota 2012	A	A1a	-1					-1
301	Padial et al. 2002	A, B	A1a	-1	B1g	1			0
302	Palma and Gurgel-Gonçalves 2007	A, B	A1a	-1	B1a, B1d	1			0
303	Panwar 1979	A	A1e	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
304	Panzacchi et al. 2008	A, B	A1a	-1	B1g	1			0
305	Paquet 1991	A, B, C	A1a	-1	B1c	1	C2	1	1
306	Paterson and Skipper 2008	A, B	A1b	-1	B1g	1			0
307	Patnaik et al 2008	A, B, C	A1e, A1g	-1	B1a	1	C1	0	0
308	Patterson et al. 2004	C					C2	1	1
309	Peters and Mech 1975	A, B, C	A1a	-1	B1c	1	C2	1	1
310	Pickering et al. 2004	C					C2	1	1
311	Picton and Kendall 1994	A, B, C	A1a	-1	B1g	1	C2	1	1
312	Pimm et al. 2015	C					C1	0	0
313	Piñeiro and Barja 2012	A, B	A1a	-1	B1g	1			0
314	Pirie et al. 2016	A, B	A1b, A1e	-1	B1a, B1b	1			0
315	Posłuszny et al. 2007	A, B	A1a, A1b,	-1	B1g	1			0
316	Prigioni et al. 2008	A, B	A1a, A1b	-1	B1g	1			0
317	Prugh and Ritland 2005	A, B, C	A1a	-1	B1g	1	C2	1	1
318	Pullianen 1980	A, C	A1e	-1			C2	0.5	-0.5

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
319	Pulliainen 1981	A, C	A1a	-1			C2	0.5	-0.5
320	Purcell et al. 2009	A, B, C	A1a	-1	B1c	1	C1	0	0
321	Purchase 2007	A, B, C	A1a	-1	B1a	1	C2	1	1
322	Rabinowitz and Walker 1991	A, B	A1a	-1	B1g, B1d, B1h	1			0
323	Rachlow et al. 1999	A, B	A1d	-1	B1c, B1h	1			0
324	Ralls 1971	C					C1	0	0
325	Rauber and Manser 2017	C					C2	1	1
326	Reed et al. 2004	A, B	A1b, A1c	-1	B1g	1			0
327	Reed et al. 2006	A	A1b, A1c	-1					-1
328	Reed 2011	A, B	A1b	-1	B1g	1			0
329	Reid et al. 1987	A, B, C	A1a	-1	B1c	1	C2	1	1
330	Reiger et al. 1979	C					C1	0	0
331	Riordan 1998	B, C			B1a	1	C2	1	2
332	Rodgers et al. 2015	A, B	A1a	-1	B1b, B1g	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
333	Romani et al. 2018	A, B	A1e	-1	B1b	1			0
334	Rosalino et al. 2005	A, B	A1a	-1	B1g	1			0
335	Rosalino et al. 2007	A, B	A1a	-1	B1g	1			0
336	Rosellini et al. 2008*b*	A, B	A1a	-1	B1b, B1g	1			0
337	Rosell et al. 2011	C					C2	1	1
338	Rosellini et al. 2008*a*	A, B	A1a	-1	B1b, B1g	1			0
339	Rostain et al. 2004	C					C2	1	1
340	Ruiz-Olmo et al. 2001	A, B	A1b	-1	B1c	1			0
341	Ruiz-Olmo et al. 2013	C					C2	1	1
342	Rumble et al. 1996	C					C2	1	1
343	Russell and Storch 2004	A, B	A1a	-1	B1g	1			0
344	Rutina et al. 2017	A, B	A1d	-1	B1a	1			0
345	Sagar and Singh 1993	A, B	A1e	-1	B1a	1			0
346	Sargeant et al. 1998	A, B	A1a	-1	B1a	1			0
347	Schaller et al. 1988	A	A1a	-1					-1
348	Selvaggio and Wilder 2001	C					C2	1	1
349	Selvaggio 1994	C					C2	1	1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
350	Sergiel et al. 2017	A, B, C	A1a	-1	B1b	1	C2	1	1
351	Servin et al. 1987	A, B	A1a	-1	B1b	1			0
352	Seryodkin 2014	A, B, C	A1a	-1	B1h	1	C2	1	1
353	Scharf et al. 2010	C					C2	1	1
354	Sharma et al. 2003	A, B	A1a	-1	B1a, B1h	1			0
355	Sharma et al. 2005	A, B	A1a	-1	B1a, B1h	1			0
356	Sharps et al. 2002	C					C2	1	1
357	Sidorovich et al. 2005	A, B, C	A1a, A1b	-1	B1c, B1d, B1g, B1h	1	C2	0.5	0.5
358	Sidorovich et al. 2010	A, B	A1a, A1b	-1	B1g	1			0
359	Sidorovich et al. 2011	A, B	A1a, A1b	-1	B1c, B1d, B1g, B1h	1			0
360	Silveira et al. 2003	A, B	A1a	-1	B1b, B1h	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
361	Singh and Bustard 1977	C					C1	0	0
362	Singh 2000*b*	C					C1	0	0
363	Singh 2000*a*	A, B, C	A1e, A1g	-1	B1a	1	C1	0	0
364	Skalski and Wierzbowska 2008	A, B	A1b	-1	B1g	1			0
365	Skalski 1991	A, B	A1a	-1	B1d	1			0
366	Smallwood and Fitzhugh 1993	A, B	A1e	-1	B1a	1			0
367	Smallwood et al. 1995	A, B	A1e	-1	B1a	1			0
368	Southgate et al. 2018	A, C	A1a	-1			C2	1	0
369	Squires et al. 2004	A, B, C	A1e	-1	B1a, B1c, B1g	1	C2	1	1
370	Squires et al. 2012	A, B, C	A1e	-1	B1c	1	C2	0.5	0.5
371	Stahler et al. 2006	A, B, C	A1a	-1	B1c	1	C1	0	0
372	Stander et al. 1997	A, B	A1d	-1	B1a, B1h	1			0
373	Stander 1998	A, B	A1d	-1	B1a, B1c, B1h	1			0

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
374	Stander 2019	A	A1d	-1					-1
375	Stanley and Royle 2005	A, B	A1a	-1	B1d	1			0
376	Stephens et al. 2006	A, B, C	A1c	-1	B1c	1	C2	1	1
377	Suryawanshi et al. 2019	A, B, C	A1a	-1	B1b, B1c, B1g	1	C1	0	0
378	Suter et al. 2011	C					C2	1	1
379	Taberlet et al. 1997	A, B	A1a, A1b	-1	B1g	1			0
380	Taylor and Raphael 1988	A, B	A1a, A1b	-1	B1a, B1d	1			0
381	Taylor et al. 2015	A, B	A1a	-1	B1b	1			0
382	Taylor 1970	C					C2	1	1
383	Telfer et al. 2006	A, B, C	A1a	-1	B1h	1	C2	1	1
384	Terry et al. 2005	C					C1	0	0
385	Thiessen and Rice 1976	C					C1	0	0
386	Thompson et al. 1989	A, C	A1a	-1			C2	0.5	-0.5
387	Thorn et al. 2011	A	A1e	-1					-1
388	Tosh et al. 2007	A	A1b	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
389	Trites and Joy 2005	A, B, C	A1a	-1	B1h	1	C2	1	1
390	Trudeau et al. 2011	A, B	A1a	-1	B1c	1			0
391	Vallon et al. 2016	C					C1	0	0
392	Van Dyke et al. 1986	A, B	A1e	-1	B1c	1			0
393	Van Etten and Bennett 1965	A	A1e	-1					-1
394	Van Sickle and Lindzey 1992	A, B	A1a	-1	B1c	1			0
395	Verlinden et al. 1998	A	A1b	-1					-1
396	Walker et al. 2016	A, B	A1a	-1	B1b	1			0
397	Walsberg 1975	C					C2	1	1
398	Weise et al. 2017	A	A1b	-1					-1
399	Weise et al. 2014	A, B	A1d	-1	B1b, B1h	1			0
400	Weise et al. 2017	A	A1a	-1					-1
401	Wiggins and Bowman 2011	A	A1a	-1					-1
402	Wilson and Delahay 2001	C					C1	0	0
403	Wilting et al. 2006	A	A1b	-1					-1
404	Winegarner 1985	A, B, C	A1a	-1	B1h	1	C2	1	1
405	Winterbach et al. 2016	A	A1d, A1e	-1					-1
406	Wolf and Ale 2009	A	A1a	-1					-1

#	Literature Cited	(A, B, C)	A	A Score	B	B Score	C	C Score	Paper Score
407	Wong et al. 2011	A, B, C	A2a	1	B1g	1	C2	1	3
408	Woodmansee et al. 1991	C					C2	1	1
409	Wooldridge et al. 2019	A, B	A1e	-1	B1b	1			0
410	Yarnell et al. 2014)	A	A1a, A1g	-1					-1
411	Zalewski 1999	A, B, C	A1b	-1	B1b	1	C2	1	1
412	Zalewski 2007	A, B, C	A1b	-1	B1b	1	C2	1	1
413	Zannése et al. 2006	C					C2	1	1
414	Zhang et al. 2009	A, B	A1b	-1	B1g	1			0
415	Zielinski and Kucera 1995	A, B, C	A1e	-1	B1a, B1b	1	C2	1	1
416	Zielinski and Stauffer 1996	A, B	A2c	1	B1a	1			2
417	Zielinski and Stauffer 1996	A, B, C	A1c	-1	B1a	1	C2	1	1
418	Zielinski and Truex 1995	A, B, C	A1e	-1	B1a	1	C2	1	1
419	Zuberogoitia et al. 2006	A, B	A1e	-1	B1c, B1d	1			0
420	Zuercher et al. 2003	A, B	A1d	-1	B1g	1			0
421	Zyznar and Urness 1969	C					C2	1	1

Literature Cited

Ahlswede, S., E. C. Fabiano, D. Keeping, and K. Birkhofer. 2019. Using the Formozov–Malyshev–Pereleshin formula to convert mammal spoor counts into density estimates for long-term community-level monitoring. African Journal of Ecology 57:1-13.

Aing, C., S. Halls, K. Oken, R. Dobrow, and J. Fieberg. 2011. A Bayesian hierarchical occupancy model for track surveys conducted in a series of linear, spatially correlated, sites. Journal of Applied Ecology 48(6):1508–1517.

Alcala-Galvan, C. H., and P. R. Krausman. 2012. Diets of desert mule deer in altered habitats in the lower Sonoran Desert. California Fish and Game 98(2):81–103.

Alcalay, Y., E. D. Barkae, O. Ovadia, and I. Scharf. 2014. Consequences of the instar stage for behavior in a pit-building antlion. Behavioural Processes 103:105–111.

Alexander, S. M., P. C. Paquet, Travis B. Logan, and D. J. Saher. 2005. Snow-tracking versus radiotelemetry for predicting wolf-environment relationships in the Rocky Mountains of Canada. Wildlife Society Bulletin 33(4):1216–1224.

Alibhai, S. K., Z. C. Jewell, and J. W. Evans. 2017. The challenge of monitoring elusive large carnivores: an accurate and cost-effective tool to identify and sex pumas (Puma concolor) from footprints. PloS One 12(3):e0172065. https://doi:10.1371/journal. pone.0172065

Alibhai, S. K., Z. C. Jewell, and P. R. Law. 2008. A footprint technique to identify white rhino *Ceratotherium simum* at individual and species levels. Endangered Species Research 4:205–218.

Alldredge, A. W., R. D. Deblinger, and J. Peterson. 1991. Birth and fawn bed site selection by pronghorns in a sagebrush-steppe community. Journal of Wildlife Management 55(2):222–227.

Allen, L., R. Engeman, and H. Krupa. 1996. Evaluation of three relative abundance indices for assessing dingo populations. Wildlife Research 23(2):197–205.

Allen, M. 2011. Violence and voice: using a feminist constructivist grounded theory to explore women's resistance to abuse. Qualitative Research 11:23–45.

Allen, M. L., H. U. Wittmer, and C. C. Wilmers. 2014. Puma communication behaviours: Understanding functional use and variation among sex and age classes. Behaviour 151(6):819-840.

Allen, M. L., L. M. Elbroch, C. C. Wilmers, and H. U. Wittmer. 2015. The comparative effects of large carnivores on the acquisition of carrion by scavengers. The American Naturalist 185:822-833. http://dx.doi.org/10.5061/dryad.dh2vr.

Allen, M. L., H. U. Wittmer, E. Setiawan, S. Jaffe, and A. J. Marshall. 2016. Scent marking in Sunda clouded leopards (*Neofelis diardi*): novel observations close a key gap in understanding felid communication behaviours. Nature: Scientific Reports 6:e35433. https://doi.org/10.1038/srep35433

Allen, M. L., H. U. Wittmer, P. Houghtaling, J. Smith, L. M. Elbroch, and C. C. Wilmers. 2015. The role of scent marking in mate selection by female pumas (*Puma concolor*). PLoS One 10:1–12.

Allen, M. L., L. M. Elbroch, C. C. Wilmers, and H. U. Wittmer. 2015. The comparative effects of large carnivores on the acquisition of carrion by scavengers. The American Naturalist 185:822-833. http://dx.doi.org/10.5061/dryad.dh2vr.

Allen, M. L., M. S. Gunther, and C. C. Wilmers. 2017. The scent of your enemy is my friend? The acquisition of large carnivore scent by a smaller carnivore. Journal of Ethology 35:13–19.

Altmann, J. 1974. Observational study of behavior: sampling methods. Behaviour 49(3-4):227–266.

Anderson, A., and E. Medin. 1969. Antler morphometry in a Colorado mule deer population. Journal of Wildlife Management 33:520–533.

Anderson, J. R. 1998. Sleep, sleeping sites, and sleep-related activities: Awakening to their significance. American Journal of Primatology 46:63–75.

Armstrong, E., D. Euler, and G. Racey. 1983. Winter bed-site selection by white-tailed deer in Central Ontario. Journal of Wildlife Management 47(3):880–884.

Aschemeier, L. M., and C. R. Maher. 2011. Eavesdropping of woodchucks (*Marmota monax*) and eastern chipmunks (*Tamias striatus*) on heterospecific alarm calls. Journal of Mammalogy 92(3):493–499.

Aubry, K. B., and D. B. Houston. 1992. Distribution and status of the fisher (*Martes pennanti*) in Washington. Northwestern Naturalist 73(3):69–79.

Aubry, K. B., and J. C. Lewis. 2003. Extirpation and reintroduction of fishers (*Martes pennanti*) in Oregon: implications for their conservation in the Pacific states. Biological Conservation 114:79–90.

Aubry, K. B., and L. Jagger. 2006. The importance of obtaining verifiable occurrence data on forest carnivores and an interactive website for archiving results from standardized surveys. Pages 159–176 *in* M. Santos-Reis, J. D. Birks, E. C. O'Doherty, and G. Proulx, editors. Martes in Carnivore Communities, Alpha Wildlife Publications, Sherwood Park, Alberta, Canada.

Azorit, C., J. Muñoz-Cobo, J. Hervás, and M. Analla. 2004. Aging through growth marks in teeth of Spanish red deer. Wildlife Society Bulletin 32(3):702–710.

Balčiauskas, L., L. Alejunas, L. Balčiauskiene, and P. Alejunas. 2011. Northern birch mouse (*Sicista betulina*) in Lithuania, findings in the diet of tawny owl (*Strix aluco*). Acta Zoologica Academiae Scientiarum Hungaricae 57(3):277–289.

Balestrieri, A., L. Remonti, and C. Prigioni. 2005. Local feeding specialization of the red fox (*Vulpes vulpes*) in response to eastern cottontail *(Sylvilagus floridanus*) introduction (NW Italy). Hystrix It. J. Mamm 16(2):113–126.

Balme, G. A., L. T. B. Hunter, and R. Slotow. 2009. Evaluating methods for counting cryptic carnivores. Journal of Wildlife Management 73(3):433–441.

Barja, I. 2005. Winter distribution of European pine marten (*Martes martes*) scats in a protected area of Galicia, Spain. Mammalia 69(3–4):435–438.

Barja, I., F. J. de Miguel, and F. Bárcena. 2004. The importance of crossroads in faecal marking behaviour of the wolves (*Canis lupus*). Die Naturwissenschaften 91(10):489–492.

Barnum, S., K. Rinehart, and L. M. Elbroch. 2007. Habitat, highway features, and animal-vehicle collision locations as indicators of wildlife crossing hotspots. Road Ecology Center, John Muir Institute of the Environment, UC Davis, Davis. http://escholarship.org/uc/item/3d35b16n

Barocas, A., H. N. Golden, M. W. Harrington, D. B. McDonald, and M. Ben-David. 2016. Coastal latrine sites as social information hubs and drivers of river otter fission–fusion dynamics. Animal Behaviour 120:103–114.

Barrett, M. 1981. Environmental characteristics and functional significance of pronghorn fawn bedding sites in Alberta. Journal of Wildlife Management 45:120–131.

Barrientos, R., and E. Virgós. 2006. Reduction of potential food interference in two sympatric carnivores by sequential use of shared resources. Acta Oecologica 30:107-116.

Barry, J. M., L. M. Elbroch, M. E. Aiello-Lammens, R. J. Sarno, L. Seelye, A. Kusler, H. B. Quigley, and M. M. Grigione. 2018. Pumas as ecosystem engineers: ungulate carcasses support beetle assemblages in the Greater Yellowstone Ecosystem. Oecologia 189(3):1–10. https://doi.org/10.1007/s00442-018-4315-z

Bauer, D., M. Schiess-Meier, D. R. Mills, and M. Gusset. 2014. Using spoor and prey counts to determine temporal and spatial variation in lion (*Panthera leo*) density. Canadian Journal of Zoology 92(2):97–104.

Beauvais, G. P., and S. W. Buskirk. 1999. An improved estimate of trail detectability for snow-trail surveys. Wildlife Society Bulletin 27:32–38.

Becker, E. F. 1991. A terrestrial furbearer estimator based on probability sampling. Journal of Wildlife Management 55(4):730–737.

Becker, E. F., M. A. Spindler, and T. O. Osborne. 1998. A Population Estimator Based on Network Sampling of Tracks in the Snow. Journal of Wildlife Management 62(2):968.

Beier, P., and S. C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. Wildlife Society Bulletin 24(3):540–546.

Belant, J. L., F. Bled, C. M. Wilton, R. Fyumagwa, S. B. Mwampeta, and D. E. J. Beyer. 2016. Estimating lion abundance using N-mixture models for social species. Scientific Reports 6:e35920. https://DOI.org/10.1038/srep35920

Belant, J. L., F. Bled, I. J. Mkasanga, C. M. Wilton, S. B. Mwampeta, D. E. Beyer, W. Mwakilema, and R. Fyumagwa. 2019. Track surveys do not provide accurate or precise lion density estimates in Serengeti. Global Ecology and Conservation e00651. https://doi.org/10.1016/j.gecco.2019.e00651

Bellis, M. A., C. R. Griffin, P. Warren, and S. D. Jackson. 2013. Utilizing a multi-technique, multi–taxa approach to monitoring wildlife passageways in southern Vermont. Oecologia Australis 17:111–128.

Berg, N. D., and E. M. Gese. 2010. Relationship between fecal pellet counts and snowshoe hare density in Western Wyoming. Journal of Wildlife Management 74(8):1745–1751.

Bider, J. R., T. Technique, and J. R. Bider. 1968. Animal activity in uncontrolled terrestrial communities as determined by a sand transect technique. Ecological Monographs 38(4):269–308.

Blackwell, G. L., M. A. Potter, and J. A. McLennan. 2002. Rodent density indices from tracking tunnels, snap-traps and Fenn traps: do they tell the same story? New Zealand Journal of Ecology 26:43–51.

Blaum, N., R. M. Engeman, B. Wasiolka, and E. Rossmanith. 2008. Indexing small mammalian carnivores in the southern Kalahari, South Africa. Wildlife Research 35:72–79.

Bleich, V. C., B. M. Pierce, J. L. Davis, and V. L. Davis. 1996. Thermal characteristics of mountain lion dens. The Great Basin Naturalist 56(3):276–278.

Boast, L. K., and A. M. Houser. 2012. Density of large predators on commercial farmland in Ghanzi, Botswana. South African Journal of Wildlife Research 42(2):138–143.

Bonesi, L., and D. W. Macdonald. 2004. Evaluation of sign surveys as a way to estimate the relative abundance of American mink (*Mustela vison*). Journal of Zoology 262:65–72.

Bothma, J. D. P., and E. A. N. le Riche. 1984. Aspects of the ecology and the behaviour of the leopard *Panthera pardus* in the Kalahari desert. Koedoe-African Protected Area Conservation and Science 27:259–279.

Bothma, J. D. P., and E. A. N. le Riche. 1993. Disturbance bias when tracking Kalahari leopards *Panthera pardus* by spoor. Koedoe-African Protected Area Conservation and Science 36(2):109–112.

Boutros, D., C. Breitenmoser-Wursten, F. Zimmermann, A. Ryser, A. Molinari-Jobin, S. Capt, M. Guntert, and U. Breitenmoser. 2007. Characterisation of Eurasian lynx *Lynx lynx* den sites and kitten survival. Wildlife Biology 13(4):417–429.

Boydston, E. E., K. M. Kapheim, and K. E. Holekamp. 2006. Patterns of den occupation by the spotted hyaena (*Crocuta crocuta*). African Journal of Ecology 44:77–86.

Brodie, J. F. 2006. An experimentally determined persistence-rate correction factor for scat-based abundance indices. Wildlife Society Bulletin 34(4):1216–1219.

Brodie, J. F., and W. Y. Brockelman. 2009. Bed site selection of red muntjac (*Muntiacus muntjak*) and sambar (*Rusa unicolor*) in a tropical seasonal forest. Ecological Research 24(6):1251–1256.

Brown, K. P., H. Moller, J. Innes, and N. Alterio. 1996. Calibration of tunnel tracking rates to estimate relative abundance of ship rats (*Rattus rattus*) and mice (*Mus musculus*) in a New Zealand forest. New Zealand Journal of Ecology 20:271–275.

Bulinski, J., and C. McArthur. 2000. Observer error in counts of macropod scats. Wildlife Research 27:277–282.

Burton, A. C., M. K. Sam, D. G. Kpelle, C. Balangtaa, E. B. Buedi, and J. S. Brashares. 2011. Evaluating persistence and its predictors in a West African carnivore community. Biological Conservation 144:2344–2353.

Cagnacci, F., A. Meriggi, and S. Lovari. 2004. Habitat selection by the red fox *Vulpes vulpes* (L. 1758) in an Alpine area. Ethology, Ecology & Evolution. 16:103–116.

Canon, S. K., and F. C. Bryant. 1997. Bed-Site Characteristics of Pronghorn Fawns. The Journal of Wildlife Management 61:1134–1141.

Cavallini, P. 1994. Faeces count as an index of fox abundance. Acta Theriologica 39(4):417–424.

Carroll, C., W. J. Zielinski, and R. F. Noss. 1999. Using presence-absence data to build and test spatial habitat models for the fisher in the Klamath region, USA. Conservation Biology 13(6):1344–1359.

Carruthers, J. 1995. The Kruger National Park: A Social and Political History. University of Natal Press. Pietermaritzburg, South Africa: 170.

Caruthers, J. 2006. Tracking in game trails: looking afresh at the politics of environmental history in South Africa. Environmental History 11:804-829.

Chame, M. 2003. Terrestrial mammal feces: a morphometric summary and description. Memórias do Instituto Oswaldo Cruz 98:71–94.

Chen, H., F. Li, L. Luo, H. Wang, J. Ma, and F. Li. 1999. Winter bed-site selection by red deer *Cervus elaphus xanthopygus* and roe deer *Capreolus capreolus bedfordi* in forests of northeastern China. Acta Theriologica 44(2):195–206.

Choudhury, S. R. 1970. Let us count our tigers. Cheetal 14(2):41–51.

Choudhury, S. R. 1972. Tiger census in India. Cheetal 15:67–84.

Clapham, M., O. T. Nevin, A. D. Ramsey, and F. Rosell. 2012. A hypothetico-deductive approach to assessing the social function of chemical signalling in a non-territorial solitary carnivore. PloS One 7(4):e35404. https://doi.org/10.1371/journal.pone.0035404

Clapham, M., O. T. Nevin, A. D. Ramsey, and F. Rosell. 2013. The function of strategic tree selectivity in the chemical signalling of brown bears. Animal Behaviour 85(6):1351-1357.

Clapperton, B. K., J. A. McLennan, and A. D. Woolhouse. 1999. Responses of stoats to scent lures in tracking tunnels. New Zealand Journal of Zoology 26(3):175–178.

Clevenger, A. P., and F. J. Purroy. 1996. Sign surveys for estimating trend of a remnant brown bear *Ursus arctos* population in northern Spain. Wildlife Biology 2(4):275–281.

Cohn, J. P. 2008. Citizen science: can volunteers do real research? Bioscience 58(3):192–197.

Crall, A. W., G. J. Newman, T. J. Stohlgren, K. A. Holfelder, J. Graham, and D. M. Waller. 2011. Assessing citizen science data quality: an invasive species case study. Conservation letters 4(6):433-442.

Crall, A. W., R. Jordan, K. Holfelder, G. J. Newman, J. Graham, and D. M. Waller. 2012. The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. Public Understanding of Science 22(6):745–764.

Crête, M., and S. Larivière. 2003. Estimating the costs of locomotion in snow for coyotes. Canadian Journal of Zoology 81(11):1808–1814.

Crooks, K. R., M. E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400(6744):563–566.

Crooks, K. R., M. Grigione, A. Scoville, and G. Scoville. 2008. Exploratory use of track and camera surveys of mammalian carnivores in the Peloncillo and Chiricahua mountains of Southeastern Arizona. The Southwestern Naturalist 53(4):510–517.

Croose, E., J. D. S. S. Birks, J. Martin, G. Ventress, J. MacPherson, and C. O'Reilly. 2019. Comparing the efficacy and cost-effectiveness of sampling methods for estimating population abundance and density of a recovering carnivore: the European pine marten (*Martes martes*). European Journal of Wildlife Research 65(37). https://doi.org/10.1007/s10344-019-1282-6

Crowley, S. M., C. J. Johnson, and D. Hodder. 2012. The role of demographic and environmental variables on the presence of snow tracks by river otters *Lontra canadensis*. Wildlife Biology 18:105–112.

Cunningham, T. J. 2011. Forensic Spoorology: Seeing and Understanding Human Behavior Through Observation, Classification and Interpretation of Spoor Evidence. Master of Military Art and Science, U.S. Army Command and General Staff College, Fort Leavenworth, KS.: 193.

Dagg, A. I. 1973. Gaits in mammals. Mammal Review 3(4):135–154.

Darden, S. K., L. K. Steffensen, and T. Dabelsteen. 2008. Information transfer among widely spaced individuals: latrines as a basis for communication networks in the swift fox? Animal Behaviour 75(2):425–432.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying “experts” when researching local ecological knowledge. Human Ecology 31(3):463–489.

Davison, A., J. D. S. S. Birks, R. C. Brookes, T. C. Braithwaite, and J. E. Messenger. 2002. On the origin of faeces: morphological versus molecular methods for surveying rare carnivores from their scats. Journal of Zoology 257(2):141–143.

Day, C. C., M. D. Westover, L. K. Hall, R. T. Larsen, and B. R. McMillan. 2016. Comparing direct and indirect methods to estimate detection rates and site use of a cryptic semi-aquatic carnivore. Ecological Indicators 66:230–234.

De Angelo, C., A. Paviolo, and M. S. Di Bitetti. 2010. Traditional versus multivariate methods for identifying jaguar, puma, and large canid tracks. Journal of Wildlife Management 74(5):1141–1151.

Dearborn, N. 1939. Sections aid in identifying hair. Journal of Mammalogy 20(3):346–348.

D’eon, R. G. 2001. Using snow-track surveys to determine deer winter distribution and habitat. Wildlife Society Bulletin 29(3):879–887.

D’hondt, B., L. Vansteenbrugge, K. Van Den Berge, J. Bastiaens, and M. Hoffmann. 2011. Scat analysis reveals a wide set of plant species to be potentially dispersed by foxes. Plant ecology and evolution 144:106-110.

Delibes-Mateos, M., J. Fernandez De Simon, R. Villafuerte, and P. Ferreras. 2008. Feeding responses of the red fox (*Vulpes vulpes*) to different wild rabbit (*Oryctolagus cuniculus*) densities: a regional approach. European Journal of Wildlife Research. 54:71–78.

Dell’Arte, G. L., T. Laaksonen, K. Norrdahl, and E. Korpimäki. 2007. Variation in the diet composition of a generalist predator, the red fox, in relation to season and density of main prey. Acta Oecologica 31(3):276–281.

DeMatteo, K. E., L. W. Blake, J. K. Young, and B. Davenport. 2018. How behavior of nontarget species affects perceived accuracy of scat detection dog surveys. Nature: Scientific Reports 8:e13830. https://doi.org/10.1038/s41598-018-32244-1

Depue, J. E., and M. Ben-David. 2010. River otter latrine site selection in arid habitats of Western Colorado, USA. Journal of Wildlife Management 74(8):1763–1767.

Devetak, D., and A. E. Arnett. 2015. Preference of antlion and wormlion larvae (*Neuroptera: Myrmeleontidae; Diptera: Vermileonidae*) for substrates according to substrate particle sizes. European Journal of Entomology 112(3):500–509.

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. Variability in grassland bird counts related to observer differences and species detection rates. The Auk 120(4):1168–1179.

Dihoff, R. E., G. M. Brosvic, and M. L. Epstein. 2003. The role of feedback during academic testing: the delay retention effect revisited. The Psychological Record 53(4):533–548.

Domínguez-Rodrigo, M., and A. Piqueras. 2003. The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviours. Journal of Archaeological Science, 30(11):1385–1391.

Dor, R., S. Rosenstein, and I. Scharf. 2014. Foraging behaviour of a neglected pit-building predator: the wormlion. Animal Behaviour 93:69–76. Academic Press.

Drennan, J. E., P. Beier, and N. L. Dodd. 1998. Use of track stations to index abundance of sciurids. Journal of Mammalogy 79:352–359.

Dudley, J. P., A. Y. Mensah-Ntiamoah, D. G. Kpelle, A. Y. Mensah-Ntiamoah, and D. G. Kpelle. 1992. Forest elephants in a rainforest fragment: preliminary findings from a wildlife conservation project in southern Ghana. African Journal of Ecology 30(2):116–126.

Duffie, D. R., R. A. Gitzen, N. W. Sharp, and A. J. Turner. 2019. Effectiveness and accuracy of track tubes for detecting small-mammal species occupancy in southeastern herbaceous wetlands and meadows. Southeastern Naturalist 18:130–146.

Dzięciołowski, R. 1976. Estimating Ungulate Numbers in a Forest by Track Counts. Acta Theriologica 21(15):217–222.

Edwards, G. P., N. D. de Preu, B. J. Shakeshaft, I. v. Crealy, N. D. de Preu, B. J. Shakeshaft, and I. V. Crealy. 2000. An evaluation of two methods of assessing feral cat and dingo abundance in central Australia. Wildlife Research 27(2):143–149.

Eiseman, C., N. Charney, and J. Carlson. 2010. Tracks & Sign of Insects & Other Invertebrates: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 592.

Elbroch, L. M. 2003. Mammal Tracks and Sign: A guide to North American Species. Stackpole Books, Mechanicsburg, PA. USA. 792.

Elbroch, L. M., B. Lowrey, and H. U. Wittmer. 2017*b*. The importance of fieldwork over predictive modeling in quantifying predation events of carnivores marked with GPS technology. Journal of Mammalogy 99:1–10. http://dx.doi.org/10.1093/jmammal/gyx176

Elbroch, L. M. 2006. Animal Skulls: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 727.

Elbroch, L. M., and A. Kusler. 2018. Are pumas subordinate carnivores, and does it matter? PeerJ 6:e4293. http://dx.doi.org/10.7717/peerj.4293

Elbroch, L. M., and C. McFarland. 2019. Mammal Tracks & Sign: a Guide to North American Species. Second edition. Stackpole Books, Mechanicsburg, PA.: 680.

Elbroch, L. M., and H. U. Wittmer. 2012*a*. Table scraps: inter-trophic food provisioning by pumas. Biology Letters 8(5):776–779.

Elbroch, L. M., and H. U. Wittmer. 2012*b*. Puma spatial ecology in open habitats with aggregate prey. Mammalian Biology 77:377–384.

Elbroch, L. M., and H. U. Wittmer. 2013*a*. The effects of puma prey selection and specialization on less abundant prey in Patagonia. Journal of Mammalogy 94(2):259–268.

Elbroch, L. M., and H. U. Wittmer. 2013*b*. Nuisance ecology: do scavenging condors exact foraging costs on pumas in Patagonia? PLoS One 8:e53595. http://dx.doi.org/10.1371/journal.pone.0053595

Elbroch, L. M., and K. A. Rinehart. 2011. Behavior of North American Mammals. Houghton Mifflin Harcourt, New York, N.Y.:374

Elbroch, L. M., E. M. Marks. 2001. Bird Tracks & Sign: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 464.

Elbroch, L. M., M. Kresky, and J. W. Evans. 2012. Field Guide to Animal Tracks and Scat of California. University of California Press, Berkeley, CA.: 398.

Elbroch, L. M., M. L. Allen, B. H. Lowrey, and H. U. Wittmer. 2014. The difference between killing and eating: ecological shortcomings of puma energetic models. Ecosphere 5(5):1–16. http://dx.doi.org/10.1890/ES13-00373.1

Elbroch, L. M., P. E. Lendrum, J. Newby, H. B. Quigley, and D. J. Thompson. 2015*c*. Recolonizing wolves influence the realized niche of resident cougars. Zoological Studies 54(41):1–11.

Elbroch, L. M., P. E. Lendrum, M. L. Allen, and H. U. Wittmer. 2015*b*. Nowhere to hide: pumas, black bears, and competition refuges. Behavioral Ecology 26:247–254.

Elbroch, L. M., P. E. Lendrum, P. Alexander, and H. B. Quigley. 2015*a*. Cougar den site selection in the Southern Yellowstone Ecosystem. Mammal Research 60:89–96.

Elbroch, L. M., C. O'Malley, M. Peziol, and H. B. Quigley. 2017*a*. Vertebrate diversity benefiting from carrion provided by pumas and other subordinate, apex felids. Biological Conservation 215:123–131.

Elbroch, L. M., T. H. Mwampamba, M. J. Santos, M. Zylberberg, L. Liebenberg, J. Minye, C. Mosser, and E. Reddy. 2011. The value, limitations, and challenges of employing local experts in conservation research. Conservation Biology 25:1195–1202.

Ellison, S. A., and B. J. Swanson. 2016. Individual identification of raccoons (*Procyon lotor*) using track plate foot printing. American Midland Naturalist 176(2):306–312.

Engeman, R. M., and P. Evangilista. 2007. Investigating the feasibility of a passive tracking index for monitoring wildlife in the Lower Omo Valley, Ethiopia. African Journal of Ecology 45(2):184–188.

Engeman, R. M., B. Constantin, M. Nelson, J. Woolard, and J. Bourassa. 2001. Monitoring changes in feral swine abundance and spatial distribution. Environmental Conservation 28(3):235–240.

Engeman, R. M., M. J. Pipas, K. S. Gruver, J. Bourassa, and L. Allen. 2002. Plot placement when using a passive tracking index to simultaneously monitor multiple species of animals. Wildlife Research 29:85–90.

Eppley, T. M., J. U. Ganzhorn, and G. Donati. 2016. Latrine behaviour as a multimodal communicatory signal station in wild lemurs: the case of *Hapalemur meridionalis*. Animal Behaviour 111:57–67.

Evans, J. W., C. A. Evans, J. M. Packard, G. Calkins, and L. M. Elbroch. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management 73(3):426–432.

Ewer, R. F., and C. Wemmer. 1974. The behaviour in captivity of the African civet, *Civettictus civetta*. Zeitschrift für Tierpsychologie 34(4):359–394.

Ferkin, M. H., and A. A. Pierce. 2007. Perspectives on over-marking: is it good to be on top? Journal of Ethology 25(2):107–116.

Fitzhugh, E. L., and W. P. Gorenzel. 1985. Design and analysis of mountain lion track surveys. Cal-Nevada Wildlife:78–87.

Flower, T. P., M. Gribble, and A. R. Ridley. 2014. Deception by flexible alarm mimicry in an African bird. Science 344:513–516. http://dx.doi.org/10.1126/science.1249723

Foelix, R., I. Rechenberg, B. Erb, A. Albín, and A. Aisenberg. 2017. Sand transport and burrow construction in sparassid and lycosid spiders. The Journal of Arachnology 45(3):255–264.

Ford, A. T., A. P. Clevenger, and A. Bennett. 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. Journal of Wildlife Management 73(7):1213–1222.

Foresman, K. R., and D. E. Pearson. 1998. Comparison of proposed survey procedures for detection of forest carnivores. Journal of Wildlife Management 62(4):1217–1226.

Forman, D. W. 2005. An assessment of the local impact of native predators on an established population of British water voles (Arvicola terrestris). Journal of Zoology 266:221–226.

Forrest, L. R. 1988. Field Guide to Tracking Animals in Snow. Stackpole Books, Mechanicsville, PA.: 181.

Fowler, F. J. Jr. 2013. Survey Research Methods. Sage Publications, Thousand Oaks, CA.: 184.

Freilich, J. E., and E. L. LaRue. 1998. Importance of observer experience in finding desert tortoises. Journal of Wildlife Management 62(2):590–596.

Fröhlich, M., A. Berger, S. Kramer-Schadt, I. Heckmann, and Q. Martins. 2012. Complementing GPS cluster analysis with activity data for studies of leopard (*Panthera pardus*) diet. African Journal of Wildlife Research 42(2):104–110.

Funston, P. J., L. Frank, T. Stephens, Z. Davidson, A. Loveridge, D. M. Macdonald, S. Durant, C. Packer, A. Mosser, and S. M. Ferreira. 2010. Substrate and species constraints on the use of track incidences to estimate African large carnivore abundance. Journal of Zoology 281:56–65.

Gallant, D., C. H. Berube, and L. Vasseur. 2007. Unveiling the limitations of scat surveys to monitor social species: a case study on river otters. Journal of Wildlife Management 71:258–265.

Gallant, D., L. Vasseur, and C. H. Bérubé. 2008. Evaluating bridge survey ability to detect river otter *Lontra canadensis* presence: a comparative study. Wildlife Biology 14:61–69.

Gamberg, M., and J. L. Atkinson. 1988. Prey hair and bone recovery in ermine scats. Journal of Wildlife Management 52(4):657–660.

García, K. P., J. Carlos Ortiz, M. Vidal, and J. R. Rau. 2010. Morphometrics of the tracks of Puma concolor: is it possible to differentiate the sexes using measurements from captive animals? Zoological Studies 49(4):577–582.

Gardner, C. L., J. P. Lawler, J. M. Ver Hoef, A. J. Magoun, K. and A. Kellie. 2010. Coarse-Scale Distribution Surveys and Occurrence Probability Modeling for Wolverine in Interior Alaska. Journal of Wildlife Management 74(8):1894–1903.

Glen, A. S., and C. R. Dickman. 2003. Monitoring bait removal in vertebrate pest control: a comparison using track identification and remote photography. Wildlife Research 30:29–33.

Godbois, I. A., L. M. Conner, B. D. Leopold, and R. J. Warren. 2005. Effect of diet on mass loss of bobcat scat after exposure to field conditions. Wildlife Society bulletin. 33:149–153.

Golden, H. N., J. David Henry, E. F. Becker, M. I. Goldstein, J. M. Morton, D. Frost, A. J. Poe Golden, P. Canada, N. Yukon, and A. J. Poe. 2007. Estimating wolverine *Gulo gulo* population size using quadrat sampling of tracks in snow. Wildlife Biology 13(2):52-61.

Goldyn, B., M. Hromada, A. Surmacki, and P. Tryjanowski. 2003. Habitat use and diet of the red fox *Vulpes vulpes* in an agricultural landscape in Poland. Zeitschrift für Jagdwissenschaft 49: 191:1–10.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D. Lapoint, D. A. Bogan, and J. R. Cryan. 2006. A comparison of noninvasive techniques to survey carnivore communities in Northeastern North America. Wildlife Society Bulletin 34(4):1142–1151.

Gore, A. P., S. A. Paranjpe, G. G. Rajgopalan, A. V. Kharshikar, N. V. Joshi, M. G. Watve, and M. G. Gogate. 1993. Tiger census: role of quantification. Current Science (Bangalore) 64(10):711–714.

Gosling, L. M. 1982. A Reassessment of the Function of Scent Marking in Territories. Zeitschrift für Tierpsychologie 60(2):89–118.

Gosling, L. M., and S. C. Roberts. 2001. Scent-marking by male mammals: Cheat-proof signals to competitors and mates. Advances in the Study of Behavior 30:169–217.

Gosselin, E. N., R. C. Lonsinger, and L. P. Waits. 2017. Comparing morphological and molecular diet analyses and fecal DNA sampling protocols for a terrestrial carnivore. Wildlife Society Bulletin 41(2):362–369.

Gossow, H., and G. Schurholtz. 1974. Social Aspects of Wallowing Behaviour in Red Deer Herds. Zeitschrift für Tierpsychologie 34(4):329–336.

Goszczyński, J. 1990. Scent marking by red foxes in Central Poland during the winter season. Acta Theriologica 35(1–2):7–1 6.

Granatosky, M. C., C. M. Bryce, J. Hanna, A. Fitzsimons, M. F. Laird, K. Stilson, C. E. Wall, and C. F. Ross. 2018. Inter-stride variability triggers gait transitions in mammals and birds. Proceedings of the Royal Society B: Biological Sciences 285:e20181766. http://dx.doi.org/10.1098/rspb.2018.1766

Graves, T. A., K. C. Kendall, J. A. Royle, J. B. Stetz, and A. C. Macleod. 2011. Linking landscape characteristics to local grizzly bear abundance using multiple detection methods in a hierarchical model. Animal Conservation 14(6):652–664.

Green, G. I., and D. J. Mattson. 2003. Tree rubbing by Yellowstone grizzly bears *Ursus arctos*. Wildlife Biology 9(4):1–10.

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.

Grovenburg, T. W., C. N. Jacques, R. W. Klaver, and J. A. Jenks. 2010. Bed Site Selection by Neonate Deer in Grassland Habitats on the Northern Great Plains. Journal of Wildlife Management 74(6):1250–1256.

Gruber, B., B. Reineking, J. M. Calabrese, A. Kranz, K. Poledníková, L. Poledník, R. Klenke, A. Valentin, and K. Henle. 2008. A new method for estimating visitation rates of cryptic animals via repeated surveys of indirect signs. Journal of Applied Ecology 45(2):728–735.

Gryz, J., D. Krauze, J. Goszczyski, and J. Goszczyński. 2008. The small mammals of Warsaw as inferred from tawny owl (*Strix aluco*) pellet analyses. Annales Zoologici Fennici 45(4):281–285.

Gu, J., S. K. Alibhai, Z. C. Jewell, G. Jiang, and J. Ma. 2014. Sex determination of Amur tigers (*Panthera tigris altaica*) from footprints in snow. Wildlife Society Bulletin 38(3):495–502.

Gu, W., and R. K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biological Conservation 116(2):195–203.

Guillera-Arroita, G., B. J. T. Morgan, M. S. Ridout, and M. Linkie. 2011. Species Occupancy Modeling for Detection Data Collected Along a Transect. Journal of Agricultural, Biological, and Environmental Statistics (JABES) 16(3):301–317.

Gusset, M., and N. Burgener. 2005. Estimating larger carnivore numbers from track counts and measurements. African Journal of Ecology 43(4):320–324.

Gutteridge, L. 2012. The Bushveld: A South African Field Guide, Including the Kruger Lowveld. Second edition. Southbound, 30 Degrees South, Pinetown, RSA.: 735.

Gutteridge, L. 2017. Invertebrates of Southern Africa and their Tracks and Signs. Jacana Media, Auckland Park, RSA.: 424.

Gutteridge, L. 2020. Birds of Southern Africa and their Tracks & Signs. Jacana Media, Aukland Park, RSA.: 400.

Gutteridge, L., and L. Liebenberg. 2013. Mammals of Southern Africa and their Tracks and Signs. Jacana Media, Auckland Park, RSA.: 291.

Halpin, M. A., and J. A. Bissonette. 1988. Influence of snow depth on prey availability and habitat use by red fox. Canadian Journal of Zoology 66:587–592

Hamilton, W. J. III. 1982. Baboon sleeping site preferences and relationships to primate grouping patterns. American Journal of Primatology 3:41–53.

Hansen, M. M., and L. Jacobsen. 1999. Identification of mustelid species: otter (*Lutra lutra*), American mink (*Mustela vison*) and polecat (*Mustela putorius*), by analysis of DNA from faecal samples. Journal of Zoology 247(2):177–181.

Harihar, A., and B. Pandav. 2012. Influence of connectivity, wild prey and disturbance on occupancy of tigers in the human dominated Western Terai Arc landscape. PLoS ONE 7(7):e40105. http://dx.doi.org/10.1371/journal.pone.0040105

Härkönen, S., and R. Heikkilä. 1999. Use of pellet group counts in determining density and habitat use of moose *Alces alces* in Finland. Wildlife Biology 5:233–240.

Harmsen, B. J., R. J. Foster, S. M. Gutierrez, S. Y. Marin, and C. P. Doncaster. 2010. Scrape-marking behavior of jaguars (*Panthera onca*) and pumas (*Puma concolor*). Journal of Mammalogy 91(5):1225–1234.

Harrington, L. A., A. L. Harrington, and D. W. Macdonald. 2007. Distinguishing tracks of mink (*Mustela vison*) and polecat (*M. putorius*). European Journal of Wildlife Research 54(2):367–371.

Harrington, L.A., A. L. Harrington, and D. W. Macdonald. 2008. Estimating the relative abundance of American mink (*Mustela vison*) on lowland rivers: evaluation and comparison of two techniques. European Journal of Wildlife Research 54(1):79-87.

Harrington, L. A., A. L. Harrington, J. Hughes, D. Stirling, and D. W. Macdonald. 2010. The accuracy of scat identification in distribution surveys: American mink, *Neovison vison*, in the northern highlands of Scotland. European Journal of Wildlife Research 56(3):377–384.

Harrison, R. L., D. J. Barr, and J. W. Dragoo. 2002. A Comparison of Population Survey Techniques for Swift Foxes (*Vulpes Velox*) in New Mexico. The American Midland Naturalist 148(2):320–337.

Harrow, R. L., V. J. Horncastle, and C. L. Chambers. 2018. Track plates detect the endangered New Mexico jumping mouse. Wildlife Society Bulletin 42(4):693–700.

Haynes, G. 1983. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. Paleobiology 9(2):164–172.

Hayward, G. D., D. G. Miquelle, E. N. Smirnov, and C. Nations. 2002. Monitoring Amur tiger populations: characteristics of track surveys in snow. Wildlife Society Bulletin 30:1150–1159.

Hayward, M. W., P. J. de Tores, M. J. Dillon, B. J. Fox, and P. B. Banks. 2005. Using faecal pellet counts along transects to estimate quokka (*Setonix brachyurus*) population density. Wildlife Research 32(6):503–507.

Hebblewhite, M., E. H. Merrill, and T. L. McDonald. 2005. Spatial decomposition of predation risk using resource selection functions: an example in a wolf-elk predator-prey system.

Heise-Pavlov, S. R., and R. D. Meade. 2012. Improving reliability of scat counts for abundance and distribution estimations of Lumholtz's Tree-kangaroo (*Dendrolagus lumholtzi*) in its rainforest habitats. Pacific Conservation Biology 18(3):153–163.

Helldin, J. O., and A. V. Danielsson. 2007. Changes in red fox *Vulpes vulpes* diet due to colonisation by lynx *Lynx lynx*. Wildlife Biology 13:475–480.

Hemming, J. E. 1969. Cemental deposition, tooth succession, and horn development as criteria of age in dall sheep. Journal of Wildlife Management 33(3):552–558.

Henry, J. D. 1977. The use of urine marking in the scavenging behavior of the red fox (*Vulpes vulpes*). Behaviour 61(1-2):82–106.

Herzog, C. J., R. W. Kays, J. C. Ray, M. E. Gompper, W. J. Zielinski, R. Higgins, and M. Tymeson. 2007. Using patterns in track-plate footprints to identify individual fishers. Journal of Wildlife Management 71(3):955–963.

Hildebrand, M. 1959. Motions of the running cheetah and horse. Journal of Mammalogy 40(4):481–495.

Hildebrand, M. 1961. Further studies on locomotion of the cheetah. Journal of Mammalogy 42:84–91.

Hildebrand, M. 1962. Walking, running, and jumping. American Zoologist 2:151–155.

Hildebrand, M. 1968. Symmetrical gaits of dogs in relation to body build. Journal of Morphology 124(3):353–359.

Hildebrand, M. 1977. Analysis of asymmetrical gaits. Journal of Mammalogy 58(2):131–156.

Hildebrand, M. 1980. The adaptive significance of tetrapod gait selection. American Zoologist 20:255–267.

Hines, J. E., J. D. Nichols, J. A. Royle, D. I. MacKenzie, A. M. Gopalaswamy, and N. Samba Kumar. 2010. Tigers on trails: occupancy modeling for cluster sampling. Ecological Applications 20(5):1456–1466.

Hitchcock, E. 1844. Report on ichnolithology, or fossil footmarks, with a description of several new species, and the coprolites of birds, from the valley of Connecticut River, and of a supposed footmark from the valley of Hudson River. American Journal of Science 47(2):292–322.

Hooper, J., and R. V. Rea. 2009. The use of an orthotic casting foam as a track-plate medium for wildlife research and monitoring. Wildlife Biology 15:106–112.

Hornocker, M. G. 1969. Winter Territoriality in Mountain Lions. Journal of Wildlife Management 33(3):457–464.

Houser, A. M., M. J. Somers, and L. K. Boast. 2009. Spoor density as a measure of true density of a known population of free-ranging wild cheetah in Botswana. Journal of Zoology 278(2):108–115.

Hüner, E. A., and J. F. B. Peter. 2012. In situ caching of a large mammal carcass by a fisher, *Martes pennanti*. The Canadian Field-Naturalist 126(3):234–237.

Hunter, J., A. Alabri, and C. Ingen. 2012. Assessing the quality and trustworthiness of citizen science data. Concurrency and Computation: Practice and Experience 25:454-466.

Janečka, J.E., R. Jackson, Z. Yuquang, L. Diqiang, B. Munkhtsog, V. Buckley-Beason, and W. J. Murphy. 2008. Population monitoring of snow leopards using noninvasive collection of scat samples: a pilot study. Animal Conservation 11(5):401–411.

Jankowiak, L., M. Antczak, and P. Tryjanowski. 2008. Habitat use, food and the importance of poultry in the diet of the red fox *Vulpes vulpes* in extensive farmland in Poland. World Applied Sciences Journal 4(6):886–890.

Jeffress, M. R., C. P. Paukert, B. K. Sandercock, and P. S. Gipson. 2011. Factors affecting detectability of river otters during sign surveys. Journal of Wildlife Management 75:144–150.

Jewell, Z. C., S. K. Alibhai, F. Weise, S. Munro, M. van Vuuren, and R. van Vuuren. 2016. Spotting cheetahs: identifying individuals by their footprints. Journal of Visualized Experiments (JOVE) 111:e10.3791/54034. http://dx.doi.org/10.3791/54034

Jewell, Z., and S. K. Alibhai. 2012. Identifying endangered species from footprints. The International Society for Optics and Photonics (SPIE). http://dx.doi.org/10.1117/2.1201212.004636

Jewell, Z. C., S. K. Alibhai, and P.R. Law. 2001. Censusing and monitoring black rhino (*Diceros bicornis*) using an objective spoor (footprint) identification technique. Journal of Zoology 254:1-16.

Jhala, Y., Q. Qureshi, and R. Gopal. 2010. Can the abundance of tigers be assessed from their signs? Journal of Applied Ecology 48:14–24.

Johnson, G. E. 1931. Hibernation in mammals. The Quarterly Review of Biology 6(4):439–461.

Johnson, M. K., and D. R. Aldred. 1982. Mammalian prey digestibility by bobcats. The Journal of Wildlife Management 46(2):530.

Johnson, M. K., R. C. Belden, and D. R. Aldred. 1984. Differentiating mountain lion and bobcat scats. Journal of Wildlife Management 48(1):239–244.

Johnson, R. P. 1973. Scent marking in mammals. Animal Behaviour 21(3):521–535.

Johnston, A., D. Fink, W. M. Hochachka, and S. Kelling. 2018. Estimates of observer expertise improve species distributions from citizen science data. Methods in Ecology and Evolution 9:88-97.

Jones, C., H. Moller, and W. Hamilton. 2004. A review of potential techniques for identifying individual stoats (*Mustela erminea*) visiting control or monitoring stations. New Zealand Journal of Zoology 31(3):193-203.

Jordan, N. R., M. B. Manser, F. Mwanguhya, S. Kyabulima, P. Rüedi, and M. A. Cant. 2011. Scent marking in wild banded mongooses: 1. sex-specific scents and overmarking. Animal Behaviour 81:31–42.

Jordan, N. R., P. J. Apps, K. A. Golabek, and J. W. McNutt. 2014. Top marks from top dogs: tandem marking and pair bond advertisement in African wild dogs. Animal Behaviour 88:211–217.

Karamanlidis, A., D. Youlatos, S. Sgardelis, and Z. Scouras. 2007. Using sign at power poles to document presence of bears in Greece. Ursus 18:54–61.

Karanth, K. U. 1987. Tigers in India: a critical review of field censuses. Pages 118–132 *in* R. L. Tilson and U. S. Seal, editors. Tigers of the World: the Biology, Biopolitics, Management, and Conservation of an Endangered Species, Noyes Publications, Park Ridge, N.J.

Karanth, K. U., A. M. Gopalaswamy, N. S. Kumar, S. Vaidyanathan, J. D. Nichols, and D. I. MacKenzie. 2011. Monitoring carnivore populations at the landscape scale: occupancy modelling of tigers from sign surveys. Journal of Applied Ecology 48(4):1048–1056.

Karanth, K. U., J. D. Nichols, J. Seidenstricker, E. Dinerstein, J. L. D. Smith, C. McDougal, A. J. T. Johnsingh, R. S. Chundawat, and V. Thapar. 2003. Science deficiency in conservation practice: the monitoring of tiger populations in India. Animal Conservation 6(2):141–146.

Karanth, K. U., J. D. Nichols, N. Kumar, W. A. Link, and J. E. Hines. 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences (PNAS) 101(14):4854–4858.

Keeping, D. 2014. Rapid assessment of wildlife abundance: estimating animal density with track counts using body mass–day range scaling rules. Animal Conservation 17(5):486–497.

Keeping, D., and R. Pelletier. 2014. Animal density and track counts: Understanding the nature of observations based on animal movements. PLoS ONE 9(5): e96598. http://dx.doi.org/10.1371/journal.pone.0096598

Keeping, D., J. H. Burger, A. O. Keitsile, M. C. Gielen, E. Mudongo, M. Wallgren, C. Skarpe, and A. L. Foote. 2018. Can trackers count free-ranging wildlife as effectively and efficiently as conventional aerial survey and distance sampling? Implications for citizen science in the Kalahari, Botswana. Biological Conservation 223:156–169. Elsevier Ltd.

Keeping, D., N. Kashe, H. Langwane, P. Sebati, N. Molese, M.-C. C. Gielen, A. Keitsile-Barungwi, Q. Xhukwe, and !Nate (Shortie) Brahman. 2019. Botswana's wildlife losing ground as Kalahari Wildlife Management Areas (WMAs) are dezoned for livestock expansion. bioRxiv 576496. http://dx.doi.org/10.1101/576496

Kelly, B. T., and E. O. Garton. 1997. Effects of prey size, meal size, meal composition, and daily frequency of feeding on the recovery of rodent remains from carnivore scats. Canadian Journal of Zoology 75(11):1811–1817.

Kendall, K. C., L. H. Metzgar, D. A. Patterson, and B. M. Steele. 1992. Power of sign surveys to monitor population trends. Ecological Applications 2(4): 422-430.

Kent, V. T., and R. A. Hill. 2013. The importance of farmland for the conservation of the brown hyaena *Parahyaena brunnea*. Oryx 47(3):431–440.

Kerley, L. L., and G. P. Salkina. 2007. Using scent-matching dogs to identify individual Amur tigers from scats. Journal of Wildlife Management 71(4):1349–1356.

Khan, I., and S. P. Goyal. 1993. Fecal pellet measurements of manipur brow-antlered deer with respect to sex and age classes. Zoological Biology 12(6):561–565.

King, C. M., and R. L. Edgar. 1977. Techniques for trapping and tracking stoats (*Mustela erminea*); a review, and a new system. New Zealand Journal of Zoology 4(2):193–212.

King, C. M., R. M. McDonald, R. D. Martin, G. W. Tempero, and S. J. Holmes. 2007. Long-term automated monitoring of the distribution of small carnivores. Wildlife Research 34(2):140–148.

Kiseleva, N. v., and P. A. Sorokin. 2013. Study of the distribution of mustelids over the Southern Urals using noninvasive methods. Contemporary Problems of Ecology 6(3):300–305.

Kleiman, D. G. 1974. Scent marking in the binturong, *Arctictis binturong*. Journal of Mammalogy 55:224.

Kobryńczuk, F., M. Krasińska, and T. Szara. 2008*a*. Sexual Dimorphism in Skulls of the Lowland European Bison, *Bison Bonasus Bonasus*. Annales Zoologici Fennici. 45(4):335–340.

Kobryńczuk, F., M. Krasińska, and T. Szara. 2008*b*. Polarization of Skull Shapes in Adult Lowland European Bison, *Bison Bonasus Bonasus*. Annales Zoologici Fennici. 45(4):341–346.

Kohn, M. M. H., and R. K. Wayne. 1997. Facts from feces revisited. Trends in Ecology & Evolution. 12(6):223–227.

Kojola, I., P. Helle, S. Heikkinen, H. Lindén, A. Paasivaara, and M. Wikman. 2014. Tracks in snow and population size estimation: the wolf *Canis lupus* in Finland. Wildlife Biology 20(5):279–284.

Kolbe, J. A., J. R. Squires, D. H. Pletscher, and L. F. Ruggiero. 2007. The effect of snowmobile trails on coyote movements within lynx home ranges. Journal of Wildlife Management 71(5):1409–1418.

Krofel, M., L. Hočevar, and M. L. Allen. 2017. Does human infrastructure shape scent marking in a solitary felid? Mammalian Biology 87:36–39.

Kurek, P. 2015. Consumption of fleshy fruit: Are central European carnivores really less frugivorous than southern European carnivores? Mammalian Biology-Zeitschrift für Säugetierkunde 80(6):527–534.

Kusler, A., L. M. Elbroch, H. Quigley, and M. Grigione. 2017. Bed site selection by a subordinate predator: An example with the cougar (*Puma concolor*) in the Greater Yellowstone Ecosystem. PeerJ 5:e4010; http://dx.doi.org/10.7717/peerj.4010

Lang, B. K., J. E. Gates, and A. E. Gates. 1985. Selection of Sites for Winter Night Beds by White-tailed Deer in a Hemlock-Northern Hardwood Forest. The American Midland Naturalist 113(2):245–254.

Lanszki, J., and M. Heltai. 2011. Feeding habits of sympatric mustelids in an agricultural area of Hungary. Acta Zoologica Academiae Scientiarum Hungaricae 57(3):291–304.

Lanszki, J., M. Heltai, and L. Szabó. 2006. Feeding habits and trophic niche overlap between sympatric golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*) in the Pannonian ecoregion (Hungary). Canadian Journal of Zoology - Revue Canadienne de Zoologie 84(11):1647-1656.

Larivière, S. 1999. Reasons Why Predators Cannot Be Inferred from Nest Remains. The Condor: Bulletin of the Cooper Ornithological Club 101(3):718–721.

Law, P. R., Z. C. Jewell, and S. K. Alibhai. 2013. Using shape and size to quantify variation in footprints for individual identification: case study with white rhinoceros (*Ceratotherium simum*). Wildlife Society Bulletin 37(2):433–438. Wiley-Blackwell.

Leach, D. H., K. Ormrod, and H. M. Clayton. 1984. Standardised terminology for the description and analysis of equine locomotion. Equine Veterinary Journal 16(6):522–528.

Leberg, P. L., M. R. Carloss, L. J. Dugas, K. L. Pilgrim, L. S. Mills, M. C. Green, and D. Scognamillo. 2004. Recent record of a cougar (*Puma concolor*) in Louisiana, with notes on diet, based on analysis of fecal materials. Southeastern Naturalist 3(4):653–658.

Leoniak, G., S. Barnum, J. L. Atwood, K. A. Rinehart, and L. M. Elbroch. 2012. Testing GIS-generated least-cost path predictions for *martes pennanti* (Fisher) and its application for identifying mammalian road-crossings in northern New Hampshire. Northeastern Naturalist 19(2):147–156.

Lewison, R., E. L. Fitzhugh, and S. P. Galentine. 2001. Validation of a rigorous track classification technique: identifying individual mountain lions by their tracks. Biological Conservation 99(3):313–321.

Li, B. v., S. K. Alibhai, Z. C. Jewell, D. Li, and H. Zhang. 2018. Using footprints to identify and sex giant pandas. Biological Conservation 218:83–90.

Liebenberg, L. 1990. The Art of Tracking: The Origin of Science. David Philip Publishers, Cape, RSA.: 187.

Liebenberg, L. 2006. Persistence hunting by modern hunter-gatherers. Current Anthropology 47(6):1017–1026.

Liebenberg, L. 2008. The relevance of persistence hunting to human evolution. Journal of Human Evolution 55(6):1156–1159.

Liebenberg, L. 2013. The Origin of Science. CyberTracker Books. www.cybertracker.org/science/books, Cape Town, RSA.: 265.

Liebenberg, L., A. Louw, and L. M. Elbroch. 2010. Practical Tracking: A Guide to Following Footprints and Finding Animals. Stackpole Books, Mechanicsburg, PA., USA.: 352.

Liebenberg, L., J. Steventon, N. Brahman, K. Benadie, J. Minye, H. K. (Karoha) Langwane, and Q. (Uase) Xhukwe. 2017. Smartphone icon user interface design for non-literate trackers and its implications for an inclusive citizen science. Biological Conservation 208:155–162. http://dx.doi.org/10.1016/j.biocon.2016.04.033

Liebenberg, L., J. Steventon, K. Benadie, and J. Minye. 1999. Rhino Tracking with the CyberTracker Field Computer. Pachyderm 27:59–61.

Liebenberg, L. 1990. A Field Guide to the Animal Tracks of Southern Africa. David Philip Publishers, Cape Town, RSA.: 306.

Lieberman, D. E., D. M. Bramble, D. A. Raichlen, and J. J. Shea. 2007. The evolution of endurance running and the tyranny of ethnography: a reply to Pickering and Bunn (2007). Journal of Human Evolution 53(4):439-442.

Linkie, M., G. Chapron, D. J. Martyr, J. Holden, and N. Leader-Williams. 2006. Assessing the viability of tiger subpopulations in a fragmented landscape. The Journal of Applied Ecology 43(3):576.

Linnell, J. D. C., E. B. Nilsen, and R. Andersen. 2004. Selection of bed-sites by roe deer *Capreolus capreolus* fawns in an agricultural landscape. Acta Theriologica 49(1):103–111.

Linnell, J. D. C., P. Nijhuis, I. Teurlings, and R. Andersen. 1999. Selection of bed-sites by roe deer *Capreolus capreolus* fawns in a boreal forest landscape. Wildlife Biology 5: 225-231.

Linnell, J. D., P. Fiske, I. Herfindal, J. Odden, H. Brøseth, and R. Andersen. 2007. An evaluation of structured snow-track surveys to monitor Eurasian lynx *Lynx lynx* populations. Wildlife Biology 13: 456-466.

Litvaitis, J. A., J. A. Sherburne, and J. A. Bissonette. n.d. A comparison of methods used to examine snowshoe hare habitat use. Journal of Wildlife Management 49(3):693-695.

Livingston, T. R., P. S. Gipson, W. B. Ballard, D. M. Sanchez, and P. R. Krausman. 2005. Scat removal: a source of bias in feces-related studies. Wildlife Society Bulletin 33:172–178.

Lokare, N., Q. Ge, W. Snyder, Z. Jewell, S. Allibhai, and E. Lobaton. 2014. Manifold Learning Approach to Curve Identification with Applications to Footprint Segmentation. IEEE Symposium on Computational Intelligence for Multimedia, Signal and Vision Processing (CIMSIVP): 1-8.

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007*b*. Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management 71(6):2018–2025.

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinski, and J. S. Buzas. 2007*a*. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Management 71(6):2007–2017.

Long, R. A., T. M. Donovan, P. MacKay, W. J. Zielinski, and J. S. Buzas. 2011. Predicting carnivore occurrence with noninvasive surveys and occupancy modeling. Landscape Ecology 26(3):327–340.

Lövei, G. L., and K. D. Sunderland. 1996. Ecology and Behavior of Ground Beetles (*Coleoptera: Carabidae*). Annual Review of Entomology 41:231–256.

Loveridge, A. J., J. E. Hunt, F. Murindagomo, and D. W. Macdonald. 2006. Influence of drought on predation of elephant (*Loxodonta africana*) calves by lions (*Panthera leo*) in an African wooded savannah. Journal of Zoology 270(3):523–530.

Lozano, J. 2010. Habitat use by European wildcats (*Felis silvestris*) in central Spain: what is the relative importance of forest variables? Animal Biodiversity and Conservation 33(2):143-150.

Lozano, J., E. Virgós, A. Malo, D. L. Huertas, and J. G. Casanovas. 2003. Importance of scrub–pastureland mosaics for wild-living cats occurrence in a Mediterranean area: implications for the conservation of the wildcat (*Felis silvestris*). Biodiversity & Conservation 12(5):921–935.

Lurz, P., and A. B. South. 1998. Cached fungi in non-native conifer forests and their importance for red squirrels (*Sciurus vulgaris L.*). Journal of Zoology 246(4): 468-471.

Lyra-Jorge, M. C., G. Ciocheti, V. R. Pivello, and S. T. Meirelles. 2008. Comparing methods for sampling large-and medium-sized mammals: camera traps and track plots. European Journal of Wildlife Research 54(4):739–744.

Macdonald, D. W. 1979. Some Observations and Field Experiments on the Urine Marking Behaviour of the Red Fox, *Vulpes vulpes*. L. Zeitschrift für Tierpsychologie 51:1–22.

Macdonald, D. W. 1980. Patterns of scent marking with urine and faeces amongst carnivore communities. Symposia of the Zoological Society of London 45:107–139.

Macdonald, S. M., and C. F. Mason. 1987. Seasonal Marking in an Otter Population. Acta Theriologica 32(27):449–462.

MacKenzie, D. I. 2005. What are the issues with presence-absence data for wildlife managers? Journal of Wildlife Management 69(3):849–860.

Magoun, A. J., J. C. Ray, D. S. Johnson, P. Valkenburg, F. N. Dawson, and J. Bowman. 2007. Modeling wolverine occurrence using aerial surveys of tracks in snow. Journal of Wildlife Management 71(7):2221–2229.

Maletzke, B. T., G. M. Koehler, R. B. Wielgus, K. B. Aubry, and M. A. Evans. 2008. Habitat conditions associated with lynx hunting behavior during winter in northern Washington. Journal of Wildlife Management 72(7):1473–1478.

Malo, A. F., J. Lozano, D. L. Huertas, and E. Virgós. 2004. A change of diet from rodents to rabbits (*Oryctolagus cuniculus*). Is the wildcat (*Felis silvestris*) a specialist predator? Journal of Zoology 263(4):401–407.

Marchal, A. F. J. 2017. Monitoring lions (*Panthera leo*) using digital 3D models of their tracks. Doctoral Dissertation, Zoology and Agricultural Sciences & Bio-engineering, University of Pretoria, Pretoria, RSA.: 151.

Marchal, A. F. J., P. Lejeune, and P. J. N. de Bruyn. 2017. Identification of the anteroposterior and mediolateral position of lion paws and tracks using 3D geometric morphometrics. South African Journal of Wildlife Research 47(2):106–113.

Marchal, A. F. J., P. Lejeune, and P. J. N. de Bruyn. 2016. Virtual plaster cast: digital 3D modelling of lion paws and tracks using close-range photogrammetry. Journal of Zoology 300(2):111–119.

Marchetti, L., M. Belvedere, S. Voigt, H. Klein, D. Castanera, I. Díaz-Martínez, D. Marty, L. Xing, S. Feola, R. N. Melchor, and J. O. Farlow. 2019. Defining the morphological quality of fossil footprints. Problems and principles of preservation in tetrapod ichnology with examples from the Palaeozoic to the present. Earth-Science Reviews 193:109-145.

Marler, P. 1961. The logical analysis of animal communication. Journal of Theoretical Biology 1(3):295–317.

Marneweck, C., A. Jürgens, and A. M. Shrader. 2018. The role of middens in white rhino olfactory communication. Animal Behaviour 140:7–18.

Martins, E. P., T. J. Ord, j. Slaven, J. L. Wright, and E. A. Housworth. 2006. Individual, Sexual, Seasonal, and Temporal Variation in the Amount of Sagebrush Lizard Scent Marks. Journal of Chemical Ecology 32. https://doi.org/10.1007/s10886-006-9029-8

Marzluff, J. M., B. Heinrich, and C. S. Marzluff. 1996. Raven roosts are mobile information centres. Animal Behaviour 51:89–103.

Mason, C. F., and S. M. Macdonald. 1987. The use of spraints for surveying otter *Lutra lutra* populations: an evaluation. Biological Conservation 41(3):167–177.

Mason, D. R. 1984. Dentition and age determination of the Warthog *Phacochoerus aethiopicus* in Zululand, South Africa. Koedoe-African Protected Area Conservation and Science 27:79.

Massei, G., P. Bacon, and P. V. Genov. 1998. Fallow Deer and Wild Boar Pellet Group Disappearance in a Mediterranean Area. Journal of Wildlife Management 62(3):1086–1094.

Matsuda, I., A. Tuuga, and S. Higashi. 2010. Effects of water level on sleeping-site selection and inter-group association in proboscis monkeys: why do they sleep alone inland on flooded days? Ecological Research 25(2):475–482.

Mcbride, R. T, R. T. Mcbride, R. M. McBride, and C. E. McBride. 2008. Counting pumas by categorizing physical evidence. Southeastern Naturalist 7(3):381–400.

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2017. Classifying carnivore tracks using dimensions that control for snow conditions. Wildlife Society Bulletin 41(2):278–285.

McCord, C. M. 1974. Selection of winter habitat by bobcats (*Lynx rufus*) on the Quabbin Reservation, Massachusetts. Journal of Mammalogy 55(2): 428-437.

McCullough, D. R. 1965. Sex characteristics of black-tailed deer hooves. Journal of Wildlife Management 29:210–212.

McHenry, E., C. O'Reilly, E. Sheerin, K. Kortland, and X. Lambin. 2016. Strong inference from transect sign surveys: combining spatial autocorrelation and misclassification occupancy models to quantify the detectability of a recovering carnivore. Wildlife Biology 22(5):209–216.

McKelvey, K. S., J. von Kienast, K. B. Aubry, G. M. Koehler, B. T. Maletzke, J. R. Squires, E. L. Lindquist, S. Loch, and M. K. Schwartz. 2006. DNA analysis of hair and scat collected along snow tracks to document the presence of Canada lynx. Wildlife Society Bulletin 34(2):451–455.

McKelvey, K. S., K. B. Aubry, and M. K. Schwartz. 2008. Using anecdotal occurrence data for rare or elusive species: the illusion of reality and a call for evidentiary standards. Bioscience 58(6):549–555.

McLellan, S. R., J. H. Vashon, E. L. Johnson, S. M. Crowley, and A. D. Vashon. 2018. Fisher predation on Canada lynx in the Northeastern United States. The Journal of Wildlife Management 82(8):1775–1783.

Melville, H. I. A. S. A. S., and J. D. P. Bothma. 2006. Using spoor counts to analyse the effect of small stock farming in Namibia on caracal density in the neighbouring Kgalagadi Transfrontier Park. Journal of Arid Environments 64(3):436–447.

Melville, H. I. A. S., J. D. P. Bothma, and M. G. L. Mills. 2004. Prey selection by caracal in the Kgalagadi Transfrontier Park. South African Journal of Wildlife Research 34:67–75.

Messier, F. F., and C. Barrette. 1985. The efficiency of yarding behaviour by white-tailed deer as an antipredator strategy. Canadian Journal of Zoology 63(4):785–789.

Midgley, J. M., I. J. Collett, and M. H. Villet. 214AD. The distribution, habitat, diet and forensic significance of the scarab *Frankenbergerius forcipatus* (Harold, 1881) (Coleoptera: Scarabaeidae). African Invertebrates 53(2):745–749.

Midlane, N., M. J. O'Riain, G. A. Balme, and L. T. B. Hunter. 2015. To track or to call: comparing methods for estimating population abundance of African lions *Panthera leo* in Kafue National Park. Biodiversity and Conservation 24(6): 1311-1327.

Midlane, N., M. J. O'Riain, G. A. Balme, H. S. Robinson, and L. T. B. Hunter. 2014. On tracks: a spoor-based occupancy survey of lion *Panthera leo* distribution in Kafue National Park, Zambia. Biological Conservation 172:101–108. https://doi.org/10.1016/j.biocon.2014.02.006

Miller, K. E., K. Laszlo, and J. M. Dietz. 2003. The role of scent marking in the social communication of wild golden lion tamarins, *Leontopithecus rosalia*. Animal behaviour. 65(4):795–803.

Mills, M. G. L. 1984. The comparative behavioural ecology of the brown hyaena *Hyaena brunnea* and the spotted hyaena *Crocuta crocuta* in the Southern Kalahari. Koedoe : African Protected Area Conservation and Science. 27(2):237.

Millspaugh, J. J., K. J. Raedeke, G. C. Brundige, and C. C. Willmott. 1998. Summer bed sites of elk (*Cervus elaphus*) in the Black Hills, South Dakota: considerations for thermal cover Management. The American Midland Naturalist. 139:133–140.

Miotto, R. A., G. Ciocheti, F. P. Rodrigues, P. M. G. Jr, and G. Jr. 2007. Identification of pumas (*Puma concolor* (Linnaeus, 1771)) through faeces: a comparison between morphological and molecular methods. Brazilian Journal of Biology - Revista Brasileira de Biologia. 67(4):963–965.

Molteno, A. J., A Sliwa, and P. R. K. Richardson. 1998. The role of scent marking in a free-ranging, female black-footed cat (*Felis nigripes*). Journal of Zoology 245:35-41.

Monclús, R., M. Arroyo, A. Valencia, and F. J. de Miguel. 2009. Red foxes (*Vulpes vulpes*) use rabbit (*Oryctolagus cuniculus*) scent marks as territorial marking sites. Journal of Ethology 27:153–156.

Monterroso, P., D. Castro, T. L. Silva, P. Ferreras, R. Godinho, and P. C. Alves. 2013. Factors affecting the (in)accuracy of mammalian mesocarnivore scat identification in South-western Europe. Journal of Zoology 289(4):243–250.

Mooty, J. J., P. D. Karns, and D. M. Heisey. 1984. The relationship between white-tailed deer track counts and pellet-group surveys. Journal of Wildlife Management 48:275–279.

Morden, C. J. C., R. B. Weladji, E. Ropstad, E. Dahl, and Ø. Holand. 2011. Use of faecal pellet size to differentiate age classes in female Svalbard reindeer *Rangifer tarandus platyrhynchus*. Wildlife Biology 17(4):441–448.

Moreira, D. O., S. K. Alibhai, Z. C. Jewell, C. J. da Cunha, J. B. Seibert, and A. Gatti. 2018. Determining the numbers of a landscape architect species (*Tapirus terrestris*), using footprints. PeerJ 6(3):e4591. https://doi.org/10.7717/peerj.4591

Mullins, J., M. J. Statham, T. Roche, P. D. Turner, and C. O'Reilly. 2010. Remotely plucked hair genotyping: a reliable and non-invasive method for censusing pine marten (*Martes martes*, L. 1758) populations. European Journal of Wildlife Research 56(3):443–453.

Murdoch, J. D., and S. Buyandelger. 2010. An account of badger diet in an arid steppe region of Mongolia. Journal of Arid Environments 74(10):1348–1350.

Murmann, D. C., P. C. Brumit, B. A. Schrader, and D. R. Senn. 2006. A comparison of animal jaws and bite mark patterns. Journal of Forensic Sciences 51(4):846–860.

Murray, D. L., and S. Boutin. 1991. The influence of snow on lynx and coyote movements: does morphology affect behavior? Oecologia 88(4):463–469.

Muybridge, E. 1957. Animals in Motion. Dover Publications, Inc., Mineola, N.Y., USA.: 416.

Mysterud, A., and E. Østbye. 1996. Bed-site selection by European roe deer (*Capreolus capreolus*) in southern Norway during summer. Canadian Journal of Zoology 73:924-932.

Mysterud, A., and E. Østbye. 2006. Comparing simple methods for ageing roe deer *Capreolus capreolus*: are any of them useful for management? Wildlife Biology 12:101–107.

Neff, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: a review. Journal of Wildlife Management 32(3):597–614.

Neter, J., M. H. Kutner, and C. Nachtsheim. 1996. Applied Linear Statistical Models. Volume 4. Irwin Publishers, Chicago, Il., USA:1408.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115(3):499–507.

Nie, Y., R. R. Swaisgood, Z. Zhang, Y. Hu, Y. Ma, and F. Wei. 2012. Giant panda scent-marking strategies in the wild: role of season, sex and marking surface. Animal Behaviour 84:39–44.

Nieminen, M. 1990. Hoof and foot loads for reindeer (*Rangifer tarandus*). Rangifer 10(3):249–254.

Norris, D., C. A. Peres, F. Michalski, and K. Hinchsliffe. 2008. Terrestrial mammal responses to edges in Amazonian forest patches: a study based on track stations. Mammalia 72:15–23.

O'Mahony, D., C. O'Reilly, and P. Turner. 2012. Pine marten (*Martes martes*) distribution and abundance in Ireland: A cross-jurisdictional analysis using non-invasive genetic survey techniques. Mammalian Biology 77(5):351–357.

O'Malley, C., L. M. Elbroch, P. E. Lendrum, and H. B. Quigley. 2018.. Motion-triggered video cameras reveal spatial and temporal patterns of red fox foraging on carrion provided by mountain lions. PeerJ 6:e5324. https://doi.org/10.7717/peerj.5324

Owen-Smith, N., and J. Chafota. 2012. Selective feeding by a megaherbivore, the African elephant (*Loxodonta africana*). Journal of Mammalogy 93(3):698-705.

Padial, J. M., E. Âvila, and J. M. Sánchez. 2002. Feeding habits and overlap among red fox (*Vulpes vulpes*) and stone marten (*Martes foina*) in two Mediterranean mountain habitats. Mammalian Biology 67(3):137–146.

Palma, A. R. T., and R. Gurgel-Gonçalves. 2007. Morphometric identification of small mammal footprints from ink tracking tunnels in the Brazilian Cerrado. Revista Brasileira de Zoologia. 24(2):333–343.

Panwar, H. S. 1979. A note on tiger census technique based on pugmark tracings. Tigerpaper FAO, Regional Office for Asia and the Far East 6(2-3):16-18.

Panzacchi, M., J. D. C. C. Linnell, G. Serrao, S. Eie, M. Odden, J. Odden, and R. Andersen. 2008. Evaluation of the importance of roe deer fawns in the spring-summer diet of red foxes in southeastern Norway. Ecological Research 23(5):889–896.

Paquet, P. C. 1991. Winter spatial relationships of wolves and coyotes in Riding Mountain National Park, Manitoba. Journal of mammalogy 72(2):397–401.

Paterson, W. D., and G. Skipper. 2008. The diet of pine martens (*Martes martes*) with reference to squirrel predation in Loch Lomond and The Trossachs National Park, Scotland. The Glasgow Naturalist 25(1):75–82.

Patnaik, B. K., L. A. K. Singh, S. K. Kar, and C. S. Kar. 2008. Let's count tigers: census of tiger and leopard *in* Wildlife Census in Orissa. Wildlife Headquarters, Forest Department, Govt. of Orissa, Bhubaneswar: 132.

Patterson, B. R., N. W. S. Quinn, E. F. Becker, and D. B. Meier. 2004. Estimating wolf densities in forested areas using network sampling of tracks in snow. Wildlife Society Bulletin 32(3):938–947.

Peters, R. P., and L. D. Mech. 1975. Scent-marking in wolves: radio-tracking of wolf packs has provided definite evidence that olfactory sign is used for territory maintenance and may serve for other forms of communication within the pack as well. American Scientist 63(6):628–637.

Pickering, T. R., M. Domínguez-Rodrigo, C. P. Egeland, and C. K. Brain. 2004. Beyond leopards: tooth marks and the contribution of multiple carnivore taxa to the accumulation of the Swartkrans Member 3 fossil assemblage. Journal of Human Evolution 46(5):595–604.

Picton, H. D., and K. C. Kendall. 1994. Chromatographic (TLC) differentiation of grizzly bear and black bear scats. International Conference on Bear Research and Management 9(1):497–501.

Pimm, S. L., S. K. Alibhai, R. Bergl, A. Dehgan, C. Giri, Z. C. Jewell, L. Joppa, R. Kays, and S. Loarie. 2015. Emerging technologies to conserve biodiversity. Trends in Ecology & Evolution 30(11):685–696. Elsevier Ltd.

Piñeiro, A., and I. Barja. 2012. The plant physical features selected by wildcats as signal posts: an economic approach to fecal marking. Die Naturwissenschaften 99(10):801–809.

Pirie, T. J., R. L. Thomas, and M. D. E. Fellowes. 2016. Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology 22:13–21.

Posłuszny, M., M. Pilot, J. Goszczyński, and B. Gralak. 2007. Diet of sympatric pine marten (*Martes martes*) and stone marten (*Martes foina*) identified by genotyping of DNA from faeces. Annales Zoologici Fennici 44(4):269–284.

Prigioni, C., A. Balestrieri, L. Remonti, and L. Cavada. 2008. Differential use of food and habitat by sympatric carnivores in the eastern Italian Alps. Italian Journal of Zoology 75(2):173–184.

Prugh, L. R., and C. E. Ritland. 2005. Molecular testing of observer identification of carnivore feces in the field. Wildlife Society Bulletin 33:189–194.

Pulliainen, E. 1980. The status, structure and behaviour of populations of the wolf (*Canis l. lupus L.*) along the Fenno-Soviet border. Annales Zoologici Fennici 17(2):107–112.

Pulliainen, E. 1981. A transect survey of small land carnivore and red fox populations on a subarctic fell in Finnish Forest Lapland over 13 winters. Annales Zoologici Fennici 18(4):270–278.

Purcell, K. L., A. K. Mazzoni, S. R. Mori, and B. B. Boroski. 2009. Resting structures and resting habitat of fishers in the southern Sierra Nevada, California. Forest Ecology and Management 258(12):2696–2706.

Purchase, D. 2007. Using spoor to determine the age and weight of subadult black rhinoceroses (*Diceros bicornis L.*). South African Journal of Wildlife Research 37:96–100.

Rabinowitz, A. R., and S. R. Walker. 1991. The carnivore community in a dry tropical forest mosaic in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Journal of Tropical Ecology 7:37–47.

Rachlow, J. L., J. G. Kie, and J. Berger. 1999. Territoriality and spatial patterns of white rhinoceros in Matobo National Park, Zimbabwe. African Journal of Ecology 37(3):295–304.

Ralls, K. 1971. Mammalian scent marking. Science 171(3970):443–449.

Reed, J. E., B. B. Warren, S. G. Philip, B. T. Kelly, P. R. Krausman, M. C. Wallace, D. B. Wester, W. B. Ballard, and P. S. Gipson. 2006. Diets of free-ranging mexican gray wolves in Arizona and New Mexico. Wildlife Society Bulletin 34(4):1127–1133.

Reed, J. E., R. J. Baker, W. B. Ballard, and B. T. Kelly. 2004. Differentiating Mexican gray wolf and coyote scats using DNA analysis. Wildlife Society Bulletin 32(3):685–692.

Reed, S. E. 2011. Non-invasive methods to assess co-occurrence of mammalian carnivores. The Southwestern Naturalist 56(2):231–240.

Reid, D. G., M. B. Bayer, T. E. Code, and B. McLean. 1987. A possible method for estimating river otter, *Lutra canadensis*, populations using snow tracks. Canadian Field-Naturalist 101(4):576–580.

Reiger, I. 1979. Scent rubbing in carnivores. Carnivore 2(1):17–25.

Riordan, P. 1998. Unsupervised recognition of individual tigers and snow leopards from their footprints. Animal Conservation 1:253–262.

Rodgers, T. W., J. Giacalone, E. J. Heske, N. C. Pawlikowski, and R. L. Schooley. 2015. Communal latrines act as potentially important communication centers in ocelots *Leopardus pardalis*. Mammalian Biology 80(5):380–384.

Romani, T., C. Giannone, E. Mori, and S. Filacorda. 2018. Use of track counts and camera traps to estimate the abundance of roe deer in North-Eastern Italy: are they effective methods? Mammal Research 63(4):477–484.

Rosalino, L. M., F. Loureiro, D. W. Macdonald, and M. Santos-Reis. 2005. Dietary shifts of the badger (*Meles meles*) in Mediterranean woodlands: an opportunistic forager with seasonal specialisms. Mammalian Biology - Zeitschrift für Säugetierkunde 70:12–23.

Rosalino, L. M., M. Rodrigues, M. Santos-Silva, and M. Santos-Reis. 2007. Unusual findings on host-tick interactions through carnivore scat analysis. Experimental and Applied Acarology. 43(4):293–302.

Rosell, F., S. M. Jojola, K. Ingdal, B. A. Lassen, J. E. Swenson, J. M. Arnemo, and A. Zedrosser. 2011. Brown bears possess anal sacs and secretions may code for sex. Journal of Zoology 283(2):143–152.

Rosellini, S, I. Barja, and A. Piñeiro. 2008. The response of European pine marten (*Martes martes L.*) feeding to the changes of small mammal abundance. Polish Journal of Ecology 56:497–503.

Rosellini, Stefano, E. Osorio, A. Ruiz- González, A. Piñeiro, and I. Barja. 2008. Monitoring the small-scale distribution of sympatric European pine martens (*Martes martes*) and stone martens (*Martes foina*): a multievidence approach using faecal DNA analysis and camera-traps. Wildlife Research 35(5):434–440.

Rostain, R. R., M. Ben-David, P. Groves, and J. A. Randall. 2004. Why do river otters scent-mark? An experimental test of several hypotheses. Animal Behaviour 68(4):703–711.

Ruiz-Olmo, J., A. Such-Sanz, and C. Piñol. 2013. Substrate selection for urine spraying in captive wildcats. Journal of Zoology 290(2):143–150.

Ruiz-Olmo, J., D. Saavedra, and J. Jiménez. 2001. Testing the surveys and visual and track censuses of Eurasian otters (*Lutra lutra*). Journal of Zoology 253(3):359–369.

Rumble, M. A., T. R. Mills, B. F. Wakeling, and R. W. Hoffman. 1996. Age and gender classification of Merriam's turkeys from foot measurements. Proceedings of the National Turkey Symposium 7:129–134.

Russell, A. M. J. M., and I. Storch. 2004. Summer food of sympatric red fox and pine marten in the German Alps. European Journal of Wildlife Research 50(2):53.

Rutina, L. P., K. M. Mogwera, S. Elford, C. Mpofu, and D. Ntloyathuto. 2017. Herders' ecological knowledge and carnivore predation on livestock investigations in Makgadikgadi and Nxai national parks, Botswana. Koedoe - African Protected Area Conservation and Science 52(2):1–9.

Sagar, S., and L. Singh. 1993. Some inference on the biology of tiger and leopard in Similipal Tiger Reserve. Paper presented at: International Symposium on the Tiger, Delhi., Ministry of Env. & Forests.

Sargeant, G. A., D. H. Johnson, and W. E. Berg. 1998. Interpreting carnivore scent-station surveys. Journal of Wildlife Management 62(4):1235–1245.

Schaller, G. B., R. Junrang, and Q. Mingjiang. 1988. Status of the snow leopard *Panthera uncia* in Qinghai and Gansu Provinces, China. Biological Conservation 45(3):179–194.

Scharf, I., E. D. Barkae, and O. Ovadia. 2010. Response of pit-building antlions to repeated unsuccessful encounters with prey. Animal Behaviour 79:153–158.

Schmidly, D. J. 2005. What it means to be a naturalist and the future of natural history at American universities. Journal of Mammalogy 86(3):449–456.

Selvaggio, M. M. 1994. Carnivore tooth marks and stone tool butchery marks on scavenged bones: archaeological implications. Journal of Human Evolution 27:215–228.

Selvaggio, M. M., and J. Wilder. 2001. Identifying the involvement of multiple carnivore taxa with archaeological bone assemblages. Journal of Archaeological Science 28(5):465–470.

Sergiel, A., J. Naves, P. Kujawski, R. Maślak, E. Serwa, and D. Ramos, A. Fernández-Gil, E. Revilla, T. Zwijacz-Kozica, F. Zięba, J. Painer, and N. Selva. 2017. Histological, chemical and behavioural evidence of pedal communication in brown bears. Nature - Scientific Reports 7:1051–1052.

Servin, J. I., J. R. Rau, M. Belibes, and M. Delibes. 1987. Use of radio tracking to improve the estimation by track counts of the relative abundance of red fox. Acta Theriologica 32(30):489–492.

Seryodkin, I. V. 2014. Marking activity of the Kamchatka brown bear (*Ursus arctos piscator*). Achievements in the Life Sciences 8(2):153–161.

Sharma, S., Y. Jhala, and V. B. Sawarkar. 2003. Gender discrimination of tigers by using their pugmarks. Wildlife Society Bulletin 31:258–264.

Sharma, S., Y. Jhala, and V. B. Sawarkar. 2005. Identification of individual tigers (*Panthera tigris*) from their pugmarks. Journal of Zoology 267:9–18.

Sharps, M. J., A. B. Villegas, M. A. Nunes, and T. L. Barber. 2002. Memory for animal tracks: a possible cognitive artifact of human evolution. Journal of Psychology 136(5):469–492.

Sidorovich, V. E., A. A. Sidorovich, and D. A. Krasko. 2010. Effect of felling on red fox (*Vulpes vulpes*) and pine marten (*Martes martes*) diets in transitional mixed forest in Belarus. Mammalian biology Zeitschrift für Säugetierkunde. 75(5):399–411.

Sidorovich, V. E., I. I. Rotenko, and D. A. Krasko. 2011. Badger *Meles meles* spatial structure and diet in an area of low earthworm biomass and high predation risk. Annales Zoologici Fennici 48(1):1-16.

Sidorovich, V., D. Krasko, and A. Dyman. 2005. Landscape-related differences in diet, food supply and distribution pattern of the pine marten, *Martes martes* in the transitional mixed forest of northern Belarus. Folia Zoologica 54:39-52.

Silveira, L., A. T. A. Jácomo, and J. A. F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114(3):351–355.

Singh, L. A. K. 1999. Guidelines for estimating wild tiger populations using the Pugmark Technique. WWF Tiger Conservation Programme, India: 40.

Singh, L. A. K. 2000. Improved approach to tiger counting through pugmarks. Presented at "Wildlife in the wake of the third millennium" Venue: Indian Museum Auditorium, Calcutta.

Singh, L. A. K. 2000. Interpreting visual signs of the Indian crocodile. Crocodile Specialist Group 19:7–9.

Singh, L. A. K., and H. R. Bustard. 1977. Locomotory behaviour during basking and spoor formation in the gharial (*Gavialis gangeticus*). British Journal of Herpetology 5:673–676.

Skalski, J. R. 1991. Using sign counts to quantify animal abundance. Journal of Wildlife Management 55(4):705–715.

Skalski, T., and I. Wierzbowska. 2008. Variation of insect assemblages in fox and marten faeces collected in southern Poland. Annales Zoologici Fennici 45(4):308–316.

Smallwood, K. S., and E. L. Fitzhugh. 1995. A track count for estimating mountain lion *Felis concolor californica* population trend. Biological Conservation 71(3):251–259.

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

Southgate, R., M. A. Dziminski, R. Paltridge, A. Schubert, and G. Gaikhorst. 2019. Verifying bilby presence and the systematic sampling of wild populations using sign-based protocols- with notes on aerial and ground survey techniques and asserting absence. Australian Mammalogy 41:27–38. https://doi.org/10.1071/AM17028

Squires, J. R., K. S. McKelvey, and L. F. Ruggiero. 2004. A snow tracking protocol used to delineate local lynx, *Lynx candensis*, distributions. The Canadian Field-Naturalist 118:583–589.

Squires, J. R., L. E. Olson, D. L. Turner, N. J. DeCesare, and J. A. Kolbe. 2012. Estimating detection probability for Canada *lynx Lynx canadensis* using snow-track surveys in the northern Rocky Mountains, Montana, USA. Wildlife Biology 18(2):215–224.

Stahler, D. R., D. W. Smith, and D. S. Guernsey. 2006. Foraging and feeding ecology of the gray wolf (*Canis lupus*): lessons from Yellowstone National Park, Wyoming, USA. The Journal of Nutrition 136(7): 1923S-1926S.

Stander, P. E. 1998. Spoor counts as indices of large carnivore populations: the relationship between spoor frequency, sampling effort and true density. Journal of Applied Ecology 35(3):378–385.

Stander, P. E. 2019. Lions (*Panthera leo*) specialising on a marine diet in the Skeleton Coast National Park, Namibia. Namibian Journal of Environment 3(A):1–10.

Stander, P. E., //. Ghau, D. Tsisaba, //. ≠Oma, and //.Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Stanley, T. R., and J. A. Royle. 2005. Estimating site occupancy and abundance using indirect detection indices. The Journal of Wildlife Management 69(3):874–883.

Stephens, P. A., O. Y. Zaumyslova, D. G. Miquelle, A. I. Myslenkov, and G. D. Hayward. 2006. Estimating population density from indirect sign: track counts and the Formozov–Malyshev–Pereleshin formula. Animal Conservation 9(3):339–348.

Suryawanshi, K. R., M. Khanyari, K. Sharma, P. Lkhagvajav, and C. Mishra. 2019. Sampling bias in snow leopard population estimation studies. Population Ecology 0:268–276. https://doi.org/10.1002/1438-390X.1027

Suter, R. B., G. E. Stratton, and P. R. Miller. 2011. Mechanics and Energetics of Excavation by Burrowing Wolf Spiders, *Geolycosa spp*. Journal of Insect Science 11:1–15.

Taberlet, P., J.-J. Camarra, S. Griffin, E. Uhres, O. Hanotte, L. P. Waits, C. Dubois-Paganon, T. Burke, and J. Bouvet. 1997. Noninvasive genetic tracking of the endangered Pyrenean brown bear population. Molecular Ecology 6(9): 869-876.

Taylor, A. P., M. S. Gunther, and M. L. Allen. 2015. Black bear marking behaviour at rub trees during the breeding season in northern California. Behaviour 152(7-8):1097–1111.

Taylor, C. A., and M. G. Raphael. 1988. Identification of mammal tracks from sooted track stations in the Pacific Northwest. California Fish and Game 74(1):4–15.

Taylor, M. E. 1970. Locomotion in some East African viverrids. Journal of Mammalogy 51(1):42–51.

Telfer, W. R., A. D. Griffiths, and D. M. J. S. J. S. Bowman. 2006. Scats can reveal the presence and habitat use of cryptic rock-dwelling macropods. Australian Journal of Zoology 54(5):325–334.

Terry, A. M. R. R., T. M. Peake, and P. K. McGregor. 2005. The role of vocal individuality in conservation. Frontiers in Zoology. 2:1-16. https://doi.org/10.1186/1742-9994-2-10

Tewksbury, J. J., J. G. T. Anderson, J. D. Bakker, T. J. Billo, P. W. Dunwiddie, M. J. Groom, S. E. Hampton, S. G. Herman, D. J. Levey, N. J. Machnicki, C. Martínez Del Rio, M. E. Power, K. Rowell, A. K. Salomon, L. Stacey, S. C. Trombulak, and T. A. Wheeler. 2014. Natural history's place in science and society. Bioscience 64(4):300–310.

Thiessen, D., and M. Rice. 1976. Mammalian scent gland marking and social behavior. Psychological Bulletin 83(4): 505-539.

Thompson, I. D., I. J. Davidson, S. O'Donnell, and F. Brazeau. 1989. Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. Canadian Journal of Zoology 67(7):1816–1823.

Thorn, M., D. M. Scott, M. Green, P. W. Bateman, and E. Z. Cameron. 2009. Estimating brown hyaena occupancy using baited camera traps. South African Journal of Wildlife Research 39(1):1-10.

Tosh, D., S. J. Preston, and R. A. McDonald. 2007. The status of pine martens *Martes martes* (L.) in Northern Ireland, 1850-2004. The Irish Naturalists' Journal. 28(11):433-439.

Trites, A. W., and R. Joy. 2005. Dietary analysis from fecal samples: how many scats are enough? Journal of Mammalogy 86(4):704–712.

Trudeau, C., L. Imbeau, P. Drapeau, and M. J. Mazerolle. 2011. Site occupancy and cavity use by the northern flying squirrel in the boreal forest. Journal of Wildlife Management 75(7):1646–1656.

Vallon, L. H., A. K. Rindsberg, and R. G. Bromley. 2016. An updated classification of animal behaviour preserved in substrates. Geodinamica Acta 28(1-2):5–20.

Van Dyke, F. G. van, R. H. Brocke, and H. G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102–109.

Van Etten, R. C., and C. L. Bennett. 1965. Some sources of error in using pellet-group counts for censusing deer. Journal of Wildlife Management 29(4):723–729.

Van Sickle, W. D., and F. G. Lindzey. 1992. Evaluation of road track surveys for cougars (*Felis concolor*). The Great Basin Naturalist 52:232–236.

Verlinden, A., J. S. Perkins, M. Murray, and G. Masunga. 1998. How are people affecting the distribution of less migratory wildlife in the southern Kalahari of Botswana? A spatial analysis. Journal of Arid Environments 38:129–141.

Walker, E. H., M. Nghikembua, B. Bibles, and L. Marker. 2016. Scent-post preference of free-ranging Namibian cheetahs. Global Ecology and Conservation 8:55–57.

Walsberg, G. E. 1975. Digestive adaptations of *Phainopepla nitens* associated with the eating of mistletoe berries. The Condor: Bulletin of the Cooper Ornithological Club 77:169–174.

Wei, W., R. R. Swaisgood, M. A. Owen, N. W. Pilfold, H. Han, M. Hong, H. Zhou, F. Wei, Y. Nie, and Z. Zhang. 2019. The role of den quality in giant panda conservation. Biological Conservation 231:189–196.

Weise, F. J., Q. Wessels, S. Munro, and M. Solberg. 2014. Using artificial passageways to facilitate the movement of wildlife on Namibian farmland. South African Journal of Wildlife Research 44:161–166.

Weise, F. J., V. Vijay, A. P. Jacobson, R. F. Schoonover, R. J. Groom, J. Horgan, D. Keeping, R. Klein, K. Marnewick, G. Maude, J. Melzheimer, G. Mills, V. van der Merwe, E. van der Meer, R. J. van Vuuren, B. Wachter, and S. L. Pimm. 2017. The distribution and numbers of cheetah (*Acinonyx jubatus*) in southern Africa. PeerJ 5:e4096. https://doi.org/10.7717/peerj.4096

Wiggins, N. L., and D. M. J. S. J. S. Bowman. 2011. Macropod habitat use and response to management interventions in an agricultural forest mosaic in north-eastern Tasmania as inferred by scat surveys. Wildlife Research 38:103–113. https://doi.org/10.1071/WR10116

Wilson, G. J., and R. J. Delahay. 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. Wildlife Research 28(2):151–164.

Wilting, A., F. Fischer, S. A. Bakar, and K. E. Linsenmair. 2006. Clouded leopards, the secretive top-carnivore of South-East Asian rainforests: Their distribution, status and conservation needs in Sabah, Malaysia. BioMed Central Ecology 6:1–13. https://doi.org/10.1186/1472-6785-6-16

Winegarner, M. S. 1985. Pugmarks and the biology of the bobcat, *Lynx rufus*. Z. Saeugertierkd 50:166–174.

Winterbach, C. W., S. M. Ferreira, P. J. Funston, and M. J. Somers. 2016. Simplified large African carnivore density estimators from track indices. PeerJ 4:e2662; https://doi.org/10.7717/peerj.2662

Wolf, M., and S. Ale. 2009. Signs at the top: habitat features influencing snow leopard *Uncia uncia* activity in Sagarmatha National Park, Nepal. Journal of Mammalogy 90(3):604–611.

Wong, P. B. Y., P. Van Coeverden de Groot, C. Fekken, H. Smith, M. Pagès, and P. T. Boag. 2012. Interpretations of polar bear (*Ursus maritimus*) tracks by Inuit hunters: inter-rater reliability and inferences concerning accuracy. The Canadian Field-Naturalist 125(2):140–153.

Woodmansee, K. B., C. J. Zabel, S. E. Glickman, L. G. Frank, and G. Keppel. 1991. Scent marking (pasting) in a colony of immature spotted hyenas (*Crocuta crocuta*): A developmental study. Journal of Comparative Psychology 105(1):10–14.

Wooldridge, R. L., R. J. Foster, and B. J. Harmsen. 2019. The functional role of scent marking in the social organization of large sympatric neotropical felids. Journal of Mammalogy 100:445–453. https://doi.org/10.1093/jmammal/gyz055

Yarnell, R. W., M. Pacheco, B. Williams, J. L. Neumann, D. J. Rymer, and P. J. Baker. 2014. Using occupancy analysis to validate the use of footprint tunnels as a method for monitoring the hedgehog *E rinaceus europaeus*. Mammal Review 44:234–238.

Zalewski, A. 1999. Identifying sex and individuals of pine marten using snow track measurements. Wildlife Society Bulletin 27:28-31.

Zalewski, A. 2007. Does size dimorphism reduce competition between sexes? The diet of male and female pine martens at local and wider geographical scales. Acta Theriologica 52:237–250. https://doi.org/10.1007/BF03194220

Zannése, A., A. Baïsse, J. M. Gaillard, A. J. M. Hewison, K. Saint-Hilaire, C. Toïgo, G. van Laere, and N. Morellet. 2006. Hind foot length: an indicator for monitoring roe deer populations at a landscape scale. Wildlife Society Bulletin 34:351–358.

Zhang, H.H., X.-P. Liu, H.S. Dou, C.D. Zhang, and Y. Ren. 2009. Food composition and food niche overlap of three kinds of canidae. Acta Ecologica Sinica 29(6):347–350.

Zielinski, W. J., and F. V. Schlexer. 2009. Inter-observer variation in identifying mammals from their tracks at enclosed track plate stations. Northwest Science 83(4):299–307.

Zielinski, W. J., and H. B. Stauffer. 1996. Monitoring Martes populations in California: survey design and power analysis. Ecological Applications 6(4):1254–1267.

Zielinski, W. J., and R. L. Truex. 1995. Distinguishing tracks of marten and fisher at track-plate stations. Journal of Wildlife Management 59(3):571–579.

Zielinski, W. J., and T. E. Kucera. 1995. American marten, fisher, lynx, and wolverine: survey methods for their detection. General Technical Report PSW GTR-157. US Department of Agriculture, Forest Service, Pacific Southwest Research Station: 172.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004. Home range characteristics of fishers in California. Journal of Mammalogy 85(4):649–657.

Zips, W., and Zips-M Mairitsch. 2007. Lost in Transition? The Politics of Conservation, Indigenous Land Rights and Community-Based Resource Management in Southern Africa. The Journal of Legal Pluralism and Unofficial Law 39(55):37-71.

Zuberogoitia, I., J. Zabala, J. A. Martinez, and J. A. Martínez. 2006. Evaluation of sign surveys and trappability of American mink: management consequences. Folia Aoologica-Praha 55:257–263.

Zuercher, G. L., P. S. Gipson, and G. C. Stewart. 2003. Identification of carnivore feces by local peoples and molecular analyses. Wildlife Society Bulletin 31(4):961–970.

Zyznar, E., and P. J. Urness. 1969. Qualitative identification of forage remnants in deer feces. Journal of Wildlife Management 33:506–510.

Chapter 3 - Evaluating the Evaluation: A mixed-methods analysis of CyberTracker evaluated wildlife trackers and suggested guidelines for collecting track-based data for science

Abstract

Wildlife tracking includes people identifying and interpreting tracks (footprints) and signs (broken branches, browsed vegetation, beds, kill sites, feathers, bones, scats, etc.). Identification and interpretation of wildlife tracks and signs are commonly required skills in wildlife research to locate and determine the presence of animal species, count populations, and identify individual animals, yet most research conducted with track-based data does not include a metric of the skill and reliability of the person collecting the data. Track-based data collected by unskilled and untrained people can result in unreliable conclusions, which can negatively impact wildlife and land management. Correctly identifying and interpreting animal tracks and signs requires practice and skill, but the training provided for both professional scientists and citizen scientists ranges from as little as a obtaining a field guide (a book) to attending a workshop of a few hours or a few days. These workshops might or might not include a field component actually looking at tracks and signs with an experienced tracker. Therefore, the data fall into a range of undeterminable reliability based on the tracker's unknown experience and skill.

An expert tracker might not be required to collect track-based data if the tracks and signs of the species under study are not easily confused with any other species, or the substrate and weather conditions at the research site yield predominately perfect tracks, or the research questions asked are not specific. However, following the same logic conversely, an expert tracker might be required to answer more specific, challenging, or confusing questions while in-the-field.

I collected data from systematic field evaluations of participants' knowledge on the identification and interpretation of wildlife tracks and signs in CyberTracker Track & Sign Evaluations in South Africa. Not concurrently, I asked participants with CyberTracker certifications to identify the tracks and signs of animals that walked though plots set with remotely triggered camera traps. This research show that participants achieving higher level of qualification in the evaluations were able to answer more questions correctly, and more complex questions correctly, than participants who achieved a lower level. Camera-trapping indicates that evaluators are identifying, teaching, and testing tracks and signs accurately. I recommend that scientists, wildlife managers, and conservationists consider the level of complexity in the questions that they want answered, the species under study, and the substrate in the study area before hiring people to collect track-based data. More complex scenarios require more experienced trackers. CyberTracker evaluations are available internationally, and are a reliable method of determining the experience level of trackers.

Introduction

Using track-based data in science

Wildlife tracking includes people identifying and interpreting tracks (footprints) and signs (broken branches, browsed vegetation, beds, kill sites, feathers, bones, scats, etc.). Collecting accurate and reliable track-based data requires specific observational skills based on personal knowledge of what characteristics and clues to look for. Obtaining this knowledge requires practice, often mentored by an experienced tracker (Liebenberg 1990*a*, Elbroch et al. 2011). Track-based data should not be collected for scientific purposes without training or a metric determining the skill of the person collecting the data. Such a system exists, called

CyberTracker Tracker Certification. CyberTracker certification consists of a series of increasingly difficult field evaluations designed to certify the skill levels of trackers, but it has never before been tested on its own for accuracy and reliability.

Surveying animals is a foundational activity in wildlife research and conservation. In order to study and conserve animals we must know where they are and how many of them there are (Wilson and Delahay 2001). Wildlife tracks and signs (T&S) are classified as indirect-signs in wildlife research and conservation. Identifying T&S of target species is a non-invasive survey technique that does not require the observer to capture, handle, or otherwise impact animals' lives or behaviors (Beier and Cunningham 1996, Gompper et al. 2006, Gruber et al. 2008). Observers are required to identify suitable habitat for, and indicators (tracks and other signs) of the target species' presence where the species are not directly observed. Identifying indirect-signs in-the field does not require purchasing expensive equipment so it is more cost-effective than other more direct or invasive methods, and becoming a reliable tracker does not require advanced education (Wilson and Delahay 2001, Gusset and Burgener 2005, Gruber et al. 2008, Elbroch et al. 2011).

Even though some research shows that collecting reliable track-based data requires experience and/or verification, and that biased data can have profound impacts on management decisions (Smallwood and Fitzhugh 1993, Karanth et al. 2003, Silveira et al. 2003, Evans et al. 2009), the trend is still to hire persons with no experience in tracking, or to provide minimal or no training or evaluation of their tracking skills, before allowing them to collect track-based data (Evans et al. 2009). Track-based data have been reported in the literature without pedigree: methods go undescribed or unreported, and, in many instances, incomplete or no independent external verification of the data occurs (DNA, camera traps, etc.) (Alibhai et al. 2008). For example, scientists assume that technicians will be able to differentiate the T&S of different carnivores in varying substrates with little training and/or by consulting drawings or pictures in a published field guide (Crooks et al. 2008, Pirie et al. 2016) – the unspoken assumption is that the data they collect will be unbiased and external verification is unnecessary.

The probability of detecting a species includes not only the probability that it is present and that the observer(s) find it if it is present, but also that the observer(s) correctly identify it (MacKenzie and Royle 2005, Stanley and Royle 2005). Observer bias can occur in two ways: false reports of non-target species that are mistakenly identified as the target species create false-positives in data; and misidentifying the target species as another species, creating a false-negative in the data (Gu and Swihart 2004, Evans 2007, Evans et al. 2009).

Some wildlife scientists use concurrent verification, in the form of technology and/or experience, to confirm identification of track-based data. This is especially so when attempting to interpret complex, interpretive questions. Interpretations from tracks include the way an animal was moving; whether the track asked was from a left or a right foot, or a front or a hind foot; the sex of the animal; the number of animals present; the social structure of the animals (ex. mother and young), or to differentiate individual animals. Interpretable behaviors include evidence of browsing or grazing, dustbathing, drinking, sleeping, sparring, greetings, mating, hunting, and other common inter- and intra- species interactions (Smallwood and Fitzhugh 1993, Grigione et al. 1999, Lewison et al. 2001, Purchase 2007).

Concurrent technologies include comparison of the observer's identification with: computer modeling and statistical analysis of measurements taken from tracks, drawings, photos, plates, or track casts (Alibhai et al. 2008, Jewell and Alibhai 2012, Marchal et al. 2016), photos from remotely triggered camera traps (Wilson and Delahay 2001, Silveira et al. 2003, Gompper et al. 2006), positions in time and space from different forms of telemetry (Lawrence-Apfel et al. 2012, Allen et al. 2015, Elbroch et al. 2015, Elbroch et al. 2015, Elbroch et al. 2016), and genetic analysis from hair or scat (McKelvey et al. 2006) (sometimes combined further with identification from scat-detection dogs).

Correct species identification of track-based data can be corroborated with camera-traps and DNA, which can provide conclusive evidence, but in many cases these methods all require interpretive experience. Interpretive experience is high when observers are skilled in all methods of data collection, and low when they are unskilled. These types of outside verification require theoretical and practical training for the practitioner to use them skillfully and are desirable when research budgets can include them (Pimm et al. 2015). In some instances, measurements and models derived from computer software are very accurate in analyzing photographs of clear tracks to determine species and even individual animals – but variations between observer measurements must be accounted for, tracks must be from a specific foot (e.g. hind left), perfect and repeated, and the software does not yet work with signs. Using software to identify tracks also requires carrying equipment into the field and detailed computer analysis later (Jewell et al. 2001, Alibhai et al. 2008) only to reach the same conclusions that have been proven possible with an experienced tracker (Stander et al. 1997, Elbroch et al. 2011, Wong et al. 2011).

Track-based data can also be collected by citizen scientists. Citizen scientists include members of the general public who collect track-based data for science and conservation in return for little or no wages. This allows project managers to hire many people to collect large datasets while keeping employment costs low (Hart et al. 2012). Citizen science projects often have multiple goals and results besides biological information. Evidence shows that citizen science projects educate people about the targeted natural organisms, and they can increase awareness and concern for the environment and for participants' local communities (Jordan et al. 2011, Crall et al. 2012, Haywood 2014). A debatable result is that citizen science projects also allow people with no scientific background learn about how to conduct science through their hands-on experiences (Brossard et al. 2005, Jordan et al. 2011).

Scientists overseeing citizen science projects have noted the need for some kind of quality control on data collected by observers with a wide variety of skill and knowledge levels (Jordan et al. 2011, Kremen et al. 2011, Hunter et al. 2012, Havens and Henderson 2013). In some instances, citizen science data is known to be much less rigorous than professionally collected data (Mueller and Tippins 2012).

Researchers collecting presence-absence information in breeding bird surveys have documented observer differences, bias' associated with errors due to observer experience or skill level, as variables that should be included in their data collection and modeling (Sauer et al. 1994, Alldredge et al. 2006, 2007, McClintock et al. 2017). Christmas Bird Counts by the Audubon Society, the longest running citizen science project, illustrate this dichotomy between rejecting the results as scientific work and emphasizing the value of teaching and learning (Mueller and Tippins 2012). Differences among observers, both between and among professionals and volunteers, in bird counts are a well-documented source of potential error (Rittenhouse et al. unpublished, Diefenbach et al. 2003, Alldredge et al. 2006, 2007).

This brings up a further question with track-based data regarding who is considered a professional, and whether or not science professionals actually collect more reliable track-based data (Lewandowski and Specht 2015). For example, a carnivore specialist might be an expert in the biology, ecology, and behavior of African wild dogs (*Lycaeon pictus*) and spotted hyenas (*Crocuta crocuta*) but have no experience in identifying and interpreting their T&S and differentiating them from each other and other species. Project or biological experience, whether at a broad or at a specific taxonomic level, infrequently includes experience with the T&S of the target animals or with other T&S that they could be commonly confused with (De Angelo et al. 2010).

Some research suggests that people from indigenous cultures may be expert trackers, perhaps because they still live (or recently lived) in a way that provides them with the prerequisite experience (Rutina et al. 2017). Elbroch et al. (2011) developed a conceptual model with which to screen potential experts from local communities giving them a score based on their experience and knowledge. They presented a case study of an expert local tracker, identified and employed by using their model, who was able to develop his own methods and collect robust data that was useful to science. Stander et al. (1997) showed that San trackers who were raised in a hunting and gathering culture were able to correctly interpret complex scenarios and identify individuals from T&S. Conversely, Rutina et al. (2017) found that indigenous herder’s in Botswana could not reliably identify the tracks and kill characteristics of different carnivore species preying on their livestock. Wong et al. (2011) showed that Inuit hunters were capable of identifying individual animals from T&S, but that there were degrees of accuracy among hunters based on the quality and duration of their experience. These types of conflicting results are not isolated or rare, making it difficult to develop consistent guidelines for collecting and reporting of track-based information provided by any type of observer, with or without concurrent use of technology. Such guidelines should include what experience an observer needs to collect track-based data, and how that experience should be verified and/or reported.

CyberTracker[4]

This research explores the only international system of evaluating wildlife trackers, known as the CyberTracker Tracker Certification. Louis Liebenberg of CyberTracker Conservation (http://www.cybertracker.org/) developed these field evaluations in the 1990's to assist with employing indigenous San trackers in wildlife conservation, and to assess the validity of their contributions.

CyberTracker evaluations take place in many countries and participants from all over the world are certified, in the field, through a rigorous two-day evaluation process where a minimum qualification requires a score of at least 70% and the accuracy and level achieved increases with an increasing score. Potential levels, from lowest to highest achievable, include *level 1, level 2, level 3, professional*, and *specialist*. There are two different types of CyberTracker Tracker Certification evaluations*: the track and sign identification and interpretation evaluation* (T&S eval), and the *trailing evaluation* (trailing eval). Achieving certification in both evaluations earns a participant the title of *tracker*, with its corresponding level, eg. T&S level 1 plus trailing level 1 = tracker level 1 (Figure 1). Even though the requirements of the system are for both T&S and trailing certifications to call oneself a tracker, in colloquial language people who are only certified in T&S often call themselves trackers, and I use the colloquial language for ease of understanding in this research.

The CyberTracker process involves two different evaluations and their paths of progression from novice to expert (Figure 1). Participants work from bottom to top in either T&S

---

[4] Information described herein comes from my personal experiences and field notes, meetings with members of the CyberTracker Evaluation Standards Committee, and the CyberTracker website. My experiences and field notes are relevant because I have spent over a decade studying wildlife tracks and signs in Africa, North America, and Europe. My skill-level in tracking has been certified to be at the highest level, Senior Tracker, in the international CyberTracker tracker-evaluation system, and I am a CyberTracker Track and Sign Evaluator and Trailing Evaluator, as described in this dissertation and according to the standards set by CyberTracker Conservation.

(left), or in trailing (right), from *not yet competent* (bottom) to *specialist* (top), or even *senior tracker* (top of figure, the highest level that can be earned). As the pyramidal structures in Figure 1 suggest, many more participants begin the process and achieve lower levels of certification than there are participants who achieve higher levels, such as Specialist or Senior Tracker.

Trailing evals focus on participants following a series of tracks and signs in an animal's trail, and finding the animal. This research focuses on T&S evals, which are further divided into two levels of difficulty. The *secondary* evaluation, and the more difficult *tertiary* evaluation. Note, the name of the lower band/standard evaluation has been changed to the *secondary* evaluation and the name of the upper band/specialist evaluation is used interchangeably with *tertiary* evaluation.

At a CyberTracker evaluation, a participant can achieve a level 1, 2, 3, or Professional (Figure 2). Again, pyramids represent the increasing difficulty in achieving higher levels. A participant must achieve 100% in the left pyramid, the secondary evaluation, before proceeding to attempt the smaller pyramid on the right, the tertiary evaluation. The terms secondary and tertiary come from descriptions of levels in western education. On the left, a participant attempts 53 questions. The first three questions in an evaluation are considered warm up questions and do not count. The remaining 50 questions are administered in the following proportions: 10 at point rating 1 (simple), 30 at point rating 2 (medium complexity), and 10 at point rating 3 (complex).[5] Tracker *levels 1, 2, and 3* are actual CyberTracker levels and correspond to coding in this research for levels 1, 2 and 3. Level 0 is not an actual CyberTracker level, but represents those

[5] In North America and Europe, the point rating system is skewed towards more difficult questions, and there is no published master list of questions and their point ratings. Evaluators there are currently working towards the standardization of their system with the established African model.

participants who attempted an evaluation and are *not-yet-competent* in this analysis. Level 4 is known officially as *professional* level, thus, levels 1, 2, 3, and professional are all levels awarded within the secondary evaluations. Scores achievable range from not-yet-competent (<69%) to professional (100%). Once a participant has achieved professional, they can progress to the tertiary level evaluation, shown in the smaller pyramid. This is a pass/fail evaluation where specialist level (labeled level 6 in this analysis) is only achieved with 100% correct answers, and with only complex (point rating 3) and very complex (point rating 4) questions. This research also contains code for a variable tracker level 5, which is not an actual level but represents a person who has attempted and not yet achieved 100% in a tertiary evaluation.

There are other systems of evaluating tracking for trackers who follow and find humans for search and rescue or fugitive purposes. In this research I use the term tracking (and variations of that term) to mean the identification, interpretation, and following and finding of animals using their tracks and signs. I am not referring to human tracking, the use of scent dogs, spatial and temporal data associated with telemetry (including GPS), genetic markers, or other technologies or laboratory procedures. This research focuses on wildlife tracking, particularly on identifying and interpreting individual T&S, or a few T&S along a short section of the animal's trail.

The original reference standard for CyberTracker T&S evals is A Field Guide to the Animal Tracks of Southern Africa (Liebenberg 1990*b*) . As the developer of the system, and of the reference standard, Liebenberg was never formally tested by it (Liebenberg L. 2012, pers. comm.). Based on interviews with evaluators and trackers who have participated in the CyberTracker system for over 20 years (Chapter 4), they believe that identification and interpretation guidelines provided by the system and reference standard are accurate and reliable.

However, in areas where ranges of species with very similar foot morphology and size overlap, trackers, scientists and land managers debate the ability to differentiate species. A common example is the difficulty in differentiating the following continuum of antelope species from each other: Sharpe's grysbok (*Raphicerus sharpei*), steenbok (*Raphicerus campestris*), common duiker (*Sylvicapra grimmia*), bushbuck (*Tragelaphus scriptus*), nyala (*Tragelaphus angasii*) and the greater kudu (*Tragelaphus strepsiceros*) - where foot sizes and shapes of the largest of one species overlap considerably with the smallest of the next species (Liebenberg, L., and A. Louw 2012, pers. comm.).

A complete description of the current international evaluation protocol is on the CyberTracker website at: http://www.cybertracker.org/downloads/tracking/CyberTracker-Tracker-Certification-2018.pdf. And the following link gives an example of the questions asked in South African T&S evaluations and their point ratings: http://www.cybertracker.org/downloads/tracking/CyberTracker-Species-List-Southern-Africa.pdf).

There are a few details in the evaluation protocol that have changed from the time this research was completed and the publication of the periodically updated protocol published on the CyberTracker website. There are also small differences in the process from country to country, often necessitated by situations like introducing the system to a new region and making people aware of it. For example, it clearly states in the international protocol that participants must get 100% on a secondary evaluation before they can participate in a more rigorous, tertiary evaluation, and this is the procedure followed in South Africa where the evaluations are well established within the ecotourism industry. But, in North America and Europe the tertiary level evaluations are can be taken by people with any previous CyberTracker score. This allows persons who are new to the system to be evaluated alongside persons who are already high scorers, up to the ten-person maximum allowed in an evaluation. In these cases, it's allowable to modify the protocol to get the system going and attract a big enough group to warrant the expenses of evaluators traveling and spending time and expertise running evaluations. Typically, the range of scores is narrower, where people with less than 90% on a secondary evaluation will self-select not to enroll in a tertiary evaluation before gaining more experience and being better prepared for it. I draw attention to further exceptions to the international protocol only when it is necessary to understand the research methods or analysis.

During T&S evals, a qualified and trained *evaluator* finds tracks and signs in the field and circles or marks them with sticks, stones, numbers, or flags, to make them obvious to participants. Potential questions include tracks and signs made by mammals, birds, invertebrates, reptiles, and amphibians, as well as marks made by humans, vehicles, and natural acts (lightning strikes, frost cracks). Sign questions can include: beds, dens, scats (feces), pellets (regurgitations), urine, scent markings (including territorial markings and anal pastings), scratching or rubbings, nipped twigs, chewed nuts, feathers, nests, galls and casings, webs, exoskeletons and other body parts, skulls and bones, gaits and track patterns, kill site analysis, behavioral interpretations, and more. Participants look at the evidence for each question, without time limits, and privately convey to the evaluator (whispering, or by writing it down and showing the evaluator what they have written) what they think the answer to each question is. The evaluator writes their answers down on the evaluation score sheet next to the participant's name, under the appropriate questions. See Table 1 for an example score sheet. Books, rulers, phones, conversations, and other resources are not allowed at the questions.

Evaluators assign a *point rating* to each question, and write each question and its associated point rating on the score sheet for the evaluation, before asking the questions. The point-rating system, whereby a track is assigned more or less points according to its degree of complexity, a published guideline to assigning these point ratings, and peer-review among evaluators, provides standardization in questions asked. For example, a clear zebra track is a 1-point question, but if it is in an area where there are also horses then it is a 2-point question; if it is also old, weathered, partial, and/or in difficult substrate, it is a 3-point question.

A 1-point question is considered of simple complexity, a 2-point question is of medium complexity, and a 3-point question is very complex. Getting a 1-point question correct results in one point, but getting it incorrect results in a penalty of minus three points; Getting a 2-point question correct results in two points, but getting it incorrect results in a penalty of minus two points; Getting a 3-point question correct results in three points, but getting it incorrect results in a penalty of minus one point. Therefore, participants are penalized heavily for getting a simple question wrong, and awarded minimally for getting it right, and penalized minimally for getting a very complex question wrong or awarded more points for correctly answering. At tertiary evaluations, seven, very complex, bonus questions are asked that do not penalize a participant if answered incorrectly but can slightly increase their score (0.33 points each) if answered correctly. Unreasonably complex questions are considered to be above the level of the standard and should not be asked.

Similar to secondary T&S evaluations, in tertiary evaluations 50 questions are asked, but all of them are complex (3-points), and seven bonus level questions are asked. This research codes bonus level questions as point rating 4 in the data analysis. Bonus level questions are considered very complex but not unreasonable. Getting three bonus level questions correct in a tertiary evaluation will cancel one incorrect 3-point question. This means that a participant can recover from getting up to two regular questions wrong by getting six bonus questions correct. Bonus questions are always announced before participants are allowed to look at and answer the question, e.g. "this is a bonus question." This prevents participant perception of point manipulation by evaluators to favor other participants. At the end of an evaluation scores are tallied by adding the number of points gained (correct) and dividing by the number points gained plus the number points lost (incorrect)), as shown below in Formula 1.1.

$$\text{Score} = \frac{(\text{Number of points correct})}{(\text{Number of points gained + number of points lost})}$$

Formula 1.1. Score calculation for T&S evaluations.

At the time of this research, evaluators did not ask the same question twice in an evaluation. For example, if a 2-point impala (*Aepyceros melampus*) track is asked as a species identification question, there will be no other 2-point impala tracks asked as a species identification question. The evaluator may ask the gait or track pattern of an impala at a 2-point rating, or some other sign or behavior, or the evaluator may ask a more complex impala track, such as a 3-point impala track in deep mud or soft sand, or a 1-point impala track in an entire track pattern among a herd. Current protocol (2018) allows some repetition of questions.

In secondary evaluations, participants can achieve the following levels of certification: 69-79% = Level 1, 80-89% = Level 2, 90-99% = Level 3, 100% = professional level (coded as level 4 in this research). After achieving professional level in a secondary evaluation, participants are automatically invited to a tertiary evaluation. The tertiary evaluations are much more difficult than secondary evaluations. Tertiary evaluations are designed to produce the next generation of true experts who are not only competent to reliably identify, interpret, follow, and find wildlife and their tracks and signs, but also to instruct others in how to do so and possibly to evaluate others in the same fashion. Tertiary evaluations are conducted on a pass/fail basis where a participant needs to achieve 100% to pass and become a specialist. Any score less than 100% results in the participant rated as not-yet-competent at the specialist level, but they are not demoted from their 100%, or professional level, status achieved at a previous secondary evaluation.

After achieving specialist, and by invitation from a CyberTracker *evaluator,* and with acceptance by the *CyberTracker Evaluation Standards Committee,* a specialist can undertake a rigorous peer-review process running evaluations under the tutelage of at least two different external evaluators to become a regional evaluator in the biomes(s) in which they have achieved their specialization(s).

Secondary evaluations are run by one evaluator. This evaluator can test up to ten participants at a time over an average period lasting two days, depending on the number of participants. Tertiary evaluations require two evaluators, where one is an *external evaluator*. External evaluators are trained to evaluate in multiple biomes, help evaluators select complex but fair questions, and remain unaware of all participants' scores until the end of the evaluation. remain This is to ensure peer-review (evaluator agreement) of the more complex questions required and to eliminate potential appearance of favoritism. Tertiary evaluations can take three days to complete for up to ten participants.

Evaluators are required to run, assist, or attend, two out of three events, in a two-year cycle to retain their evaluator status and maintain common standards. These three events include: a secondary evaluation with another evaluator, a tertiary evaluation with other evaluators, or the annual *CyberTracker evaluators workshop* (including practical field sessions). All three of these events allow evaluators to calibrate their thoughts about question selection and point ratings with other evaluators, in the field. Note: this requirement has not been enforced nor adhered to by many evaluators in the system, as of the time of this writing.

Goals and Objectives

The goals of this research are to determine whether or not the information that CyberTracker certified wildlife trackers provide can be verified for reporting and use in science and conservation. Objectives include: using camera-traps to validate whether or not the CyberTracker Tracker Certification System is an accurate and reliable method to test the skill level of trackers (Are evaluators testing people on the animals that they think they are testing them on?); using T&S evaluation data to assess the range of difficulty when identifying and interpreting track-based data, and whether observer certification level increases the range of track-based data available for collection; and using survey instruments to discover what demographic variables are important to consider when hiring someone to collect track-based data.

Study area

This study took place in South Africa. There were two phases of data collection. Phase one included data collected from CyberTracker track and sign evaluations (eval data) across South Africa. Phase two included data collected from camera-trap studies (photo data) conducted in two different regions. The first region was a 23,000-hectare private game reserve in the bushveld habitat of the Waterberg Biosphere Reserve in the Limpopo Province. The second region included five different game reserves in the lowveld habitat of the Greater Kruger

National Park in the Mpumalanga Province (Figure 3). Additional, qualitative components included the results from survey instruments administered to trackers during phase two and a comparison of the eval and photo datasets (all data).

The Kruger region includes South Africa's first national park, and is one of the largest game reserves in Africa. It is part of the Great Limpopo Transfrontier Park, a peace park that links Kruger National Park in South Africa with the Gonarezhou National Park in Zimbabwe, and with the Limpopo National Park in Mozambique, covering an approximate area of 35,000 square kilometers (Carruthers, J. 1995, 2006). Game reserves in the Kruger region each have a finite area of traversing (permissible movement for humans by vehicle and on foot) but animal movement is not restricted to that area.

Methodology

Variability among questions asked by region

Species composition was similar in across the region, with some differences between the bushveld and lowveld habitats. For example, more brown hyenas than spotted hyenas are found in some parts, but not in others. This was not a problem for most participants because they lived and worked in the areas where they were tested and were familiar with the potential species that could be encountered. Participants were also encouraged to research what species' T&S they were likely to see in habitats where the evaluation was scheduled to occur.

Additionally, the point rating system was designed, in part, to account for encountering the T&S of potentially rare or novel species. Even a perfect track, in good substrate and lighting conditions, is rated as more complex in an area where it is infrequently encountered or has not been previously documented. Thus, a participant is penalized less for getting a rare question incorrect in the scoring. It is worth noting that, during evaluations, evaluators have occasionally documented previously undetected species on reserves through identification of their T&S. The presence of these species were then confirmed through visual sightings or photography, either by guides, guests, or camera-traps (Gutteridge, L. and Louw, A. 2012, pers. comms.).

Participation of human subjects and animal welfare protocols

This research was approved by the UCONN Institutional Review Board (IRB) for Research with Human Subjects (Protocol H10-127). Evaluation data was historical. Participants in evaluations were either self-selecting, part of an entry level guide training course, or employees of lodges involved in providing their employees with increasing levels of training and certification. Participants were only identified by their first names on datasheets and remain anonymous. Participants in the camera-trapping study, including those who participated in surveys and interviews, were self-selecting volunteers at participating reserves. Before any data was collected, participants verbally consented to participation, with the additional agreement that their name or place of employment would not be revealed unless they specifically asked to be identified. This research was exempt from the requirement for an Institutional Animal Care and Use Committee (IACUC) protocol and approval (Exemption E13-007). No animals were harmed, captured, or manipulated in any way.

Phase one – Evaluation data

Eval data, were collected from previously completed evaluation score sheets (Table 1) provided by CyberTracker evaluators in South Africa. When possible, I attended evaluations as an observer and collected copies of the score sheets directly after the evaluations were completed. Variables taken directly from the score sheets included: the questions asked, question point rating (level of complexity), participant identifier (first name, nickname, or alias), whether or not the question was answered correctly, the answer given if the question was answered incorrectly (what species or object the track was mistaken for), the resulting score and tracker level achieved by the participant, and whether or not the evaluation was at the secondary or tertiary level. The score sheets typically did not include information about the dates or venues where the evaluations were given, unless I was in attendance and recorded it. Personal communications with each of the five different evaluators indicated that the data spanned approximately a decade of evaluations administered in South Africa. Most of the data came from only two different participating evaluators.

Phase two – Camera-trapping data

I set remotely-triggered camera-traps on sand roads and game trails (track-traps) to photograph animals making tracks (the questions) and then asked evaluated trackers to identify the track makers to the species level. None of the trackers attempted to identify specific, individual animals. In some instances, with leopard or lion tracks, for example, trackers identified specific feet, gaits, numbers of animals, and the sex of individuals, but I did not prompt them for specific answers at each station, which occasionally resulted in them overlooking some T&S. At each camera trap station, all trackers answered the same question, "what do you see here?" Participating trackers varied from day-to-day, depending on their availability. I recorded the observations of the trackers in a field notebook and compared it with the information in the photos (the answers) from the camera-traps. I determined whether the answer given by the tracker was correct or incorrect, and recorded any answers (species, etc.) that were incorrectly given.

I created track-traps that were approximately four meters long by four meters wide. I swept each track-trap daily, after checking it with trackers and recording their data. Sweeping erased the previous 24 hours of tracks and signs and smoothed out the surface of the track-trap for optimum recording substrate. This track-trap differs from tracking evaluation conditions, where T&S are asked as they are encountered, in all substrates and of all ages. Conditions were similar to evaluations in that the majority of tracks encountered during evaluations are less than 24 hours old, in good substrate on sand roads or game trails, and were provable in their morphology and/or behavior (a prerequisite for a question to be asked by evaluators). Conditions differed from evaluations in that no old tracks were asked. Weather conditions and substrate depths and types were not recorded. T&S from the camera-trapping phase were not assigned a point rating, because I was not yet a trained evaluator in the system and therefore not yet qualified to assign the point rating.

I attached Cuddeback, Reconyx, or Bushnell camera-traps to small trees at the side of the road or along the game trails at each track-trap. I used two cameras per site to: provide redundancy, ensure identifiable photographs of all species if one camera malfunctions, and identify individual animals (such as individual leopards by spot pattern) and their sex where possible. Cameras varied in their settings by manufacturer, but were set to take multiple photos at the shortest time lag or highest sensitivity. Cuddeback cameras were the slowest, taking a set of three photos with a lag of three seconds between sets, upon triggering by motion. Reconyx cameras were the fastest, taking almost continuous photos upon triggering, without lag before taking subsequent photos.

I also administered voluntary survey instruments (Appendix A) to 141 participants to explore qualitative and demographic qualities of trackers. Variables from survey instruments included the months of experience doing track and sign identification a participant had before the evaluation, their gender, whether or not they self-identified as an indigenous person, and what major community they self-identified from.

Comparison of the Eval and Photo datasets (All Data)

The two models, evaluation and photo, could not be compared statistically because they did not share enough independent variables. They were qualitatively compared using descriptive statistics and graphical summaries of tracker level performance on getting questions correct and through comparisons of example questions.

Data analysis

I transcribed data from scoresheets (evaluations) and field notebooks (camera-trapping) into Microsoft Excel spreadsheets, which was then imported into a Microsoft Access database. Survey instrument data provided by participating trackers were also transcribed and included in the same Access database. I used Access to create queries, explore the data, and to generate initial descriptive statistics. The data were unstacked according to their method of collection (eval or photo) into two different datasets. Text string variables were converted to integer variables for analysis and visualization. The data met the following assumptions: a binary dependent variable, independent observations, little or no multicollinearity among independent variables, linearity of independent variables and log odds of the response variable, and a large sample size. I used Pearson’s coefficient to test for correlations and then binary logistic regression in Minitab 19 and Python 3.6 for null hypothesis testing and prediction. Results were considered significant at $p < 0.05$.

The binary, dependent variable in the logistic regression model for the evaluation data was *match*. When an answer given by a participant in an evaluation matched the question asked, the question was answered correctly and the value recorded for that question/participant combination was either match = correct or if the participant's answer did not match the question, the answer was match = incorrect. The independent, categorical variables recorded from the evaluation score sheets were:

- *Tracker level* achieved (0, 1, 2, 3, and 4 in secondary evaluations, and 5 and 6 in tertiary evaluations) Note, it's important to clarify the differences between actual tracker levels achievable in each type of evaluation, and the coding terms used in this analysis (Figure 2). Figure 2 also emphasizes a critical point, which is that in the evaluation model, the analysis includes terms for tracker levels 0 through 6, while in the photo model the analysis omits "level 5" because it does not exist in a non-evaluation situation. Level 5 are participants who have achieved 100%, or Professional level, in the secondary evaluation, and then attempted the more rigorous Specialist level evaluations but not yet passed the Specialist level with 100%.
- *point rating* for each question asked (1, 2, 3, 4, where a point rating of 4 is considered a "bonus' question of extreme complexity), and
- *band* (secondary or tertiary, formerly known as lower and upper band, or standard and specialist, respectively).

For each question, I also created ten additional descriptive, categorical variables to try to determine if one or more made significant contributions to predicting that participants of different tracker levels answered more questions correctly:

- *Taxon* (amphibia, aves, invertebrates, mammalia, none, plantae, reptilia, variable (for example, aves is clearly a bird, but alarm call varies with species)),
- *group* (bird, herp, hoof, human, invert, mega, other (natural, number, body part, age, alarm), pad, or vehicle),
- *type* (interpretation (sex, foot, gait, etc.), other (wind, stone, vegetation), scat, sign, track, trail)
- *number of legs* (num legs = 0, 1, 2, 4, 6, 8, 16, 30 or 80),
- *number of toes on the front foot* (num toes front = 0, 1, 2, 3, 4, or 5),
- *number of toes on the hind foot* (num toes hind = 0, 1, 2, 3, 4, or 5),
- *foot complexity* (based on number of pads/angles or distinct identifying features always present: complex, medium, none, simple, variable),
- size of track or sign (*TorS size* = large, medium, small, variable, very large, very small),
- social structure (*spp social structure,* or *sss* = groups, none, pairs, solitary, variable), and
- common (*TorS common* = yes or no, if a track or sign is commonly found).

I performed the same logistic regression analyses with the photo data as with the evaluation data, above, where the dependent, binary, variable was match (correct or incorrect), based on whether or not the participant identified the tracks or sign of the species in the photo correctly. The independent variables were the same as in the evaluation data, except that there were no point ratings for photo data because I was not yet an evaluator and there were no other evaluators present to assign point ratings. The following four qualitative variables were also added from the survey instruments:

- *Indigenous* (yes or no, based on South Africa tribal affiliation (Shangaan)),

- *gender* (female or male),
- *community* (European, Indian, North American, Shangaan, South African), and
- *experience* with tracking (months experience, converted to *years experience*, ranging from 1 to 18 years as a continuous variable).

Results

Total number of questions

In total, participants were asked 365 unique questions about tracks and signs during evaluations and camera-trapping. 462 unique answers were given because a participant could give any possible answer for a question. There were 78 questions that were asked in both the evaluations and the camera-trapping. Example questions are: aardvark (tracks), white rhinoceros dung, lion gait correct, and leopard sex correct (gait and sex questions, respectively, were pooled and matched as correct or incorrect. For example, a lion trotting was coded as *lion gait correct* just as a lion in an overstep walk would be *lion gait correct* and their corresponding answers could either be *lion gait correct* as a correct answer, or *lion gait incorrect* if the participant answered incorrectly.

Evaluation data

The evaluation dataset includes information from 147 evaluations (139 secondary and eight tertiary) and 1027 participants (985 secondary and 42 tertiary). There were 323 unique questions asked during evaluations (314 secondary and 160 tertiary), and 419 unique answers given (408 secondary and 190 tertiary).

For each tracker level, as the point rating increases, trackers get fewer questions correct (Table 2). For example, at tracker level 1, questions at point rating 1 were answered correctly 91% of the time (*n*=2269), questions at point rating 2 were answered correctly 73% of the time (*n*=6527), questions at point rating 3 were answered correctly 48% of the time (*n*=2440), and the 35 questions asked at the bonus level (point rating 4) were answered correctly 9% of the time. Note: bonus level questions are not typically asked at the secondary level. This trend is seen throughout the data, from a robust sample size of 49,000 questions asked. Then, in an example going down the data, questions with simple complexity (point rating 1) are answered correctly 82% of the time (*n*=1454) by participants that are rated as not yet competent, 91% by level 1 trackers (*n*=2269), 95% by level 2 trackers (*n*= 3221), 98% by level 3 trackers (*n*=2499), and 99% by professional trackers (*n*=89). Questions with simple complexity are not asked in tertiary evaluations, so there is no data for specialists or specialist attempts. On the other end of the spectrum (excluding bonus level questions, coded here as point rating 4), complex questions (point rating 3) are answered correctly only 40% of the time (*n*=1603) by participants that are rated as not yet competent, 48% by level 1 trackers (*n*=2440), 65% by level 2 trackers (*n*=3498), 76% by level 3 trackers (*n*=2738), and 95% by professional trackers (*n*=95). In tertiary evaluations, 86% of complex questions are answered correctly (*n*=1720) by trackers who are technically still professional trackers who attempt but are not yet competent at the specialist level, and 94% of these more numerous and difficult questions are answered correctly by specialists (*n*=181).

I found that higher-level trackers are able to answer more, and more complex, questions correctly (Figure 4). In Figure 4, the plot on the left includes the dummy code for level 5 at the tertiary evaluations, which drags that point down in the figure because those participants score lower than professional level and even some level 3 participants from secondary evaluations, but they are doing so in a much more difficult evaluation. The plot on the right groups level 5 in with professional level, which makes the 3-D graph less discontinuous at that point. Neither plot is incorrect, they each merely depict different ways the data were analyzed, removing and including level 5 as a dummy variable because it was not an official CyberTracker level but was distinct from professional level and specialist level.

Pearson correlation tests revealed that band was correlated with tracker level (58%), number of toes front was correlated with number of toes hind (81%), and number of toes hind and foot complexity were correlated (74%), and number of toes front was correlated with foot complexity (51%). I left band and number of toes hind in the model. I chose to leave number of toes hind instead of number of toes front and foot complexity because birds were categorized as only having hind toes on hind feet, with front feet representing wings with zero toes. Regardless, band, both numbers of toes variables, and foot complexity were not-significant and were removed from the model.

Significance and coefficients for logistic regression

The explanatory variables significant to the evaluation model at $p \leq 0.05$ (Wald test, n=49,000) were tracker level, point rating, type (of track or sign), TorS size (size of track or sign), species (spp) social structure, and TorS common (how common was the track or sign). The two variables contributing most to the evaluation model were tracker level and point rating. Statistically significant, but not contributing much to the model were the variables type, size, social structure, and common.

Notable among the test results for the coefficients, is the non-significant p-values for type = trail (P=0.092), TorS size = small (p=0.119), species social structure (sss) = solitary sss (*p*=0.110) and variable sss (*p*=0.239). These results indicate even though the variable was significant overall, the means of those coefficients within the variables are not different from the mean of the reference event of the variable, trail from interpretation, small from large, and groups from solitary and individual (Table 3).

In addition to *p*-values, Table 3 also shows the variance inflation factors (VIF), coefficients (Coef), the standard errors of the coefficients (SE coef), Z-values, and 95% confidence intervals (95% CI). In the table, all VIF values are all between 1 and 5, indicating little or no multicollinearity. The coefficients for tracker level are all positive, indicating that a participant answering a question correctly at each increasing tracker level is more likely than at the reference level (0). The standard errors of the coefficients (SE coef) for tracker level are all small (near 0), indicating that they are precise. Z-values for the 95% confidence intervals (95% CI) are large enough (absolute value >2) to also indicate a statistical difference from zero. Conversely, the coefficients for point rating are all negative, indicating that a participant answering a question correctly at each increasingly complex point rating is less likely than at the reference event (point rating 1, or simple complexity). VIF, SE Coef, 95% CI, and Z-values are similar to those described above. With the exception of the already mentioned significant difference between interpretation questions and trail questions, the other events in type (other, scat, sign, and track) follow the same significance test pattern as those in tracker level. What this means is that other, scat, sign, and track questions are more likely to be correct than interpretation and trail questions. The reference event in TorS size = large and all coef of the other events (except veryLarge) are negative, they follow the same significance test pattern as indicated in point rating. This result is interpreted as larger tracks are identified correctly more frequently than smaller tracks, across all size ranges. As previously mentioned, species social structure contains two non-significant events to the reference event (groups sss), solitary sss and variable sss. The remaining events, none and pairs, have negative coefficients. This indicates that they are less likely to be answered correctly than a question about a species with a group social structure. The variable TorS common has a small but positive coefficient, indicating that when a species is common (yes) a participant is more likely to answer questions about it correctly than if it is uncommon (no).

Odds-ratios for logistic regression

The odds-ratios illustrate the within-groups relationships with greater detail (Table 4). Odds-ratios compare each event in each variable with the other events in that variable. Therefore, each event in the first column, level A, is compared to each reference event in the second column, level B, by its odds-ratio and 95% confidence interval. If the odds-ratio for a comparison is >1, then questions are more likely to be correct at level A. If the odds-ratio for a comparison is <1, then questions are more likely to be correct at level B. For example, tracker levels where A=1 and B=0, we interpret this as the odds of a tracker level 1 getting a question correct are almost 2 (1.7787) times more likely than a tracker level 0. This trend continues throughout increasing tracker levels, with smaller odds-ratios between levels that are close together than in ones that are further apart. For example, the odds of a tracker level 4 (professional) getting a question correct are almost 40 times (39.7721) more likely than a tracker level 0 (not-yet-competent), odds of a tracker level 4 getting a question correct are over 22 times (22.3607) more likely than a tracker level 1, odds of a tracker level 4 getting a question correct are over 12 times (12.4853) more likely than a tracker level 2, and the odds of a tracker level 4 getting a question correct are almost 6 times (5.7553) more likely than a tracker level 3. At the tertiary evaluation level, the odds of a tracker level 6 (specialist) getting a question correct are only 0.7 times (0.7045) more likely than a professional level tracker. It's important to remember though, that participants are being asked only complex and very complex questions at that level, whereas professional level trackers are being asked questions with a mix of complexity levels in a secondary evaluation. Within the tertiary evaluation itself, the odds of a specialist level tracker getting a question correct are approximately 3 times (2.6549) more likely than a non-specialist, level 5.

Odds-ratios for point rating are all small but <1, indicating that the questions are more likely to be correct at Level B. Therefore, as point rating increases, the likelihood of a participant getting a question correct decreases slightly with the question's increasing complexity. The variable type has a mix of odds-ratios that are <1 and >1, where interpretation questions are less likely to be answered correctly than the other types of events, and other (natural, stone, vegetation, alarm calls, etc), scat, and sign are all less likely to be answered correctly than track questions. While trail was not significantly different from interpretation, odds-ratios indicate trail questions (which often contain invertebrates and snakes) to be less likely correct than the other events, except for tracks, where trails are more likely to be answered correctly. For the variable TorS size, there are also odds-ratios of <1 and >1, and the trend indicates that questions are more likely to be correct when the track or sign is larger, rather than smaller. Recall that within species social structure, the events solitary sss and variable sss were not significantly different from the reference event, groups, but otherwise having a social structure of any kind generally increased the likelihood of a question being answered correctly. The odds-ratio for TorS common indicated that the odds of getting a common track or sign question correct are approximately 2 times more likely than an uncommon one.

Model fit and predictive ability for logistic regression

The predictive ability of the binary logistic regression models was low, eval model: r-sq = 0.143, r-sq (adj) = 0.1426 (df model = 5, df residuals = 49993). The small r^2 value could be for many reasons, and will be addressed in the discussion section. Additionally, reducing the model to all but the two variables that contributed the most, tracker level and point rating, only decreased the model fit to r-sq = 13.00%, r-sq (adj) = 12.99% (df model = 5, df residuals = 49993).

Camera-trapping data

I camera-trapped in seven different venues over three field seasons (May – Aug, 2010, 2011, 2012), testing 111 previously evaluated participants (Table 5). Eighty-two days (1968 hours) of camera-trapping were conducted (Table 6). There were 120 different species photographed/questions asked during camera-trapping, and 133 different answers given.

In Table 2, the light grey columns on the right show both the number of trackers participating at each tracker level and their mean percentage of correct answers. There are two zeros in two different cells, for level 0 (not yet competent), and also for level 5 (not yet a specialist). This is because all participants in the study were certified at some level of competency, and technically a level 5 tracker is still a professional level because this study was not actually conducted within an evaluation. So, the data from trackers that were not yet specialist but had attempted at least one tertiary evaluation are recorded under the professional level. Going down the photo column, tracker level 1 mean percent correct was 71% (*n*=547), tracker level 2 mean percent correct was 80% (*n*=1622), tracker level 3 mean percent correct was 88% (*n*=1550), professional level mean percent correct was 94% (*n*=888), and specialist level mean percent correct was 98% (*n*=2713).

Many of the same variables from the evaluation model were also included in the photo model. Band and point rating were not included because the photo data was not collected during evaluations. Camera-trapping data included additional demographic variables taken from survey instruments, such as the community a tracker comes from, whether a participant was male or female (gender), whether or not the participant considered themselves *indigenous* to that land, and their estimated months of experience with tracking. The variable for months experience was converted to years experience and from categorical to continuous.

Pearson correlation tests revealed that number of toes hind and foot complexity were correlated (87%), taxon was correlated with group (67%) and gender was correlated with indigenous (60%). Similarly, with the evaluation data, I kept number of toes hind in the model, but the variables for number of toes hind, foot complexity, taxon, group, type, number of legs, species social structure, gender, and community were not-significant and were dropped.

In the photo model, tracker level, TorS size, and TorS common were significant variables, and among the additional demographic variables, years experience with tracking and indigenous were significant at $< P = 0.05$.

Significance and coefficients for logistic regression

The explanatory variables significant to the evaluation model at $P \leq 0.05$ (Wald test, n=7320) were years experience, tracker level, TorS size (size of track or sign), TorS common (how common was the track or sign), and indigenous. The two significant variables that contributed most to the photo model were tracker level and years experience (Table 7).

All VIF values for significant variables in the photo model are between 1 and 5 (Table 7), indicating little or no multicollinearity. The coefficients for tracker level are all positive, indicating that a participant answering a question correctly at each increasing tracker level is more likely than at the reference level (1). The standard errors of the coefficients (SE coef) for tracker level are all small (near 0), indicating that they are precise. Z-values for the 95% confidence intervals (95% CI) are large enough (absolute value >2) to also indicate a statistical difference from zero. The reference event for TorS size = large, and all the coefficients of the other events (except veryLarge) are negative. This result is interpreted as larger tracks are correct more frequently than smaller tracks, across all size ranges. The variable for TorS common has a positive coefficient, indicating that when a species is common (yes) a participant is more likely to answer questions correctly than when a species is uncommon (no). Interestingly, indigenous is significant in the model, with a small negative coefficient. The negative coefficient indicates that questions are more likely to be answered correctly by non-indigenous participants (see discussion, and chapter 4).

Odds-ratios for logistic regression

The odds-ratios given illustrate the within-groups relationships for the photo model (Table 8). Years experience with tracking is positive and >1 (1.1). This result indicates that as experience accumulates trackers are increasingly likely to answer questions correctly. Tracker levels A=2 and B=1, indicates that the odds of a tracker level 2 getting a question correct are 2.1 times more likely than a tracker level 1. This trend continues throughout increasing tracker levels, with smaller odds-ratios between levels that are close together than in ones that are further apart. For example, the odds of a professional tracker level 4 getting a question correct are 5.9 times more likely than a tracker level 1, odds of a professional tracker getting a question correct are 2.8 times more likely than a tracker level 2, odds of a tracker level 4 getting a question correct are 1.9 times more likely than a tracker level 3. Between the tertiary and secondary levels, the odds of a specialist tracker getting a question correct are 2.4 times more likely than a professional level tracker, odds of a specialist tracker getting a question correct are 4.4 times more likely than a tracker level 3, odds of a specialist tracker getting a question correct are 6.7 times more likely than a tracker level 2, and the odds of a specialist tracker getting a question correct are 14.2 times more likely than a tracker level 1.

For the variable TorS size, there are odds-ratios of <1 and >1, yet the trend indicates that questions are more likely to be correct when the track or sign is larger, rather than smaller. The odds-ratio for TorS common indicates that the odds of getting a common track or sign question correct are approximately 4 times more likely than an uncommon one, and indigenous trackers are slightly less than 1 time (0.7) less likely to answer a question correctly than non-indigenous trackers (see discussion, and chapter 4).

Model fit and predictive ability for logistic regression

The predictive ability of the photo model was low: r-sq = 0.1924%, r-sq (adj) = 0.190% (df model = 4, df residuals = 7315). This could be for many reasons, and will be discussed further in the next section. Additionally, reducing the model to all but the two variables that contributed the most, years experience and tracker level, only decreased the model fit to r-sq = 14.26%, r-sq (adj) = 14.00% (df model = 4, df residuals = 7315).

All data

Evaluation participants answered 38960 question correctly (78%) and 11039 incorrectly, and photo participants answered 6542 questions correctly (89%) and 778 questions incorrectly. The percentages of correct answers are high, suggesting that identifying tracks and signs correctly might accomplished by unskilled observers. However, only 17 out of 365 questions were always answered correctly, and those questions were generally less complex in their point ratings. In the evaluation study, the number of correct answers given by participants in evaluations clearly increases with tracker level and decreases with point rating, and in the camera-trapping study, the number of correct answers also increases with tracker level and years experience (Table 2.). Tracker level was the only variable that was shared, significant, and contributed much to the predictive value of both models. All other significant explanatory variables appear to have only small effects on the outcome of a participant getting a question correct. Figure 5 shows a side-by-side line plot comparing the percentage of questions answered correctly by trackers of increasing levels of certification in evaluations and in the camera-trapping study. The dip in tracker level 5 is caused by trackers not obtaining 100% in the more difficult tertiary evaluations, and it corresponds to a gap in the photo data where that level does not exist because those trackers remain officially certified as professional level.

Discussion and Conclusion

Descriptive statistics indicate that people hired to collect track-based data will, on average, be correct 82% of the time when answering questions of simple complexity. These percentages indicate what level of skill is necessary to accurately collect simple track-based data, on average. But, some species/questions are more complex than others, and therefore more difficult to answer and require a higher level of expertise.

The average score of specialist trackers was 97.94% in T&S evaluations, with respect to the mean number of questions answered correctly in evaluations. Bonus questions were answered correctly less than 50% of the times answered by specialist level candidates (both those that passed and those that did not). Therefore, I conclude that higher certified trackers, on average, will perform better than lower certified trackers, and lower certified trackers perform better than non-trackers. Experience and effort matter most to expertise in tracking. Evaluation through the CyberTracker standard reflects the quality of a tracker's experience, effort, and ability to correctly identify species from tracks and signs.

Evaluation data corroborated by camera-trap data also showed that trackers certified by CyberTracker evaluations in South Africa accurately identified and interpreted wildlife tracks and signs, and differentiated the tracks and signs of similar species. Unqualified or low-level participants in CyberTracker evaluations in South Africa were able to answer some questions correctly, but the percentage of questions answered correctly increased as participants achieved higher levels. Some questions of simple complexity, such as fresh elephant tracks (*Loxodonta Africana*) were almost always answered correctly by all levels of participants, whereas other questions of higher complexity, such as fresh caracal tracks (*Caracal caracal*) required higher scoring participants to answer them correctly.

Results from the evaluation model indicated that the main variables of tracker level and point rating are significant and contribute the most to the model. Results from the camera-trapping model indicate that years of experience and tracker level are significant and contribute most to the model. In both models, the likelihood of answering questions increased with T&S size, and with how common a T&S was. In the evaluation model, track questions were the most likely to be answered correctly, and scats, other signs and interpretations were less likely to be answered correctly. Questions where the species had a recognizable social structure were correct more frequently in the evaluation model that species without a recognizable social structure. Social structure was not significant in photo model, possibly due to the low sample size.

The predictive values of getting a question correct with any of the variables included on was low for both models. Could this be because of confounding effects of substrate, weather, size of tracks, and scarcity of particular species? The number of different questions asked (n =

323 eval, n = 120 photo, with 78 similar questions in both) at different levels of complexity (n = 4), some of which were always answered correctly, some were always answered incorrectly, and with many combinations in between by trackers of seven different levels of quantifiable skill on the evaluations results in extremely high variability. Thus, even though the model accurately indicates that higher level trackers will answer more, and more difficult, questions correctly, how a participant will answer a singular question, can vary widely. Alternatively, there are unmeasured variables that could contribute to the predictive ability of the model, such as the local knowledge of the number of different species present in the area where the evaluation question was asked. For example, on a specific reserve where the trackers and guides live and work, there might be an area where they frequently see a caracal (*Caracal caracal*) while conducting their game drives, but have never seen a serval (*Leptailurus serval*) or an African wildcat (*Felis lybica*) in the same area. This familiarity could benefit trackers in answering the question because caracals are behaviorally territorial and a good guess would be a caracal for a medium sized cat track in that area if they knew one lived there. If, however, the trackers and guides know that servals, African wildcats, black-backed jackals (*Canis mesomelas*), and African civets (*Civettictis civetta*) occur in the same area, this complicates their choice of answer by at least four other species, without even considering the quality of the substrate. Point rating captures some of this variability, but is limited to 4 selections: simple complexity (1), complex (2), very complex (3), extremely complex but not impossible (4). Evaluators never ask caracal tracks at a 1-point rating because they are inherently challenging. They are always asked at, at least, a point rating of 2, and the point rating can increase to a 3 in a secondary evaluation or to a 4 in a tertiary evaluation based on the condition of the tracks: details present or absent, whether or not there is a sequence of multiple tracks to examine, and whether or not there are any other

species in the area that caracal tracks are confused with. So, while the complexity of a question does increase and is reflected in the point rating, it does not account for the exact variables that made it increase nor the potential number of species it could be confused with. Thus, questions reach a threshold of complexity that might not encapsulate the true complexity of the question. In order to include the true complexity of the question, evaluators would need to record the number of species with similar foot morphology from reserve to reserve, based on a reserve species list. Such a list would miss species that are present but not yet recognized to be so.

The amount of experience a tracker has indicates very slow growth over time, on average, and could be refined as a predictive variable in the future. As the variable experience is currently used, specialist level trackers range from having 3 years to 18 years of experience. Perhaps a more useful, or additional, measure would be how long the tracker has been a specialist for. Similarly, most tracker levels contain a range of scores. Participants at level 0 that are not yet competent achieve scores between zero and 69%; level 1 at 70-79%, level 2 at 80-89%, level 3 at 90-99%, only level 4 (professional level) in secondary evaluations is strictly 100%. In the more challenging tertiary evaluations, where no questions of simple complexity are asked, the only passing score is 100% (specialist level), with scores seen as low as 87% in this data, which would result in those participants remaining at the previously achieved professional level (they are not demoted to level 3). Yet, when the model is run using the participants' actual scores as the dependent variable instead of their tracker levels achieved, the predictive power of the model does not change. Separating the analysis into two models, one for secondary evaluations and one for tertiary evaluations does also does not change the predictive value of the model for secondary evaluations, and decreases the predictive value of the tertiary evaluations (probably due to the reduced sample size).

Large numbers of unusual observations are present in both models, but careful review of these provides no justification for removing them. They are unusual, but sometimes novice trackers get lucky in an evaluation by answering a question correctly, just as sometimes high-level trackers get questions wrong. While this provides evidence for independence of observations, it also increases variance around the means of the explanatory variables.

Explanatory variables that might be missing from the analysis include how many years a question has been asked, and at what point rating. In my observations, the question of a single rhinoceros's single toe (not the entire track) was very difficult for participants to recognize when rhino toe was a new question. But, as participants were increasingly exposed to the question and people informed one another, they learned to study what a single rhinoceros toe looked like very carefully under different conditions to increase the likelihood of recognizing a single rhino toe in an evaluation. This learning process transferred itself to other animal's tracks, like hippopotamus, or even hyenas, where a single toe became a recognizable question. This isolated recognition process, might even fail to encapsulate the statistical nature of the process, because someone who is employed every day to follow and find rhinoceros might have already seen thousands of variations of a rhino's single toe in many different substrates, behaviors and weather conditions. So that might be a simple question to them. But trackers are not usually asked to follow and find things like hyenas, so a single toe of a hyena might be an extremely complex question to the same tracker. Additionally, as a new question is introduced to the system, e.g. rhino toe, the question begins at a bonus level rating, and over the course of years becomes less complex in rating because – once you learn to see it, it's almost unmistakable, and trackers who get it wrong to begin with rarely do so again. So, what then is the true complexity of a rhino's single toe?

Other possibly important explanatory variables include differences among the evaluators. The length of time an evaluator has been qualified or how many evaluations they have completed, and the number of additional evaluations they have attended as a peer-reviewer, or the number of times they have been peer-reviewed by another evaluator, are all variables not considered here.

The experience of evaluators and the peer review component of this system is critical to establishing and maintaining a standard. Even with rigorous training to become an evaluator, I have observed that new evaluators are not as clear in the way they ask some questions, or what an allowable question is, as more seasoned evaluators are. Conversely, more seasoned evaluators have more experience, which leads to more skill, and they are constantly exposed to new information from participants wherever they travel to conducting evaluations. This exposure can lead to a situation where a seasoned evaluator has seen a question enough, with enough variation, that s/he thinks a question is of simple complexity, and it might be to him or her, but in reality, it's a very complex question for the majority of participants attempting an evaluation. If evaluators don't meet regularly to share information and compare how they are currently wording and rating questions, there can be migration of complexity from the standard in both directions – where some questions become more difficult and others too easy.

Finally, the explanatory variable indigenous was significant in the photo model. The odds-ratios showed that indigenous trackers are 0.7078 times less likely to answer a question correctly than non-indigenous trackers. This variable contributed minimally to the model overall, but is still intriguing because I expected indigenous trackers to be more likely to answer questions correctly than non-indigenous trackers. The indigenous culture studied in this dissertation are the Shangaan people living around the Kruger National Park. People from indigenous cultures purportedly retain some amount of traditional ecological knowledge from living in close association with the land. Traditional ecological knowledge usually revolves around culturally specific ways of obtaining or creating food, medicine, shelter, or some characteristic that improved a group of people's qualities of life. Since the end of the apartheid era in South Africa, indigenous peoples have moved, largely *en masse*, towards towns and cities where children can be educated by western systems and jobs can be obtained. Trackers are aging, and no longer passing on these skills to the younger generation, who all claim to want to become engineers, lawyers, and doctors. The relationship with land is no longer noticeable. At the same time, there is a shift, towards non-indigenous people, from all over the world, to learn tracking out of a simple interest to know what is living and moving around them. This will be discussed further in chapter 4.

Recommendations

My research has demonstrated that measurable training or experience matters when observers collect track-based data. More experienced trackers are more reliable in the questions that they can answer, especially when those questions are complex. The CyberTracker evaluations form a good baseline for determining the reliability of observers collecting track-based data for science. When questions are simple in complexity (unmistakable, even by a novice, with no confusing species present and in areas with good substrate), an unrated or low-level tracker will suffice. In other areas and with other, more complex questions, a minimum of a level 3 tracker should be hired to expect data to be reliable approximately 75% of the time. In South Africa, the desired level in most reserves is the professional level, because those trackers have demonstrated competency at a high level. Under extremely difficult conditions, or in supervisory or teaching capacities, hiring a specialist, or having a specialist mentor available to the research team, is advised. Complexity can include such characteristics as old, weathered, partial, easily confused with other species, uncommon, small, and no obvious social structure. Moreover, scats, signs, and interpretations can be more difficult than tracks to identify.

Figures and tables

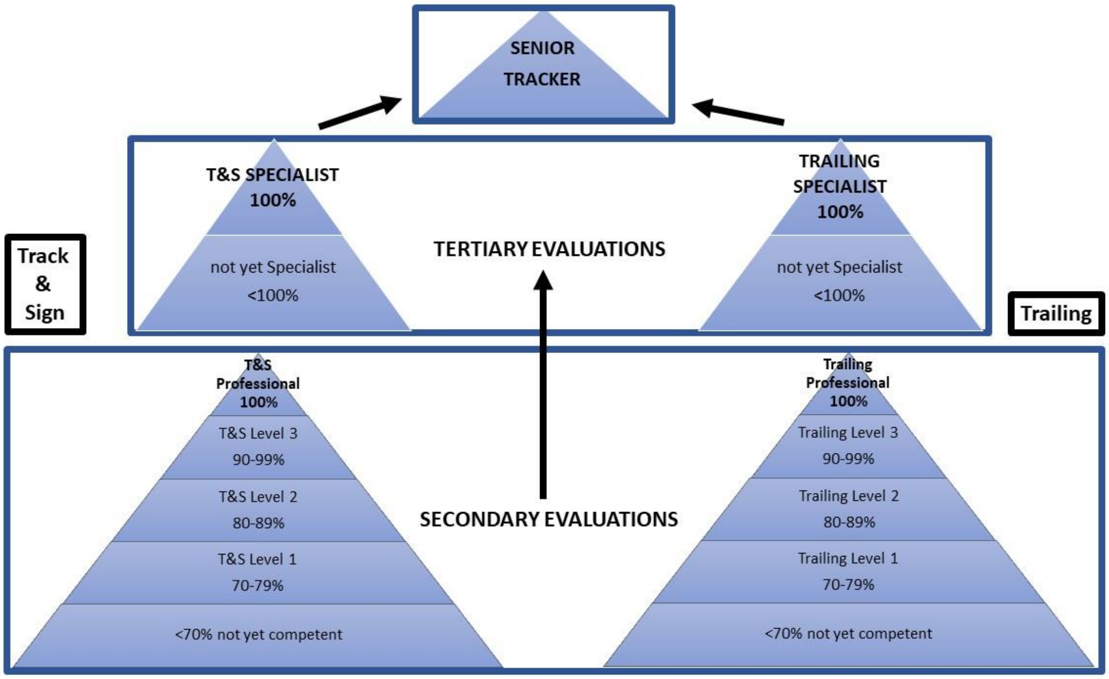


Figure 1. The potential progression of trackers in CyberTracker evaluations.

Working from bottom to top in either T&S Identification and Interpretation (left), or in Trailing (right), from "Not yet competent" (bottom) to "Specialist" (top), or even "Senior Tracker" (top of figure, the highest level that can be earned). As the pyramids suggest, there are fewer participants are able to achieve higher levels than lower ones. Note, the name of the lower band/standard evaluation has been changed to the secondary evaluation and the name of the upper band/specialist evaluation is used interchangeably with tertiary evaluation.

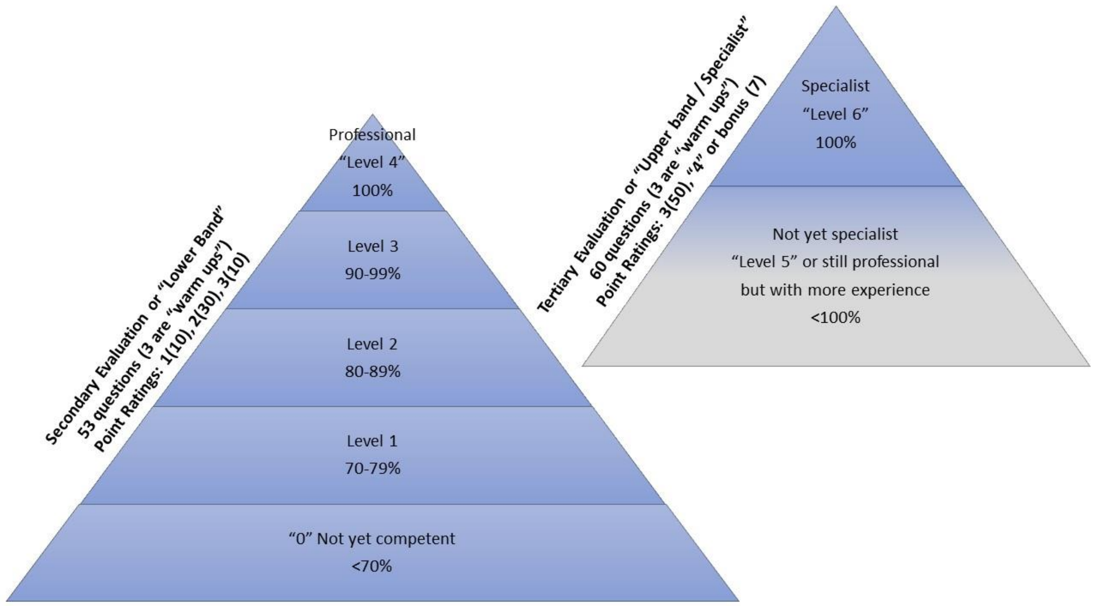


Figure 2. Achievable tracker levels in track and sign evaluations.

There are two different levels of track and sign evaluations that participants can attempt. Labels in quotation marks, above, are either previously used terminology within the system or the term used for convenience in this analysis. Pyramids represent the increasing difficulty in achieving higher levels. A participant must achieve 100% in the left pyramid, the secondary evaluation, before proceeding to attempt the smaller pyramid on the right, the tertiary evaluation. The terms secondary and tertiary come from descriptions of levels in western education. On the left, a participant attempts 53 questions. The first three questions in an evaluation are "warm up questions" and do not count. The remaining 50 questions are administered in the following proportions: 10 at point rating 1 (simple), 30 at point rating 2 (medium complexity), and 10 at point rating 3 (complex). Tracker levels 1, 2 and 3 are actual levels that can be awarded. Zero is not a level, and is "not-yet competent". Level 4 is known officially as professional, thus, levels 1, 2, 3, and professional are all levels awarded within the secondary (lower band) evaluations. Scores achievable range from not yet competent (<70%) to professional (100%). Once a participant has achieved professional, they can progress to the tertiary level evaluation, shown in the right pyramid. This is a pass/fail evaluation where specialist level (labeled level 6 in this analysis) is only achieved with 100% correct answers, and with only complex (point rating 3) and very complex (point rating 4) questions. *The grey color at the bottom of the tertiary evaluation pyramid represents a "vague area" where a participant is not yet a specialist (labeled a level 5 in this analysis) and thus, is still a professional but has the additional benefit and experience from taking a tertiary evaluation. In the evaluation model, the analysis includes terms for tracker levels 0 through 6, while in the photo model the analysis omits "level 5" because it does not exist in a non-evaluation situation.*

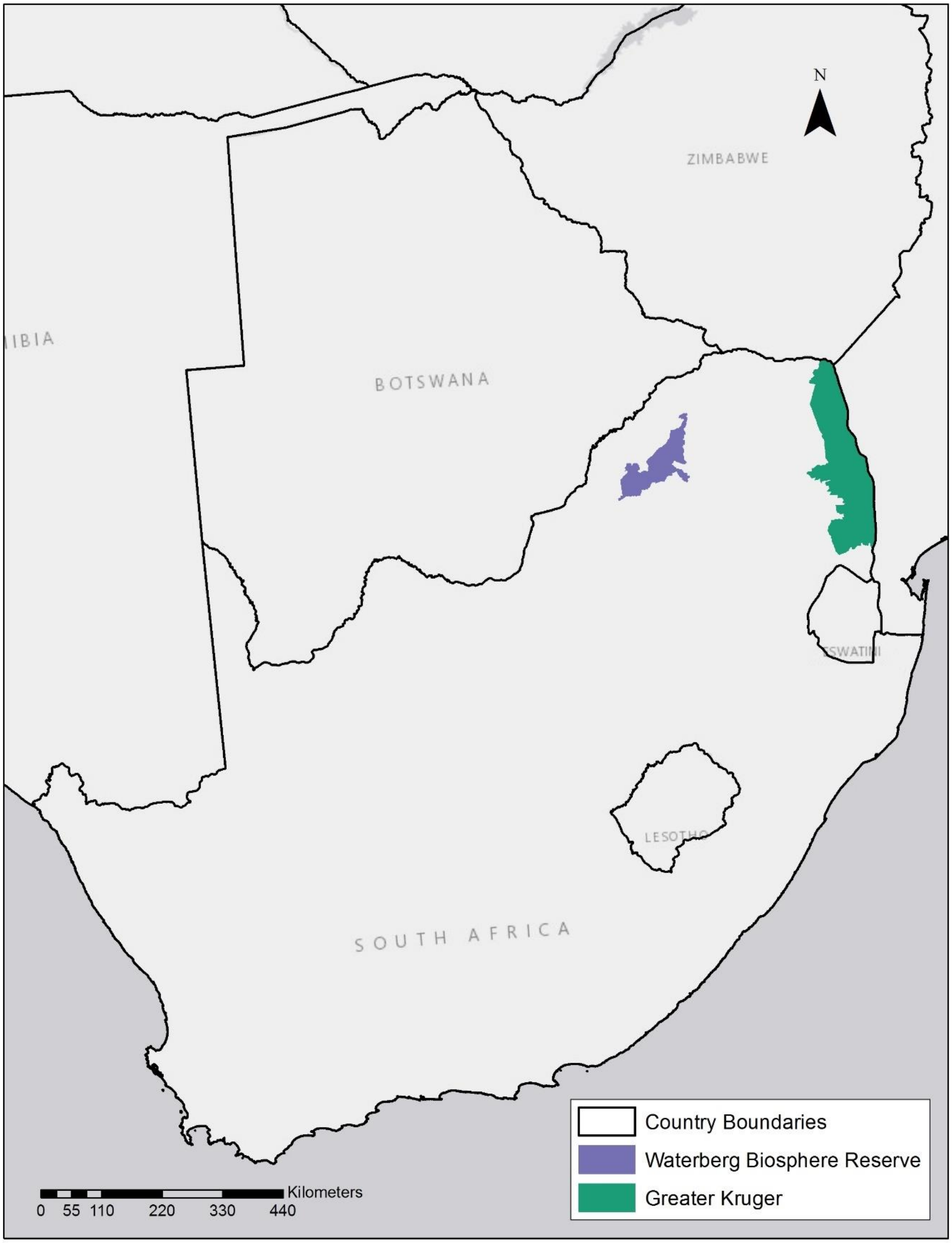


Figure 3. A map of the major study areas where camera trapping and surveys were conducted with CyberTracker certified trackers in South Africa. Map created by Elaine Linden.

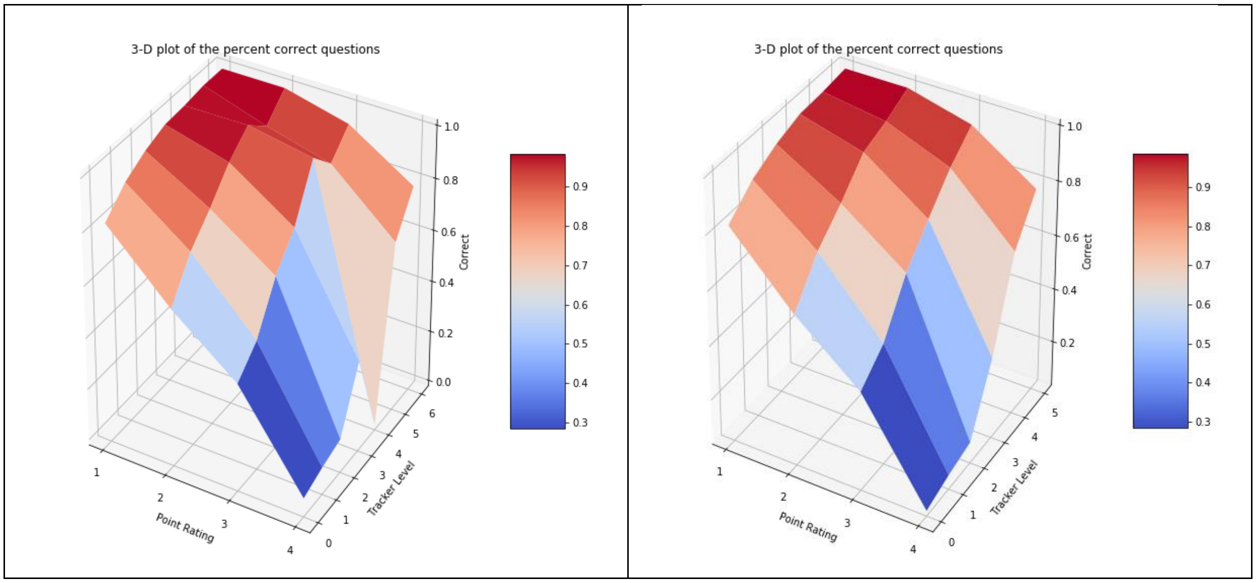


Figure 4. Three-dimensional plots showing the impact of tracker level and point rating on getting a question correct.

The plot on the left separates out participants that do not obtain specialist from those that do in the more difficult tertiary evaluations, whereas the plot on the right combines non-specialists with professional level trackers.

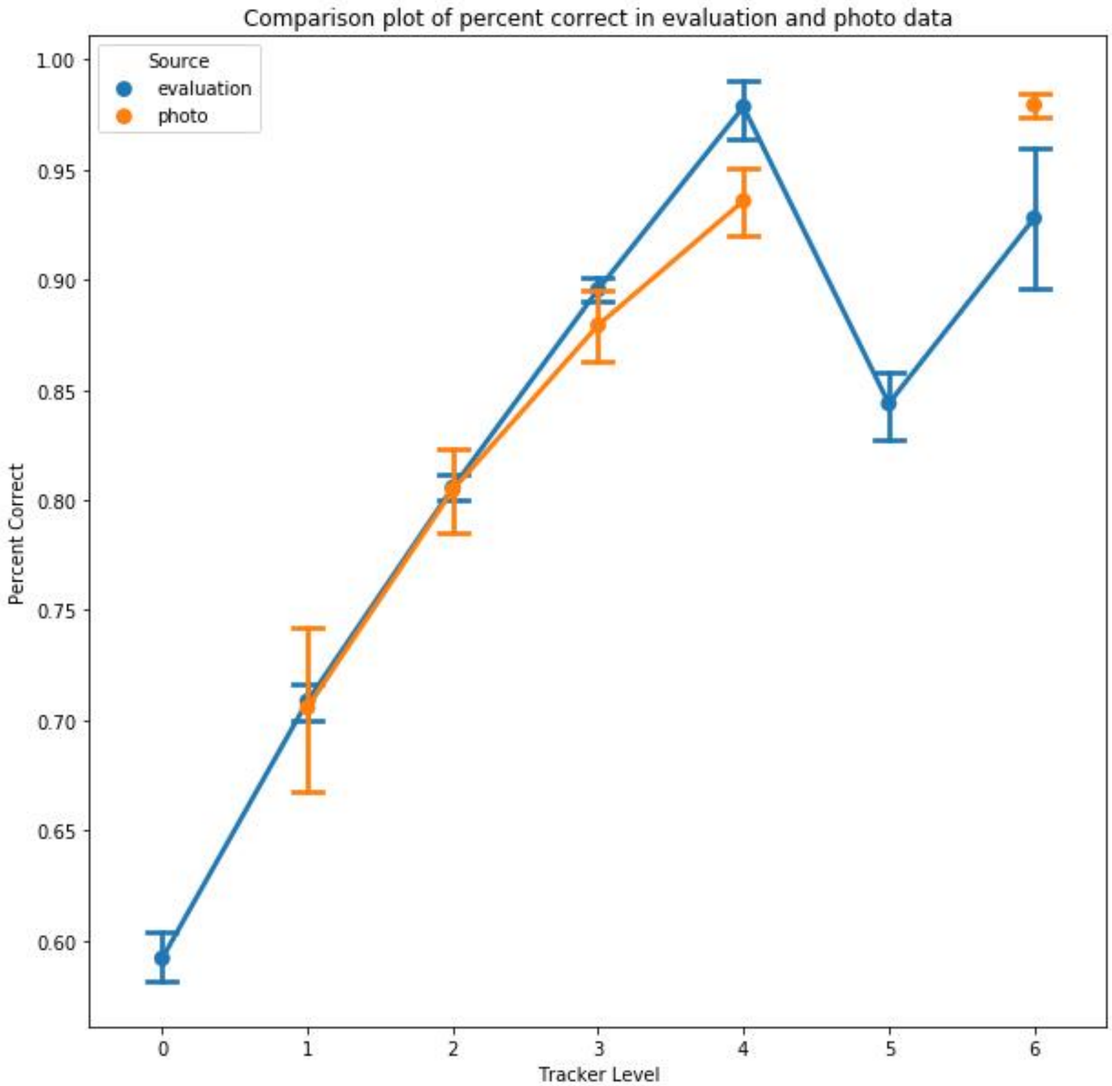


Figure 5. Line plots comparing the performance of different levels of trackers in getting questions correct from evaluations with the camera-trapping data.

Table 1. An example of a completed, secondary, CyberTracker Track and Sign evaluation score sheet.

		✓ xxx 10 1	✓✓ xx 30 2	✓✓✓ x 10 3	MARTIN	ISAAC	ORLANDO	BJINSE	ALAN								
Q #	Question																
1	WHITE RHINO DUNG		//		//	//	//	//	//								
2	IMPALA		//		//	//	xx [illegible]	//	//								
3	IMPALA MIDDEN	/			/	/	/	/	/								
4	DUNG B. EXCAVATION		//		//	//	//	//	//								
5	BUFF DUNG		//		//	//	//	//	//								
6	ELLIE DUNG	/			/	/	/	/	/								
7	BUFF RUBBING BOSS			///	///	///	///	///	///								
8	TERMITE FEEDING			///	///	///	///	///	///								
9	TERMITE NEST		//		xx ANTS	xx ANTS	xx ANTS	//	//								
10	BUFF TRACK		//		//	//	//	//	//								
11	BABOON SPIDER HOLE			///	///	///	///	///	x TR DOOR								
12	GUINEAFOWL FEATHER		//		//	//	//	//	//								
13	GFOWL TRACK		//		//	//	//	//	//								
14	ROADBUILDER ANT TR	/			/	/	/	/	xxx BEETLE								
15	LEOPARD	/			/	/	/	/	/								
16	HIND		//		xx FRONT	//	xx FR	//	//								
17	LEFT		//		//	//	//	//	//								
18	SEX ♀			///	///	x ♂	x ♂	///	///								
19	BABOON SHIT			///	///	///	///	///	x MONG								
20	GIRAFFE		//		//	//	//	//	//								
21	JACKAL TRACK		//		//	//	//	xx BABOON	xx WH RH								
22	POTTERY SHARD		//		//	//	//	//	//								
23	GIRAFFE DUNG		//		//	//	//	//	xx KUDU								
24	CIVET			///	x AF WC	///	///	///	///								
25	PORCUPINE DUNG		//		//	//	xx JACK	//	//								
26	LION	/			/	/	xxx BAB	xxx LEOP.	xxx LEOP								
27	WARTHOG		//		//	//	//	//	//								
28	MILLIPEDE	/			/	/	/	/	/								
29	LION		//		//	//	//	//	xx BABOON								
30	HYENA			///	///	///	///	///	x JACK								
31	GFOWL FEEDING			///	x FR	///	///	x FR	x FR								
32	TORTOISE		//		//	//	//	//	//								
33	ANTLION PIT	/			/	/	/	/	/								
34	JACKAL		//		//	//	//	//	//								
35	GAIT = TROT			///	///	x WALK	x WALK	///	///								
36	SNAKE TRACK		//		xx [illegible]	//	//	//	xx MILLIP								
37	LION & L	/	//		//	//	//	//	xx LEOP								
38	LIZARD		//		//	//	xx LOCUST	//	//								
39	GREY DUIKER		//		xx STEENB	//	//	xx STEENB	xx STEENB								
40	ZEBRA	/			/	/	/	/	/								
41	ZEBRA DUNG		//		//	//	//	xx WHOG	//								
42	KUDU		//		xx NYALA	//	//	//	//								
43	HYENA	/			/	/	/	/	/								
44	PORCUPINE		//		//	//	//	//	xx MONG								
45	GNU		//		//	//	//	//	//								
46	ELLIE	/			/	/	/	/	xxx RHINO								
47	SCRUBHARE DUNG		//		//	//	//	//	//								
48	WILDEBEEST HAIR		//		//	//	//	//	//								
49	WARTHOG RUB		//		//	//	//	//	//								
50	SQUIRREL			///	x WARTH	///	x GR DUIK	///	x WARTH								
51																	
52																	
53																	
54																	
55																	
	ticks				81	92	80	90	68								
	x				13	4	16	10	28								
	Total (ticks + x)				94	96	96	100	96								
	ticks / Total = %				86%	96%	83%	90%	71%								

Table 2. The percent of questions answered correctly at each combination of track and sign level achieved and question point rating (level of complexity) in evaluations and camera-trapping.

	Evaluation Data	**Point Rating**				**(nE) Eval Sample Size**	**Photo Data**	**(nP) Photo Sample Size**	**(nE + nP) Total Sample Size**
		1	**2**	**3**	**(4) Bonus**				
Secondary Track & Sign Levels	(0) Not Yet Competent (<70% Secondary Eval)	82.39% n=1454	58.8% n=4129	39.7%4 n=1603	5.2% n=19*	**7205**	0	**0**	**7205**
	(1) Level 1 (70-79% Secondary Eval)	90.52% n=2269	72.85% n=6527	48.16% n=2440	8.57% n=35*	**11271**	70.57%	**547**	**11818**
	(2) Level 2 (80-89% Secondary Eval)	95.28% n=3221	81.71% n=9353	64.84% n=3498	11.11% n=45*	**16117**	80.46%	**1622**	**17739**
	(3) Level 3 (90-99% Secondary Eval)	98.36% n=2499	92.03% n=7287	75.75% n=2738	33.33% n=39*	**12563**	87.94%	**1550**	**14113**
	(4) Professional (100% Secondary Eval)	98.88% n=89	99.15% n=234	94.74% n=95	0% n=1*	**419**	93.58%	**888**	**1307**
Tertiary Track & Sign Levels	(5) Not yet a Specialist but still Professional (<100% Tertiary Eval)****	0*	92.16% n=268	85.70% n=1720	64.02% n=214	**2202**	0****	**0**	**2202**
	(6) Specialist (100% Tertiary Eval)	0**	100% n=18***	93.92% n=181	78.26% n=23	**222**	97.94%	**2713**	**2935**
	(n) Sample Size	**9532**	**27816**	**12275**	**376**	**49999**		**7320**	**57319**

Special character explanations:

* Sample size is small for Bonus Level questions in Secondary Evaluations because they were generally not asked and reserved for Tertiary Evaluations.

** Questions rated as Simple in complexity (Point Rating 1) were not asked in Tertiary Evaluations.

*** A small number of Complex questions (Point Rating 2) are allowed in Tertiary Evaluations when conditions are too difficult to find a sufficient number of more complex questions.

**** A participant is not demoted from Professional Level Track & Sign if they do not achieve Specialist on a Tertiary Evaluation, regardless of score because this is a more complex evaluation. In the Photo dataset these participants are Professional Level (4).

Table 3. Significance tests for evaluation data

Evaluation data						
Variables	**Coef**	**SE Coef**	**95% CI**	**Z-Value**	**P-Value**	**VIF**
Constant	1.0277	0.0719	(0.8867, 1.1687)	14.28	0.000	
Tracker Level ref=0						
1	0.5759	0.0338	(0.5095, 0.6422)	17.01	0.000	1.70
2	1.1586	0.0333	(1.0934, 1.2238)	34.84	0.000	1.74
3	1.9330	0.0399	(1.8548, 2.0113)	48.43	0.000	1.49
4	3.683	0.341	(3.015, 4.352)	10.80	0.000	1.01
5	2.3565	0.0725	(2.2144, 2.4986)	32.50	0.000	1.35
6	3.333	0.269	(2.805, 3.861)	12.38	0.000	1.03
Point Rating ref=1						
2	-1.2275	0.0464	(-1.3185, -1.1365)	-26.43	0.000	3.84
3	-2.0243	0.0501	(-2.1225, -1.9261)	-40.41	0.000	4.05
4	-3.535	0.130	(-3.790, -3.280)	-27.16	0.000	1.32
Type ref = interp						
other	0.624	0.198	(0.236, 1.011)	3.16	0.002	1.51
scat	0.3126	0.0554	(0.2040, 0.4213)	5.64	0.000	1.39
sign	0.2105	0.0624	(0.0882, 0.3328)	3.37	0.001	1.40
track	0.1147	0.0366	(0.0431, 0.1864)	3.14	0.002	2.12
trail	0.1234	0.0731	(-0.0199, 0.2666)	1.69	0.092	1.65
TorS Size ref=large						
medium	-0.1295	0.0340	(-0.1960, -0.0629)	-3.81	0.000	1.44
small	-0.0592	0.0379	(-0.1335, 0.0151)	-1.56	0.119	1.68
variable	-0.2545	0.0596	(-0.3712, -0.1377)	-4.27	0.000	1.46
veryLarge	0.4090	0.0491	(0.3128, 0.5052)	8.33	0.000	1.24
verySmall	-0.3687	0.0485	(-0.4636, -0.2737)	-7.61	0.000	1.57
Spp Social Structure ref=groups						
none	-0.582	0.139	(-0.854, -0.310)	-4.19	0.000	1.41
pairs	-0.1681	0.0427	(-0.2518, -0.0845)	-3.94	0.000	1.30
solitary	-0.0508	0.0318	(-0.1132, 0.0115)	-1.60	0.110	1.43
variable	0.0576	0.0489	(-0.0383, 0.1535)	1.18	0.239	1.30
TorS Common ref=no						
yes	0.5919	0.0342	(0.5249, 0.6590)	17.31	0.000	1.22

Table 4. Odds-ratios for evaluation data.

Evaluation data – Odds-ratios for categorical predictors			
Level A	**Level B**	**Odds Ratio**	**95% CI**
Tracker Level			
1	0	1.7787	(1.6645, 1.9007)
2	0	3.1855	(2.9845, 3.4001)
3	0	6.9105	(6.3905, 7.4729)
4	0	39.7721	(20.3810, 77.6124)
5	0	10.5543	(9.1562, 12.1660)
6	0	28.0204	(16.5327, 47.4903)
2	1	1.7910	(1.6875, 1.9007)
3	1	3.8852	(3.6103, 4.1810)
4	1	22.3607	(11.4653, 43.6097)
5	1	5.9339	(5.1638, 6.8187)
6	1	15.7536	(9.3029, 26.6774)
3	2	2.1694	(2.0189, 2.3310)
4	2	12.4853	(6.4030, 24.3453)
5	2	3.3132	(2.8873, 3.8020)
6	2	8.7962	(5.1963, 14.8900)
4	3	5.7553	(2.9477, 11.2371)
5	3	1.5273	(1.3236, 1.7623)
6	3	4.0548	(2.3919, 6.8737)
5	4	0.2654	(0.1346, 0.5232)
6	4	0.7045	(0.3018, 1.6448)
6	5	2.6549	(1.5564, 4.5287)
Point Rating			
2	1	0.2930	(0.2675, 0.3209)
3	1	0.1321	(0.1197, 0.1457)
4	1	0.0292	(0.0226, 0.0376)
3	2	0.4508	(0.4261, 0.4769)
4	2	0.0995	(0.0781, 0.1267)
4	3	0.2207	(0.1739, 0.2801)
Type			
other	interp	1.8658	(1.2666, 2.7486)
scat	interp	1.3670	(1.2263, 1.5240)
sign	interp	1.2343	(1.0922, 1.3949)
track	interp	1.1216	(1.0440, 1.2049)
trail	interp	1.1313	(0.9803, 1.3056)
scat	other	0.7327	(0.4959, 1.0824)
sign	other	0.6615	(0.4497, 0.9733)
track	other	0.6011	(0.4098, 0.8818)

trail	other	0.6063	(0.4074, 0.9024)
sign	scat	0.9029	(0.7870, 1.0359)
track	scat	0.8204	(0.7454, 0.9030)
trail	scat	0.8275	(0.7074, 0.9681)
track	sign	0.9086	(0.8149, 1.0132)
trail	sign	0.9165	(0.7832, 1.0726)
trail	track	1.0087	(0.8867, 1.1475)
TorS Size			
medium	large	0.8785	(0.8220, 0.9390)
small	large	0.9425	(0.8751, 1.0152)
variable	large	0.7753	(0.6899, 0.8714)
veryLarge	large	1.5053	(1.3673, 1.6574)
verySmall	large	0.6917	(0.6290, 0.7606)
small	medium	1.0729	(0.9964, 1.1552)
variable	medium	0.8825	(0.7814, 0.9968)
veryLarge	medium	1.7134	(1.5406, 1.9056)
verySmall	medium	0.7873	(0.7134, 0.8688)
variable	small	0.8226	(0.7283, 0.9290)
veryLarge	small	1.5971	(1.4291, 1.7848)
verySmall	small	0.7338	(0.6658, 0.8088)
veryLarge	variable	1.9415	(1.6962, 2.2224)
verySmall	variable	0.8921	(0.7806, 1.0195)
verySmall	veryLarge	0.4595	(0.4056, 0.5205)
Spp Social Structure			
none	groups	0.5590	(0.4259, 0.7338)
pairs	groups	0.8452	(0.7774, 0.9189)
solitary	groups	0.9504	(0.8930, 1.0116)
variable	groups	1.0593	(0.9625, 1.1659)
pairs	none	1.5119	(1.1402, 2.0048)
solitary	none	1.7001	(1.2920, 2.2372)
variable	none	1.8949	(1.4278, 2.5148)
solitary	pairs	1.1245	(1.0299, 1.2277)
variable	pairs	1.2533	(1.1108, 1.4140)
variable	solitary	1.1145	(1.0068, 1.2338)
TorS Common			
yes	no	1.8075	(1.6903, 1.9328)

Table 5. The number of trackers participating in the camera trap study by year, and in total.

They are further categorized by the T&S level that each had already achieved.

Number of Participants by Year	2010	2011	2012	TOTAL
Level 1 (70-79%)	9	8	1	18
Level 2 (80-89%)	12	14	5	31
Level 3 (90-99%)	9	8	9	26
Level 4 or Professional (100% on Secondary)	1	0	15	16
Level 5 or Specialist (100% on Tertiary)	1	2	17	20
Total number of trackers participating	32	32	47	111

Table 6. The number of 24-hour camera-trapping days and hours by year, and in total

				TOTAL
YEAR	2010	2011	2012	
Days	18	29	35	82
Hours	432	696	840	1968

Table 7. Significance tests for photo data.

Term	**Coef**	**SE Coef**	**95% CI**	**Z-Value**	**P-Value**	**VIF**
Constant	-0.097	0.161	(-0.412, 0.218)	-0.60	0.546	
TrackerLvl ref=1						
2	0.756	0.138	(0.485, 1.027)	5.46	0.000	2.70
3	1.167	0.151	(0.871, 1.463)	7.73	0.000	2.58
4	1.791	0.222	(1.356, 2.226)	8.07	0.000	2.29
6	2.656	0.231	(2.203, 3.109)	11.49	0.000	2.61
YearsExp ref=1	0.1059	0.0232	(0.0604, 0.1513)	4.57	0.000	2.92
TorS_Size ref=large						
medium	-0.616	0.112	(-0.835, -0.397)	-5.51	0.000	1.71
small	-0.985	0.123	(-1.225, -0.745)	-8.03	0.000	1.77
variable	-1.307	0.270	(-1.837, -0.778)	-4.84	0.000	1.12
veryLarge	0.781	0.199	(0.391, 1.171)	3.92	0.000	1.19
verySmall	-1.271	0.207	(-1.677, -0.866)	-6.15	0.000	1.26
TorS_Common ref=no						
yes	1.406	0.111	(1.189, 1.622)	12.71	0.000	1.07
Indigenous ref=no						

Y	-0.346	0.107	(-0.555, -0.137)	-3.24	0.001	1.67

Table 8. Odds-ratios for photo data.

Photo data

Odds Ratios for Continuous Predictors

	Odds Ratio	95% CI
YearsExp	1.1117	(1.0623, 1.1633)

Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
TrackerLvl			
2	1	2.1291	(1.6234, 2.7924)
3	1	3.2115	(2.3893, 4.3168)
4	1	5.9965	(3.8809, 9.2653)
6	1	14.2342	(9.0495, 22.3892)
3	2	1.5084	(1.1947, 1.9045)
4	2	2.8164	(1.8616, 4.2609)
6	2	6.6854	(4.2649, 10.4796)
4	3	1.8672	(1.2999, 2.6821)
6	3	4.4322	(3.0139, 6.5180)
6	4	2.3737	(1.6038, 3.5133)
TorS_Size			
medium	large	0.5401	(0.4339, 0.6723)
small	large	0.3735	(0.2937, 0.4749)
variable	large	0.2705	(0.1593, 0.4595)
veryLarge	large	2.1830	(1.4782, 3.2240)
verySmall	large	0.2804	(0.1870, 0.4205)
small	medium	0.6915	(0.5614, 0.8516)
variable	medium	0.5009	(0.2988, 0.8395)
veryLarge	medium	4.0420	(2.7801, 5.8767)
verySmall	medium	0.5192	(0.3527, 0.7643)
variable	small	0.7243	(0.4305, 1.2187)
veryLarge	small	5.8455	(3.9752, 8.5959)
verySmall	small	0.7509	(0.5094, 1.1067)
veryLarge	variable	8.0701	(4.3752, 14.8855)
verySmall	variable	1.0366	(0.5629, 1.9090)
verySmall	veryLarge	0.1285	(0.0775, 0.2129)
TorS_Common			
yes	no	4.0777	(3.2830, 5.0648)
Indigenous			
Y	N	0.7078	(0.5742, 0.8724)

Appendices
Appendix A. Survey Instrument

Name____

Date_____________________Venue______________________Evaluator________________

Section 1. Demographic information:

1. I am: Male Female (please circle one).

2. My age is: ________.

3. I am: white black (please circle one), or other: ________________ (please provide "other").

4. My cultural group is:____(please provide description, for example: American Indian/Cherokee, Chinese, Hawaiian, Shangaan, Zulu, etc.)

5. The highest grade level I have completed in school is _______________________________________ (please fill in grade level).

6. I grew up in an area that can mostly be described as: (please circle one choice, in the table below)

City	Small Town	Large Town	Village	Farming	Natural Area (forest, desert, bush)

7. I currently live in an area that can mostly be described as: (please circle one choice in the table below)

City	Large Town	Small Town	Village	Farming	Natural Area (forest, desert, bush, etc.)

Section 2. Previous Tracking Experience:

8. Please put an X next to the most appropriate statement below:

• I have no previous tracking experience_______

• I have only the tracking experience provided by this course/evaluation_______

• I have practiced tracking before as part of a class, an occupation, or as an interest_______

9. I have approximately ________ years tracking experience (please write number of years).

• During that time my tracking experience was: (please circle one)

Occasional (1-3 times a month)	Frequent (4-10 times a month)	Intensive (10-19 times a month)	Occupational (20 or more times a month)

10. In the past two (2) years my tracking experience was: (please circle one)

Occasional (1-3 times a month)	Frequent (4-10 times a month)	Intensive (10-19 times a month)	Occupational (20 or more times a month)

Section 3. Previous CyberTracker Evaluations:

11. The number of CyberTracker Track and Sign Evaluations I have participated in is:

1-2	3-4	5-6	6-7	8-9	10 or more

12. My highest score on a CyberTracker Track and Sign Evaluation so far is ________ (percent %).

13. The number of CyberTracker Trailing Evaluations I have participated in is:

1-2	3-4	5-6	6-7	8-9	10 or more

14. My highest score on a CyberTracker Trailing Evaluation so far is ________ (percent %).

Section 4. Current CyberTracker Evaluation:

15. This evaluation is part of a course: YES NO (please circle one).

• In this course we spent ________ days focused on tracking (please fill in number).

16. My level of enjoyment with this evaluation was: Low Medium High (please circle one).

17. The amount I learned during this evaluation was: Low Medium High (please circle one).

18. For today's evaluation, I expect to receive a certification level of: (please circle one)

No Level (less than 70%)	Level 1 (70-79%)	Level 2 (80-89%)	Level 3 (90-99%)	Level 4 (100%)	Specialist (100% on Specialist evaluation)	Senior (100% on both Track and Sign and Trailing evaluations)

Literature Cited

Alibhai, S. K., Z. C. Jewell, and P. R. Law. 2008. A footprint technique to identify white rhino *Ceratotherium simum* at individual and species levels. Endangered Species Research 4:205–218.

Alldredge, M. W., K. H. Pollock, and T. R. Simons. 2006. Estimating detection probabilities from multiple-observer point counts. The Auk 123(4):1172–1182.

Alldredge, M. W., T. R. Simons, and K. H. Pollock. 2007. Factors affecting aural detections of songbirds. Ecological Applications 17(3):948–955.

Allen, M. L., H. U. Wittmer, P. Houghtaling, J. Smith, L. M. Elbroch, and C. C. Wilmers. 2015. The role of scent marking in mate selection by female pumas (*Puma concolor*). PLoS One 10:1–12.

Beier, P., and S. C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. Wildlife Society Bulletin 24(3):540–546.

Brossard, D., B. Lewenstein, and R. Bonney. 2005. Scientific knowledge and attitude change: the impact of a citizen science project. International Journal of Science Education 27(9):1099–1121.

Carruthers, J. 1995. The Kruger National Park: A Social and Political History. University of Natal Press. Pietermaritzburg, South Africa: 170.

Caruthers, J. 2006. Tracking in game trails: looking afresh at the politics of environmental history in South Africa. Environmental History 11:804-829.

Crall, A. W., R. Jordan, K. Holfelder, G. J. Newman, J. Graham, and D. M. Waller. 2012. The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. Public Understanding of Science 22(6):745–764.

Crooks, K. R., M. Grigione, A. Scoville, and G. Scoville. 2008. Exploratory use of track and camera surveys of mammalian carnivores in the Peloncillo and Chiricahua mountains of Southeastern Arizona. The Southwestern Naturalist 53(4):510–517.

De Angelo, C., A. Paviolo, and M. S. Di Bitetti. 2010. Traditional versus multivariate methods for identifying jaguar, puma, and large canid tracks. Journal of Wildlife Management 74(5):1141–1151.

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. Variability in grassland bird counts related to observer differences and species detection rates. The Auk 120(4):1168–1179.

Duffie, D. R., R. A. Gitzen, N. W. Sharp, and A. J. Turner. 2019. Effectiveness and accuracy of track tubes for detecting small-mammal species occupancy in southeastern herbaceous wetlands and meadows. Southeastern Naturalist 18:130–146.

Dzięciołowski, R. 1976. Estimating Ungulate Numbers in a Forest by Track Counts. Acta Theriologica 21(15):217–222.

Elbroch, L. M., P. E. Lendrum, H. Robinson, and H. B. Quigley. 2016. Population-and individual-level prey selection by a solitary predator as determined with two estimates of prey availability. Canadian Journal of Zoology 94(4):275–282.

Elbroch, L. M., P. E. Lendrum, H. B. Quigley, and A. Caragiulo. 2016. Spatial overlap in a solitary carnivore: support for the land tenure, kinship or resource dispersion hypothesis? Journal of Animal Ecology 85:487-496.

Elbroch, L. M., P. E. Lendrum, J. Newby, H. B. Quigley, and D. J. Thompson. 2015. Recolonizing wolves influence the realized niche of resident cougars. Zoological Studies 54(41):1–11.

Elbroch, L. M., P. E. Lendrum, M. L. Allen, and H. U. Wittmer. 2015. Nowhere to hide: pumas, black bears, and competition refuges. Behavioral Ecology 26:247–254.

Elbroch, L. M., P. E. Lendrum, P. Alexander, and H. B. Quigley. 2015. Cougar den site selection in the Southern Yellowstone Ecosystem. Mammal Research 60:89–96.

Elbroch, L. M., T. H. Mwampamba, M. J. Santos, M. Zylberberg, L. Liebenberg, J. Minye, C. Mosser, and E. Reddy. 2011. The value, limitations, and challenges of employing local experts in conservation research. Conservation Biology 25:1195–1202.

Evans, J. W. 2007. Observer error in identifying species using indirect sigs: analysis of a river otter track survey technique. Master of Science, Wildlife and Fisheries Science, Texas A&M University: 63.

Evans, J. W., C. A. Evans, J. M. Packard, G. Calkins, M. Elbroch, and L. M. Elbroch. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management 73(3):426–432.

Ewer, R. F., and C. Wemmer. 1974. The behaviour in captivity of the African civet, *Civettictus civetta*. Zeitschrift für Tierpsychologie 34(4):359–394.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D. Lapoint, D. A. Bogan, and J. R. Cryan. 2006. A comparison of noninvasive techniques to survey carnivore communities in Northeastern North America. Wildlife Society Bulletin 34(4):1142–1151.

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.

Gruber, B., B. Reineking, J. M. Calabrese, A. Kranz, K. Poledníková, L. Poledník, R. Klenke, A. Valentin, and K. Henle. 2008. A new method for estimating visitation rates of cryptic animals via repeated surveys of indirect signs. Journal of Applied Ecology 45:728–735.

Gu, W., and R. K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biological Conservation 116(2):195–203.

Gusset, M., and N. Burgener. 2005. Estimating larger carnivore numbers from track counts and measurements. African Journal of Ecology 43(4):320–324.

Hart, A., R. Stafford, A. Goodenough, and S. Morgan. 2012. The role of citizen science and volunteer data collection in zoological research. International Journal of Zoology 2012(105345):1–3. http://dx.doi.org/10.1155/2012/105345

Havens, K., and S. Henderson. 2013. Citizen science takes root. American Scientist 101:378–385.

Haywood, B. K. 2014. A "sense of place" in public participation in scientific research. Science Education 98:64–83.

Hunter, J., A. Alabri, and C. Ingen. 2012. Assessing the quality and trustworthiness of citizen science data. Concurrency and Computation: Practice and Experience 25:454-466.

Jewell, Z. C., S. K. Alibhai, F. Weise, S. Munro, M. van Vuuren, and R. van Vuuren. 2016. Spotting cheetahs: identifying individuals by their footprints. Journal of Visualized Experiments (JOVE) 111:e10.3791/54034. http://dx.doi.org/10.3791/54034

Jewell, Z., and S. K. Alibhai. 2012. Identifying endangered species from footprints. The International Society for Optics and Photonics (SPIE). http://dx.doi.org/10.1117/2.1201212.004636

Jewell, Z. C., S. K. Alibhai, and P.R. Law. 2001. Censusing and monitoring black rhino (*Diceros bicornis*) using an objective spoor (footprint) identification technique. Journal of Zoology 254:1-16.

Jordan, R. C., S. A. Gray, D. v Howe, W. R. Brooks, and J. G. Ehrenfeld. 2011. Knowledge Gain and Behavioral Change in Citizen-Science Programs. Conservation Biology 25(6):1148–1154.

Karanth, K. U., J. D. Nichols, J. Seidenstricker, E. Dinerstein, J. L. D. Smith, C. McDougal, A. J. T. Johnsingh, R. S. Chundawat, and V. Thapar. 2003. Science deficiency in conservation practice: the monitoring of tiger populations in India. Animal Conservation 6(2):141–146.

Kremen, C., K. S. Ullman, and R. W. Thorp. 2011. Evaluating the quality of citizen-scientist data on pollinator communities. Conservation Biology 25(3):607–617.

Lawrence-Apfel, K., K. Arifuzzaman, and T. H. Meyer. 2012. An accuracy assessment of global navigation satellite system wildlife-tracking collars in the southern Chilean Patagonia. Anales Instituto Patagonia 40:105–113.

Lewandowski, E., and H. Specht. 2015. Influence of volunteer and project characteristics on data quality of biological surveys. Conservation Biology 29(3):713–723.

Lewison, R., E. L. Fitzhugh, and S. P. Galentine. 2001. Validation of a rigorous track classification technique: identifying individual mountain lions by their tracks. Biological Conservation 99(3):313–321.

Liebenberg, L. 1990. The Art of Tracking: The Origin of Science. David Philip Publishers, Cape, RSA.: 187.

Liebenberg, L. 1990. A Field Guide to the Animal Tracks of Southern Africa. David Philip Publishers, Cape Town, RSA.: 306.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42(6):1105–1114.

Marchal, A. F. J., P. Lejeune, and P. J. N. de Bruyn. 2016. Virtual plaster cast: digital 3D modelling of lion paws and tracks using close-range photogrammetry. Journal of Zoology 300(2):111–119.

McClintock, B. T., L. L. Bailey, K. H. Pollock, and T. R. Simons. 2010. Unmodeled observation error induces bias when inferring patterns and dynamics of species occurrence via aural detections. Ecology 91(8):2446–2454.

McKelvey, K. S., J. von Kienast, K. B. Aubry, G. M. Koehler, B. T. Maletzke, J. R. Squires, E. L. Lindquist, S. Loch, and M. K. Schwartz. 2006. DNA analysis of hair and scat collected along snow tracks to document the presence of Canada lynx. Wildlife Society Bulletin 34(2):451–455.

Mueller, M. P., D. Tippins, and L. Bryan. 2012. The Future of Citizen Science. Democracy and Education 20(1):1-12.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models. 4th ed. Irwin Publishers, Chicago, IL. USA:1408.

Pimm, S. L., S. K. Alibhai, R. Bergl, A. Dehgan, C. Giri, Z. C. Jewell, L. Joppa, R. Kays, and S. Loarie. 2015. Emerging technologies to conserve biodiversity. Trends in Ecology & Evolution 30(11):685–696. Elsevier Ltd.

Pirie, T. J., R. L. Thomas, and M. D. E. Fellowes. 2016. Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology 22:13–21.

Purchase, D. 2007. Using spoor to determine the age and weight of subadult black rhinoceroses (*Diceros bicornis L.*). South African Journal of Wildlife Research 37:96–100.

Rittenhouse, C. D., A. Pidgeon, T. Albright, T. Culbert, M. Clayton, C. Flather, and V. Radelof. Accounting for observer effects in bird surveys: Does experience matter? Unpublished 1–24.

Rutina, L. P., K. M. Mogwera, S. Elford, C. Mpofu, and D. Ntloyathuto. 2017. Herders' ecological knowledge and carnivore predation on livestock investigations in Makgadikgadi and Nxai national parks, Botswana. Koedoe - African Protected Area Conservation and Science 52(2):1–9.

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American breeding bird survey. The Auk 11(1): 50–62.

Silveira, L., A. T. A. Jácomo, and J. A. F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114(3):351–355.

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

Stander, P. E., //. Ghau, D. Tsisaba, //. ≠Oma, and //.Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Stanley, T. R., and J. A. Royle. 2005. Estimating site occupancy and abundance using indirect detection indices. The Journal of Wildlife Management 69(3):874–883.

Wilson, G. J., and R. J. Delahay. 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. Wildlife Research 28(2):151–164.

Wong, P. B. Y., P. Van Coeverden de Groot, C. Fekken, H. Smith, M. Pagès, and P. T. Boag. 2012. Interpretations of polar bear (*Ursus maritimus*) tracks by Inuit hunters: inter-rater reliability and inferences concerning accuracy. The Canadian Field-Naturalist 125(2):140–153.

Chapter 4. Tracking is Original Wisdom & The Culture of Trackers, a Constructivist Grounded Theory

Abstract

Using constructivist grounded theory, this research co-constructs a theory to identify wildlife tracking experts and explain patterns of behaviour that are relevant to and problematic for people in becoming expert wildlife trackers in an international system for evaluating trackers called CyberTracker. Thirty-eight certified trackers from three different cultural backgrounds were interviewed in South Africa, where tracking is an occupation and the CyberTracker system was developed. Even though there are different obstacles and opportunities for learning based on what culture a tracker comes from, the route to mastery is the same for all trackers, regardless of culture. Four categories emerged from the data supporting a theory that Tracking is Original Wisdom, common to the culture of all trackers where traditional ecological knowledge is actually being preserved and extended by western knowledge systems.

Introduction

Using constructivist grounded theory (CGT) (Charmaz 1991, 2014, 2017, Hsieh and Shannon 2005, Allen 2011, Barnett 2012, Martin and Barnard 2013, Kenny and Fourie 2015, O'Connor et al. 2018), this research co-constructs a theory to identify wildlife tracking experts, both as a means to determine who is an expert, and what it takes to become and expert, and to explain patterns of behaviour that are relevant to and problematic for people in becoming expert wildlife trackers in an international system for evaluating trackers called CyberTracker. Wildlife trackers identify and interpret tracks and signs and follow and find animals using their tracks, signs, and behaviors. Tracks are footprints, gaits, and track patterns. Signs include scats, scent-marks, kill-sites, burrows, dens, beds, browse and other feeding signs, nests, feathers, skulls and other bones, and much more (Murie et al. 1954, Liebenberg 1990*a*, Elbroch and Marks 2001, Elbroch 2006, Scott and McFarland 2010, Elbroch and Rinehart 2011, Gutteridge 2012, 2017, 2020, Gutteridge and Liebenberg 2013).

In many African countries, including South Africa, trackers are local people employed in the tourism industry, and being a tracker is a job title at lodges where guests book safari experiences. Trackers sit in a special chair mounted on the front of a safari vehicle, the tracker seat, that allows them the opportunity to identify the fresh tracks of an animal of interest, such as a leopard (*Panthera pardus)*, or a lion (*Panthera leo)* while the vehicle moves forward over dirt roads. From the tracker seat, trackers notice tracks of a species of interest, they motion to the guide to stop, they get off to confirm the identity and the freshness of the tracks, and if they think the trail is worth following they attempt to follow it through the landscape until they find the animal. After they have found the animal, they radio back to the person driving the vehicle, the guide, and tell him or her the location and best approach so that the guests can be driven into the bush, to the animal's exact location, to view and photograph it from a safe vantage point on the vehicle.

At many of the better lodges, managers understand that the central experience guests desire is a quintessential safari, a wildlife experience to remember, such as roaring lions in the twilight, watching a baby rhino play around its mother's feet, or sitting quietly while an enormous bull elephant passes within meters of the vehicle. Trackers play an integral role in providing these experiences when the animals are not found standing in or near the roads. Luxury accommodation and gourmet cuisine are designed around the safari experience, so financial success of these lodges depends on extremely experienced guides and trackers to ensure high quality memories and guest satisfaction. Lodges are numerous and when one lodge can advertise that its guide team has hundreds of years of experience, collectively, or that its tracker team is among the most highly qualified in the world, it helps to set them apart in their advertising.

The certifying agency for guides in Southern Africa is the Field Guides Association of Southern Africa (FGASA) and the agency setting the standards for certifying the skill level of wildlife trackers across the world is CyberTracker.[6,7] Developed in South Africa in the 1990s, CyberTracker evaluations have spread across Africa and were introduced to North America in 2006 by Louis Liebenberg and Dr. L. Mark Elbroch. Since then, they have spread throughout Europe and into Australasia.

CyberTracker was developed by Liebenberg when he was tracking with the San people of Lone Tree in the Kalahari. They asked him to help them to get jobs, and subsequently he developed icon-based, GPS-enabled software (the Cyber Tracker) that allowed non-literate users to collect descriptive, geo-located data from wildlife tracks and signs that they encountered.[8] The tracker certification system was developed afterwards, separately from the software, to help determine the quality of the track-based data collected.[9] Tracker certifications are conducted entirely in the field. The original idea was that certifying trackers according to increasing levels of their skill would provide them with more job opportunities, plus collecting data for science, and with salaries that increased with their increasing certification levels, according to their expertise.

---

6 http://www.cybertracker.org/
7 http://trackercertification.com/
8 http://www.cybertracker.org/background/our-story
9 http://www.cybertracker.org/tracking/evaluations

Tracker certification consists of a series of two different types of in-the-field evaluations, one on the identification and interpretation of tracks and signs (the track and sign evaluation, also called the T&S evaluation), and the other on the following of tracks to find animals (the trailing evaluation). Certification in both a T&S evaluation and a trailing evaluation qualifies a participant as a tracker in the system. Certification is stratified into different tracker levels, where a level 1 is the lowest that can be achieved, and Senior Tracker is the highest. Master Tracker is an honorary designation earned after being a Senior Tracker for at least ten years and contributing significantly to the field of tracking through mentoring, publishing, or some other means. Evaluations are described in more detail in the other chapters of this dissertation.

There is a distinction between a Master Tracker who earns the accolade by achieving the top levels of T&S and trailing, plus ten years of contributions, and a traditional or elder Master Tracker.[10] The elder accolade is awarded to people who are still using a persistence hunting method (following the tracks of an animal at a running pace, on a hot day, for hours, causing it to overheat and collapse from exhaustion[11] (Liebenberg 2006, 2008), and other traditional hunting techniques such as traditional poison arrows with bows. The elder Master Tracker certification also allows for additional consideration for a lifetime spent tracking, but with potential limitations arising from modern issues with literacy, education, and geographical range.[12]

Geographical range is both the range of an animal species, where it commonly occurs, and the range that the San travel over. Its limitation is illustrated here with a short story I've paraphrased as told to me by Louis Liebenberg in 2012, about several San who had been evaluated. They were asked to identify a cheetah track and they all individually identified it as a

[10] http://www.cybertracker.org/tracking/evaluations
[11] http://www.cybertracker.org/persistance-hunting/introduction-persistence-hunting
[12] http://www.cybertracker.org/tracking/evaluations

leopard, because none of them had ever seen a cheetah or its tracks before. The species had not passed through their area since before their people had been relocated onto smaller areas on the edges of the parks. But the track bothered them, because it didn't look quite right. So, they discussed it, and reached a consensus where one tracker in the group said that his grandfather had told him of another cat, one with claws always out who runs down its prey. He mentioned further that he had not seen such a cat, but had heard of one, here and there, over the years. The trackers had talked together and agreed that something was not right with the track being made by a leopard, so they must be from that type of cat that they had never seen before. They did not know the name of the cat that walked with claws out, but they could describe it, and they knew that the track they were seeing must be it, and not a leopard, so they were allowed to revise their answer.

Liebenberg designed the tracker certification system around his personal experience of what it means to be a tracker. Rather than using a published definition, he developed his own by observing people practicing tracking. He saw two major skill sets involved in the practice. First, trackers needed to be able to identify the tracks and signs of animals, and to conduct basic interpretations of their behaviors through their tracks and signs. They needed to identify and interpret a scenario such as: two male (sex) kudus (species identification) walked (way of moving) here. They browsed (sign, behaviour) under these small trees and rested in the shade (sign, behaviour). It's early morning now, so this must have happened yesterday during the sun (age of tracks and signs). Thus, identification and interpretation of tracks and signs form the building blocks of becoming a tracker. Identification is like learning letters and word formation in constructing tracking literacy. Trailing involves more complex interpretation to follow tracks and find animals. Therefore, it is putting together the letters and words into coherent sentences and paragraphs that tell a story. Becoming literate in tracking involves competency in both skills (Liebenberg 1990*a*, *b*).

African trackers have been used to assist with data collection in scientific research (Bothma and le Riche 1984, 1993, 1994, Stander et al. 1997, Stander 1998, Rachlow et al. 1999, Melville et al. 2004, Gaidet-Drapier et al. 2006, Melville and Bothma 2006, du Plessis 2010, 2018, Thorn et al. 2011, Tobler and Powell 2013, Midlane et al. 2014, 2015, Pirie et al. 2016, Marchal 2017, Rutina et al. 2017, Keeping et al. 2018, Belant et al. 2019), without regard for their training, certification, or expertise (but see Elbroch et al. 2011). Often, these trackers are assumed to be skilled because they come from a San (Bothma and le Riche 1984, 1993, 1995, Stander et al. 1997, Stander 1998, Bothma and Coertze 2004, Bothma and Bothma 2006) culture or another local culture that is historically known for having good trackers. This might or might not be true, however, depending on experience level of the individual trackers, the complexity of the questions asked, the study species (both the species under study and any other species present that could be confused with the study species) and the substrate for track-based data collection (tracks and signs, which are indirect-signs of an animal) (Wharton 2006, Evans et al. 2009).

In addition to research conducted in Africa, research conducted all over the world requires accurate and unbiased identification of wildlife tracks and signs to enable researchers and managers to determine where animals are, how many of a species there are, and what resources those animals need. Accuracy is particularly important with species of concern (near-threatened, vulnerable, endangered, and critically endangered) (https://www.iucnredlist.org/). Even so, there is a persistent doubt that wildlife tracks and signs themselves are inherently accurate and reliable, and a plethora of peer-reviewed journal articles have been published that either support or refute this, often without taking into consideration the experience level of the people hired to collect track-based data.

In chapter two of this dissertation, I reviewed 421 peer-reviewed, published journal articles, from 56 different countries, spanning 88 years, and studying 153 different species, where some form of track or sign identification was used in the research. Only seven percent of those publications gave evidence of observer skill or experience level from the tracker collecting track-based data. In chapter three of this dissertation, I presented an accuracy assessment on the CyberTracker track and sign evaluation for evaluating trackers. Results indicated that trackers who scored higher in the evaluations were more accurate in identifying wildlife tracks and signs than those who scored lower. Furthermore, in a comparison between tracker identification of tracks and signs with camera trapping photos, trackers who scored higher in the evaluations were more accurate in identifying wildlife tracks and signs than those who scored lower. The CyberTracker evaluations are, therefore, a quick and suitable way to determine which level trackers to hire, especially when background information on tracker experience is variable, questionable, or unavailable.

My general area of interest in this research was investigating who becomes a tracker, how trackers become experts in their field, and in the traditional ecological knowledge they might use. Specifically, I wanted to find out how to identify a good tracker, which I expected would depend on the purpose (e.g. T&S or Trailing, tourism or science), life experience, work experience, and evaluations. The research problem is: why do some people become expert trackers while others don’t, when it is a fundamental skill, considered traditional ecological knowledge to all cultures? This problem is different between people living in supplementedsubsistence cultures, and people living in more affluent westernized cultures, but the process that leads to and resolves the research problem is the same.

Three different groups of people emerged from the data. One group includes the Shangaan people living in rural villages near Kruger National Park (KNP). The Shangaan have a history of tracking expertise in the region and are commonly employed as trackers in the safari industry. The other two groups are South Africans of European descent (some whose families had been in the region for hundreds of years) where tracking forms one part of a larger portfolio of skills in what they do for a living, and then Americans who participate in tracking activities as a form of recreation and personal interest, usually outside their profession. In all three groups, some people are known to be expert trackers, and label themselves as trackers even though their occupation and their definition of what tracking means, differ. All 38 of the people interviewed for this research were certified trackers within the only international system for evaluating the skill of wildlife trackers, the CyberTracker Tracker Certification System.

A Brief Review of Available Literature and Previously Exiting Frameworks of Knowledge

Research on wildlife trackers themselves is sparse. Research that includes track-based data collected by technicians and biologists is more abundant, but frequently without reference to the accuracy of the observer or the data. Four publications stand out, among hundreds reviewed in Chapter 2 of this dissertation, as representative for the potential use and misuse of trackers in conservation, and the need for a metric of their reliability. Stander et al. (1997) showed that indigenous San trackers could reconstruct a track-based scenario with up to 98% accuracy. Unfortunately, this paper has been cited since then as evidence that any San, or any indigenous person, can be considered an expert tracker, without evidence of their expertise. Evans et al. (2009) showed that even professional biologists, who trained citizen scientist to collect data on one species, year after year (over a period of almost 20 years), provided track-based data that was incorrect in two ways. First, species that were not the target were misidentified as the target, and second, species that were the target were misidentified as other non-target species. Evans et al. (2009) further show the efficacy of the CyberTracker T&S evaluations as a tool to increase and validate the skill level of those biologists and citizen scientists. Even so, track-based data is still collected by untrained, or minimally trained observers.

In 2011, Elbroch et al. published a paper showing that local tracking experts, certified through CyberTracker, were capable of collecting accurate and methodologically sound track-based data for science. They developed a knowledge gradient, *K*, whereby the quality of the research conducted increased with the reliability of the data generated, and these were scored on a gradient reflecting the observers' knowledge through formal or informal learning. For example, a low score might reflect an amateur citizen scientist who has no scientific training and no local expertise in tracking, and a higher score might reflect someone more training and/or expertise. Thus, a community member with little education but vast local knowledge could score as high as a formally trained scientist without local knowledge, and the highest scoring observers involved collaborations between trained scientists and local experts.

Wong et al. (2011) then showed that Inuit hunters could identify male and female polar bears with accuracy from their tracks, but the degree of their accuracy depended on their experience, with more experienced trackers giving more accurate results. What these four papers illustrate, among the hundreds without a measure of observer bias, or data reliability, is that experience matters more than culture, and some individuals are more reliable than others.

Traditional ecological knowledge (TEK), is also known as indigenous ecological knowledge (IEK) and local ecological knowledge (LEK), and by many other labels and acronyms. Although there is no universally accepted definition, TEK represents the cumulative knowledge of a group of people in relationship to each other and to their historical land, including other organisms that share that space. It can include ecological information, as well as spiritual beliefs, cultural aspects, and other social rules, laws, values and norms. Communities possessing TEK are often less technologically advanced and knowledge is passed down from one generation to another through oral traditions (Berkes 1993, Doubleday 1993, Lalonde 1993). The general thinking is that, "people who pursue land-based economies know things about nature" (Cruikshank 2012) and these people should be increasingly consulted and given credit for their contributions in western research conducting ecological science. While increasing support for social justice and "general endorsements of the value of local ecological knowledge" are incorporated into case studies of land and species management and research, in some fields there remains little systematic documentation of TEK (Davis and Wagner 2003).

In my travels among communities with trackers for this research, the words traditional ecological knowledge and variations of it, were frequently used by people describing their local trackers. For example, I often heard statements about the potential loss of traditional tracking knowledge as specific tribal groups, such as the Shangaan people, modernized. Claims were also made by people I met or authors of books that I read that they were helping to document the traditional ecological knowledge of local or indigenous people before it became lost to the modern world. What I saw, and what I heard from trackers, however, was different.

There was very little traditional knowledge being shared. In the years of this research, I witnessed two instances. One was with a group of employed Shangaan trackers at a lodge, who showed me large holes in the trunk of a fallen and decaying marula tree (*Sclerocarya birrea*). The trackers described these holes as made by an insect they called mobongo, and they later showed me an adult specimen of the species, a giant long-horned beetle (*Petrognatha gigas*). They recognized the holes as made by the larval stage of the species, which they called a worm, boring tunnels into the marula trees, and they recognized them because they were good to eat. The other instance was when another group of employed Shangaan trackers showed one of CyberTracker's Master Trackers, Adriaan Louw, two similar, but different, gerbil (*Gerbilliscus spp*.) burrows in the ground. They described the characteristics of one, going straight down, and the other at an angle, one under cover and the other more in the open, and explained that one was good to eat and one was not. It therefore benefitted them to know the difference so they would not waste time trying to capture the one that was not good to eat. They could not, at that time, tell which burrow was the burrow was of good species, or identify the specific animals from pictures in a comprehensive book of mammals for the region.

What the aforementioned could imply is that traditional tracking knowledge is already lost in the cultures studied, or that tracking TEK revolved around food, in the form of being able to identify the tracks and signs of food species, or to follow the footprints and find the animal of a food species. Also implied in this is that trackers would be able to keep themselves safe in a landscape filled with elephants, lions, and other dangerous animals. They might not know the tracks and signs of every species, but would be able to tell the ones of those most useful to them, and how to differentiate those useful species from similarly appearing ones. This further implies a decline in the ability to recognize these food species tracks and signs and similar ones to those food species. What it does not imply is an overall, all-encompassing knowledge of tracks and signs, and tracking, which we seem to expect from all local or indigenous people. If a track or sign wasn't useful, that track or sign might not be known by everyone, and even useful information was known well by some people and less well by other people. Moreover, knowledge based on observation and research by non-local, nonindigenous people was being shared with other trackers, from many cultures, at lodges and gatherings such as CyberTracker evaluations, and in published books. Where then, does the compilation of traditional facts end, and the documentation of observations and the discoveries of new information begin, and who do these mostly overlapping knowledges belong to?

A noted problem in TEK research that compounds the questions of what knowledge is TEK, and who possesses it, has been in documenting processes for identifying people who are “knowledgeable enough” to be considered contributing experts (Davis and Wagner 2003).

> Certainly an essential issue in LEK research concerns the means by which local knowledge experts are identified. This goal must be a critical initial focus of LEK research design since not all persons within local settings are of similar stature in terms of the substance and character of their knowledge. A second, equally critical, issue must concern specifying the parameters and nature of the experiences, and understandings under investigation. Several key questions come to mind. What are the attributes constituting local ecological knowledge and what attributes is the research intended to document? For instance, how widely must statements, experiences, and descriptions be shared within a community in order to be considered attributes of the local knowledge "system?" While the knowledge that is unique to a single individual may be as sound empirically as knowledge that is widely shared, it cannot be considered representative of the knowledge system as a whole and is not likely to inform social behavior as it relates to resource use. Such knowledge, sound as it may be in its own right, may well be discounted as mere "anecdotal" evidence if presented in a resource management setting where final decisions are made by external regulatory agencies (Davis and Wagner 2003).

This research indicates that tracking knowledge is both an old, traditional skill, and a learnable skill that has survived tribal modernization through the retention of some traditional knowledge as well as through increasing modern knowledge by observation, documentation, and even technology. It remains possible to find skilled traditional trackers, but it is becoming increasingly rare, and more and more people that are not considered indigenous to a region are sharing track-based information and skills with each other and developing relationships with the lands they practice tracking on. Thus, especially when track-based data contributes to science and conservation decisions, TEK should be considered in conjunction with the verified skill level of the person collecting the data. Furthermore, while it might be desirable to employ traditional trackers to collect track-based data, the primary employment criteria should be skill level instead of culture.

Place-based theory, also called sense of place theory, or place theory, also explores the relationships that people have to land, especially their ethics and behaviors around how they appreciate, enjoy, or value the environment (Hay 1988, Kruger and Jakes 2003). One of the pioneers of this theory, David Ehrenfeld, described how feelings of conservation (the wise use of resources), preservation, and identity with a place develop naturally through direct past experiences of historical or cultural basis with it (Kruger and Jakes 2003). Similarly to TEK, in this research, place-based theory does not fully encompass the culture of trackers. Trackers come from both land-and-historically connected and disconnected traditional cultures, and also modern cultures that grow into a closer relationship to land through the practice of tracking.

Self-determination theory (SDT) incorporates varying levels of intrinsic and extrinsic motivation, which arise from having met the needs for competence, autonomy, and relatedness. Intrinsic motivation is self-generated and engaged in for one’s own pleasure and satisfaction. Extrinsic motivation is not performed out of interest but is instrumental to some separable consequence. Examples of extrinsic motivations include completing an undesirable task to avoid being fired from a job, or to undertake a training or examination process solely to make more money at a job (Deci et al. 1991, Deci and Ryan 2008). In this research, more often, non-indigenous trackers were the most intrinsically motivated group, while the indigenous trackers were more extrinsically motivated by obtaining or retaining a job and receiving money for their skills. Although individual trackers in this research show evidence of having elements of traditional ecological knowledge, knowledge of place, and self-determined motivation, as a group they can't be generalized into any one of those theories.

Methodology

I chose to use CGT to develop a more encompassing theory on the culture of trackers, both indigenous and non-indigenous to their current place, elucidating how they define themselves, their profession, and their skill. CGT methodology is used to develop theoretical understandings of psychosocial phenomena (Singh and Estefan 2018).

> Psychosocial - "pertaining to the influence of social factors on an individual's mind or behavior, and to the interrelation of behavioral and social factors" (Oxford University Press 2020).

Steps in CGT include data collection; conducting iterative comparative analysis with initial-coding and recoding; creating memos that describe, sort, and link ideas; identifying limitations, gaps, and future research (theoretical sampling). This occurs until a saturation point is attained and no new categories/stages emerge. Then, a theoretical outline is developed and any existing literature is consulted (Molinari and Vander Linden 2019). CGT precludes conducting a literature review prior to the data collection and analysis to avoid fitting data into an existing idea or theory instead of allowing a theory to emerge from the data (Glaser 1998).

The study took place in person in South Africa and the USA during 2010 – 2012, with additional data collected via telephone and through the internet (e-mail, Facebook). The sample included 38 trackers, eight in a pilot study, and 30 additional. Of the 38 trackers, there were twenty-eight South Africans (fourteen of which were Shangaan), and ten Americans. Five participants were women (zero Shangaans, two South Africans, and three Americans). All participants were certified trackers (both T&S and trailing) within the CyberTracker system. Most participants were highly certified within CyberTracker, having earned a level 3 or higher.

As a tracker myself, and as someone who has achieved the highest CyberTracker certification achievable, Senior Tracker, I counted a self-interview among the American women trackers and added my interview and field observations for coding and analyzation (Charmaz 2014, 2017, Garratt 2018). My interview and field observations added more individual data points to the already existing coded categories but were consistent with the other participant's data and did not add new information (Glaser 1998, Garratt 2018). This result supported my strong effort to bring my experience to the research while remaining unbiased in my data collection and analysis (Garratt 2018), and to co-construct a theory with the other trackers explaining how to become an expert tracker in an international system (Charmaz 2014).

In most cases where trackers are quoted, their words are left in the order, grammar, and overall voice in which they were spoken. In some cases, repeated words or phrases were omitted. Word order or tense has only been modified when necessary for understanding, and my clarifications are provided in parentheses. At the onset of interviews, all participating trackers gave their informed consent for any information they provided to be used in publications. This informed consent was contingent upon my guarantee that they would not be identified. This was important for some of them to feel that they could speak freely about their stories, especially to the employed, lodge-based, Shangaan trackers. All names have been changed or removed, and specific references to other people or places have been generalized to protect the privacy of the individuals providing information. Translators were offered to participants who were not primarily English speaking. This research was approved by the UCONN Institutional Review Board (IRB) for Research with Human Subjects (Protocol H10-127).

The cultural groups studied, North American, Shangaan, and South African of European descent, were redefined into two categories of trackers that more aptly described the differences and similarities of the ways in which they perceived and practiced tracking (described in the following section, what it means to be a tracker). Those categories are full-time trackers (FTTs) and part-time trackers (PTTs). FTTs were employed to track every day. PTTs conducted tracking as one of many parts of their occupation, or for recreation. Without exception, Shangaan trackers were FTTs, while Americans and European descended South Africans were PTTs. While information provided by all trackers was used in this research, not all trackers were quoted. Table 1 provides a key linking quotes anonymously to the trackers who said them, as well as to relevant but non-identifying information on their status (FTT or PTT), their years' experience, and their CyberTracker levels at the time of the interviews.

Data collection and analysis began with a semi-structured interview with the first tracker, one employed at a lodge in KNP. Every concept in the interview was recorded, transcribed, and coded according to CGT (Glaser 1992, Anselm and Corbin 1998, Charmaz 2014, Glaser and Strauss 2017). As more data was added from subsequent interviews, more categories were identified and refined, until no new categories were discovered. I wrote memos as ideas occurred to me, and for connections, contrasts, and comparisons between codes throughout the research.

Interviews typically lasted one to two hours and were recorded on a Zoom handheld recording device. Thereafter, I spent several days with some trackers, sometimes with more than one tracker at once, walking the landscapes where they lived or worked, and tracking with them. Conversations that occurred during those times were spontaneous, and they tested me on my tracking knowledge as I asked them questions about what they knew and how they knew it. This was as much a conversation as it was a trust-building period. Conversations that occurred in the field were recorded in a field notebook as they occurred, or as soon as possible after they occurred, and also coded as data. Trackers recommended other trackers for me to interview. One interview occurred over the phone, and another in a written, question and answer format.

During one of my first interviews in South Africa, we heard on the lodge's private-network radio that there were lions in a dry, overgrown riverbed, so we drove to the area. The trackers jumped off the vehicle, and one, the senior tracker (FTT3) in the group, said to me, "The lions, their tracks are right down there. They went down the river. You stay here and we will find them." I nodded, then jumped off the vehicle and followed them. They looked around at me, surprised, and I said, "Where you go, I go." They admitted later that they had never tracked with a woman, and their instinct was to protect me by leaving me safely behind in the vehicle. Not only were there lions somewhere in the riverbed, but hippos, buffalos, anything dangerous, could be hiding in the reeds. Even so, they were happy to see me with them and testing myself. Unintentionally, in this way, I became an active participant in their lives instead of an outside observer, and we built trust and rapport between us all. I say unintentionally, because my intent had not been to participate to build trust, but simply because I wanted to track, too, and would not be left behind just because I was a woman or a guest. Many of these trackers knew me a little bit prior to the interviews, too, which also helped. They had seen me and spoken with me at previous CyberTracker evaluations, where I had been going through the same stressful process of being tested on my tracking knowledge and skill as they were, at the same time (Lawrence, K. 2012, unpublished field notes).

Word by word, line by line, concept by concept, initial coding became focused coding as I identified the most pertinent codes through memos and began to ask trackers additional questions related to those codes, and to look deeper into information given, identify gaps, and to integrate a theory (Glaser 1998, Charmaz 2014, Molinari and Vander Linden 2019). This was an iterative process of constant comparison that continued until there were no new codes or variation provided in the data from interviewing and observing additional trackers (Glaser 1992, 1998, 2018, Charmaz 2014, Molinari and Vander Linden 2019). Codes merged into core categories that encompassed the collected data into a new theory (Charmaz 2014, Singh and Estefan 2018).

During coding, I attempted to eliminate my preconceptions of what I would find (Charmaz 2014, Glaser 2014), because I wanted to understand the tracker's viewpoints, first and foremost (Charmaz 2014). However, because I am a Senior Tracker and Evaluator in the CyberTracker system, I recognized that my own knowledge and opinions could influence the questions I ask and my interpretation of tracker's answers, as reflected in Charmaz's version of constructivist grounded theory methodology:

> Fundamentally, the empirical world does not appear to us in some natural state apart from human experience. Instead we know the empirical world through language and the actions we take toward it. In this sense, no researcher is neutral because language confers form and meaning on observed realities. Specific use of language reflects views and values (Charmaz 2014).

Charmaz's constructivist grounded theory promotes the idea that informed researchers can co-construct a useful theory by using inductive (the researcher collects data, identifies patterns, and develops a theory), deductive (the researcher makes an informed hypothesis, collects and analyzes data, and shows that the results support or fail to support the hypothesis), and abductive (the researcher uses their own expertise to intuit ideas that explain unanswered observations) approaches (Charmaz 2014, Singh and Estefan 2018). Instead of simply engaged observation and emergent codes, categories, and theory (Glaser 2014), the questions and answers I discussed with trackers, and trackers discussed with me, became an ongoing conversation where trackers told their stories and revealed their concerns as we co-constructed the major categories of supporting data and the theory of original wisdom, according to our collective experience and expertise (Charmaz 2014, Singh and Estefan 2018).

Results

Consistent with the research objective pursued, the grounded theory analysis led to four categories of interest where data support a theory of a culture belonging to all trackers, that of tracking is original wisdom. Original wisdom is a blend of TEK and Western science that encompasses the culture of all trackers, no matter what culture or community that they were born into. It's old, and knowledge and skill are gained by trackers from family, through ancestral relationships to land. But in both recently modernizing and in already modern societies, tracking also includes new knowledge and skill being discovered by trackers through research, technology, and publications.

Many of the categories are summarized and then illustrated with representative quotes from a tracker or multiple trackers from the different cultures studied. These quotes are mostly in agreement between different trackers, but opposing opinions are pointed out, even where they are not shared by others in their community, because these were interesting digressions that led to further exploration of the concepts and categories.

The Culture of Trackers and the Theory of Original Wisdom

Four major categories to emerged among trackers in this research.

1. What it means to be a Tracker
2. Developing the Skill
3. CyberTracker and Certification of Expertise
4. Obtaining Mastery

Category 1 – What it means to be a Tracker

The explanation or definition of tracking, trackers, and tracks initially depended on who was giving the explanation or definition. More specifically, the initial perceptions of tracking depended on whether the person was North American, Shangaan, or European descended South Africans. Upon closer inspection, the differences came from whether or not a person was an employed as a tracker full-time, or only practiced tracking part-time, either as one piece of their business or employment, or for recreation. All trackers' initial thoughts and actions expanded, however, when moved beyond the confines of the semi-structured interview, and grew to include a comprehensive definition of tracking that did not exclude any other group's viewpoint.

In North America, tracking is first perceived as track and sign identification (which blurs into naturalist knowledge). North American trackers tend to begin by describing tracking as identifying tracks and signs, and then go into great detail of many other aspects to know and practice first, before putting it all together into trailing an animal.

> PTT 4: It's the ability to recognize all kinds of tracks and signs of animals and people and even natural events like lightning strikes and frost cracks, so you can tell those events apart from animal signs. To become really good at it you must be able to recognize animals by their partial tracks using little details in their foot morphology, or skull structure, or feathers and nests. It's really endless.

Stories told by North American trackers were about exciting discoveries of tracks and signs, and about animal behaviors and ecological processes and ways of thinking that resulted from figuring out who made a track or sign, and why.

> PTT 3: Trackers have a developed a skill over time, a sense of awareness that allows one to notice changes in the natural environment. The art of tracking involves the science of investigating those changes and deciphering their cause and story. The changes may be anything from animal footprints to weather to geological changes within the Earth's crust.

Among European descended South Africans, tracking is both T&S and trailing. Trackers frequently start explaining tracking with a simple description of T&S that quickly moves into a more holistic explanation that includes trailing, awareness, behaviour, and the process of ecological linking of clues in an environment.

> PTT2: It's a lot of things, um, it's like a spider web. It connects everything together for me. You know, tracking, it links you to the mammals, it links you to the fungi, it links you to all the different types of insects and birds. So, for me, it's a way of interpreting everything and it's also very much a mindset, a way of learning things. As a tracker, you look at things differently from most other people that are involved with nature and science. You know it can be quite a revelation when you spend time with scientists and they have a look at what we consider a normal observation. The types of things we look for, the way that we connect aspects of nature, of ecology, the total environment. We just see it as one entity because it's all linked, all one commonality for me. Tracking is more than a footprint.

A North American tracker described the difference between a tracker and a naturalist as follows.

> PTT3: I resist a complete separation. I believe that not all naturalists are trackers but all trackers are naturalists. Naturalists see things more in isolation, though this is a generalization. For example, they may study tree identification but may be unaware or unable to read the story that involves an individual tree. They call it a hickory tree and can determine some details like age. However, they miss the awareness of the flying squirrel chew marks on the hickory nuts. A tracker has a wider lens than the naturalist but a good naturalist can fall into tracking through direct Earth experience. While naturalists might know how to identify some T&S,

> they generally do not go so far as to trail an animal and use all the skills required to put the story together and find the animal.

And a South African tracker of European descent described the same thoughts but in a slightly different way, as follows.

> PTT1: Tracking includes safety, ability to identify T&S, and then all-around bush knowledge, bush awareness. You're going to be a better tracker if you in tune with bird calls, the local plant species, the whole ecosystem, if you can connect the dots in the ecosystem, then you are going to be a better tracker. For example, if you hear oxpecker calls you can be sure there is some game around possibly big game, if you're on buffalo tracks you know you're close if you start hearing oxpecker. So that's an obvious birdcall. Other bird calls, once you start knowing the alarm calls, you would be aware of secondary disturbance, you would be aware that your presence in the bush is causing birds to make alarm calls and disturb the animal that you are trailing, similar to the snorts of antelopes they are all secondary disturbance factors. One you know how to move stealthily through the bush and avoid being seen and alarm called about, I don't think anyone will ever move through the bush and avoid being alarmed called but if you know how to minimize disturbance and work around it. For example, an antelope starts to snort at you and you're on open ground, keep on walking till you get to the tree line, a troop of baboons when an antelope snorts at them they don't stop they just keep moving. So, you just try to blend in and become natural as possible, so it's unnatural to stop once an animal snorts at you, it's best to get to a tree line and then assess the situation. That's one small thing. Try to act like the animals act in the bush, try not to be the one thing standing out.

Shangaan trackers unanimously made the assumption when asked, what is tracking, that the question referred to trailing dangerous game to find for guests in ecotourism. As a group, they responded with, "Tracking is the following of tracks to find an animal." Only after more conversation, often as they demonstrated how to follow an actual animal trail, would they tell me more about the types of things a tracker needs to know to be able to follow and find animals, such as (FTT1): "Tracking, it means trailing. Tracking (=) trailing. But in order to trail, you have to know what the tracks looks like, so it is some track identification," and, it is also awareness, as described below.

> FTT9: Tracking is following animals on foot. Finding them. I mean, you have to look for tracks. You listen. You really just open you ears while walking because sometimes an oxpecker can do the alarm call and if you ignore, there's a rhino lying close or a buffalo, so you have to be, you have to paying attention and all those alarm calls.

Beyond the Basics

Listening and animal communication

Beyond the basics, listening, it turns out, is one of the most important skills of a good tracker. Not only can it keep the tracker safe by not allowing him or her to stumble into dangerous situations, but listening can help them find their quarry.

> FTT1: Yes, when I'm tracking, also, I'm keep listening. Right, the alarm calls, and the monkeys, and the baboons, sometimes even the go-away bird. Even the birds, the black birds we call the fork-tailed drongo, also even the flycatchers. Yeah, we know that this one (the leopard) must be close if we hear it. When they're flying, sometimes we follow their tracks (alarm calls and flight patterns) for the leopard. And also, you'll hear the birds talking, so you find the leopard using their tail like this *motions 'swish'*. You don't know they're moving, I'm not coming to you, you're small, and I can't eat the birds, and from there I know, must be close by, this leopard. (The birds are not moving far, they are intent on the leopard, but small birds are not a substantial meal for a leopard and the leopard ignores them, so the birds don't put a lot of intensity into their alarms.)

As indicated, listening includes more than bird alarm-call vocalizations. Birds and other animals have a suite of communications that includes direct vocalizations within species, eavesdropping on communications within and between species, body language, and flight patterns (Macedonia and Evans 1993, Blumstein 2007, Seyfarth et al. 2010, Adreani 2019, Lilly et al. 2019, Snowdon 2020). A series of sharp, short, high-intensity barking calls by a vervet monkey can alert other monkeys in the troop to a nearby predator such as a leopard. Another monkey, or an observant tracker, hearing those alarm calls, can watch the alarm-calling monkeys to determine the direction they are looking. The whole troop will turn to face the direction of the leopard, often climbing into the canopy of the tallest nearby trees, so they can watch the leopard until it has moved far away (Seyfarth et al. 1980, Cheney and Seyfarth 1985, Baldellou et al. 1992). This combination of alarm calling and body language is one part of animal communication. Of course, trackers must know something about the different intraspecific calls of monkeys (or other animals), in order to distinguish regular communications from alarm calling (Cheney and Seyfarth 1985, Snowdon 2020).

Trackers further differentiate the alarm calls of monkeys into their species-specific calls. Studies have shown that vervet monkey have at least a dozen recognizable calls, each for a different specific threat. Knowing the difference between these calls will help the tracker to determine whether the monkeys are specifically alarming at a large bird of prey such as a crowned eagle, a dangerous reptile such as a southern African python or a large terrestrial predator such as a leopard or lion (Seyfarth et al. 1980, Cheney and Seyfarth 1985, Owren and Bernacki 1988, Snowdon 2020).

The intensity of alarming can also help the tracker to determine the proximity of a predator. If the predator is close, several monkeys may call together, in its direction. As it gets further away, less dominant members of the troop seem to lose interest in the threat, although larger male monkeys might continue for a longer time period. The intensity of alarming can also help the tracker to determine the type of predator. Leopards are well known predators of monkeys and baboons, therefore, the alarm calls for leopards are extremely intense in sound and cadence, whereas a predator like a hyena won’t initiate the same intensity because they can’t climb and aren't as successful in catching monkeys and baboons (Seyfarth et al. 1980, Cheney and Seyfarth 1985, Snowdon 2020).

Rodents, such as African tree squirrels, also have a variety of alarm vocalizations and behaviors. Squirrels, like monkeys and baboons, also have a less general set of upward and downward alarm calls, and similar systems of body language for their predators. Whether or not the squirrel goes to the top of the tree, or remains under cover of branches, can help with determining if it is a terrestrial or aerial predator, and whether or not the predator can climb (Viljoen 1983, Blumstein 2007, Snowdon 2020). Ungulates, such as bushbucks, impalas, and kudus, also have a sharp barking alarm call for their predators and a vigilant body posture with senses focused towards the threat (Hunter and Skinner 1998). Even vocally silent creatures, like giraffes, are sometimes able to see predators from far away and stand, focused in that direction until the threat passes (Schmitt et al. 2016).

Birds, too, have systems of communication through alarm calls, body language, and flight patterns (Carlson et al. 2020, Yasukawa et al. 2020). Some of the most useful birds to know in South Africa are two species of oxpeckers, the red-billed and the yellow-billed. Oxpeckers eat insects, especially ticks, from hairy animals. A tracker, hearing the calls of oxpeckers while walking through the bush, can become alerted to Cape buffalos or rhinos nearby. Hearing the calls of oxpeckers flying overhead in the air, and then watching the oxpeckers suddenly fly down, as a group, into thick bush ahead can indicate the presence of dangerous animals. Trackers are not the only ones using this oxpecker early-warning system, as animals are also alerted to the approach of humans (Plotz and Linklater 2020).

Alarm calls of almost any bird, combined with intensity of vocalizations and body language (pointing position and the height a smaller animal flees to in vegetation), and flight patterns, can warn trackers of snakes or other animals of interest and concern (Seyfarth and Cheney 1990). Flight patterns include mobbing, vs fleeing behaviours, and the flight distance often tells the tracker something about the intensity of the threat. Some animals will even follow predators, at a safe distance, to keep them in view until they leave their territories (Schmitt et al. 2016).

Soaring-dynamics in birds-of-prey and scavenger-birds can give away the presence of the kills of predators. First arrivals to a kill site are bateleurs and tawny eagles, which can see from great heights. Their presence is noted by different species of vultures, who then arrive in great numbers, dropping from the sky. If these birds remain perched in nearby trees, it's likely that the predator(s) are still feeding on the kill, whereas if the birds are dropping all the way to the ground, the predator has left the kill and this allows the birds to come in and feed (Kane et al. 2014).

Looking ahead

As we followed trails, the practice demonstrated more complexity, additional elements of safety and awareness emerged from trackers of all backgrounds. FTT1 said, "I keep the eyes… scan, I'm still pushing. So, you must know a lot of things as a tracker, not just how to identify and follow tracks." And a PTT also said,

> PTT1: I would say safety is important, if you're trailing animals you can't just have your head down. You have to be aware of the dangerous game in the area and not bump into them without knowing you're bumping into them. It has happened to people who are so immersed on the trail.

Knowledge of animal behaviours and potential hazards

In many places in North America, dangerous animals have been eradicated and are not as concerning, but,

> PTT4: There are situations to look out for, even without considering areas with wolves, bears, or mountain lions. Many people are very afraid of smaller animals like coyotes and bobcats, even raccoons and squirrels, especially when they don’t know the normal behavior of the animal. Raccoons are supposed to be nocturnal, for example, but seeing one out and about during the day is actually not unusual. What’s more important is does the animal look healthy, and how does it respond to your presence? Animals typically run away rather than approach a human. Sometimes rabies does make one of the smaller animals aggressive, and it’s definitely something to watch for. Larger animals, like deer, elk, boars, and moose can be aggressive when mating, with young, or when cornered. There are also some medically important snakes and spiders in different regions, and knowing what those look like and what habitats they are likely to be found in can help a tracker to avoid them. Other concerns include humans and their potentially illicit motivations, sudden and dramatic weather changes, and even medically important plants like poison ivy or poison oak can create potentially dangerous situations. There are a lot of things to keep in mind while out trailing or practicing track and sign.

Recognizing animal behaviour in tracking, what’s normal and what’s not, was also linked to being able to recognize different plant species.

> FTT2: Especially if you are trailing your herbivores because you know that they like to feed on grass or which type of trees they prefer. So, like your giraffe you know they like to be more on your acacia trees, so if you are trailing them you know that they’re heading towards areas where there is acacia trees you know that if you head to that direction you might end up picking up their tracks there or find them there as well. So, more like your black rhino, you know that they like to feed more on your marula and tamboti tree. So if you are trailing them and lose the trail and you can see there is marula there (points) or tamboti there (points) you easily make your decision to quickly go and check there and pick up their tracks much quicker than if you don’t know so you might lose their trail much easier.

Aging

The ability to tell how old a track or sign is, is essential to trailing, and can sometimes be determined through knowledge of T&S identification.

> FTT1: I can tell you the genet it walks at night, I can make this tracks not fresh (a track found in daylight with genet tracks on top of it). That's good. Sometimes you see the mongoose, and they walk during the day. So, it's important to look at the little things because they can tell you the age of a track. And the frog, when the frog walking on top of the tracks I know it's not good track, it's old track. And you need to know other small animals like we do track and sign, otherwise if you don't know most of that stuff you'll end up following old tracks.

Connection and Process

Additional uses and benefits of tracking that trackers mentioned were an increased sense of connection to nature.

> PTT1: I think people not normally connected to nature connect to nature through tracking, almost any activity that gets them immersed in nature, curious, and paying attention, which is what tracking does. It's a very interactive pastime people of all ages can be introduced to it; I mean you can teach people at their level of understanding. I think it's a good way to show people how to appreciate nature or at least instill that appreciation in them.

Simply being in the bush and getting dirt under your fingernails, or on the seat of your pants, was also mentioned in relation to increasing comfort levels in nature. Only by spending time outside could someone ever become comfortable with being near potentially dangerous animals and learn to recognize and respect the animal's comfort zones, as well as their own.

Thus, the initial interpretation of FTTs strongly centered on trailing, and then focused back to the details a tracker must know to trail well, such as T&S, listening, looking ahead, aging, behaviours, etc.

> FTT9: They (the CyberTracker evaluators) did help us a lot because they open our minds. We were thinking that it's only just follow an animal. We're not checking all the small things. From there, that's why you know that everywhere you're going, you have to look even for the small things, so it opens your mind not focusing on the big five only. Those evaluations that's where you can check yourself that you're on the up. It's also good for me to check myself that I'm really on the best track. I mean, it's also helping me. It's not only for you (to know my skill), I mean, also for me.

PTTs came at it from the opposite angle, often starting their definition at T&S and then expanding it to include myriad other detailed concepts, including trailing.

> PTT4: Tracking could be misconstrued as naturalist knowledge if we only consider basic T&S. When we add trailing to it, that's when it becomes the full expression of tracking. Naturalists will have a good amount of T&S knowledge, maybe not as in-depth as a tracker, but a good amount. Where a clear divide occurs, though, is when you start to follow and find animals. Then, it's clearly no longer anywhere close to the label of naturalist knowledge, then, it's tracking.

All trackers ended up with descriptions that included listening, animal behaviors, naturalist knowledge, and respect for/connection to nature. In the end, trackers all described that tracking is both identifying T&S, and trailing, "I do not feel that they can be separated. To be a tracker is to know both (PTT3)." We will see that this might be a direct result of how and when they grew up, and what they currently do for a living wage and for recreation. In both cultures, people describe an evolution from only basic explanations to advanced criteria. Although some trackers seem to practice either T&S or trailing more than the other, and to gain overall proficiency in one before the other, the best trackers gain proficiency in both.

> PTT3: I would say that all humans are trackers. Just as a child who writes their first word is a writer. A tracker is someone who interprets their first signs and gains data or information from it. And they are suddenly aware of what they have done. Of the process of figuring things out from clues, from deviations in the

> environment. They are suddenly aware of what they have done, and how to figure things out. That's tracking in its most basic form. However, just like that child wrote her first word is not a writer, she is not accomplished. Most human trackers remain in elementary school. Few become novelists and only a very few are accomplished poets.

Category 2 – Developing the Skill
Time in nature

Time spent in nature, particularly as children, was a commonality among all trackers. For many FTTs, the cause for going outside was fulfillment of their familial responsibilities, but the result included hours on end spent outside engaged in free play and discovery, and interactions with family members who were knowledgeable about nature. Most PTTs were devoid of the same type of childhood responsibilities as FTTs, and the availability of free-time and access to an outdoor space also included the ability to learn about nature through books and television when they returned indoors, and even when their family were not as interested or knowledgeable about nature.

> FTT9: As growing up, that's the elder brothers, because they like taking you out, and then you find a place, and then you let the cattle move away like we still play. And then they say, the cows are not here, just go out and find them. Then I start working and other guys they're very much helpful, if you ask them, they'll go out with you. But if you sit with your hands, folding your hands, you're not doing anything.

> PTT3: I remember getting up at dawn when I was in kindergarten to watch the sun come up through the window. I used to sit by myself in the yard, and as I got older, I'd wander through the neighborhood by myself, often at night. My earliest memories have a strong longing for nature and I would read books about nature and animals every chance I got. I was a voracious reader. I went through books like water. I also remember being a kid and riding my bike and stopping to stare at the mud at these really big tracks. I thought it was a bear! Of course, it was really a dog but I believed bears were around for years. When I was in high school my science teachers took me camping and birdwatching. I always wanted

> to track but only had teachers in the last decade. Learning on my own was super frustrating.

Why trackers learn

Reasons to learn tracking can be divided into three major categories, traditional, economic, and recreational. Food and safety are traditional reasons, money and prestige are economic reasons, and curiosity, passion, and connection are recreational reasons. The categories are not mutually exclusive, but FTTs generally talked about direct economic benefits and traditions, while PTTs talked about mostly recreational reasons and some indirect economic benefits.

Until recently, local Shangaan people still used tracking for food and safety. FTT4 said he learned to track because he needed to, he needed to make money so he could eat, and then to feed his family. Many FTTs related a common childhood history of very little schooling, or schooling punctuated with long periods of spending time in the bush with grandfathers, fathers, uncles, brothers, or friends taking care of the family's goats or cattle, and hunting for small animals to supplement store-bought and garden-grown food items. In both activities, herders and hunters needed to know when dangerous animals were present.

> FTT9: So, I grew up when we were being young after school, we were checking our cattles. We were going out leaving our studies. So, from there that's where most of the things started. So, I have to follow those tracks until you find them. Every day. There are times where we didn't find them. Maybe you find them, maybe two days later. So, but you will be punished if you don't bring them the first day. So, the second time you have to check, go far to the group of them. And then bring them home.

All of the trackers interviewed were born before 1994, in the era of Apartheid in South Africa. In South Africa, there appears a shift in culture, coincident with the shift from an apartheid system to democracy. During Apartheid, the primary childhood task of FTTs interviewed for this research was tending to the family livestock in the bush, with only a secondary, at-best, emphasis on low-quality education. Since the beginning of the democratic evolution, the primary emphasis has become education (much of which is still low-quality in rural areas), with tending livestock only one of many secondary and optional pursuits for children.

> FTT8: Not much in school. I was tending cows. I was always forgetting school and with the cows with my father. He was not care about me to be at the school or whatever. He was only happy about he see me out in the bush (laughter).

Children helped to supplement food provisioning by hunting small animals with snares, dogs, or small hand-held slingshots, while they wiled away the hours tending the family's livestock. Through hunting and direct observation of animals making tracks, they learned the tracks and signs of the small animals that were good for food.

> FTT2: I've learned it while I was still at home because we used to hunt small animals like your steenbok and your duiker as well, and other birds like guineafowl and francolin and few other small birds as well. We leave in the morning and come back late afternoon. It was what we did. We didn't have anything else to do.

> FTT8: I know how to make a difference (between the tracks of) in duiker and a steenbok, because the time when I was young, because I have dogs. When I find when I was walking, the duiker so I saw this is a duiker and it's walking this way (different from the steenbok). Also, I saw the dogs follow these tracks, and we followed them, and they find the duiker, started chasing. Sometimes they missed, sometimes they catch him. Then take him back at home (for food).

FTT5 recalled following his family livestock so much that he knew them individually by their tracks from amongst a herd of animals in the township that did not belong to him. He did not think he could do this now because he hadn’t followed livestock in a long time and he said it is more about the personality of the tracks than the shape, but he now follows lions and leopards every day and he can tell those apart from their tracks. He said that his community now is not the same. There is livestock and kids help with it and go to school, but their responsibility is split now between the livestock and school, with school having priority in hopes for a better outcome/job.

Reasons to learn tracking for PTTs were mostly for recreational purposes, or for a facet of their job, which spilled over into an abiding interest in learning more about the environment they lived in, and the tracks and signs that could be found there. Most of them described having access to free time in nature, growing up, where their passion for learning developed. Even when there was little physical access to nature, they described hours spent reading and learning about various aspects of nature, which eventually led to their interest in tracking.

> PTT1: The exposure that I had as a child definitely set me on a path of wanting to work in the bush, the African Bushveld, not necessarily as a tracker I don’t think I targeted tracking as a profession but from a very early age, let’s say age five, probably until my teens, until about fifteen, I was exposed to the bush of southern Africa personally. We actually lived on a farm which bordered a nature reserve. Kids just playing in the bush, you know and that became my norm. In the bush you know not to be in the city or town. You know to be barefoot and running around on a farm. There were no boundaries, no fences or anything. No responsibilities like the Shangaan may have had like to herd cattle or anything. No responsibility. That just to be immersed in nature was a big factor. And then later on when I was a teenager, like the early teens, I went with my father for his work, mapping. I would ditch school and go on these field trips with him and camp out and again, it was that immersion. Did I ever look at tracks, did I ever come across trackers? Nothing formal that I can lay my finger on. But I was just fascinated by all aspects of the bush, and from that age, from an early age, younger than ten

> years, I wanted to be, let's call it a game ranger. That was my ideal goal. I wanted to become a game ranger in Africa. That's what I wanted.

Descriptions from PTTs also included more abstract benefits of tracking, such as increasing the general comfort level of a person with being outside in heat or cold, rain or sun, and sitting or kneeling on the earth and getting dirt underneath their fingernails. This increased physical comfort level, combined with an intensive experience that familiarizes people with how to recognize things around them, initiates a physiological-psychological connection between people and nature that is accelerated by a developing sense of curiosity. Recognition and curiosity become a circular route that draws people into more discoveries, and this familiarity with their surroundings promotes greater personal value for the well-being of wild things and wild spaces.

FTTs in this study rarely expressed a personal value for or connection with nature. They did, however, frequently cite a measure of respect, especially for dangerous animals, as a criterion for expert tracking. Respect, in these cases, required enough physical experience in the bush to become comfortable, but not unconcerned, with the practice of walking alone and occasionally accidentally bumping into potentially dangerous animals. In part, this respect also came from stories, both real and imagined, of how wild animals can kill people. The following two stories illustrate the different ways that myth and fact have been passed on and facilitate respect.

> FTT2: (When growing up) about ellies I did hear that if, if you do find them, or they do find you out in the bush you'll find that they are more aggressive, so they'll start chasing you down. And once they find you, you know that they'll come and find somewhere like a Marula tree, one of the big trees like Marula trees, and they'll just go to where that Marula is, make a fork and they will just break it apart. And obviously once they've got you they'll put you in between and

> they just squeeze you up and you'll be gone by that. So that's what we, we all know about ellies, that they are not good at all. And for lion as well, that they do feed on meat, so anything that is meat they feed on it. So, if they do find you again, so just you, you don't need to turn your back at them, but obviously you need to run away from them. But I don't know how you can run without turning your back. So just like, some of those stories that they, they told us as well. There is no way you can outrun a lion. Once it sees you, it is over for you. Now, I tell them my stories about encounters with lions and ellies. But most of them, they don't believe. They said stuff like that cannot happen in this world.

> FTT7: We live next to a game reserve. There's a fence like our fence here. One day one of the elephants broke that fence and go into the village because they saw the watermelon at our village. People used to just plant watermelon. They saw them while they were inside the fence, then he broke the fence and go outside. Because he wanted the watermelon [laughter]. Ate that watermelons, and when he finished that watermelons then he is going straight away our village. So, the people of our village they see him heading away. They wanted it to be at our village because they knew when the rangers got it outside of the fence, they used to kill it. So, they wanted to get meat. So, they tried to turn the elephant come back to our village, while one of my cousins was following them. And he weren't aware that the elephant is coming back. And he met with the elephant on their way. And elephant chased him because he was already angry. So, he just managed to catch him, and throw him up. And when he comes down, he just broke his legs separately, and break his head by his foot. And he died from there. What I explained about animals like the elephant. They are so relaxed, when we respect them, they respect us. At our game drive, we can just watch, and you can some way find that he's just here. And they don't know about it because we don't provoke him, we just leave him, just like that, until he goes back. But, throw something like a rock to him or something like that we can make him angry. So, he can become angry and just try to charge us. So that is what happened, the elephant get angry, then killed.

In the first story, the tracker expresses frustration about myths people in his village have about elephants and lions. It again illustrates that misinformation can be passed from one person to another, just as easily as facts. Even though he spends time with these animals, both in a vehicle and on foot, every day, the villagers don't believe his stories. They do not have the same respect that he does, coming from his experience on the land, following their tracks and interacting with these animals. They are fearful because they don't have the same experiences to draw conclusions and comfort from, so they feel unsafe, under any circumstances where an elephant or lion is present. Their lack of knowledge leads to discomfort and disconnect from nature, while his experience leads him to respect the animals and feel comfortable, but not complacent, around them.

In the second story the tracker described a horrible situation where the villagers angered an elephant, who then killed his cousin. Hearing stories like this makes it more understandable why people might fear elephants and prefer the safety of the village or civilization to that unpredictability of wild animals in nature. However, the tracker makes sure to point out that under circumstances where people respect elephants, the elephants also respect people. This knowledge comes directly from his experience, on-the-job, tracking and interacting with, and respecting elephants.

Women trackers

When an occupation is historically male dominated, participants are often unwilling to accommodate women, which also makes the occupation less appealing to women (Martin and Barnard 2013). Women were sometimes noted as excellent trackers, for example in Ju'Hoan (Biesele and Barclay 2001) and Inupiat cultures (Bodenhorn 1990). Historically, and in the current hunting and ecotourism industries in South Africa, and within the Shangaan tribe, trackers are men, almost without exception.

> FTT3: Only men participated in tracking. It was all men. Women stayed home and cooked and took care of the children while the men hunted. There was one woman tracker, but she gave up because she didn't want to meet the animals (she was afraid).

> PTT2: In South Africa, 99% black male and 1% black female, maybe. I've never met a black female tracker. But I've heard of one. It's traditionally the job of the man to go strolling off through the bush and find a lion. That's how they see it, that's how the Shangaan guys see it, I think. I think if you were to put a female tracker into a team of Shangaans I think they'd be quite disgruntled and I don't know whether they would be, I mean, you know how difficult it is to be accepted by a lot of African trackers. You've really had to prove yourself. And even now, if there is something going on, they quickly jump in to help, because you can't handle this, you're a lady! That's how the guys treat you, so, can you imagine a lady within that culture? That's got to be hard, eh?

FTTs said that women knew tracks, even though it was a male role. Living in a semi-subsistence, natural environment, with dangerous animals throughout, would necessitate some knowledge of tracks and signs, and a general awareness of one's surroundings.

> FTT1: Even our grandmother knew, because she would collect the food in the bush, yeah because we collecting the food, and the water in the river. The women would know what the tracks are. It was safe and for smaller animals (for safety and food).

Among PTTs, there is more interest shown and aptitude demonstrated from women to learn tracking.

> PTT2: I'm finding a lot of women from other countries getting involved. It's a very skewed sort of number. I think that I've probably assessed more women over the years than I have men. When I go into the industry, though, into the various lodges, it's men. The women are not necessarily people who stay in tracking. They don't become professional trackers because it's only black men who are hired as trackers in South Africa, and those jobs don't exist in other countries.

A shift of culture in FTTs from emphasizing the skills inherent to agro-pastoralism to those emphasized by modern education and employment might not be viewed as an obstacle, if people are able to get a good education and decently paying jobs. Many leave their village for the cities, only to return, looking for simpler employment opportunities when they find a shortage of jobs in the cities, or that their education was not sufficient to get a decently paying job.

> FTT7: The Shangaan have been herding cattle for hundred of years. Hundred of years. Hundreds of years. Yeah. (Laughter). From a long time ago, there was trackers, in every culture, but not lots of them. There's still people who grew up tracking. But what I see is that this new generation now is no longer tracking. No longer. No more.

FTT2 mentioned that everyone learned a little bit about their environment and tracking by listening to stories that people told, such as when they caught something for food and told the story of its capture and some of the things they saw and responded to. He cautioned that such stories were often embellished to make the story sound more interesting, though.

> FTT2: Everyone. You find that most of them, they will know a little bit by hearing the stories. Not like being there and experiencing the stuff, because each and every when they come there, they will tell you a story about how they've catched their steenbok, but what happened with the steenbok and what, so they give you more of the info that they've seen out there. So, you'll have a little bit of loop on some of the stuff, but they are trying to make it sound interesting so they sometimes put little bit of stuff as well which are not true.

How trackers learn

Why trackers learn affects how they learn. How they learn affects what they learn, and how they perceive the importance of their accuracy. If the why question in learning tracking is for a job because it's the only job that you feel qualified to do to feed your family, even if you enjoy and are good at your job, that puts a very different emphasis on how and what you learn than if you are doing it simply because it interests you. Likewise, if you are interested in learning more about what tracking can tell you about your environment, and being accurate in your interpretations, rather than in defending your skill in your occupational position, you learn in every way you can, every time you can, and are open to being wrong if presented evidence for something else, or to admitting that you don't know or don't have enough evidence to draw a conclusion.

Practice

Trackers unanimously stated that the most important way to learn tracking and eventually become an expert was to spend time doing it. Often, this required trackers to put in time and effort to learn while on their own. It also involved watching animals. By watching an animal create tracks or signs, the tracker could approach the area after the animal had left, and examine the tracks or signs. Over time, this built a metaphorical library or catalog of different images in the tracker's mind, whereby s/he would begin to observe differences between species, sexes, or individuals. Not just for identification, though, observing specific behaviors, for example, watching and then examining an animal scent marking on a small stick, rock, shrub, caused a tracker to begin to look more carefully at small sticks, rocks, or shrubs, to see if they had also been scent marked, and thereby potentially identify a previously unknown sign.

Another tracker (PTT1) realized his experience watching animals helped advance his trailing certification in later years because he knew what to look for in terms of tracks, signs, and behaviors of the species he was following.

> PTT1: (You need to) observe animals, you need to see them making footprints, making dung, defecating, scrapings, urine, you need to observe them browsing and grazing. I spent a lot of time following rhinos, which was before my official tracking days, I monitored rhinos. I followed them for my job so I got to know all their habits. That was when I started trailing properly, then five years later for tracking assessments I didn't have to think about a rhino or how a rhino behaved at mid-day because I (had spent years) in the tree above it. I positioned myself in the tree above where I thought the rhino would come and sleep when I was monitoring them. When I was in the tree they would come and sleep on the

> ground below me and they were not aware of me other times I would just stay with them and follow them all day and sketch their ears and horns and things like that of rhinos. I could not imagine doing those rhino trails later without that knowledge. It would have been half the jigsaw puzzle was missing. It would have taken me twice as long to learn to trail rhino.

Tracking with other people

Following practice, trackers mentioned the ability to track with other people as important to learning tracking and becoming an expert. Many of the older FTTs had learned their skills from family and friends while tending livestock. Those that hadn't learned it as children were learning it, on-the-job, from other trackers, who had been brought up doing it and had also been exposed to the CyberTracker system. FTTs also mentioned that they didn't have a lot of free time during work days, so it was up to the novice trackers to ask the more experienced trackers for help.

> FTT10: You need to grow up with that teaching. (If you don't) you have to get that from the other guys, asking him questions, asking help, that's where you can become a better tracker.

PTTs also had accessibility to peers who practiced using the CyberTracker system as a model for learning. Practice with peers, learning together as a shared experience, was punctuated by evaluations to test the accuracy of what they were learning. In some cases, for both FTTs and PTTs, the evaluator became a teacher or even a mentor. Mentors were described as people who took interest in the learners as people, helped to motivate them, identified their weaknesses in tracking and offered advice on how to solve those problems. A mentor was not necessarily someone who was available every day, or even every month or year, but showed compassionate interest in teaching the correct material or process of learning to the learners, whenever the opportunity arose.

> PTT1: There were at least two stages of learning for me. If I was able to follow the tracks and find an animal or better yet see an animal making tracks and go look at them, then I was teaching myself and I was learning. Then I went on my first CyberTracker tracking course and the evaluator became my main mentor that I've had and in the last years I have done a lot of tracking in the more serious way in where the proper analytical analysis of the tracks occurs, and so on, and I am not talking just about the systematic tracking of animals I'm talking about using the knowledge that is available and being mentored a lot and being mentored by the right type of people (experts) that's what I'm talking about. In summary, I had a period of time where I messed around with tracking, and then got serious with CyberTracker and then it was more of a mentorship. And that's how I learned. And from this mentorship I was able to spend intensive amounts of time with a mentor and then go away from that and practice on my own.

Just as working with other people, especially those that knew more, was seen as an advantage, the value of teaching someone with less experience was also frequently mentioned as a useful mechanism that increased a more experienced tracker's skill.

> PTT2: The teaching of the little bit that I'd learned, just reiterating it so many times, it made me look at how I was doing things, because I had to analyze it to teach it. I still am learning tracking. But repetition helps, just time after time after time of talking to other trackers and teaching the same duiker tracks 5000 times and teaching the same kudu track 5000 times, so that kind of repetition kind of glues it into your head, as well.

> FTT8: Like now I'm taking a drive. And we find a track. I said, "let's go" (to the trainee). And I said, "Always, just stay behind me." I'll keep pointing and pointing and pointing. And I said you to go ahead. And I'll point. You look that and that and that and that. Animal will go around here. You don't have to look here and here and here. You look once up you can see the point of the grass showing you there, there. Track can go right there. You should cut through there. And from there you see the sign of the track. You take another step through other side. You go. Let's see. But only you can do that when you know. The lions under grass, they do that a lot. But you have to know that you have to know the specific age of

> point of those grasses. So, you have to make sure that which one look fresh, and lion's you can walk for a distance, like maybe 400 meters without track. Make sure that you need to see the sign of one toe or two toe to make sure you're still in a point of the lion tracks. And you see the sign, you still know that you're still on the same tracks. And they go on. You'll see. I'll see. We both get better.

Caveats mentioned included the fact that an excellent tracker might not also be a good teacher. In those instances, a two-day evaluation with an evaluator who had undergone a rigorous training process was preferred to almost constant access to inexperienced teachers. Also, in the guide-tracker team for FTTs in South Africa, both needed to know how to track. If a knowledgeable tracker leaves to go work someplace else, the guide must be able to show the new tracker how to do it. "You have to know something if they give you a new tracker and no one to train (him). Don't consider guiding to just be driving. You have to know how to track the animals (FTT4)." In such cases, the guide might or might not also have accurate tracking experience or teaching experience to draw upon.

Other resources

While PTTs frequently mentioned using books and other resources after practice and tracking with other people as learning tools, FTTs did not. FTTs cited mistrust of books, mistakes in books, and a preference to be taught, in the field, instead of reading about or looking up material in the books. This could come from comparing those with a literate vs a non-literate background, or from differences among learning styles, or from differences in opportunities to purchase such materials. PPTs did use books and other resources, not as a substitute for practical learning, but as an enhancement. They also recognized that there were good and bad resources.

> PTT1: Obviously researching books is valuable, but that's not necessarily learning about the track, it's often learning about the animal that's associated or other aspects around the tracking. I remember the days before I knew who Louis

Liebenberg was and using other books where the sketches of tracks were black on white and there was no definition or shape. Then I got serious, using the Louis Liebenberg books, his sketches of tracks. So, when I started using the right tools and using the right mentors, I also got serious about identification of tracks and signs and also following tracks.

PTT3: Definitely certain books as resources. The Internet groups on Facebook, as well as videos on YouTube and specific websites are very helpful. The ones that allow you to interact with other trackers, including some expert trackers willing to share their knowledge, are extremely helpful. They provide direct feedback to your questions and tracking pictures. In the old days before internet and cell phones (there are some excellent aps and the camera on the phone is very helpful for documenting track and sign) you used to simply not know what a track is. Now you can always know by taking a picture and finding out from others very quickly. The learning curve has become incredibly fast.

FTT6: I was practical, not for the books. (I learn) In the field. That's why, even now I don't have the books. I don't trust the books. Sometimes when you reading the books, sometimes they can make the mistakes. You know by yourself how behavior for the animals. You learn from that. We know all the animals. We're not concentrating for the books. It's like the guide manual. It says if a leopard charges you, you must shoot it because it will not stop. But I have heard the story of a leopard charging one of the trackers here and it stopped. I work in the bush, now, almost, I'm completing 17 years. I do charge a lot by the animals. I never shoot even one animals, you know.

FTT2: I just listen to them, what they say (evaluators, mentors). I know they've gone through some of the books and they've already pick up some important stuff in the books, so no need to go through the books because they've got the important stuff already. Listening is much better than writing and stuff.

Effective shortcuts to learning

FTTs gave a simplistic description of a shortcut to learning tracking, based directly on their work experience. They described driving blocks as a shortcut to finding the animal. Game reserves are laced with a road network, often of irregular blocks, and when an animal goes off the road, rather than follow it on foot, trackers would ask the guide to drive the next road over, in the direction that the animal was going. If the tracker, from the tracker seat, did not see the animal’s tracks crossing the roads driven, they could assume that the animal was still in the last block. If the animal’s tracks did cross the road, they’d drive to the roads on the edge of the next block, to see if it had come out there, and so forth. Using this process, they use the vehicle to reduce the time to finding the animal by only tracking it on foot into the block it hadn’t yet come out of.

> FTT7: What's helping me is when you, let's check the leopard come in this block here and you have seen there is track on the road when you turn in to this bush here. And before you get inside there, you have to check all the roads that he didn't cross, come out and go out into the other block. So, once you see that there is no tracks coming out, then you'll be sure that the animals see and that is blocked and you get inside there and you check every way thoroughly. Then you might as well get it because it didn't go out of the bush.

More complex shortcuts were also described by both FTTs and PTTs. These included knowing the behavior of the animals they followed, knowing how to age tracks, and, again, having a mentor. Often, trackers would start by saying there were no shortcuts to learning tracking, that you just have to spend the time doing it, but then they’d follow-up with a statement about having a mentor as a valuable shortcut.

> PTT2: If you look at tracking as a whole, there is no shortcut. It’s all experience, and whether your experience is one day a week for ten years or seven days a week for three years you are still accruing experience. So, I think experience is massively important and there is really no shortcut for getting the experience. The experience that you have makes you good, but having a mentor to guide and redirect you during that experience speeds up the process.

Opportunities and obstructions

Trackers from any background have opportunities and obstructions. In South Africa, one of the only jobs historically reserved for Shangaan men has been as a tracker in hunting or ecotourism. The generation born during Apartheid in South Africa became FTTs because they were already practicing and had learned tracking from older family members and friends while hunting or tending livestock. They became the employed trackers of the hunting and eco-tourism industry due to the recognized expertise that their practice and the transition of the skill from family and friends had given them. But this experience is fading with a change of culture from having their own children follow the herds and keep them safe, to an emphasis on school. The generation born after democracy in South Africa have different goals and aspirations, and no longer take advantage of learning tracking in their villages as children, in-order-to to become the employed trackers at lodges. So, the model has shifted, to one where tracker training occurs outside of the villages, either through CyberTracker certification or through on-the-job training from older trackers or guides. “We are lucky here (at this lodge) because we having good trainers (FTT9).”

> FTT6: I’m born in this area. I can say, my father used to work not too far from me. He was a tracker. So, I learned a little bit of the tracker from him, but a lot of things I learned when I’m still young just because I used to look after my father’s cattle. I lived for most of my life in the bush. We used to hunt the small things like duiker, impala sometimes, birds. Kill the birds for food. So, I just started to identify the tracks there, but after that I went to the lodge and got trained there.

> FTT4: A lot explains by being working under a reserve. They show me how to follow the animal like a lion and things like that. Because to know about tracking, to do the tracking the reserve, you can know how to see the tracks here to here. Something happening there you can't see, but they see you. So, to do the proper training, you need to be at a training course where they'll teach you properly. And then you do the thing exactly to save yourself because it's a kind of dangerous job. So, it's not an easy job that you will say, "I'm just going to go there and do job," is to kill yourself. It's more vulnerable job. So yeah, I will say to train first is good. To do job with a person like now I have a junior guard who needs to train. I can train him. And he can come be very good tracker because I walk with the person. I will walk with him while I'm talking with the person. I'm pointing, I'm showing a action how to look, how to follow, how to see in front, how to see the movement, how to hear, and everything like that, see? Then just do the thing without the know. It's difficult like now I go out to community to bring somebody, said, "Go ahead, follow tracks," when they haven't do it before. Some lion will growl in the front you'll never know what his sound is from. And you

> will just walk in there up to an animal jump and kill him, or jump and run away. When you are walking out there, you're not expecting to find angry lion that you follow. You can walk and it comes out a buffalo, comes out a rhino, it comes out a elephant. Myself, I always walk. Buffalo there I'm not running away. I will make sure that I must walk past the thing and straight with my tracks. Can the elephant see people, they can see. Even here, you find other trackers they said, "No, no, no we cannot walk there." They just run back. And I said, "Okay, go to the car, run to that side, and I'll walk straight to the head of buffalo." They will all run away and I walk past. It's easy. But the thing that they have to know is to know if something happen like this, you have to do this to save yourself. Before buffalo run directly where I'm going, I know that can be dangerous, because the second time buffalo turned round in fact. Animal doesn't need any pressure from us human. Always we need to respect the animal while they're also respecting us. Animal running away is to show the respect. It's not just because they're afraid of us. They're showing a respect. So, if you keep walking where the animal running to, they only think are you planning to do something with? You're chasing to catch to do something. And then they will change their mind and turn back and fight with you. And they'll kill you maybe. Animal run that side, you forget about that direction, take another one. You're safe.

FTTs often mentioned that they did not want their children to become trackers. They wanted better paying, more prestigious jobs for their children. With few exceptions, their children also did not aspire to become trackers. In addition to more prestigious and lucrative aspirations, young people were no longer comfortable with living with, and following and finding, dangerous animals. The youngest FTT(2) interviewed stated, "I mean, with the young generation, they are looking at me like, why is he doing that? Why he's following animals? Animals will kill me." As well as proximity to more employment opportunities, young people were desirous for the excitement of a city and the company of many other young people engaged in social activities and starting families.

> FTT2: I've also heard that I shouldn't want to work in the bush because it's only old people working in the bush. And I think it's more money in the city. And you know, when you are still young you are more interested to be amongst other people, so to have fun and all that stuff. So, when they out here in the bush they don't think you can have fun like they do in the city.

Tracking at a lodge is not considered a well-paying profession by FTTs, although it can be if trackers earn substantial gratuities, which are never guaranteed.

> FTT10: Tracking is a commitment because you are never going to make a lot of money, so only young people who don't have the means to study further or the education to get higher paying jobs will ask to learn, or older people who are ready to retire but not really capable of walking for hours to find a leopard for guests.

> FTT9: I think in future, we'll be having old, old, old trackers. Because the young generation is not interest. They say, those people they are not having enough money. You know, the big money is a very big status symbol now. If you don't have money, then – rather you say, a guy coming from working in a bank is having a nice car and also, he has a nice suit, a nice shoes and a nice phone, and a nice car. So, we are different, we are very much different.

Just as there are higher salaried, more complex positions available in the bush, there are also lower salaried, entry level, positions requiring less skill available in lodges, such as gardeners and laborers. One tracker-in-training (FTT7) was trying to be promoted from his current position as a night-porter, a guard who stands outside the rooms and makes sure that an unsuspecting guest walking back from the bar at night does not walk into a prowling leopard or a grazing hippo on the lawn. He had been asked by the lodge to complete a three-month, on-the-job training to become a tracker. He was showing promise, and was demonstrating dedication to learning. The lodge was unaware, though, that his wife had given birth to a child eight days ago, and he still had one week of training to complete before going home to meet his newborn daughter. His fear was that the lodge would not consider him dedicated enough to become a tracker, something he desperately wanted, if he left his training early and this would limit his opportunity for advancement.

> FTT7: I have a wife with four children. Yeah, I have a new baby, now, for, I think she's having, what date is today? Eight, she's living eight days now. I have not seen her yet, but next week, next week. I will go there (laughter).

Shangaan trackers often have large and extended families. Not only do they have many children, sometimes from multiple wives, but they often live in the same home as their mother and/or father, and their sisters and their children, and sometimes aunts and uncle. When divorce occurs, the father retains physical custody of children, and his mother (the children's grandmother) will care for them when he is away at work. Wives are considered the head of the household, and while some wives do work outside the home, the husband is expected to support the family financially. People have an advantage, belonging to a tribal system, where the chief will sell them a plot of land to build a house, have a garden, and raise a few goats or cows communally with those from other families, with taxation. But, they can never sell house or land to improve their situation like non-tribal South Africans can, because it belongs to the chief.

> FTT2: I got my own house, because to us, it's easy, because you go to the headman if you need space to build your house. So, and the headman is going to show you a space, yeah. So, you're not buying that area, you're just taking care for that area. That area still under the Chief. Yeah, so it's easy to get the space. I will say they are farming, just to eat for themselves, like a gardens, just to eat for them, not for to sell in to the overseas or other places.

A typical FTT works six weeks and then gets two weeks off. During his off-time, he goes home, sometimes several hours away, to see his family. A schedule like this can make taking the time away from family to practice seem difficult or undesirable. This type of work cycle is fairly common for all employees at a lodge, however, not just for trackers.

> FTT9: Someday, I want to be (a Senior Tracker). I mean, there are times where you coming back from working, maybe dropping. You've been working twenty, fifteen days in a row. You sit down, It's just, you're tired. Yeah, and I want to maybe, went home for two days to see my family instead of training. When you come back, you come back to work again, no family.

Children can also visit parents at work, but often only on the parent's leave days. This is an opportunity for children to spend time with their parent and see some iconic wildlife, and maybe experience what their tracker-father does for his wages. Parent's usually pay a small fee for the child's food, and are expected to supervise them. In many instances, a lodge environment is not considered a good place for children, for safety reasons, and because it is not the image that high-end lodges wish to portray. So, even though it is possible, it's rarely done.

> FTT9: If you get a day, we said, "Let me go and see the family." Because, I mean we have to pay money for them to come (gate fees, food). So, he can work for six weeks without going out, seeing them.

Contrast this with PTTs, who were often further removed from a time when their ancestral culture had needed to practice tracking, and also had a simpler history of learning how to track. Instead of being an occupation, it is considered a passion, which they can afford to pursue because their basic needs are already met through good educations and lucrative occupations. They aren't typically learning from family members what tracks and signs indicate food and safety, although they can be, but tracking helps them to form and maintain a relationship with the land, and the connections they make with other trackers builds a community of like-minded practitioners increasing their skill together. CyberTracker evaluators become teachers and sometimes mentors, and evaluations become classes that push their knowledge forward after months or years of studying and practicing.

> PTT3: I do not work as a tracker. I use my tracking skills to teach others awareness skills and primitive living skills. I use it to expand my personal knowledge. I use it to reveal to others the stories that are going on around them in the natural world. I use it to help people solve little mysteries they stumble upon.

Anyone who wants to can practice tracking or become a certified tracker, but there are no fulltime jobs for white trackers in South Africa, or for any tracker in North America. So, it is a hobby for anyone or a skill obtained to enrich your current job.

> PTT1: I remember times following every track I found on the riverbed, otters and water mongoose and so on, and that's when I started following tracks about 20 years ago (as a part of field guiding). So it was an escape from the job just to look for tracks and try to figure them out but later on when I got into the CyberTracker system I was already in management at a game lodge and doing this thing I do with desk work and I used to ditch it every day at about 3 pm and sometimes early morning at 5 am and go and track and follow animals with my good friend and we would follow animals for a long time and have a few beers afterward and we became quite good at identifying sign and then following it and sometimes locating the animals, so I guess it's always been an escape from my real job because tracking was never my regular or real job.

> PTT2: I guess, if I broadly look at my culture as much more South African, it's mainly guides. It's done professionally. It's guides that have an interest and want to improve their skills and make their CVs look a little more rosy. Occasionally I've encountered hobbyists, but nowhere near the same extent as I've seen in the USA. So, mainly professionals and it's treated as a small part of what they do, within my culture, obviously not looking at the typical, various African tribal cultures I interact with. In Southern Africa outside of my culture it's job-seeking, rural Africans of various tribes, various tribal groups and I don't think it's more for the same reasons of interest or reasons of passion for just answering questions or a desire to learn more. I think it's more a job that's tangible and within the reach of any educational level. It's just because it's a job, which is very much the opposite of what I see in the US, for example.

Shangaan trackers in this research came from limited educational backgrounds, ranging from leaving school in grade one, some graduated from high school, and one tracker had some trade school after matriculation from a public and severely under-funded high school. Most rural schools described in the communities were one-room schoolhouses, or in the shanty-home of a volunteer schoolteacher, with no heating or cooling systems, no desks, no books, and no food provided to the children. This limited scope of learning resulted in obstacles to using books, internet, and other written resources. It further resulted in difficulty with speaking English, and communicating with English-speaking guests. “So, for us, most of the black people, English is not very good (FTT11).”

South Africa has eleven official languages, which ones are most useful to learn? The language spoken in the local villages was and is still primarily the language of the Shangaan people, also called Shangaan, or XitSonga. Children were also required to learn the Afrikaans language during the Apartheid era, when, and if, they attended school. Today, with much of the business language in South Africa conducted in English, there is a desire, if not a means, for children to learn English. With low-quality education, and rudimentary English, many rural local children live in depressed economies and have limited prospects in the job market. One young man (FTT2), who used to go to work with his mother at a lodge during his school vacations, said he could not understand the Afrikaans or English being spoken around him, at first.

Many Shangaan trackers view their limited use of English as a barrier to learning and to getting promoted to a guide or management position, which requires extensive communication with English-speaking guests. They also view their broken use of English as an embarrassment that prevents them from trying to communicate.

> FTT8: In 1993 my head guide, he put me through an (on-site) training course and said to me, you must work as a guide. And I said, no my communication is not nice. I’m not going to be good for the guests. And he said, no, I could hear it

> when I talk to you. You'll be nice. You're good. You'll be good for the guests. I said, I'm not going to be good.

FTT2 recognized this limitation when he was in his final year of high school and approached a reserve owner where the tracker's mother worked in the housekeeping department. He asked the owner to teach him English, recognizing that this would be his biggest challenge in working. He then used his English to develop his interest in learning about the bush and becoming a tracker.

> FTT2: I was coming to visit my mother, and I see guides going out with guests and I didn't know what they were saying with their guests because I didn't believe that I can learn English. So, I wished that I can also learn English so I can speak as well with the guides, and with the guests so they can understand me as well. So that was my biggest challenge to be more interested on this trailing. I chat with (owner) that I'm interested on learning some of the stuff in the bush and I can help him if he is willing to help me as well. So, he said yeah, that's a good idea, he can give me a job to help the guides and he can put some money to keep me going, to learn about trialing and to be a guide as well. So, I worked for him for one year and a half, learning, and he was just putting most of the money for me being at school and bringing the guides in to assist me to have a certificate. From then on, I've been more on the tracking side not more on the guiding side, so that's where I put a lot of my effort now, but I, I do both. I like tracking stuff more than guiding stuff. I think that the tracking is more relationship with the natural world, whereas the guiding is relationship with people. I'm more interested in the tracking and everyday learning, seeing something new. You learn a lot more and you know that you don't know nothing yet, you still need to learn more. That's what makes me more interested is of course, like every day when you go out you learn something, every day, yeah.

PTTs who were South Africans of European descent all had matric, a high school diploma. In addition, many had certificates of further education, if not some university experience. PTTs from North America also all had a high school diploma and some had advanced education. These opportunities for education and subsequent ability to choose varied and interesting job employment opportunities were passed on to their children.

> PTT1: I have a three-year undergraduate degree in communications from a university in South Africa, and a two-year certificate in nature conservation. And then in terms of field guiding I have the progressive level 3 on the FGASA standard and the SKS specialized skills in dangerous game, and in birding. And I have the CyberTracker track and sign specialist with a trailing level 4, so I am a level 4 tracker, or professional tracker.

> PTT3: I have a master's degree. My son will be graduating in two months with a degree in music technology and a minor in computer science. He loves the outdoors. He spent a year living on a mountain with two other young men in a primitive shelter. My daughter is currently a college student in her junior year. She will graduate in the spring with a degree in graphic design and two minors, including photography. She has outdoor experiences but is not interested in pursuing them.

Compounding the obstacles of poor education and language barriers for FTTs, there are other, simple obstacles that are taken for granted in more affluent PTT communities, such as the ability to get a driver's license and a car, in order to become a reliable employee. Public transportation, in the form of privately owned taxis (13 to14 seat mini-busses) are more commonly used, but are poorly regulated and often unsafe, have limited routes that still require walking or hitchhiking several kilometers to a taxi-stand, and cost money that people don't have until after they become gainfully employed.

Category 3 – CyberTracker and Certification of Expertise

The original idea behind tracker certification was to acknowledge the skill level of individuals, including non-literate individuals, who could become employed as a result of certification. An additional intention was to recognize and promote the knowledge of indigenous trackers to incentivize them to keep doing it and to teach it to others, thus preventing it from dying out where it was still being used. A product of certification is to elevate tracking from only a subsistence or ecotourism activity into a proven technique for collecting scientific data.

In the recent South African past, awareness and use of CyberTracker certification spread slowly, and trackers were more likely to undertake the process of evaluations only after being employed by a lodge where it had already been introduced. Some lodge managers saw the benefits of having a certified tracking team and required all their trackers to become increasingly better qualified, often paying for the evaluation and promising a small salary increase with increasing qualification. As professional trackers already, some well-entrenched trackers harbored resentment over what they considered being forced to verify what they already believed to be expert skill. In these instances, they were especially resentful if they failed to get a perfect score on the first or second attempt, and even more so if they didn't fully understand where their errors came from (confusing the scoring of bonus questions with three-point questions, losing points for not trailing safely while doing the same things they do on a trail on a day-to-day basis, etc.). Already proficient, FTTs whose job, reputation, or salary depends on their score might consider an evaluation as unnecessary, or even a threat to their reputation and livelihood. Furthermore, earning the level of Professional or Senior Tracker does not always award trackers with additional esteem in their communities, because it does not benefit the community directly or result in a salary equivalent to doctors or even policemen.

Awareness of the system and of the reliability of its certifications has grown, and today, the ability of a job applicant in South Africa to put a CyberTracker tracking certification on their *curriculum vitae* is more likely to help them to get a job as a tracker with a lodge. Even though it is not a high paying job, and wouldn't be the first choice of many people if they had other opportunities, it is a job. FTTs with lodges are often mentored by other FTTs until they are safe and proficient at finding animals. Until they reach the level desired by a lodge, trackers still undergo certification at the requests of their employers, but there is increasing evidence to support that trackers see value in it beyond a simple means of certifying their current skill level as a stand-alone learning process. Even though FTTs say that they like, and have come to appreciate, the learning and certification provided by evaluations, most wouldn't do them if the company didn't pay for it, unless it was cheap.

PTTs rarely have an industry devoted to paying them to track full time. PTTs who are South Africans of European descent spend a percentage of their working time conducting various tracking exercises for their own development, or the development of others, particularly for their own students. Many of these are enrolled in guide training courses, where tracking forms but one aspect of their training. PTTs in North America can also use tracking as a small percentage of their occupation, but most are hobbyists, who practice tracking recreationally. Others can be hunters, or part of citizen science networks. An even smaller subset of people are employed in research projects that include an aspect of tracking, with or without certification.

> PTT3: CyberTracker certification does nothing for me from my employer's perspective at work as an educator and researcher in the USA. As much as I appreciate the knowledge it gives me, it would not help me get a job.

> PTT2: Well, I conduct CyberTracker assessments so if I wasn't qualified on the CyberTracker system as an assessor it would affect the products that I can offer. I offer a lot of track and sign as a part of, or as a component of my products that makes my products more attractive, even though I don't necessarily get paid for that track and sign product or trailing evaluation but I include it as part of my overall product, so yeah, in that way it definitely benefits me.

Both FTTs and PTTs have come to view the evaluations themselves, and the evaluators, as personal mentors. "My personal experience was that it supported me a learning opportunity as well as an assessment opportunity (PTT3)." As established trackers age and train new trackers, on-the-job, fewer and fewer had actual experience with tracking or with dangerous game, and both the practical experience given by other trackers at the lodge, and by evaluators and trackers within the CyberTracker system, appear to be replacing a childhood spent trailing cattle under the tutelage of a relative or close friend, and keeping the livestock and village safe from lions and elephants.

Opportunities to learn small things

Within the community of CyberTracker certified trackers, evaluations are seen not just as a test but also as opportunities to look more deeply at things trackers already think they know, and to learn new things. This is especially true about small details, such as invertebrate or bird tracks and sign that don't relate to aging a larger animal's trail, or finding food. FTTs who follow and find animals every day for work tend to become more skilled in the aspects of trailing, first, because they don't have as much time and opportunity to focus on the tracks and signs of animals that aren't significant to their paycheck. "I will learn something in the evaluation. I learnt the small things. Little birds and insects and lizards. So, learn more. That's good (FTT6)."

Among non-trackers and beginner trackers, the overall perception of tracking is about knowing mammal tracks and signs, and mostly the larger, more charismatic animals. People usually start learning tracking by learning the common animals, like deer or domestic dogs (often erroneously mistaken for wolves (*Canis lupus*), lynx (*Lynx canadensis*), mountain lions (*Puma concolor*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and foxes (*Vulpes vulpes*), or the potentially dangerous ones in their area, such as leopard, mountain lion, or coyote. Common questions can include, what is the practical relevance of knowing the difference between the tracks of a jumping mouse (*Zapus spp*.) and a white-footed mouse (*Peromyscus spp*.), a white-browed robin-chat (*Cossypha heuglini*) or a white-browed scrub robin (*Cercotrichas leucophrys*), or a solifuge (*Solifugae spp*.) vs a rain spider (*Palystes spp*.)? The answer currently is, there is no relevance, unless knowing these differences create a sense of personal gain by fulfilling a sense of curiosity and exploration, or where tests, such as CyberTracker evaluations, create the context for learning and the impetus to know more. In these instances, the evaluation itself becomes a learning opportunity and the evaluator becomes a teacher. “Worth it, very much. I tell you that we’re considering only big things. But now, I know. There are small things (FTT9).” The evaluations pinpoint any areas where trackers are weak in their knowledge and skills, and evaluators provide answers and feedback in a dynamic workshop-esc format.

The perceptions of most trackers were that evaluations were fun and that they enjoyed the learning and camaraderie involved with being tested. “It’s fair. They give you a certificate to make your heart to agree with what you are doing. They teach me about things I know and I must agree, then they help me learn it more (FTT1).”

> FTT8: On this job is no other tracking that we can do except what we're doing at the moment (FTTs trail animals, they don’t get many opportunities to learn T&S, unless they see an animal making a track or a sign and then take the time to walk over and look at it). I'm very excited about how we're learning because we're learning all the tracks, beds, and everything by tracking them and things like that. But being out, doing a job like this, which is good, we get guests that doesn't know which one of the tracks were the buffalo, or whatever, or the lion. Easy for the guest to ask, "This is a lion tracks? What is a bird's tracks?" So, it's more important to learn everything because at the end, you can come that way the bird's tracks, and the guest asks, "What is these tracks?" And you learn.

Trackers also stated that evaluations created a more focused learning environment than just a lesson in the bush, where,

> FTT2: You find that there will be higher concentration level during that specific day. And if you, he walk with you around the bush and showing you some stuff you might forget most of the stuff, but the day that you are doing evaluation you

> get to, to keep everything so in mind that in your next eval you don't want to miss that, the same stuff as well so, you want to get it right.

Offering a process for learning

The CyberTracker evaluations are a test, not a workshop or class. Through taking one, however, most trackers come away, not just with specific details about behavior and foot morphology that helps differentiate between a wild dog (*Lycaon Pictus*), and leopard, and a hyena track (*Hyaenidae* family), or what a bag-net from reticulate bagnet moths, known as processionary moth caterpillars (*Anaphe reticulata*) looks like, but also with a process to enhance their own learning, if they choose to do so. The detailed knowledge and the learning process vary between the two types of evaluation.

> PTT3: It motivates me to learn. The process is a teaching tool. It's an opportunity to be with other trackers, including some expert trackers, you get on a learning curve that takes you further in one weekend then you can get on your own in a year.

In T&S evaluations, getting questions correct, or having them explained to you why they are incorrect so that you can learn a process for how to look at a track or a sign critically and determine what it is, or that you don't know what it is, is valuable by itself. "The validation of what you know, and the process of making a decision and then having any errors in your thinking explained, gives trackers confidence about what they do, and do not yet know (PTT4)." If ten people are participating, when a question is answered it's possible to have gotten ten different answers for that question. Evaluators often discuss with participants, in detail, why each question is what they think it is, and is not what some participants had answered. So, answering a question about a wild dog track allows participants to hear answers for why it is a wild dog track, and also why it's not a hyena, a leopard, a jackal, a civet, etc. Often, those answers include minute details about toe position, or overt details about track size, but also general characteristics about how to tell the difference between a member of the cat family's track and a member of the dog family's track, etc. In accordance with effective learning and assessment theories (Dihoff et al. 2003, Gibbs 2006, Nutbrown et al. 2016), the slightly delayed feedback (depending on how long it takes all ten participants to answer the question) allows participants to immediately understand why their answers were incorrect and retain the information. Even when participants get an answer correct, evaluations allow them to look at a question from different perspectives (their own, the evaluators, and their peers), with additional information that they might not yet know, in different substrates, and offers further learning about other species that they might yet encounter on the evaluation. At the end of a T&S evaluation, scores are distributed within a small group format, where each candidate is encouraged to discuss with the evaluator what they felt their strengths and weaknesses were, and those thoughts are compared against the results on the score sheet. So, it can be pointed out that a participant was strong on mammal tracks, but weak on sign and bird tracks, for example. It gives the participant information on what to practice and study for to become a more well-rounded, better tracker, and to improve their score in future evaluations.

Trailing evaluations are smaller, with only four participants, and very little discussion takes places during the evaluation itself. Discussions are reserved for a thorough, small-group debrief among participants and the evaluator, after the evaluation. This is partly because a trail can turn from old to fresh within a matter of steps. For example, when an animal has bedded down nearby several hours can be gained on a trail, or it might still be bedded down, or when it has circled back on its own trail. The group needs to be as quiet as possible in order to allow the candidate doing the trailing as favorable an opportunity as possible to sneak up on an animal without it becoming alerted to their presence. Lack of continuous discussion makes the trailing evaluation feel like less of a learning opportunity than a T&S evaluation, and more like the test that it is. If participants are observant, however, and watch how their peers attempt to follow and find animals, they can learn different techniques, both good and bad, and learn from them while watching or in the debrief after the evaluation. Similar to the T&S evaluation, at the end of the trailing evaluation, each participant receives detailed feedback from the evaluator in the debrief. The feedback includes specific examples that the evaluator observed on their trail, of what they did well, and what they need to improve on.

These examples are compared to criteria on the trailing evaluation scoresheet, and are broken down into five major aspects, each with five sub-points. See Figure 1 for an example of the scoresheet. The major aspects scored are spoor recognition, spoor anticipation, anticipation of dangerous situations, alertness, and stealth. Participants start with a perfect score of 10 in each sub-category, and points are taken off for each repeated mistake. The emphasis here is on the repetition of mistakes, because it's well recognized that even the best trackers will make mistakes, and what they do to recover from those mistakes and to avoid making them again is often more important than the fact that they made a mistake. For example, if a tracker is moving too fast on a trail and this causes them to lose the trail at any place where the lighting or substrate changes, or the animal takes a turn, and they do this repeatedly, then they would lose points and those activities would be discussed with them in the debrief, with advice to slow down on the trail in the future.

The debriefs during and after a T&S evaluation, and after a trailing evaluation, are designed to give trackers advice on how to develop their own process for learning when there is no evaluator present. Specifics of a process will look different for each person, but evaluations and evaluators give participants specific knowledge on what they need to improve on, and how they can do so. T&S evaluations give participants a grounding-point, where they can use what they've learned to problem-solve when they come across something they don't know. Trailing evaluations result in a series of suggestions for trackers, based on the scoring criteria, on how to improve the methods they use to follow and find animals to make it more efficient. For example, when a tracker loses the trail, they should always return directly to the last confirmed track, and try to move forward from there on the most obvious route. If no tracks are found on the most obvious route, and the substrate is soft enough that it should have shown tracks if they are there, the tracker should, again, go back to the last confirmed track, and move forward checking the next most obvious route. This seems tedious to new trackers, and their impulse is to circle widely when they lose the trail, instead of going back to the last track and choosing obvious routes in a systematic fashion. But, circling only allows a tracker to see one track, from the side or front, which makes it easier to overlook than when a tracker is moving down a trail and the tracks are oriented in a line, going forward. Thus, new trackers will generally spend more time searching, and potentially not recover the trail, if they circle. Going back to the last track, once it becomes habit, actually saves time and is overall, more efficient. A trailing evaluation debrief contains many such suggestions for a tracker to improve the way they follow and find animals when they are on their own.

> FTT2: I think most of my stuff was correct when I started, but you know with us we didn't have those principles of tracking. So, I find it more interesting once I've got that principles of tracking because for me now it's much better, I can trail much better than before. So, because before that I used just to follow the tracks and if I lose it I didn't know much to do, but I can easier locate the other tracks so I can carry on until I find my quarry. But now as I run through the, the principles I see that it's much better to trail than before, while we used to do it. Yeah, it keeps me going. And it's not that easy anymore for me to lose my, my trail as well. But

> first time it used to be difficult, I find that I end up other trail that is going the other way around—all that stuff. So, it was just like, mixed up. But now once I've run through all those principles it looks like it's much better.

Misunderstanding the scoring

Evaluations were seen as stressful, and even potentially unfair when a participant was attempting the highest levels, where a passing score can depend on the interpretation of a single question in T&S, or understanding one pattern of behavior in an animal's trail (the tracker's behavior or the animal's). Trackers who did not understand the scoring process sometimes thought that the evaluations were too subjective and allowed the evaluator to favor certain people over others. For example, in Specialist level T&S evaluations, where a score of 100% is required to pass, there are 60 questions asked. The first three are non-scoring, introductory questions, which are used to allow trackers time to focus, get familiar with the lighting and substrate, and assuage nerves. Then, 50 three-point questions are asked, and seven bonus questions. Getting a three-point question incorrect results in a score of -1 for that question, but getting a bonus question correct gives a participant +0.33% so getting three bonus questions correct cancels out one incorrect three-point question. Prior to these interviews, bonus questions were not announced. After giving the evaluator their answers and while waiting for everyone else to answer the questions in a section, candidates often chat quietly with each other, comparing answers before they are reviewed by the evaluator. Everyone is aware of who said what, and then who got the answers wrong or right. Thus, a candidate who did not understand the scoring could think that someone who had gotten more questions incorrect (potentially seven bonus questions) than themself (three 3-point questions, or one three point question and 5 bonus questions, or some other combination) was allowed to pass and favored over themselves due to their position, a friendship with the evaluator, or even the color of their skin.

Announcing the bonus questions at the end of an evaluation, or even directly after the question was explained, was not sufficient to deflect the potential accusation by a candidate that the evaluator had changed a question's point rating from a three-point question to a bonus question to favor someone s/he liked better. When this was reported and discussed at the CyberTracker South African Evaluator's Meeting in 2014, the international protocol was immediately changed to, "The Evaluators must announce that a question is a bonus before testing, so that evaluators cannot be accused of manipulating scores to help some." As usual, there are some evaluators who disagree with this change, claiming that it could also influence the way a candidate approaches a question, that they might not take it as seriously and give it enough consideration and time, but the CyberTracker Evaluation Standards Committee believe that the issues of question transparency and evaluator integrity in a recognized international tracking standard are more important. This is a real example of how a problem with the evaluation system was identified through these interviews with trackers, the problem was brought before the CyberTracker Evaluation Standards Committee (ESC), and the international evaluation protocol was officially changed to remedy that problem.

When the system makes sense to you, you're more patient with it and appreciate the learning it provides, even if you fail to achieve the score you thought you would. FTTs tended to be more resistant to unannounced and unexplained changes in the system as it developed, and to appreciating the system when they were proven wrong, probably because they already had a reputation to defend as a tracker. Younger FTTs, and PTTs were more open minded, making statements similar to the following:

> PTT2: I like that we are exposing new knowledge through bonus questions and all those things. There are a few things that need to be fine-tuned, like putting up a

> master list, more consistency for the US and Europe, and things like that. I found that the Senior evaluation (RSA) was not very transparent at first, but I like the system and I think it has developed into a system that is fair and works well.

While FTTs agreed that the evaluations were fair and taught them a lot that they didn't already know, some felt that the lodge's system of announcing to the trackers the night before that they would be taking an evaluation the next day was a bit unfair because it did not give them time to prepare, and that the evaluators should give a description of what they wanted the trackers to do before they had to do it, so they could know what to do and do it better the first time (instead of finding out what was expected of them after they finished an evaluation). Conversely, lodge managers felt that this was something that trackers practiced every day, so they shouldn't need time to prepare, and evaluators stated that they wanted to see what trackers did, every day, and it should not matter if they did things differently than others as long as they were safe and efficient.

Older FTTs grew up tracking, by tending cattle and goats as part of their familial responsibilities. Often, they learned from their fathers, brothers, or uncles. Younger trackers, however, went to school instead of spending their days in the bush, and didn't get the same knowledge transfer from generation to generation. Instead, they learn on-the-job, from older trackers employed at lodges. These older trackers sometimes train them well, and other times don't train them well. When trained well, they are able to follow and find dangerous animals every day for work, so they assume that they know what they are doing, and are doing it well if they are able to find the animals. Yet, when they get to an evaluation, doing the same things that they do for work might get them penalized in a trailing evaluation. What they do in practice works, but it might be considered unsafe in an evaluation.

For example, when following lions, the lions might lead them through dense vegetation with no way around it, so the tracker has to go through it if he wants to find the lions for his guests. In an evaluation, safety is one of the scoring criteria, and he would lose points for unsafe behavior. Experienced FTTs know that they can track lions – they do it every day and find them – but evaluators have specific scoring criteria that they are looking for, such as that a tracker does not follow lions into dangerous areas. But to a FTT, that is not realistic because they do follow lions into dangerous areas because they have to find them quickly, during the three hours allotted for a morning or afternoon activity, but the evaluators tell them to follow and find the animals and then afterwards say this is not safe and take off points, so they have to come back and try again after they figure out what the evaluator wants to see, and not to see. Thus, evaluations differ from real life, where FTTs do take risks to fulfill their job.

FTTs argument that knowing the parameters you are being evaluated under would help them to achieve success was shared by PTTs, but PTTs were more likely to ask about criteria before an evaluation, or to be accepting of a lower score after an evaluation with an explanation of why they lost points in an unsafe area because it helped them to become better trackers and achieve a higher score, potentially, in the next evaluation.

This difference of practice and opinion over something as simple as one point was exacerbated by the fact that FTTs were being told to do an evaluation occasionally, paid for by their lodge, whereas it was selected for and enrolled in personally and frequently by PTTs. Thus, because FTTs would not willingly spend their own money on evaluations, FTTs had infrequent opportunities to retake an evaluation while under great pressure from their peers to get a perfect score and prove their tracking prowess at something they accomplished daily for a living, while

PTTs were able to take evaluations as often as they wanted to pay for them, to increase their learning and their score.

One thing that helped ease this type of tension with FTTs was when lodges demonstrated willingness to bring in evaluators regularly for tracker training. Then, FTTs could learn new material, and the evaluation process and scoring criteria, before taking an evaluation. They still might not achieve 100% on the evaluation, but they were more accepting of their mistakes as their own, and not due to the evaluation or evaluator.

Trust and the value of knowing the system

Just as misunderstanding or not understanding the scoring in evaluations can create mistrust of the system, similar feelings occur when the system, terminology, or even the certificate awarded changes. Since their initial development in the 1990's, CyberTracker evaluations have evolved in protocol, such as how many questions are asked in a T&S evaluation, or what questions are, and are not allowed to be asked by evaluators, and how long a participant must trail and animal for, what species it must be, and whether or not the tracker must actually find it to receive a perfect score. Terms have changed, such as a Level 4 tracker is now called a Professional Tracker, and a Lower band evaluation is now called a secondary evaluation. The logo, font, and vocabulary used in official certificates has been changed and standardized to reflect these changes and discourage forgery. These changes, over approximately 30 years, were helpful to clarify and refine the scoring, but when a system changes when a tracker is in the midst of it, it can seem deceitful, even if those changes are mentioned before evaluations and published on the international website because not everyone potentially understands what those changes mean or has access to the website. One incident can sour a tracker on the whole process, especially when they are within a point or two of attaining the highest levels of achievement and recognition.

> FTT1: So, you need to know where you are but what I don't sometimes agree with these guys is once you find something and they made a mistake and you find something and argue with them and finally, they see. So, they cancel those ones so they don't give the credit to you so it's mistake for them but they just say we cancelled the question. I tell them it's not fair because of this.

Documented in the above example, a FTT expressed frustration with an evaluation where the evaluator chose a question, which, when it came time for the discussion, the tracker was able to provide additional information that cast doubt upon the certainty of the answer the evaluator had written on the score sheet as correct. In this case, the evaluator recognized his error, or at least his ambiguity, and discarded the question out of a mistaken sense of fairness to the participants. The tracker who had proven the evaluator wrong however, felt that he should have gotten the points for the question. The system has subsequently evolved so that, in similar instances, the answer will be changed and the participants who had gotten it correct will receive the points for it. Evaluators have recognized that the evaluation is not about what they know, it's about what the participants know, and it's the participants' evaluation, not the evaluator's, so the evaluator must be humble enough to accept when s/he is wrong, or there isn't enough evidence to prove themselves correct, and give the points to the people who deserve them. Conversely, this sometimes leads to participants just arguing over answers because they believe that they can get a question changed or thrown out, without providing evidence in their argument. In these cases, an evaluator must also be able to provide the evidence needed to determine, without a doubt, that an answer is what they say it is.

Participants tend to do better in evaluations once they know the system, and the types of questions that are asked in T&S, or what is expected of them in the trailing. It's possible to become familiar with one evaluator's method of selecting questions, and the types of questions that s/he likes to ask. But it's impossible for trackers to know everything that could be seen in nature, even if it's on the master list of acceptable questions, due to possible variations in tracks, signs, or behaviours, so they need to be able to think creatively and critically about new things that they see in order to interpret them. But, at the highest levels of evaluation, unexpected or new questions are frequently resented, and participants sometimes falsely create scenarios where evaluators have manipulated questions, or chosen unfair questions.

> FTT9: I think sometimes it's not fair, sometimes it's fair. I mean, that's where you argue with the guy (evaluator). Maybe a child and walking in the river, argue with baboon. So, for me that's where I was arguing a lot. I feel the baboon, because there's no kids, why would a child… (laughter)? They said, "what if the child gets lost?" So, I mean, I said, "All the kids here, they are having nannies. They are looking for them in the room, so why do you think (laughter) the kid to the river?" So that's what I said it's not fair from that.

In the above incident, the question was a child's track and the tracker answered that it was a baboon and proceeded to argue with the evaluator over it. The tracker's argument was that a child would not be in that area, and that the nannies hired by parents do not let children out of the house. The argument was not based on the morphology of the track, but on the tracker's assumption that it was impossible for a human child to be in that area. The evaluator pointed out all of the differences between the morphology of a human track and a baboon track in soft sand, including ways of moving and social structures. Due to the preponderance of evidence, the other trackers being evaluated agreed with the evaluator, even ones who had also initially given baboon as an answer. The question was kept in the evaluation, even though this tracker never agreed because they did not want to admit fault and the question was fair.

The majority of trackers, however, are willing to admit their mistakes and are excited to learn from them, as noted below.

> FTT6: To me it's fair. There's some that think it was not fair. Just because they think maybe they can make it (specialist) in the first time. It's fair just because sometimes, I get there, they ask me a new question and I didn't make it, but when I'm coming back, well, they ask me the same question and you're going to get it. It makes me think. I think yeah, because I will learn more. I will learn something in the evaluation.

CyberTracker is a standard

A common misconception about the CyberTracker evaluations is that becoming a specialist or senior tracker means that you are an expert that will never make mistakes, and that all experts are the same, i.e. have the same degree of knowledge and skill. The evaluations, like any academic assessment are a standard. PTT2: "It doesn't stop (at Senior Tracker). You still learn. It's a standard." Achieving that standard can look very different between any two people. One person might barely achieve Senior Tracker, while another far exceeds the minimum standards required, and both people receive certification at the same standard level within the system, Senior Tracker. Even for the tracker who far exceeds the standard, there is always more to learn, and the possibility for making mistakes always exists with both new information, and even with already known information that's presented in different ways, on occasion.

> PTT3: The certification process is a good one but unlike other tests, being out there doing it is different every single time and constant evals will increase knowledge and reveal knowledge as well. I think the certification process is rigorous and I appreciate that the levels are earned, not given.

> PTT3: While it may not be the most perfect system to identify one high-level tracker's skill from another's perfectly, it is an important marker and the only one we have. The important thing, however, is not to differentiate who is better among high-level trackers, but who are, consistently, the accurate and reliable trackers, which is what the standard does identify. CyberTracker might not have even identified the "best trackers" in the world, yet, because not everyone knows about the evaluations or has access to them, but CyberTracker has identified those trackers that meet an expert standard.

In chapter 3 of this dissertation, results show that the average score of specialist trackers is 97.94% in T&S evaluations, with respect to the mean number of questions answered correctly in evaluations, and bonus questions were answered correctly less than 50% of the times answered by specialist level candidates (both those that passed and those that did not). On average, higher certified trackers will perform better than lower certified trackers, and lower certified trackers perform better than non-trackers. Experience and effort matter most to expertise in tracking, but the only way that we can know the quality of a tracker's experience and effort is if they have demonstrated it through evaluation and met the CyberTracker standard.

Category 4 - Obtaining Mastery

In its simplest form, obtaining mastery in tracking requires that trackers have access to places with wild animals, and the ability to spend time doing it. The physical and mental skills required should not be underestimated. Tracking takes an incredible amount of focus, attention to detail, and awareness of your surroundings. Mentally, trackers must have the patience and persistence to spend hour after hour looking at tracks and signs, watching animals, and following trails. Having a mentor helps to speed up the process. FTT5: "To be a good tracker you have to spend a lot of time in the bush and you have to put in the effort, a lot of effort. It also helps to have someone nearby that can help."

CyberTracker is the only international system for evaluating the skill of trackers, but that doesn't mean that there are not expert trackers out there who have not yet been evaluated. It's likely that there are expert trackers in Aboriginal Australia, or other cultures that maintain some root to the TEK of their relationship with food and safety in a landscape through tracking. It's also likely that there are people in modern North America or other areas who grew up hunting and setting traps, or who have simply chosen to spend as much of their free time outside developing their skills.

How, then can we identify someone who is an expert, without certification? An expert tracker can identify the skill level in other trackers. "An experienced tracker often knows, within 20 minutes of observation, where the approximate skill level of another tracker is, and then takes a few more hours to confirm exactly where they are (PTT4)."

> FTT1: You can see they have experience of tracking. You can compare one who's three years in tracking, five years in tracking, you can't compare with the one who's 20 years. But sometimes it happens somebody he has many years and he doesn't have that experience. He knows how to do but he doesn't go deep, yeah. How do you figure out the difference in somebody like that? I mean, you watch them and what do you see in them that tells you, Okay, this person, they've spent a lot of time here but they're not as good as this other person. What do you look for? It's when you follow, for example, me and you, we follow the animal and then we find the tracks coming up and down, you don't know how to tell the fresh one. A person can follow the wrong one instead of the right one. And that takes practice.

Often, the skill of an expert tracker can be traced back to, not just the time spent practicing, but also to the effort put into that time. If a tracker is passionate about tracking, it shows through their curiosity to learn more. A tracker can become an expert if it's just a job to him/her, and also when it is just a recreational hobby. Trackers who do it for a living, when it's not their preferred occupation, might become proficient and never achieve mastery, whereas trackers who pursue it passionately will.

> FTT2: It's a good job to be a tracker, and it's fun. So, I'm sure if you want to be a tracker, I think it will be fun for you. But if you don't want to be a tracker and work as a tracker you won't enjoy it. Because it, it is a hard work, but if you enjoy it it's not a hard work, so it's like fun for you.

Good trackers know that they will make mistakes, or that they will lose the trail, but they are also open to learning from their mistakes instead of becoming defensive from them, and they have the confidence to know what to do that will give them the best chance to recover a lost trail. The evidence of their experience is in their comfort with not knowing everything, in being curious and humble.

> PTT2: I'm not sure I'm one yet (an expert, yet he was already a Senior Tracker and Evaluator). I think we all just need to keep striving to learn more, keep practicing, keep using every opportunity we can to document and to learn and to teach. You can very quickly tell if that person is a very good tracker, if you spend a bit of time with them. It doesn't mean that they can see silver like that American tracker who claimed to be able to see silver lines where an animal had walked, or read the mind of an animal, like that animal communicator that claimed to know where the animal was without following it, or some such bullshit. Those people just do so much damage to tracking as a whole that it's ridiculous. In a good tracker, there's an acceptance, does that make sense? There's a comfort within the environment that I see in really good trackers, and an appreciation, and a curiosity, and there's something special, something really nice. Comfort in their own ability and knowing that they are going to make mistakes, everyone does, it's part of the process. But how they respond to those mistakes tells me as much as when they are doing exceptionally well. That mental attitude, in conjunction with having the opportunity to see their knowledge in practice, shows mastery. It's not something that, they don't go and say, I can do this and I know about that. You just see it. So, I typically will gauge a tracker by his or her skills, not by what they tell me they can do, when we are in the field together, that's one of the things that I use. In fact, if they are telling me stories that sound fantastical, I become skeptical. And I think that the CyberTracker system actually separates that out and allows for real skills to be tangible in terms of a certificate, because the fundamental aspects of a good tracker are all assessed. How you move in the bush, where you move in the bush, what you know about the bush, your alertness, your awareness of situations, where you go, where you don't go, why you go there, and the humility. I mean the really great trackers that I've met have actually been pretty nice, humble, pretty quiet people. As for benchmarks or indicators of improvement, seeing their scores improve in a track and sign type evaluation or a

> trailing evaluation. There are things that I see if I assess someone one year and then 3 year later there are changes that I see on an assessment if that person has spent a lot of time practicing, there's definitely changes but it's varied and will change from person to person. But, leading up to the kind of things we've just discussed: no longer being, "I am the best tracker and I will get 100%, you might as well print my certificate." Right, to "Geez, I'm not sure how I'm going to do on this, but let's go." And you head out there and they just show you that they can do it and that they understand their environment.

FTTs and PTTs were asked about the phenomenon of following and finding animals using silver lines or connecting with the animal through some form of telepathy. They unanimously responded in the negative, and that a tracker must just follow the tracks. Louis Liebenberg (1990*b*) describes three major aspects included in trailing animals successfully, systematic, speculative, and intuitive. A beginner tracker will spend most of their time using systematic tracking, moving from track to track slowly, as they are able to see them, and spend a lot of time looking down at the ground and searching, losing the trail, searching again, and will not gain a lot of momentum that would allow them to catch up to the animal. As the tracker becomes more proficient, they will speculate where the most obvious routes the animal was likely to have traveled and where the places are that are likely to show tracks if the animal stepped there, and they will check those routes and places, first, which speeds up their momentum. When a tracker does not see tracks, and begins to intuit where they might find an animal, such as at the next waterhole, drinking water, based on the trajectory of the animal's overall trail and their knowledge of the animal's behavior, this is based on their experience, not telepathy. A good tracker will use all three aspects, switching back and forth between them as needed.

Conclusion

In this research, the context was wildlife trackers in the CyberTracker Conservation Tracker Certification System. Trackers from three cultures were included, the Shangaan Tribe of

South Africans located near Kruger National Park, European descended South Africans, and North Americans. Trackers were interviewed, and discussions continued while in the field tracking. The focus of the inquiry was to (a) understand patterns of people's behavior (what they do), (b) understand how they interpret their experiences, and (c) develop theory that calls forth rather than suppresses or obscures participants' voices. A local study of trackers is transferrable across populations. However, it may take years to develop a theory to this higher level of abstraction and, as such, could complicate and fall outside of the scope of manageable Ph.D. work (Singh and Estefan 2018).

Trackers were separated into full-time trackers and part-time trackers, based on their experiences. Shangaan trackers were all full-time trackers, because they were employed in full time positions as trackers for lodges in the ecotourism industry. This was both an opportunity for them and an obstacle. It was an opportunity because it was a job that could provide them with money for food for their families, but also an obstacle because it was no longer a sought-after occupation within their culture. All other trackers were part-time trackers.

The four categories supporting the theory that Tracking is Original Wisdom, are 1) what it means to be a tracker, 2) developing the skill, 3) CyberTracker and certification of expertise, and 4) obtaining mastery.

1) What it means to be a tracker.

Trackers that spent more time doing T&S initially described aspects of T&S as tracking and trackers that spent more time trailing initially described aspects of trailing as tracking, but, the more they spoke, the more their focal point merged into the other by explaining the details that they needed to know to be a good tracker. Those details included so much more than track (and sign) recognition. Characteristics of good trackers were that they were always aware of their surroundings, including stopping to look around and ahead, to listen, and to engage all of their senses. Knowledge of animal behavior and animal communication was critical, as well as track aging. Track aging, is, in fact, one of the most complex aspects of good tracking to learn, and probably takes the longest because it is so variable from area to area, species to species, substrate to substrate, and dependent on local and regional weather conditions. Trackers also noted that they developed a connection, a relationship with the land, that they practiced on, even if they were not indigenous to that land and their own culture had not been close to a land for many generations.

2) Developing the skill.

Trackers all had some formative experience with time spent in nature as children, where they developed a fondness for being outside and a curiosity about what they saw. They learned tracking for three reasons, traditional, economic, and/or recreational. FTTs employed during the Apartheid era came from a traditional background where, as children they learned from their families how to track in order to find food and to keep themselves safe, and to follow their livestock and keep them safe. After the abolishment of Apartheid, the family focus shifted from having children follow the herds and spending time outside, to one of indoor education and its promise of better paying, more prestigious jobs (economics). For the most part, children of FTTs have stopped becoming trackers, and when they do, they are trained on the job by older, unrelated trackers, a CyberTracker trained guide (a PTT), or by an outside trainer, such as a CyberTracker evaluator being brought in by the lodge where they are employed. Conversely, PTTs, including women, cannot get a job as a tracker because the job market does not exist for them, so they either track as one facet of their job, or recreationally. Both FTTs and PTTs have achieved the highest levels of certification in CyberTracker, but for different reasons – one does it because it's their job, and the other because it's their passion.

Trackers unanimously stated that the most important thing to do to become a good tracker was to spend time doing it. Beyond the physical aspects of tracking well, trackers also cited patience, persistence, humility and curiosity as qualities of a good trackers. There are many varied obstacles and opportunities for the cultures studies in becoming a good tracker, but, beyond simple practice, the only shortcut to becoming a good tracker mentioned was the presence of a mentor, and in some instances, the CyberTracker evaluations took the place of a mentor.

3) CyberTracker and Certification of Expertise

Overall, trackers enjoyed the learning provided by CyberTracker Evaluations and felt that they provided them with valuable information about how to improve their skills. When trackers had issues with how evaluations were being run, the CyberTracker Evaluation Standards Committee stepped in to clarify or change the protocol to make it more transparent. The residual dissatisfaction stemmed not from the evaluations themselves, but from lodge management not providing enough training, or time to prepare, for an evaluation, or from personal ego when a tracker expected to receive a better score than they actually ended up getting.

4) Obtaining mastery.

CyberTracker is a system whereby a tracker can identify their current level of skill, and how to improve. It's likely that there are many excellent trackers who have not been evaluated and should not be excluded from employment, especially in research. A good tracker can recognize when another person is also a good tracker, because they know what to look for. To recognize if someone has obtained mastery, trackers look for the ability to recognize tracks and signs, and also the humility to recognize when they are wrong, or don't know an answer. They at what a tracker does on a trail, right and wrong, and how s/he fixes mistakes – not that they never make them.

Table 2 shows the foundational concepts described in this research for the trackers studied, and how they achieve mastery at tracking. Tracking is Original Wisdom in the sense that it is a fundamental, old knowledge to all cultures. It was once practiced during hunting for food, and for knowledge of and safety from dangerous animals. Tracking is also Original Wisdom in the sense that it is new knowledge that comes from curiosity and passion to use modern resources and technologies to dive into deeper explorations of the smaller details of tracking that drives it forward with new discoveries and publications that are not related to food, shelter, or quality of life. The culture of trackers, therefore, seems not to be composed of an either/or culture, but of many, all of which can lead to holistic expertise. When hiring a tracker for research, a more important consideration than whether or not someone comes from an indigenous culture, should be whether or not they have mastered the skills required.

Discussion

Trackers from cultures where tracking is still practiced as a life-skill or an occupation have retained some of their traditional ecological knowledge that they were raised with, in the areas where they were raised. All humans, however, come from lineages where tracking was a necessary skill. More westernized cultures might not have people practicing specific culture-based or specific land-based traditional ecological knowledge, but these trackers are rediscovering and sharing old ways of learning and relating to land, and discovering and publishing new information about species and ecosystems, and conservation and management of species and ecosystems.

Tracking is an Original Wisdom in the sense that it is a fundamental, old knowledge to all cultures. It was once practiced during hunting for food, and for knowledge of and safety from dangerous animals. In all cultures, and like any skill, some trackers were better than others and known for their tracking skills and hunting prowess (Liebenberg 1990*b*, 2013). Most modern cultures are disconnected from the historical thread whereby tracking skills were necessary and passed on from one generation to the next. In some isolated cultures, however, like the San in the Kalahari, tracking is still practiced by a few as a part of their current culture, although less so than historically (Liebenberg 1990*b*, 2013). Some of the Shangaan people living near Kruger National Park (KNP), South Africa, have also maintained a marginalized tracking tradition, although, like the San, they have been pushed out of their original lands, and, unlike the San, they still participate in a tribal culture that prevents accumulation of wealth through land ownership because their elected chief retains ownership of the land that people pay to build a house on or graze cattle on.

Tracking is also Original Wisdom in the sense that it is new knowledge that comes from curiosity and passion to use modern resources and technologies to dive into deeper explorations of the smaller details of tracking that drives it forward with new discoveries and publications that are not related to food, shelter, or quality of life. The culture of trackers, therefore, seems not to be composed of an either/or culture, but of many, all of which can lead to holistic expertise.

Grounded theory research is the study of abstract problems and their processes (Glaser and Strauss 2017). Thus, studying people who are expert trackers is to discover their emergent problems and their resolutions for managing their journey to become an expert tracker within the

CyberTracker system. For trackers, these problems vary by country, area, and culture. A hallmark of a good grounded theory, however, is that the new theory is modifiable to a different area, culture, and with new trackers having different perspectives on the same problem (Glaser 1992, 2018). Superseding the three actual groups (Shangaan, White South African, and American) studied in this research, a broader culture emerged, a culture of trackers encompassing all who practice the Original Wisdom contained in the art and science of tracking, each with their own unique interpretations and obstacles.

Tracking can be learned with or without formal education, and with or without relationship to a particular land. The theory of Original Wisdom explains that anyone from any culture or background can meet the standards set by CyberTracker and achieve expert certification. However, only a small percentage of people who live in rural, local villages, with a recent cultural history of using wildlife tracking to obtain food, for safety, and for better quality of life will become expert trackers, according to the standards set by CyberTracker Conservation. These people are tracking as a full-time job, not necessarily because of a deep relationship with land or due to a passion for wildlife or conservation. Likewise, only a small percentage of people from more affluent, western-educated cultures will meet the standards set for being an expert tracker, but these people are generally able to devote free time to exploring a deep curiosity about and passion for wildlife and the natural world. The unifying element of becoming an expert tracker is time-on-task, or experience, which is gained in many different ways depending on how a tracker grows up, learns to track, encounters opportunities and obstructions, and eventually follows their own passion to excellence as opposed to choosing to pursue alternate interests or obligations, or accepting a position of non-advancement (both in level of certification and in interest) as the path of least resistance.

Figures and Tables

Tracking Evaluation Sheet

Tracker:	Specie:
Evaluators:	Group Size:
Location:	Group Composition:
Date:	Wet/Dry
Time Started:	Windy: Yes/No
Time Completed:	Cloudy: Yes/No
Time Duration:	Animal Found: Yes/No

(1) Spoor recognition

- [ ] Not looking down in front of feet, but looking for signs five to ten metres ahead.
- [ ] Moving at a steady rate, not in stop-start manner.
- [ ] Recognising signs in grass or hard substrate.
- [ ] Recognising when there are no signs when no longer on trail.
- [ ] Ability to recognise signs after losing spoor.

(2) Spoor anticipation

- [ ] Looking well ahead, reading the terrain to look for most probable route.
- [ ] Interpret behaviour from tracks.
- [ ] Using knowledge of terrain (water, dongas, clearings) to predict movements of animal.
- [ ] Not over cautious (too slow), but not too confident (too fast).
- [ ] Anticipate where to find tracks after losing spoor.

(3) Anticipation of dangerous situations

- [ ] Awareness of wind direction.
- [ ] Knowledge of behaviour, e.g. animals resting at mid-day.
- [ ] Animal behaviour indicating danger.
- [ ] Avoid danger by leaving the spoor and picking it up further ahead, but not over cautious.
- [ ] Determine the position of dangerous animals without putting him or herself at risk.

(4) Alertness

- [ ] Looking well ahead for signs of danger.
- [ ] Stop to listen when necessary.
- [ ] Warning signs, alarm calls and smells.
- [ ] Signs of other animals.
- [ ] Seeing an animal before it sees the tracker.

(5) Stealth

- [ ] Minimise noise levels (walking, talking vs hand signals, etc.).
- [ ] Low impact on other animals.
- [ ] Use of cover to approach animal and exit route.
- [ ] Appropriate proximity to animal (close enough to observe, but not too close).
- [ ] Animal unaware of tracker

Comments:

Figure 1. A CyberTracker Trailing Evaluation scoresheet, showing the five major aspects scored and the five sub-categories in each aspect.

Table 1. Coding labels for quoted trackers.

Number	Status	**Coding label**	Years' experience (approximate)	CyberTracker level
1	Full-Time Tracker	**FTT1**	34	Tracker 3
2	Full-Time Tracker	**FTT2**	16	Tracker 3
3	Full-Time Tracker	**FTT3**	22	Senior Tracker
4	Full-Time Tracker	**FTT4**	22	T&S Professional, Trailing Specialist
5	Full-Time Tracker	**FTT5**	28	Senior Tracker
8	Full-Time Tracker	**FTT6**	17	Tracker 3
9	Full-Time Tracker	**FTT7**	2	Tracker 1
10	Full-Time Tracker	**FTT8**	30	T&S Professional, Trailing Specialist
11	Full-Time Tracker	**FTT9**	11	Tracker 2
12	Full-Time Tracker	**FTT10**	19	Professional Tracker
14	Full-Time Tracker	**FTT11**	31	Senior Tracker
6	Part-Time Tracker	**PTT1**	20	T&S Specialist, Trailing Professional
7	Part-Time Tracker	**PTT2**	24	Senior Tracker
13	Part-Time Tracker	**PTT3**	6	Tracker 2
15	Part-Time Tracker	**PTT4**	10	Senior Tracker

Table 2. Foundational concepts of Tracking is Original Wisdom.

TRACKING IS ORIGINAL WISDOM - FOUNDATIONAL CONCEPTS

1. Part-time trackers tend to have more opportunities to maintain or re-establish tracking skills.
2. Full-time trackers tend to have more obstructions to learning and are either cut off from learning tracking skills, or learn them to fulfill their basic needs.
3. An existing relationship with a land is not necessary to develop expert tracking skills, but it helps, and one often develops from being on the land frequently and learning what's living and moving, and interacting, in the environment that one lives in.
4. Tracking is an **Original Wisdom.** It's **Original** in that **it's old**, and was **Wisdom** practiced by all first peoples relating to food and safety, some of this information might be exclusive to a land or a culture based on regional species and substrates, but the concepts and processes for learning are universal.
5. Tracking is an **Original Wisdom.** It's **Original** in that **it's new**, and is **Wisdom** practiced by modern peoples for recreational uses that include resources and technologies that push the boundaries of what's possible to know much further than for food and safety.
6. There is a lot of overlap in the information provided by both first peoples and modern peoples, yet each group has "areas of expertise" based on why and how they learn tracking, and what they spend their time focusing on.
7. The primary mechanisms for developing expert tracking skills are time and practice, thereafter, having a teacher or a mentor helps to accelerate the process.
8. CyberTracker includes mentoring aspects through its evaluations, by its evaluators, and builds a community of trackers among participants.
9. The best trackers have spent more time doing it, no matter their background.
10. An attitude of humility and patience is important to learning and to becoming an expert. Whether this is causal to a person becoming a tracker, or a result of becoming a tracker, is uncertain. It might come from the fact that even expert trackers will sometimes be wrong in an identification or interpretation, or will lose the trail of an animal or mess-up an approach.

Literature Cited

Adreani, M. N. 2019. From emitters to receivers: call-based communication in groups of zebra finches. Doctoral Dissertation, Biology, Universitat Konstanz: 202.

Allen, M. 2011. Violence and voice: using a feminist constructivist grounded theory to explore women's resistance to abuse. Qualitative Research 11:23–45.

Anselm, S., and J. Corbin. 1998. Basics of qualitative research: techniques and procedures for developing grounded theory. Sage Publications, Thousand Oaks, CA.: 431.

Baldellou, M., S. Peter Henzi, and S. P. Henzi. 1992. Vigilance, predator detection and the presence of supernumerary males in vervet monkey troops. Animal Behaviour 43(3):451–461.

Barnett, D. 2012. Constructing new theory for identifying students with emotional disturbance: a constructivist approach to grounded theory. Grounded Theory Review 11:47–58.

Belant, J. L., F. Bled, I. J. Mkasanga, C. M. Wilton, S. B. Mwampeta, D. E. Beyer, W. Mwakilema, and R. Fyumagwa. 2019. Track surveys do not provide accurate or precise lion density estimates in Serengeti. Global Ecology and Conservation e00651. https://doi.org/10.1016/j.gecco.2019.e00651

Berkes, F. 1993. Traditional Ecological Knowledge in Perspective. Pages 1–10 *in*. Traditional Ecological Knowledge Concepts and Cases. International Program on Traditional Ecological Knowledge and International Development Research Centre, Ottawa, Canada. https://www.idrc.ca/sites/default/files/openebooks/683-6/index.html

Bernard, H. R. 2011. Research Methods in Anthropology: Qualitative and Quantitative Approaches. 5th edition. Altamira Press, Lanham, Maryland: 728.

Biesele, M., and S. Barclay. 2001. Ju/'hoan women's tracking knowledge and its contribution to their husbands' hunting success. African Study Monographs 26:67–84.

Blumstein, D. T. 2007. The evolution of alarm communication in rodents: structure, function, and the puzzle of apparently altruistic calling. Pages 317–327 *in* J. O. Wolff and P. W. Sherman, editors. Rodent Societies an Ecological & Evolutionary Perspective. University of Chicago Press, Chicago.

Bodenhorn, B. 1990. "I'm not the great hunter, my wife is": Iñupiat and anthropological models of gender. Études/Inuit/Studies 14(1-2):55–74.

Bothma, J. D. P., and E. A. N. le Riche. 1984. Aspects of the ecology and the behaviour of the leopard *Panthera pardus* in the Kalahari desert. Koedoe-African Protected Area Conservation and Science 27:259–279.

Bothma, J. D. P., and E. A. N. le Riche. 1993. Disturbance bias when tracking Kalahari leopards *Panthera pardus* by spoor. Koedoe-African Protected Area Conservation and Science 36(2):109–112.

Bothma, J. D. P., and E. A. N. le Riche. 1995. Evidence of the use of rubbing, scent-marking and scratching-posts by Kalahari leopards. Journal of Arid Environments 29(4):511–517.

Bothma, J. D. P., and M. D. Bothma. 2006. Activity patterns in southern Kalahari leopards. African Zoology 41:150–152.

Bothma, J. D. P., and R. J. Coertze. 2004. Motherhood increases hunting success in southern Kalahari leopards. Journal of Mammalogy 85(4):756–760.

Carlson, N. V., E. Greene, and C. N. Templeton. 2020. Nuthatches vary their alarm calls based upon the source of the eavesdropped signals. Nature Communications 11:1–7. http://dx.doi.org/10.1038/s41467-020-14414-w

Carruthers, J. 1995. The Kruger National Park: A Social and Political History. University of Natal Press. Pietermaritzburg, South Africa: 170.

Caruthers, J. 2006. Tracking in game trails: looking afresh at the politics of environmental history in South Africa. Environmental History 11:804-829.

Charmaz, K. 1991. Translating graduate qualitative methods into undergraduate teaching: intensive interviewing as a case example. Teaching Sociology 19(3):384–395.

Charmaz, K. 2014. Constructing Grounded Theory. Sage Publications, Los Angeles, CA.: 416.

Charmaz, K. 2017. The power of constructivist grounded theory for critical inquiry. Qualitative Inquiry 23:34–45.

Cheney, D. L., and R. M. Seyfarth. 1985. Vervet monkey alarm calls: manipulation through shared information? Behaviour 94(1-2):150–166.

Cruikshank, J. 2012. Are glaciers 'good to think with'? Recognising indigenous environmental knowledge. Anthropological Forum 22(3):239–250.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying "experts" when researching local ecological knowledge. Human Ecology 31(3):463–489.

Deci, E. L., and R. M. Ryan. 2008. Self-determination theory: A macrotheory of human motivation, development, and health. Canadian Psychology/Psychologie Canadienne 49(3):182–185.

Deci, E. L., R. J. Vallerand, L. G. Pelletier, and R. M. Ryan. 1991. Motivation and education: the self-determination perspective. Educational psychologist 26(3-4):325–346.

Dihoff, R. E., G. M. Brosvic, and M. L. Epstein. 2003. The role of feedback during academic testing: the delay retention effect revisited. The Psychological Record 53(4):533–548.

Doubleday, N. C. 1993. Finding Common Ground: Natural Law and Collective Wisdom. Pages 41–54 *in*. Traditional Ecological Knowledge Concepts and Cases. International Program on Traditional Ecological Knowledge and International Development Research Centre, Ottawa, Ontario. https://www.idrc.ca/sites/default/files/openebooks/683-6/index.html

Du Plessis, P. 2010. Tracking knowledge: science, tracking and technology. Master of Social Science, University of Cape Town, RSA.: 83.

Du Plessis, P. 2018. Gathering the Kalahari: tracking landscapes in motion. Doctoral Dissertation, Anthropolgy, University of Santa Crus, CA.: 331.

Elbroch, L. M. 2006. Animal Skulls: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 727.

Elbroch, L. M., and C. McFarland. 2019. Mammal Tracks & Sign: a Guide to North American Species. Second edition. Stackpole Books, Mechanicsburg, PA.: 680.

Elbroch, L. M., and K. A. Rinehart. 2011. Behavior of North American Mammals. Houghton Mifflin Harcourt, New York, N.Y.:374

Elbroch, L. M., E. M. Marks. 2001. Bird Tracks & Sign: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA.: 464.

Elbroch, L. M., T. H. Mwampamba, M. J. Santos, M. Zylberberg, L. Liebenberg, J. Minye, C. Mosser, and E. Reddy. 2011. The value, limitations, and challenges of employing local experts in conservation research. Conservation Biology 25:1195–1202.

Evans, J. W., C. A. Evans, J. M. Packard, G. Calkins, and L. M. Elbroch. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management 73(3):426–432.

Gaidet-Drapier, N., H. Fritz, M. Bourgarel, P. C. Renaud, P. Poilecot, P. Chardonnet, C. Coid, D. Poulet, and S. Le Bel. 2006. Cost and efficiency of large mammal census techniques: comparison of methods for a participatory approach in a communal area, Zimbabwe. Biodiversity Conservation 15(2):735–754.

Garratt, D. 2018. Reflections on being an expert. Grounded Theory Review 17:86–89.

Gibbs, G. 2006. Innovative assessment in higher education. Pages 23–36 *in* C. Bryan and K. Clegg, editors. Innovative Assessment in Higher Education, Routledge, New York, N.Y.

Glaser, B. G. 1992. Basics of Grounded Theory Analysis. Sociology Press, Mill Valley, CA.: 128.

Glaser, B. G. 1998. Doing Grounded Theory: Issues and Discussions. Sociology Press, Mill Valley, CA.: 254.

Glaser, B. G. 2014. Choosing grounded theory. The Grounded Theory Review 13(2):3–19.

Glaser, B. G. 2018. Getting started. Grounded Theory Review 17(1):3–6.

Glaser, B. G., and A. L. Strauss. 2017. Discovery of Grounded Theory: Strategies for Qualitative Research. First edition. Transaction Publishers, New York, N.Y.: 270.

Gutteridge, L. 2012. The Bushveld: A South African Field Guide, Including the Kruger Lowveld. Second edition. Southbound, 30 Degrees South, Pinetown, RSA.: 735.

Gutteridge, L. 2017. Invertebrates of Southern Africa and their Tracks and Signs. Jacana Media, Auckland Park, RSA.: 424.

Gutteridge, L. 2020. Birds of Southern Africa and their Tracks & Signs. Jacana Media, Aukland Park, RSA.: 400.

Gutteridge, L., and L. Liebenberg. 2013. Mammals of Southern Africa and their Tracks and Signs. Jacana Media, Auckland Park, RSA.: 291.

Hay, R. B. 1988. Toward a theory of sense of place. The Trumpeter 5(4):159–164.

Hsieh, H. F., and S. E. Shannon. 2005. Three approaches to qualitative content analysis. Qualitative Health Research 15(9):1277–1288.

Hunter, L. T. B., and J. D. Skinner. 1998. Vigilance behaviour in African ungulates: the role of predation pressure. Behaviour 135(2):195–211.

Kane, A., A. L. Jackson, D. L. Ogada, A. Monadjem, and L. McNally. 2014. Vultures acquire information on carcass location from scavenging eagles. Proceedings of the Royal Society B: Biological Sciences 281:e20141072. http://dx.doi.org/10.1098/rspb.2014.1072

Keeping, D., J. H. Burger, A. O. Keitsile, M. C. Gielen, E. Mudongo, M. Wallgren, C. Skarpe, and A. L. Foote. 2018. Can trackers count free-ranging wildlife as effectively and efficiently as conventional aerial survey and distance sampling? Implications for citizen science in the Kalahari, Botswana. Biological Conservation 223:156–169. Elsevier Ltd.

Kenny, M., and R. Fourie. 2015. Contrasting Classic, Straussian, and Constructivist grounded theory: methodological and philosophical conflicts. The Qualitative Report 20(8):1270–1289.

Kruger, L. E., and P. J. Jakes. 2003. The importance of place: advances in science and application. Forest Science 49(6):819–821.

Lalonde, A. 1993. African Indigenous Knowledge and its Relevance to Sustainable Development. Pages 55–62 *in*. Traditional Ecological Knowledge Concepts and Cases. International Program on Traditional Ecological Knowledge and International Development Research Centre. https://www.idrc.ca/sites/default/files/openebooks/683-6/index.html

Liebenberg, L. 1990. The Art of Tracking: The Origin of Science. David Philip Publishers, Cape, RSA.: 187.

Liebenberg, L. 2006. Persistence hunting by modern hunter-gatherers. Current Anthropology 47(6):1017–1026.

Liebenberg, L. 2008. The relevance of persistence hunting to human evolution. Journal of Human Evolution 55(6):1156–1159.

Liebenberg, L. 2013. The Origin of Science. CyberTracker Books. www.cybertracker.org/science/books, Cape Town, RSA.: 265.

Liebenberg, L., A. Louw, and L. M. Elbroch. 2010. Practical Tracking: A Guide to Following Footprints and Finding Animals. Stackpole Books, Mechanicsburg, PA., USA.: 352.

Liebenberg, L. 1990. A Field Guide to the Animal Tracks of Southern Africa. David Philip Publishers, Cape Town, RSA.: 306.

Lilly, M. V, E. C. Lucore, and K. A. Tarvin. 2019. Eavesdropping grey squirrels infer safety from bird chatter. PloS One 14(9):e0221279. https://doi.org/10.1371/journal.pone.0221279

Macedonia, J. M., and C. S. Evans. 1993. Essay on contemporary issues in ethology: variation among mammalian alarm call systems and the problem of meaning in animal signals. Ethology 93(3):177–197.

Marchal, A. F. J. 2017. Monitoring lions (*Panthera leo*) using digital 3D models of their tracks. Doctoral Dissertation, Zoology and Agricultural Sciences & Bio-engineering, University of Pretoria, Pretoria, RSA.: 151.

Martin, P., and A. Barnard. 2013. The experience of women in male-dominated occupations: A constructivist grounded theory inquiry. South African Journal of Industrial Psychology 39(2):1–12.

Melville, H. I. A. S., and J. D. P. Bothma. 2006. Using spoor counts to analyse the effect of small stock farming in Namibia on caracal density in the neighbouring Kgalagadi Transfrontier Park. Journal of Arid Environments 64(3):436–447.

Melville, H. I. A. S., J. D. P. Bothma, and M. G. L. Mills. 2004. Prey selection by caracal in the Kgalagadi Transfrontier Park. South African Journal of Wildlife Research 34:67–75.

Midlane, N., M. J. O’Riain, G. A. Balme, and L. T. B. Hunter. 2015. To track or to call: comparing methods for estimating population abundance of African lions *Panthera leo* in Kafue National Park. Biodiversity and Conservation 24(6): 1311-1327.

Midlane, N., M. J. O’Riain, G. A. Balme, H. S. Robinson, and L. T. B. Hunter. 2014. On tracks: a spoor-based occupancy survey of lion *Panthera leo* distribution in Kafue National Park, Zambia. Biological Conservation 172:101–108. https://doi.org/10.1016/j.biocon.2014.02.006

Molinari, M. P., and K. Vander Linden. 2019. Value-based mavericking. Grounded Theory Review 18(1):83–98.

Murie, O. J., and L. M. Elbroch. 1954. A Field Guide to Animal Tracks - The Peterson Field Guide Series. Second edition. Hougthon Mifflin Company, New York, N.Y. USA.: 448.

Nutbrown, S., C. Higgins, and S. Beesley. 2016. Measuring the impact of high quality instant feedback on learning. Practitioner Research in Higher Education 10:130–139.

O'Connor, A., B. Carpenter, and B. Coughlan. 2018. An exploration of key issues in the debate between classic and constructivist grounded theory. Grounded Theory Review 17(1):90–103.

Owren, M. J., and R. H. Bernacki. 1988. The acoustic features of vervet monkey alarm calls. Journal of the Acoustical Society of America 83(5):1927–1935.

Oxford English Dictionary (OED) Online. (2020). Oxford University Press. Dictionary online http://www.oed.com/. Retrieved 29 April 202.

Pirie, T. J., R. L. Thomas, and M. D. E. Fellowes. 2016. Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology 22:13–21.

Plotz, R. D., and W. L. Linklater. 2020. Oxpeckers help rhinos evade humans. Current Biology 30:1965-1969.e2. https://doi.org/10.1016/j.cub.2020.03.015

Rachlow, J. L., J. G. Kie, and J. Berger. 1999. Territoriality and spatial patterns of white rhinoceros in Matobo National Park, Zimbabwe. African Journal of Ecology 37(3):295–304.

Rutina, L. P., K. M. Mogwera, S. Elford, C. Mpofu, and D. Ntloyathuto. 2017. Herders' ecological knowledge and carnivore predation on livestock investigations in Makgadikgadi and Nxai national parks, Botswana. Koedoe - African Protected Area Conservation and Science 52(2):1–9.

Schmitt, M. H., K. Stears, and A. M. Shrader. 2016. Zebra reduce predation risk in mixed-species herds by eavesdropping on cues from giraffe. Behavioral Ecology 27(4):1073–1077.

Scott, S. D., and C. McFarland. 2010. Bird Feathers: A Guide to North American Species. Stackpole Books, Mechanicsburg, PA., USA.: 368.

Seyfarth, R. M., D. L. Cheney, and P. Marler. 1980. Vervet monkey alarm calls: semantic communication in a free-ranging primate. Animal Behaviour 28(4):1070–1094.

Seyfarth, R. M., D. L. Cheney, T. Bergman, J. Fischer, K. Zuberbühler, and K. Hammerschmidt. 2010. The central importance of information in studies of animal communication. Animal Behaviour 80:3–8.

Seyfarth, R., and D. Cheney. 1990. The assessment by vervet monkeys of their own and another species' alarm calls. Animal Behaviour 40(4):754–764.

Singh, S., and A. Estefan. 2018. Selecting a grounded theory approach for nursing research. Global Qualitative Nursing Research 5:1-9. https://doi.org/10.1177/2333393618799571

Snowdon, C. T. 2020. Vervet monkey alarm calls: setting the historical context. Animal Behavior and Cognition 7(2):87–94.

Stander, P. E. 1998. Spoor counts as indices of large carnivore populations: the relationship between spoor frequency, sampling effort and true density. Journal of Applied Ecology 35(3):378–385.

Stander, P. E., //. Ghau, D. Tsisaba, //. ≠Oma, and //.Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Thorn, M., D. M. Scott, M. Green, P. W. Bateman, and E. Z. Cameron. 2009. Estimating brown hyaena occupancy using baited camera traps. South African Journal of Wildlife Research 39(1):1-10.

Tobler, M. W., and G. V. N. N. Powell. 2013. Estimating jaguar densities with camera traps: problems with current designs and recommendations for future studies. Biological Conservation 159:109–118.

Viljoen, S. 1983. Communicatory behaviour of southern African tree squirrels, *Paraxerus palliatus ornatus, P. p. tongensis, P. c. cepapi* and *Funisciurus congicus*. Mammalia 47(4):441–462.

Wharton, C. A. 2006. Are we gathering reliable data? The need for measuring observer skill in wildlife monitoring. Master of Science, Wildlife and Fisheries Science, Texas A&M University: 52.

Wong, P. B. Y., P. Van Coeverden de Groot, C. Fekken, H. Smith, M. Pagès, and P. T. Boag. 2012. Interpretations of polar bear (*Ursus maritimus*) tracks by Inuit hunters: inter-rater reliability and inferences concerning accuracy. The Canadian Field-Naturalist 125(2):140–153.

Yasukawa, K., J. Sollenberger, J. Lindsey-Robbins, and E. DeBruyn. 2020. Calling in the face of danger: do nestling red-winged blackbirds (*Agelaius phoeniceus*) suppress begging in response to predator playbacks? The Auk 137:1–11. https://doi.org/10.1093/auk/ukz071