

Supplementary Material

Appendix 3A

Detailed sampling effort planning

We applied a multi factorial design in which several independent factors were tested for their main effect as well as the effect of some of their interactions on our response variable, here the probability of track detection $\hat{p}_2$ along the total transect length. The total survey effort for each factor is summarised in **Table 3A- 1**, both in terms of kilometres surveyed and number of tracks recorded.

Table 3A- 1 Summary of the factors tested for their possible impact on the probability of track detection in this study, and their respective sampling effort.

Factor X	Category	Number of tracks observed (transect length while in the first vehicle) ^a per tracker pair ^b		Total number of unique tracks observed (total transect length) ^a
		NG pair	XZ pair	
Substrate	Sand cutline	546 (38 km)	498 (40 km)	694 (78 km)
	Sand road	230 (24 km)	254 (24 km)	329 (48 km)
	Gravel road	195 (17.5 km)	185 (17.5 km)	261 (35 km)
	Off-road	266 (7 km)	204 (7 km)	328 (14 km)
	Total	1237 (86.5 km)	1141 (88.5 km)	1612 (175 km)
Livestock track density	Low	1071 (74.5 km)	974 (74.5 km)	1388 (149 km)
	High	166 (12 km)	167 (14 km)	224 (26 km)
	Total	1237 (86.5 km)	1141 (88.5 km)	1612 (175 km)
Crossing behaviour	Followers	234	217	313
	Crossers	1003	924	1299
	Total	1237	1141	1612
Age of track	Fresh	326	319	401
	Older	911	822	1211

Total	1237	1141	1612
^a Factors that could be controlled in planning have the associated transect length indicated between brackets.			
^b The effect of the observer factor was tested by tracker pairs surveying the same transects, alternatively being in the first or the second vehicle for portions totalling 50% of the transect length for each pair.			

Appendix 3B

Two sessions Capture-Mark-Recapture approach

In order to estimate the probability of track detection, we used a Capture-Mark-Recapture (CMR) approach. This method was originally designed to estimate the size of closed populations (Nichols, 1992; Seber, 1986). First, a population of size N is sampled by capturing and marking n_1 individuals in a recognizable way, which are then released back into the population. After enough time has elapsed to allow complete remixing with the rest of it, the population is resampled a second time; out of the n_2 individuals captured, m_2 were already marked from the first sample. The proportion of recaptured individuals in the second sample should then estimate the proportion of marked individuals in the population such as:

$$m_2/n_2 = n_1/N \quad \text{Eq. (3B.1)}$$

We can then accordingly estimate the total population size $\hat{N}$, that is:

$$\hat{N} = n_1 \cdot m_2/n_2 \quad \text{Eq. (3B.2)}$$

In the present study, the population is represented by the animal track pool imprinted along the transect. Practically, each transect was surveyed twice by the two different data collecting teams (i.e. a pair of trackers sit in front of a vehicle driven by a recorder) following each other. The first team is “capturing and marking” the tracks on the transect, and the second team is “recapturing” them. The track population can reasonably be considered as invariant (i.e. “closed” in CMR terminology).

The data resulting from CMR studies are generally summarised in the form of capture histories, i.e. a list of numbers, one for each capture session, where 1 represents capture and 0 represents no capture of the individuals. Here, there were two capture sessions, collected respectively by the first team then the second team. Capture histories for closed populations can be modelled in terms of capture probabilities, which here translate into the *probability that tracks are detected by observers after they were left on the transect* or probability of track detection. So, let $\widehat{p}_{2i}$ denote the detection probability of all tracks for the sampling session i . **Table 3B- 1** illustrates the approach for deriving $\hat{N}$ and $\widehat{p}_{2i}$ based on the four possible capture histories for tracks to be recorded at sampling period A or B or both (i.e. Team A or B or both).

Table 3B- 1 Mathematical approach^a to derive track population estimate $\hat{N}$ and the probability of track detection $\hat{p}_{2i}$ from capture histories of tracks by two collecting teams.

Track capture history		Number of tracks recorded	Track capture probability
Team A	Team B		
1	1	$m2$	$\widehat{p}_{2A} \cdot \widehat{p}_{2B}$
0	1	$n2 - m2$	$(1 - \widehat{p}_{2A}) \cdot \widehat{p}_{2B}$
1	0	$n1 - m2$	$\widehat{p}_{2A} \cdot (1 - \widehat{p}_{2B})$
0	0	$N - n1 - n2 - m2$	$(1 - \widehat{p}_{2A}) \cdot (1 - \widehat{p}_{2B})$
Parameter estimation			
Track abundance		Probability of track detection	
$\widehat{N} = m2 / (\widehat{p}_{2A} \cdot \widehat{p}_{2B})$		$\widehat{p}_{2A} = m2 / n2$	
$= n1 / \widehat{p}_{2A}$		$\widehat{p}_{2B} = m2 / n1$	
$= n2 / \widehat{p}_{2B}$			
Demonstration			
$\widehat{p}_{2A} \cdot \widehat{p}_{2B} \cdot N = m2$ and $\widehat{p}_{2A} \cdot (1 - \widehat{p}_{2B}) \cdot N = (n1 - m2)$			
$\Rightarrow (m2 / \widehat{p}_{2B}) \cdot (1 - \widehat{p}_{2B}) = (n1 - m2)$			
$\Rightarrow (m2 / \widehat{p}_{2B}) - m2 = (n1 - m2)$			
$\Rightarrow \widehat{p}_{2B} = m2 / n1$			
$\widehat{p}_{2A} \cdot \widehat{p}_{2B} \cdot N = m2$ and $(1 - \widehat{p}_{2A}) \cdot \widehat{p}_{2B} \cdot N = (n2 - m2)$			
$\Rightarrow (1 - \widehat{p}_{2A}) \cdot (m2 / \widehat{p}_{2A}) = (n2 - m2)$			
$\Rightarrow (m2 / \widehat{p}_{2A}) - m2 = (n2 - m2)$			
$\Rightarrow \widehat{p}_{2A} = m2 / n1$			

^aWhere n1 is the total number of tracks collected by Team A, n2 is the number of tracks collected by Team B, and m2 is the number of tracks collected both by Team A and Team B.

Appendix 3C

Procedure for matching tracks detected by the two Teams

Contrary to classical CMR studies, tracks detected by Team A cannot be formally marked for later “recapture” because this would make obvious their detection by Team B. We therefore defined specific criteria to determine whether a track recorded by Team B matched a track previously recorded by Team A, i.e. is considered a “recapture” of a track “marked” by Team A.

A pair of tracks recorded each by one of the team was eligible for matching if it met the requirements set in terms of (1) distance between the tracks’ location (**Table 3C- 1**); (2) similarity in terms of species identification relative to the tracks’ aspect (**Table 3C- 2**); and (3) similarity in terms of track age estimation (**Table 3C- 3**):

- **Distance:** due to various factors, the geolocation of a same track by both teams is likely separated by a certain distance. A first reason lays into the accuracy error of the Global Positioning System (GPS), up to 11 meters and depending on the GPS device used. A second factor implies the difference between teams in the delay (distance-wise) between the time the track is detected by the trackers, and the time it is communicated to the recorder then recorded through the data collection application. The vehicle is often still slowly moving during this process. Finally, a third reason, probably the most important in our case, lays in the fact that both teams will not necessarily detect the animal trails and subsequent track interceptions with the transect at the exact same place. On sand cutlines and gravel roads, the transect sides offer good visibility and display trails of various animals intertwining, crossing and following the transect for a short or longer distance. This results in a complex ground map likely causing tracks to sometimes be detected at different locations between teams. Also, tracks are perceived and analysed by the trackers as more or less continuous trails. Therefore, there is a variability in the moment a tracker pair is able to confirm the identification and declares the track, especially when the animal walks along the transect. Sand roads and off-road transects simplify track detection as the complexity of animal trail spatial arrangement is not easily visible on the side of the transect. However, the tires of the first vehicle may erase the trails of animals walking on the transect for a more or less long distances, causing delay in detection Team B. The maximum distance values tolerated for a track match was determined by expert opinion, per substrate and per species crossing behaviour towards the transect. Such values are higher for

followers (i.e. large carnivores & ostriches) than for crossers (i.e. large antelopes) as the first ones tend to walk long distances along the transects as opposed to the second ones, creating more variation in the exact point the trackers will declare the track.

Table 3C- 1 Maximum distances^a between the location of a track recorded by Team A and a track recorded Team B for which a potential match is considered, per transect substrate and per species group.

		Transect substrate			
		Gravel road	Sand cutline	Sand road	Off-road
Species	Antelopes	400	400	250	60
group	Carnivores & ostrich	1 000	1 000	1 000	60

^aTo avoid preventing a meaningful match of two tracks that would exceed these distances by a few meters, the distance thresholds used for matching tracks correspond to 110% of the maximum distances.

- **Species:** Some species do have similar tracks (e.g. gemsbok and red hartebeest), and a substantial number of the tracks detected on the transects are not in optimal state, which renders track identification challenging at times. This is especially the case for older tracks, as the clarity of the track contours and details erode with time and disturbance. Atypical tracks and population age structures can also make difficult the differentiation between species with similar tracks (e.g. subadult lion versus adult leopard). Some level of confusion in track identification must therefore be tolerated when validating a track match in terms of detection. In fact, in view of parsimony, it is more likely that two track interceptions of different but similar species geolocated close to one another are representing the same track, rather than two different tracks of two different species, each one being missed by one of the two teams.

Table 3C- 2 Pairs of species for which the tracks are similar and a potential match between a track recorded by Team A and a track recorded by Team B were considered.

		Species with similar tracks	
Probability of confusion between species ^b	Most probable	Gemsbok	Red hartebeest
		Brown hyena	Spotted hyena
	Less probable	Gemsbok	Wildebeest
		Leopard	Lion
	Exceptional	Kudu	Red hartebeest
		Kudu	Gemsbok
		Wildebeest	Red hartebeest
		Leopard	Cheetah

^bMore the probability of confusion between species decreased, more cautious the validation process of a track match was.

- **Age of track:** The accuracy in determining the age of a track decreases exponentially with the increase of the actual age of the track, as track erosion from various causes increases with time. Trackers base their estimation of a track erosion rate on the detection of environmental clues (e.g. known time of recent rains or disturbances, accumulation of leaves/twigs in the track depression), but also experience and deduction, which will intrinsically vary between trackers. Some level of discrepancy in track age estimation must therefore be tolerated when validating a track match in terms of detection. The age track categories used in this study account for the increasing uncertainty in the aging process once tracks get older. They were defined as follows: ≤24h, 2 days, 3 days, 3 days + (i.e. 3-6 days), 1 week + (i.e. 7-30 days), 1 month + (i.e. 1 month or older).

Table 3C- 3 Similarity in track age category between a track recorded by Team A and a track recorded by Team B for which a track match was considered or not in terms of detection.

Track match validation decision		
Similarity in track age category	Same or 1 category apart	Accepted
	2 categories apart	Accepted with caution
	>2 categories apart	Rejected

In case several closely geolocated tracks were detected, it is possible that more than one track recorded by the Team B were eligible to match a track recorded by Team A, and vice versa. In such cases (maximum 2 tracks were candidates to match another one), a system of points was applied to the candidate tracks. The candidate track that accumulated the higher number of points was selected for the track match (**Table 3C- 4**):

- **Distance, species and age of track** criteria were applied within the track eligibility values for a match, as detailed above.
- **Group:** although tracks from both teams were matched one by one, some of these individual tracks were part of a track set. A track set represents a group of individuals of the same species, whose trails crossed the transect together. It is recorded as one single geolocation at time of data collection, with the number of individuals composing the track set clearly indicated. When one track recorded by Team B and one recorded by Team A were both part of a track set (ideally accounting for the same or similar number of individuals), they were more likely to represent the detection of a same track than if one track was part of a track set and the other was recorded as a single track.
- **Sexes (large carnivores):** Because large carnivore tracks are less numerous in the region, the trackers were asked to take extra time to identify the sex of the animal, in order to assist the track match process further. However, this is not entirely reliable (Stander et al., 1997), especially as population age structure can cause confusion (e.g. female adult and male subadult tracks can be similar). Therefore, the sex criterion has been added as a support to the point system, but having less weight than the other criteria (i.e. 0.5 point maximum).

Table 3C- 4 Points system applied to the candidate tracks in relation to the track to be matched, when more than one tracks recorded by Team B were eligible to match a track recorded by Team A, and vice versa.

Criteria	Levels	Points
Distance	Closest track candidate	1
	Farthest track candidate	0
Species	Same	1
	Similar	0
Age of track	Same	1
	1 category apart	0.5
	2 categories apart	0
Group	Tracks are both part of a track sets (≥ 2 individuals)	1
	Only one track is part of a track set or	0
	both tracks are single individual animal tracks	
Sex (Carnivores)	Same	0.5
	Different	0

Applied to our dataset, the procedure described above yielded 766 matched track pairs. Amongst those, 95% had their tracks geolocated within maximum 283m from each other (71% within maximum 50m) (**Figure 3C- 1**); 81% had their track identified as the same species and 19% as similar species (**Appendix 3E**); and 81% had the age of their tracks estimated within the same category (0.46) or one category apart (0.35), and 19% two categories apart (**Figure 3C- 2**). Although possible errors are not to be excluded in our track matching system, we believe that their number is low enough not to affect significantly the results of our analyses. This process has been carefully designed and executed based on the extensive experience gained by the lead author after a cumulative 6 months of surveys on the same transects, accumulated over a period of 4 years in the Kalahari.

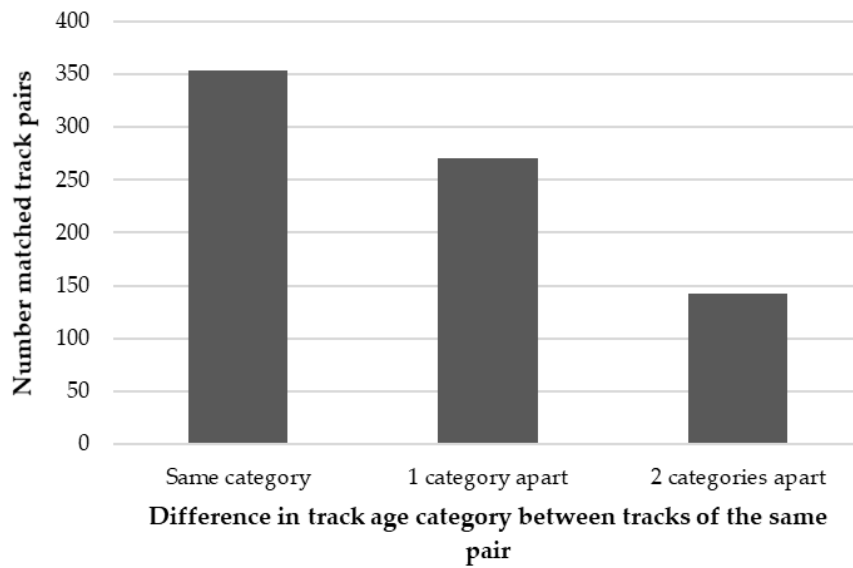


Figure 3C- 2 Number of matched track pairs whose tracks were aged as within the same category, or 1 or 2 categories apart.

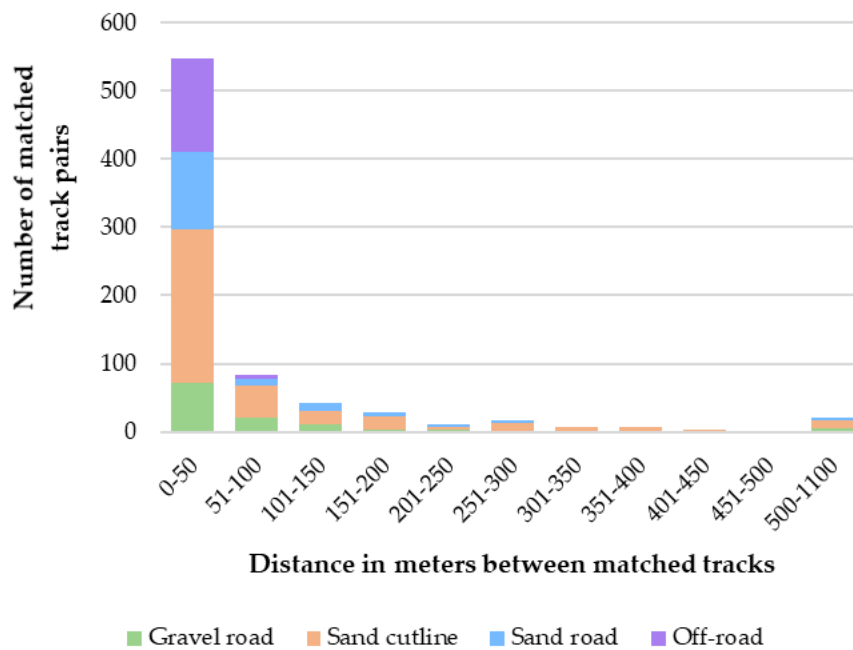


Figure 3C- 1 Number of matched track pairs per type of transect substrate according to the distance between the two tracks matched as a same detection.

Appendix 3D

Detailed statistical results of the logistic regression models

Statistical results for the four logistic linear regression performed in this study are presented in **Table 3D- 1**, **Table 3D- 2**, **Table 3D- 3** and **Table 3D- 4** below. Model assumptions for logistic linear models were respected: observations are independent as collected through a random encounter model; factors are independent by design, although not perfectly in reality due to the data not being perfectly balanced as the number of tracks recorded for each combination of conditions could not be controlled. As a consequence, fitting full models with all the interactions between factors was not possible due to limited sample size for some of the treatment level combinations, making some parameters inestimable. We therefore included only some of all the potential interactions between factors, those considered to be most likely to occur, as described in section 2.5. for each analysis.

Table 3D- 1 Results of the logistic model on the probability of double detection (vs detection by one Team only) on all tracks (1612 tracks).

Effect	DF	Wald Chi-	
		Square	<i>p</i> value
tracker pair in team A	1	3.2509	0.0714
Substrate	3	6.5981	0.0859
age of track	1	31.283	<0.0001
crossing behaviour	1	1.5329	0.2157
livestock track density	1	0.0451	0.8318
tracker pair in team A * substrate	3	1.0865	0.7803
tracker pair in team A * age of track	1	0.3199	0.5717
tracker pair in team A * crossing behaviour	1	0.4051	0.5245
substrate * age of track	3	2.3122	0.5102
substrate * crossing behaviour	3	0.9896	0.8038
age of track * crossing behaviour	1	5.1782	0.0229

Table 3D- 2 Results of the logistic model on the probability of detection by NG pair only (versus XZ pair only) on tracks detected by a single team (846 tracks).

Effect	DF	Wald Chi-Square	<i>p</i> value
Substrate	3	5.4776	0.14
age of track	1	0.2029	0.6524
crossing behaviour	1	0.3001	0.5838
livestock track density	1	1.0534	0.3047
substrate * age of track	3	17.9378	0.0005
substrate * crossing behaviour	3	12.9852	0.0047
age of track * crossing behaviour	1	0.0463	0.8296

Table 3D- 3 Results of the logistic model on the probability of species disagreement (vs agreement) on tracks detected by both teams (766 tracks).

Effect	DF	Wald Chi-Square	<i>p</i> value
age of track	1	7.0442	0.0080
crossing behaviour	1	15.9829	<0.0001
substrate	3	1.0747	0.7832

Table 3D- 4 Results of the logistic model on the probability of track age disagreement (vs agreement) on tracks detected by both teams (766 tracks).

Effect	DF	Wald Chi-Square	<i>p</i> value
substrate	3	11.5314	0.0092
crossing behaviour	1	1.4461	0.2291

Appendix 3E

Detailed species and track ageing matching results.

Results comparing species identification and track age categories between tracks identified as a same detection from the teams' datasets are presented in **Table 3E- 1**, **Table 3E- 2**, **Table 3E- 3** and **Table 3E- 4** below.

Table 3E- 1 Large carnivore species and ostrich (followers) identification matrix^a for the tracks identified as a same detection from the teams' datasets (766 matched track pairs).

		Species assigned by XZ pair							Total track counts ^b		
		Brown hyena	Cheetah	Leopard	Lion	Spotted hyena	Wild dog	Ostrich	NG pair	XZ pair	Absolute team difference
Species assigned by NG pair	Brown hyaena	64	0	0	0	0	0	0	64	66	3%
	Cheetah	0	10	2	0	0	0	0	12	12	0%
	Leopard	0	2	8	0	0	0	0	10	11	10%
	Lion	0	0	1	5	0	0	0	6	5	18%
	Spotted hyaena	2	0	0	0	0	0	0	2	0	200%
	African wild dog	0	0	0	0	0	14	0	14	14	0%
	Ostrich	0	0	0	0	0	0	30	30	30	0%
Total		66	12	11	5	0	14	30	138		

^a Green cells highlight the number of matched track pairs identified as a same species, while the other coloured cells indicated the number of matched track pairs with a different species identification between the teams. These pairs of similar species are each assigned with a specific colour for easier table reading.

^b The total number of tracks counted per species by each tracker pair is enumerated under the "Total track counts" section, from which the absolute difference in track counts between the two data collecting teams has been calculated.

Table 3E- 2 Large antelope species (crossers) identification matrix^c for the tracks identified as a same detection from the teams' datasets (766 matched track pairs).

		Species assigned by XZ pair					Total track counts ^d		
		Eland	Gemsbok	Kudu	Red hartebeest	Wildebeest	NG pair	XZ pair	Absolute team difference
Species assigned by NG pair	Eland	9	0	0	0	0	9	9	0%
	Gemsbok	0	216	3	48	2	269	293	9%
	Greater kudu	0	0	182	2	0	184	193	5%
	Red hartebeest	0	71	8	77	0	156	129	19%
	Blue wildebeest	0	6	0	2	2	10	4	86%
	Total	9	293	193	129	4	628		

^c Green cells highlight the number of matched track pairs identified as a same species, while the other coloured cells indicated the number of matched track pairs with a different species identification between the teams. These pairs of similar species are each assigned with a specific colour for easier table reading.

^d The total number of tracks counted per species by each tracker pair is enumerated under the "Total track counts" section, from which the absolute difference in track counts between the two data collecting teams has been calculated.

Table 3E- 3 Large carnivore species and ostrich (followers) and large antelope species (crossers) track ageing matrix^e for the tracks identified as a same detection from the teams' datasets (766 matched track pairs).

Track age assigned by XZ pair					Total track counts ^f		
					NG pair	XZ pair	Absolute team difference
Track age assigned by NG pair	Followers	Older	74	7	81	87	7%
		Fresh	13	44	57	51	11%
		Total	87	51	138		
	Crossers	Older	448	32	480	490	2%
		Fresh	42	106	148	138	7%
		Total	490	138	628		

^e Green cells highlight the number of matched track pairs identified as belonging to the same age category, while the red coloured cells indicate the number of matched track pairs aged differently between the teams.

^f The total number of tracks counted per track age category by each tracker pair is enumerated under the "Total track counts" section, from which the absolute difference in track counts between the two data collecting teams has been calculated.

Table 3E- 4 Individual species track ageing matrix^s for the tracks identified as a same detection from the teams' datasets (766 matched track pairs).

		Track age assigned by XZ pair		Total track counts ^b			
		Older	Fresh	NG pair	XZ pair	Absolute team difference	
Track age assigned by NG pair	Brown hyena	Older	32	5	37	39	5%
		Fresh	7	21	28	26	7%
		Total	39	26	65		
	Cheetah	Older	6	0	6	6	0%
		Fresh	0	5	5	5	0%
		Total	6	5	11		
	Leopard	Older	11	1	12	11	7%
		Fresh	0	0	0	1	200%
		Total	11	1	12		
	Lion	Older	5	0	5	5	0%
		Fresh	0	0	0	0	0%
		Total	5	0	5		
	Spotted hyena	Older	0	0	0	1	200%
		Fresh	1	0	1	0	200%
		Total	1	0	1		
	African wild dog	Older	2	0	2	5	86%
		Fresh	3	9	12	9	26%
		Total	5	9	14		
	Ostrich	Older	18	1	19	20	5%
		Fresh	2	9	11	10	10%
		Total	20	10	30		
	Eland	Older	0	3	3	0	200%
		Fresh	0	6	6	9	40%
		Total	0	9	9		
Gemsbok	Older	178	21	199	200	0.5%	
	Fresh	22	48	70	69	1%	
	Total	200	69	269			
Greater kudu	Older	141	6	147	152	3%	
	Fresh	11	26	37	32	14%	
	Total	152	32	184			
Red hartebeest	Older	199	2	121	128	6%	
	Fresh	9	26	35	28	22%	
	Total	128	28	156			
	Older	10	0	10	10	0%	

Blue wildebeest	Fresh	0	0	0	0	0%
	Total	10	0	10		

^g Green cells highlight the number of matched track pairs identified as belonging to the same age category, while the red coloured cells indicate the number of matched track pairs aged differently between the teams.

^h The total number of tracks counted per track age category by each tracker pair is enumerated under the “Total track counts” section, from which the absolute difference in track counts between the two data collecting teams has been calculated.

Appendix 4A

Extended derivation of the Formozov-Pereleshin-Malyshev formula in relation to detectability

A “track” is commonly referred as an animal footprint on the substrate. More particularly in this appendix, “track” represents the result of an intersection between an individual animal movement path and a transect; although appearing as series of footprints on the latter, this intersection is conceptualised as one individual track interception.

In population monitoring techniques, “detectability” refers to the probability of detecting an individual animal from a population of size n , within in a study area of size A , during a survey (Anderson, 2001; Barker & Sauer, 1995). Therefore, detectability is a parameter that applies to all individuals within this population. In the context of track counts along transects, detectability consists of two components, i.e. $\hat{p}_1$ and $\hat{p}_2$ (Gielen et al., 2024). This is because recording a track involves two processes assumed to be independent ($\widehat{p_{1\cap 2}} = \hat{p}_1 * \hat{p}_2$): the animal movement path must intersect the transect within a given time period and this track interception by the transect must be recorded. Therefore, we define $\hat{p}_1$ and $\hat{p}_2$ as follows:

- $\hat{p}_1$ represents the probability that an animal movement path within area A intersects the total transect length S at least once within a given time period. Assuming this probability is constant for all individual animals, it can be estimated as the proportion of the n animals in A that intersect S at least once. Therefore, $\hat{p}_1=1$ means every individual animal in A crosses S at least once.
- $\hat{p}_2$ represents the probability that a track interception is detected on S by the observers. Therefore, $\hat{p}_2=1$ means every track interception is detected.

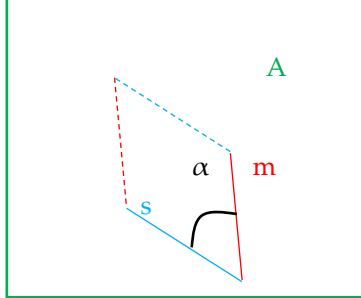
Here, we aim to explicitly demonstrate how $\hat{p}_1$ and $\hat{p}_2$ are incorporated into the track-based density estimator known as the Formozov-Pereleshin-Malyshev (FMP) formula. Therefore, we propose a review of the FMP derivation presented in Stephens et al. (2006) (quotes displayed in boxes below):

Denote a study area, A , populated by the tracks of n animals. Consider a transect of total length, S , made up of a large number (J) of short sections, each of length s . Similarly, consider the movement path of an animal to have total length M , and to be made up of K short sections, each of length m . Taking the j^{th} transect section and the k^{th} movement section, assume that these lie at an angle, α , to each other. Clearly, the probability, $P(j,k,\alpha)$, that these two sections will intersect is given by the probability that the movement begins within an area described by a parallelogram with sides of length s and m and with internal angles α and $\pi-\alpha$. Specifically,

$$P(j,k,\alpha) = \frac{ms |\sin(\alpha)|}{A} \quad (1)$$

Note: we have displayed $\sin(\alpha)$ as an absolute value in eq. 1 and 2 to be mathematically correct, a point probably assumed by Stephens et al. (2006) but missing in their paper.

The geometrical description of the intersection between the j^{th} transect section (of length s) and the k^{th} movement section (of length m) can be visually represented as follows:



In equation (1), because s and m are two small linear features, they can intercept only once. Therefore, $P(j,k)$ can be interpreted as $\hat{p}_1$ (i.e. the probability that an animal movement path of length M intersects the total transect length S at least once) if we imagine, in this theoretical context only, that the k^{th} movement section represents one entire individual animal movement crossing the transect.

Assuming that α has a uniform probability between 0 and 2π , then the mean value of $P(j,k)$ (i.e. over all values of α) is the integral of probabilities from 0 to 2π , divided by 2π . Consequently,

$$P(j,k) = \frac{1}{2\pi} \int_0^{2\pi} P(j,k,\alpha) d\alpha = \frac{sm}{2\pi A} \int_0^{2\pi} |\sin(\alpha)| d\alpha = \frac{2sm}{\pi A} \quad (2)$$

Summing this expression for all J transect sections and all K movement sections, we get the probability with which the total transect will intercept a movement path of length M:

$$P = \frac{2SM}{\pi A} \quad (3)$$

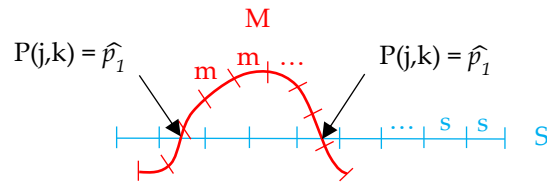
Given that the mean travel distance for all n animals in the study area is $\bar{M}$, and the expected total number of track crossings, x , is simply nP , then

$$x = \frac{2SM\bar{n}}{\pi A} \quad (4)$$

Finally, rearranging for density, D, gives

$$D = \frac{\pi x}{2SM} \quad (5)$$

Specifics related to equation (2) have been further investigated by Kondratenkov (2019), who gives a detailed interpretation of the factor $\frac{\pi}{2}$ of equation (5). Then, in equation (3), theoretically, $x = nP$ is only valid if individual animals cross S a maximum of one time. In such a case, P is indeed “the probability with which the total transect will intercept a movement path of length M” (i.e. $\hat{p}_1$), and n can be obtained as x/P . However, in a practical context, an animal movement path can cross the transect multiple times within 24 hours. When laid end to end, the J transect sections of length s (forming the total transect length S) and the K movement sections of length m (forming the animal movement path of total length M) can be visually represented, for instance, as follows:



In this case, P in equation (3) becomes a sum of probabilities (can range over 1), as also described by Chelintsev (1995), and is not anymore equal to $\hat{p}_1$.

Let's then define C as the average number of times an individual animal intersects the transect S within A, each time with the same probability P(j,k) (or $\hat{p}_1$) to happen. For instance, in the illustration just above, C=2. Then,

$$P = \sum_{i=1}^C P(k,j)_i = \sum_{i=1}^C \hat{p}_{1_i} = C \cdot \hat{p}_1 \quad (a)$$

If C=1, then $P=\hat{p}_1$. Otherwise, P is not a probability, but is a metric proportional to both $\hat{p}_1$ and C (therefore inclusive of individual animal re-crossings).

Now, let's define y the number of animals (amongst the total population n) crossing S, at least one time. Then, on average,

$$x = \sum_{i=1}^C y_i = C \cdot y \quad (b)$$

Re-working the FMP with equation (3), (a) and (b), we have:

$$\frac{n}{A} = D = \frac{\pi \cdot x}{2 \cdot S \cdot \bar{M}} = \frac{x}{A} \cdot \frac{\pi \cdot A}{2 \cdot S \cdot \bar{M}} = \frac{x}{A} \cdot \frac{1}{P} = \frac{C \cdot y}{A \cdot C \cdot \hat{p}_1} = \frac{y}{A \cdot \hat{p}_1} \quad (c)$$

Therefore, regardless of the value of C, its impact on x and P is identical, causing C to cancel itself out within the FMP formula. In other words, if each animal intersects the transect C times (regardless of the reason), it will multiply the number of recorded tracks x by C, but it will also multiply $\hat{p}_1$ by C. This point was verified by the simulation work of Keeping & Pelletier (2014), showing that “individuals with more tortuous movements are detected less but, when encountered, those individuals are generally counted a larger number of times by virtue of the convoluted pattern of their movement”. Equation (c) also reveals how D is the number of different animals (y) that cross S at least once over the study area A, corrected by the probability of the species average daily movement path $\bar{M}$ to intersect S at least once ($\hat{p}_1$). In particular, we can now algebraically define $\hat{p}_1$ as:

$$\hat{p}_1 = \frac{y \cdot P}{x} = \frac{y}{n} = \frac{P}{C} \quad (d)$$

Practically, because we do not know neither C , $\hat{p}_1$ or y in the field, we use x and P , both measurable, to estimate D . Using equation (a) and (c), P can be further defined as:

$$P = \frac{x \cdot \hat{p}_1}{y} = \frac{x}{n} = C \cdot \hat{p}_1 \quad (e)$$

In other words, **P is the expected average number of tracks left on S per individual animal forming the population size n within area A , given an average movement path $\widehat{M}$.**

In conclusion, $\hat{p}_1$ is part of the theoretical and algebraical foundation of the equation. However, it is not directly measurable in the field (and does not need to be) and is not explicitly included as such in the final algebraical form of the FMP equation. It is only indirectly incorporated into it through P relatively to x (and so basically through all the FMP parameters, except for A intrinsic to D).

Lastly, we can also include $\hat{p}_2$ in the FMP such as:

$$\hat{x} = \frac{x}{\hat{p}_2} \quad (f)$$

where $\hat{x}$ is the estimated real number of track interceptions by S , of which x are detected by observers, with a probability of track detection $\hat{p}_2$ (Gielen et al., 2024). Combining equation (c) and (f), we can now present the FMP equation under the light of its two detectability components as follows:

$$\frac{\hat{n}}{A} = \widehat{D} = \frac{\pi \cdot \hat{x}}{2 \cdot S \cdot \widehat{M}} = \frac{x}{A \cdot P \cdot \hat{p}_2} = \frac{y}{A \cdot \hat{p}_1 \cdot \hat{p}_2} \quad (g)$$

As $\hat{x}$ and $\widehat{M}$ are both estimates, the output density is also naturally an estimate and should be presented as $\widehat{D}$ (so should $\hat{n}$).

Appendix 4B

Forward trailing field protocol

This field protocol primarily aims at collecting daily movement path of individuals or groups for given species at high spatial resolution. It can also be used to collect detailed behaviours interpreted by observers from the tracks and other indirect signs along the trail. This protocol has been developed by M.-C. Gielen and A. Araldi in 2023 with the fundamental technical support of Dr. D. Keeping and Leopard Ecology & Conservation tracking team.

This protocol was tested on five medium-size to large Kalahari herbivore species: eland (*Taurotragus oryx*), red hartebeest (*Alcephalus buselaphus*), greater kudu (*Tragelaphus strepsiceros*), springbok (*Antidorcas marsupialis*), and ostrich (*Struthio camelus*).

1. Field equipment

The essential equipment items needed for successfully performing forward trailing are:

- 2 phones with CyberTracker App (i.e. 1 main and 1 spare phone) + 1 charging cable
- 1 handheld GPS + 2 sets of spare batteries (i.e. systematically used as back up to the phone)
- 1 binocular
- 1 camera
- 1 vehicle

Depending on the environmental context, optional equipment items are:

- 2 walkie-talkie radios + 2 earphones
- 1 satellite phone

2. Day 1: animal spotting

Field team: 1 recorder, 1 observer (tracker) minimum, 1 driver with 1 vehicle.

On day 1, individuals or groups of the species of interest (thereafter referred as the target) are opportunistically spotted from a vehicle, predominantly along existing roads. Having a team member on the top of the vehicle roof optimises the chance of detecting an animal, especially further

away from the roads. If animals are scarce, another option is to search for fresh tracks on the road and carefully follow the trail in hopes of spotting the animal(s). Camera traps could also be used in strategic locations (e.g. game trail) to spot animals indirectly. Upon detection, the vehicle stops and maintain its distances from the target to avoid altering its behaviour as much as possible. The following data are recorded using a custom-made CyberTracker (<https://cybertracker.org/>) application on a smartphone (see **Appendix 4C**) and Garmin GPSMAP® 64s as back up: date and spotting time, GPS location of the target, species, number of individuals, their sex and age class, their behaviour and a photograph. Additional photographs are taken with a camera; both close-ups for sex and age class identification and landscape views to assess the target's location relative to its surroundings. Such information is collected to facilitate the identification of the trailing starting point the next day.

During a spotting event, it is advised to observe the target as long as possible (up to an hour) without disturbing the target and record the same data every 5 minutes if it moves. This practice provides a time buffer for re-sighting the target the next day. For example, if we observe the target between 11:30am and 12:00am on day 1, we can record an unbiased 24-hour trail if catching up with the target any time between 11:30am and 12:00am on day 2.

Spotting is directed between midday and afternoon when animals move less and rest, typically when temperatures are higher (Berry et al., 2023; Owen-Smith & Goodall, 2014; Selebatso et al., 2017). Usually, such timing also offers a good re-sighting margin on day 2. In fact, there are good chance that the trailing ends by meeting the target at a resting place, where it hasn't moved or will not move for some time. This prevents bias when catching up with it a little bit before or after the exact 24-hour travelling period.

Additionally, spotting from midday also provides the necessary daylight hours for trailing in the morning of day 2. During our study period (i.e. May-August), trailing starts at 7am at the earliest, coinciding with sun rise. Consequently, elands, greater kudu and red hartebeests are typically spotted no earlier than 11am. This is because at least 4 hours are necessary on day 2 to record the distance the target travelled since the initial spotting and to progressively catch up with it at the required time (see Fig. 2 in the main manuscript). This is possible because the trailing pace was faster than the animals' speed of movement. Regarding ostriches, their soft feet, long strides, and zig-zag foraging patterns make their trails difficult to follow, especially on hard terrain where only their nail prints are occasionally visible. This make trailing laborious around pans and calcareous ridges. Therefore, ostriches are

spotted as late as possible in the afternoon to provide ample time to catch up with them on time on day 2. Additionally, it is advised to spot ostriches away from large pans and in groups of minimum two individuals. Although this does not preclude them to cross other pans, it maximises the chances to successfully complete the trail. Finally, as an exception, springboks are exclusively found in pans, where they can be spotted at any time between sun rise and two hours before sunset. Pans are their primary habitat, from where they rarely move during the cold dry season (Moatswi, 2019), often remaining in the same pan from day 1 to day 2. Consequently, if springboks are spotted at 4pm on day 1, their location can easily be recorded at 4pm on day 2 after exactly 24 hours has elapsed, allowing to perform the trailing without disturbing their movements in the last two hours before sunset.

Over the course of a day, it is advised to record multiple spottings, encompassing different species, individuals, locations, and times, to the extent possible. They can be primarily conducted by the main field team after completing the day's trailing, or opportunistically during trailing, but can also be made by other field teams working in the same study area. First, this practice allows to select the most suitable target for trailing the next day, based on the quantity and spatio-temporal distribution of the data already collected for each species. Where feasible, one can consider the size of the group and its demographic structure (i.e. sex and age class), while avoiding re-sampling the same targets, in order to form samples as diverse as possible. Second, having multiple sightings provides the field team with backup targets in case the trailing of the selected target cannot be completed (e.g. due to losing the trail or finding the animal deceased). In such situations, depending on the time remaining, the field team can potentially start trailing another target, thereby avoiding losing an entire day's work.

3. Day 2: animal trailing

Field team: 1 or 2 recorders, 2 observers (trackers) minimum, 1 driver with 1 vehicle.

On day 2, the field team returns to the exact location where the selected target has been spotted on day 1. For elands, greater kudu and red hartebeests, trailing begins four to five hours before the expected end time of the trailing (e.g. at 8am on day 2 if the spotting was at 1pm on day 1). For ostriches, it begins seven to eight hours before. Lastly, for springboks, the field team arrives on site 15 minutes before 24 hours has elapsed since the spotting time of day 1 (e.g. at 3:45pm on day 2 if the spotting was at 4pm on day 1). The location where the trailing should end is recorded where the springboks

stand exactly 24 hours later (e.g. at 4pm on day 2), and the trailing begins shortly after, so that their movements are not disturbed.

Trailing begins at the exact location where the target was standing at the spotting time on day 1. This location is determined from the coordinates and photographs taken, as well as the concordance between the observed behaviour on day 1 and the tracks and signs interpreted by the observers. From there, the recorder starts recording the trail on the CyberTracker application on the main smartphone, set to capture one GPS fix per second (see **Appendix 4C**). The starting point is also marked on the handheld Garmin GPSMAP® 64s, and the track log is activated at the same or the most frequent recording interval available. The trail recorded with the handheld GPS serves as backup in case of a malfunction of the CyberTracker application or the smartphone.

During the trailing, the trackers indicate the path taken by the target to the recorder, who walks as much as possible in the target's tracks while carrying both the smartphone and handheld GPS. For logistical and safety reasons, the driver follows the team on foot with the vehicle, although maintaining a certain distance to minimise noise disturbance. A second recorder, if present, or the driver regularly stand on the vehicle's roof to increase the chances of detecting the target, spot animals for the next day, or alert the field team on foot to any potential danger. The two recorders can swap roles as needed. Communication between the vehicle and team of foot is conducted via walkie-talkies equipped with headphones to avoid noise disturbance.

Any interruptions in the trailing is recorded on the CyberTracker application. These interruptions occur when the trail is temporarily lost, requiring trackers time to recover it. In such cases, the recorder stands in the last visible target track and resumes the trailing once trackers find the next track. In case of proximity to lion or elephants, for instance, the team on foot can sometimes return and wait in the vehicle until trackers deem it safe to continue. The trailing is then resumed from the location where the team has left the trail before heading to the vehicle. Interruptions also occur when the recorder needs to document the target behaviour along the trail, or indicates changes in the target group composition (i.e. number of individuals, sex and age class) (see **Appendix 4C**). In case of changes in group composition, the trailing follows the sub-group with the higher number of individuals, which is easier to trail. Recording each interruption in the trailing is necessary to facilitate efficient data curation later (see **Appendix 4D**).

Trailing requires a fine estimation of the trail's freshness for continuously adjusting the trailing pace, in order to meet the target at the required time. Highly skilled trackers and former traditional hunters are quite capable to approach the target animal without being detected. However, when the trail is fresh, the field team must aim for utmost silence, as they may approach the target prematurely, especially if it has looped in its trajectory. In case of early re-sighting, the team can observe the target from a distance without being detected, ensuring no impact on its natural behaviour until the required time. Once 24 hours have elapsed since the spotting time on day 1, the team can approach the target (which will flee) and end the trailing exactly where it was standing. If the target detects the field team, it often runs away before or at the moment the team sees it. In such instances, the team interrupts the trailing up to an hour (depending on the intended end time of the trailing) to allow the target to resume its natural behaviour before continuing. These observer-induced running distances are usually small, accounting for only a few minutes of the 24-hour movement period. They are subsequently removed from the trail's length during data curation (see **Appendix 4D**). Hence, the start and end point of such observer-induced behaviours should be recorded. Note that running or trotting behaviours can occur naturally and may not be induced by observers. Trackers must distinguish between natural and induced behaviours based on the trail's freshness and environmental cues, which the recorder notes. If the target is startled by the observer within 30 minutes of the intended end time of the trailing while the target was resting or slowly foraging, the trailing typically stops where the target starts running. This is because it is very likely the target would have remained in the same place at the required time if it had not detected the observers' presence. Therefore, it is important to spot animals during hours where they are less active.

The trail is ended where the target is re-sighted, or just fled upon the field team's approach, at the same time it was spotted the previous day, ensuring the recording of a 24-hour trail. If the target is not met on time, trailing continues when possible, until trackers estimate that 24 hours of travel distance has been sampled based on the trail's freshness. The trailing is ended on both the CyberTracker application (see **Appendix 4C**) and the handheld GPS, with the end point also recorded on the latter. However, the trail can sometimes end for other reasons, such as losing the trail, encountering a hazard, or experiencing a vehicle breakdown. In such a case, or when the trailing pace is too slow to meet the target on time, the team can attempt to recover the trail at a more distant location or to catch up with the target more quickly using the vehicle. Once the target has been met on time, the team can then backtrail the target's movement path to the point where the trail was

previously ended. This ensures the recording of the entire 24-hour movement path.

Most of the time, data collection is limited to one trail per day. However, depending on the spotting time and species, two trails can be collected on the same day, typically one completed around midday or earlier in the morning for springbok, and the other later in the afternoon.

Appendix 4C

CyberTracker application for animal trailing

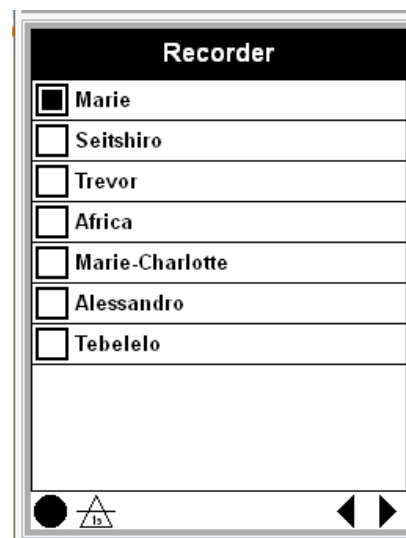
This CyberTracker application primarily aims at collecting daily movement path of individuals or groups for given wildlife species at high spatial resolution (i.e. GPS fix every one second). It can also be used to collect detailed behaviours interpreted by observers from the tracks and other indirect signs along the trail. This application has been developed by M.-C. Gielen and A. Araldi in 2023. The screenshots below have been collated by M. Jardeaux.

I. Day 1: animal spotting

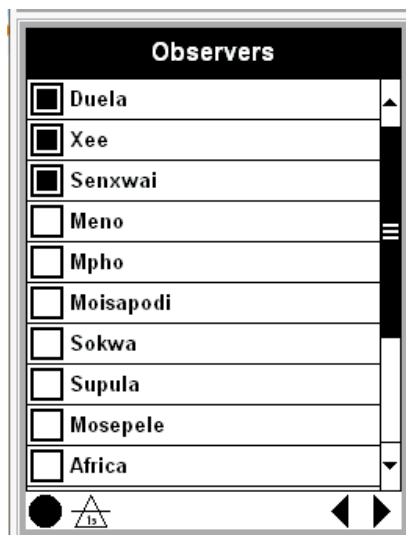
Below, the series of screenshots of the CyberTracker application interface illustrate the recording of a spotting of a group of six greater kudu (*Tragelaphus strepsiceros*) composed of four adult females and two subadult males.



Step 1: application introduction page



Step 2: Select the recorder(s)



Step 3: Select the observers



Step 4: select the activity

Species followed
Eland
Kudu
Ostrich
Red Hartebeest
Springbok
Giraffe

Navigation icons: a black circle, a triangle with '15', and left/right arrows.

Step 5: select the species spotted

Number			
6.			
7	8	9	C
4	5	6	<
1	2	3	.
0			+/-

Navigation icons: a black circle, a triangle with '15', and left/right arrows.

Step 6: enter the number of individuals

Sex/Age Class	
☐	Adult male  -
☒	Adult female  4.
☐	Adult unknown  -
☒	Subadult male  2.
☐	Subadult female  -
☐	Subadult unknown  -
☐	Juvenile  -
☐	Unknown  -

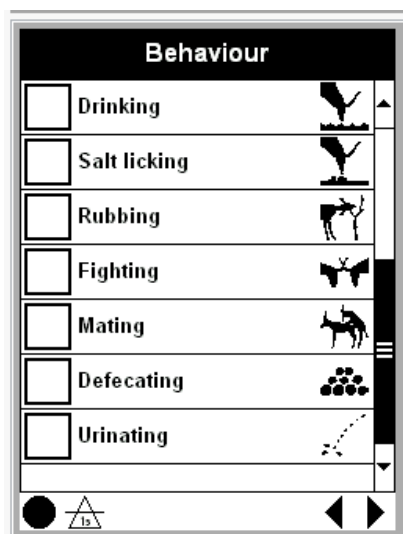
Navigation icons: a black circle, a triangle with '15', and left/right arrows.

Step 7: select the sex of the individuals and enter their number by sex

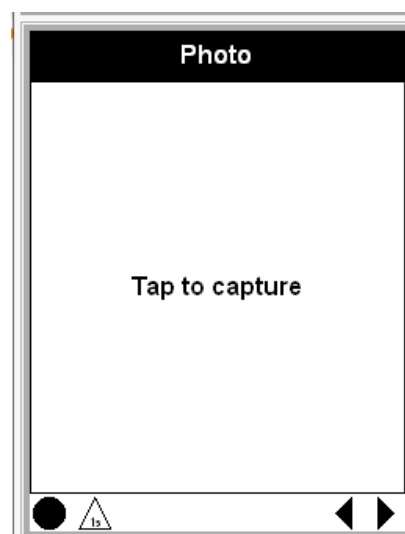
Behaviour	
☐	Trotting 
☐	Running 
☐	Walking again 
☐	Resting 
☐	Foraging 
☒	Drinking 
☐	Salt licking 
☐	Rubbing 

Navigation icons: a black circle, a triangle with '15', and left/right arrows.

Step 8: select the animals' behaviour at the time when they were spotted



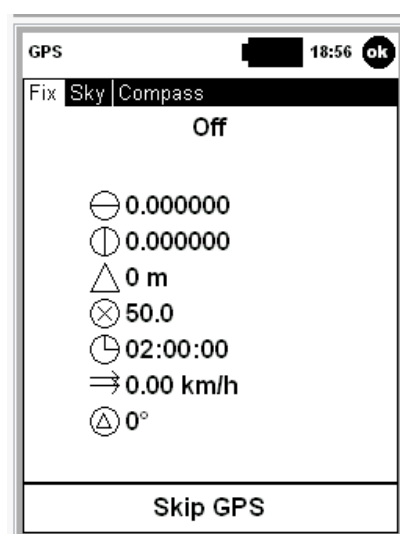
Step 8: cont.



Step 9: take a photo of the spotted animal(s)



Step 10: enter any important additional detail



Step 11: spotting information saved along with GPS coordinates

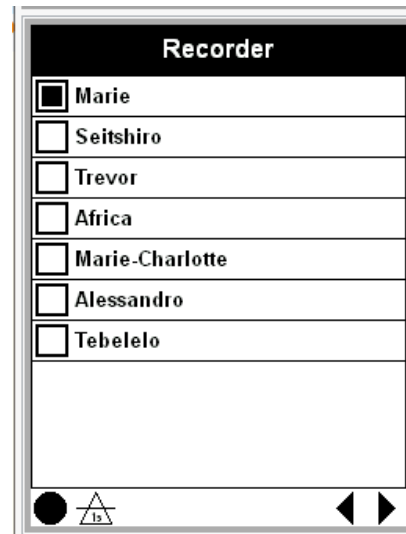
2. Day 2: animal trailing

Below, the series of screenshots of the CyberTracker application interface illustrate the recording of the trailing of the same group of six greater kudu composed of four adult females and two subadult males.

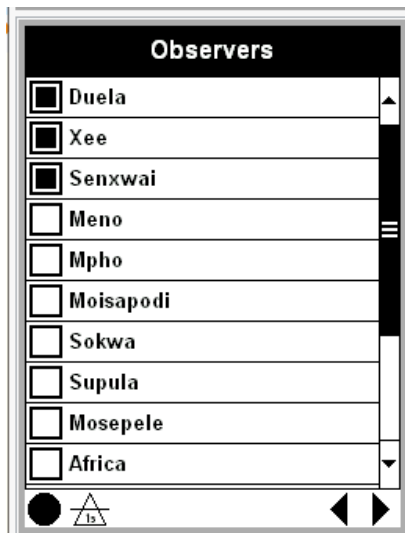
To start the trailing, proceed as follows:



Step 1: application introduction page



Step 2: select the recorder(s)



Step 3: select the observers



Step 4: select the activity

Species followed
Eland
Kudu
Ostrich
Red Hartebeest
Springbok
Giraffe

Navigation icons: back, forward, home, and a small triangle with '1s'.

Step 5: select the species to trail

Number			
6.			
7	8	9	C
4	5	6	<
1	2	3	.
0			+/-

Navigation icons: back, forward, home, and a small triangle with '1s'.

Step 6: enter the number of individuals

Sex/Age Class	
☐	Adult male
☒	Adult female
☐	Adult unknown
☒	Subadult male
☐	Subadult female
☐	Subadult unknown
☐	Juvenile
☐	Unknown

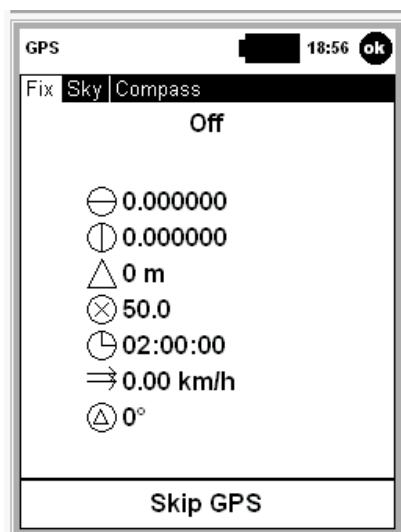
Navigation icons: back, forward, home, and a small triangle with '1s'.

Step 7: select the sex of the individuals and enter their number by sex

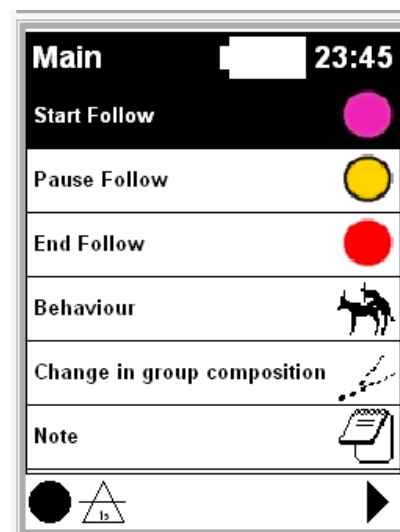
Start GPS Timer
1 second
Press timer above, then Save arrow below.

Navigation icons: back, forward, home, and a small triangle with '1s'.

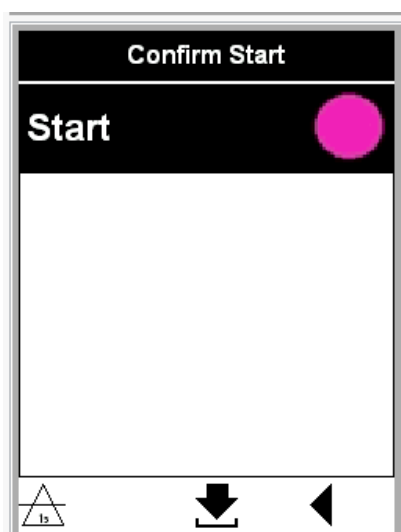
Step 8: start the GPS timer which will record a fix every one second



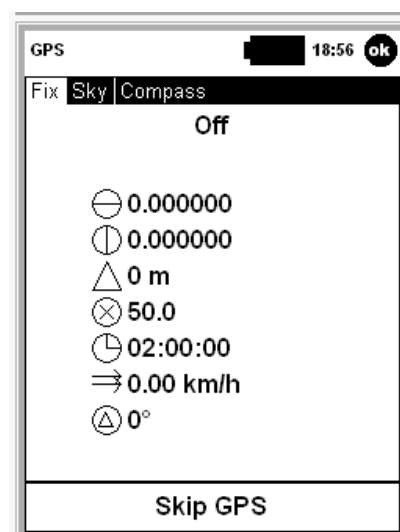
Step 9: trailing information saved along with GPS coordinates



Step 10: indicate the trailing is starting

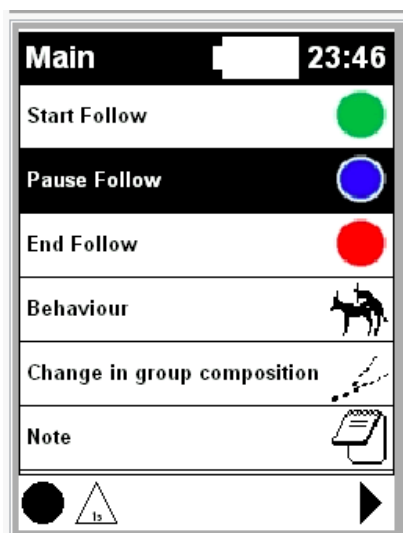


Step 11: confirm the information

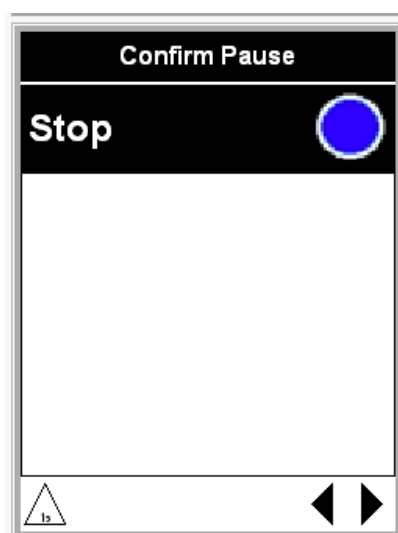


Step 12: GPS coordinates of the starting point saved

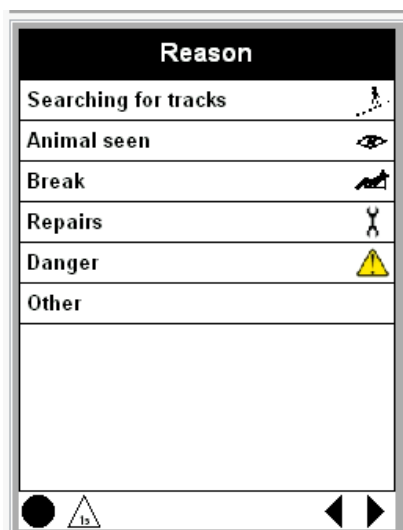
In case the trailing is interrupted, i.e. the recorder stopped actively walking on the animal path, proceed as follows:



Step 13: indicate the trailing is paused



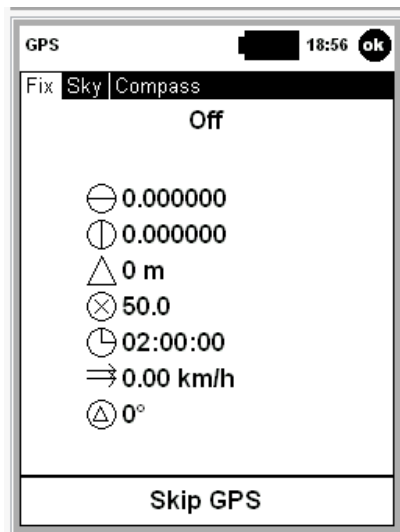
Step 14: confirm the information



Step 15: indicate the reason of the interruption



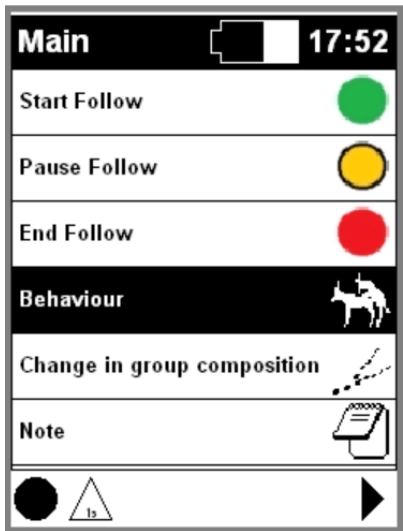
Step 16: enter any important additional detail



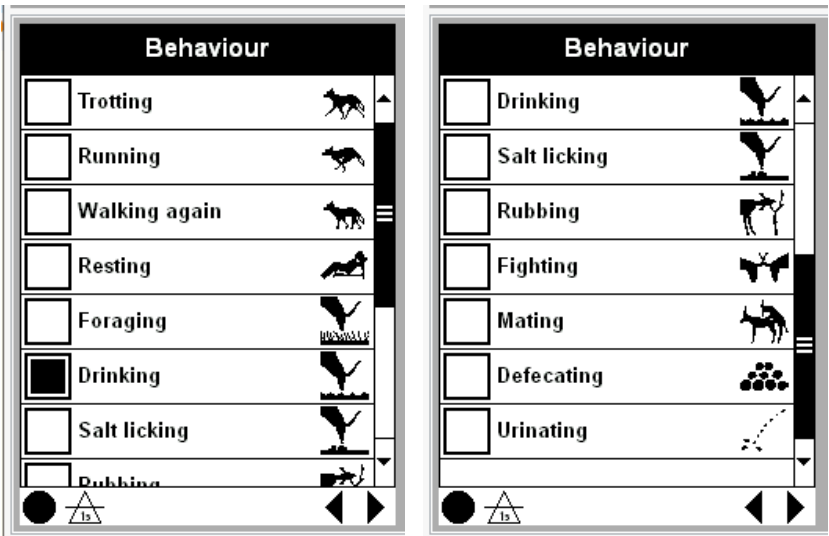
Step 17: GPS coordinates of the interruption point saved

When resuming trailing, proceed through steps 10 to 12 before walking again. Marking the pauses during trailing facilitates data curation later on. Specifically, after data collection, the trail is uploaded on the CyberTracker desktop application on a computer. Then, the stop/start data points associated with pauses are used to exclude all GPS points between each stop and start points when exporting the trail as a shapefile. These fixes are irrelevant to the trail trajectory (see **Appendix 4D** for more details).

To record a behaviour reconstructed by the observers along its path, proceed as follows:



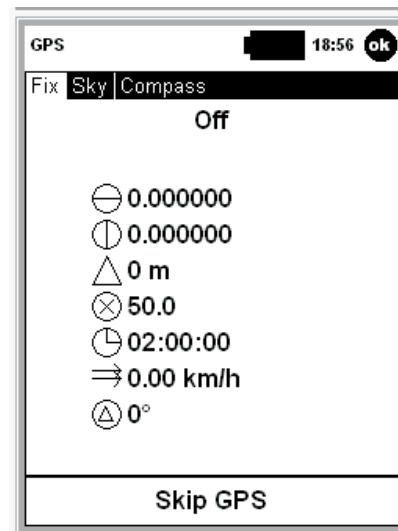
Step 18: select the “Behaviour” dial



Step 19: select the animals’ behaviour(s)

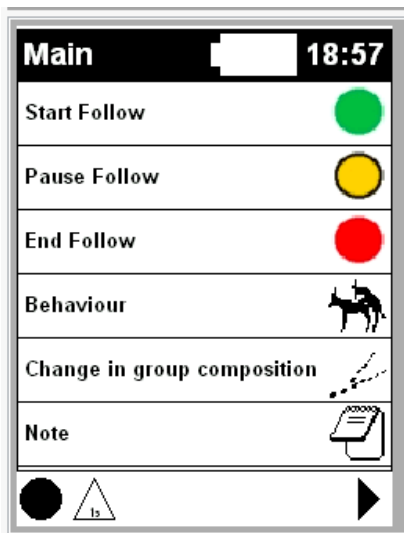


Step 20: enter any important additional detail, such as an estimate of the time or period (e.g. morning, midday, afternoon, evening, night) at which the target performed the behaviour, if known.

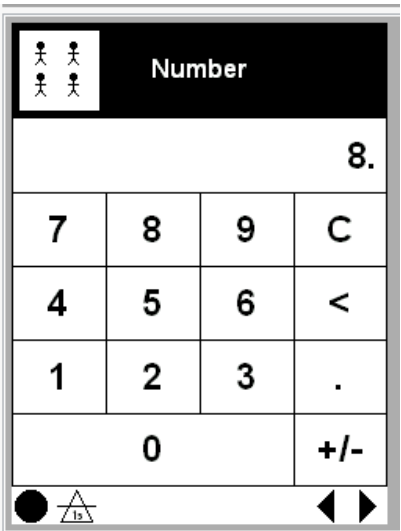


Step 21: behaviour information saved along with GPS coordinates

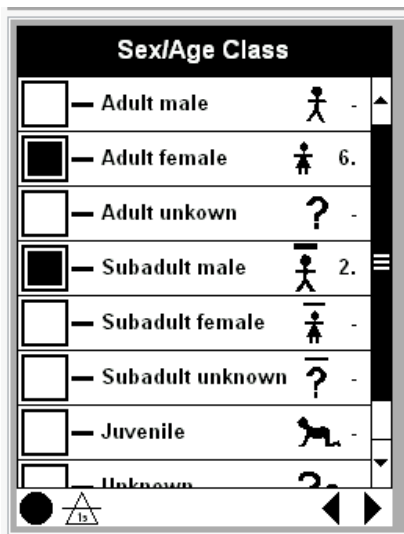
To indicate a change in the number or sex/age class of the animals during the trailing, proceed as follows:



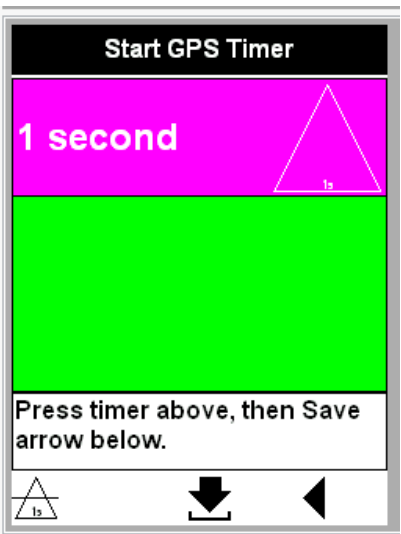
Step 22: select the “Change in group composition” dial



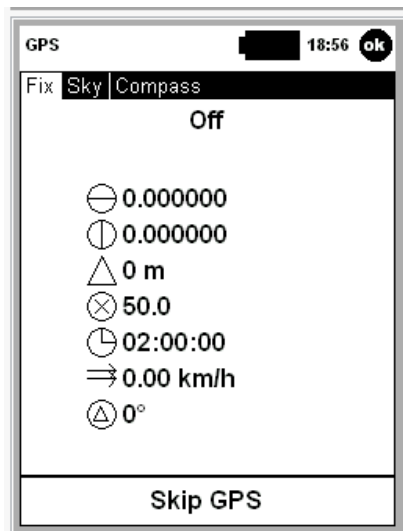
Step 23: select the new number of individuals



Step 24: select the sex of the individuals and enter their number by sex

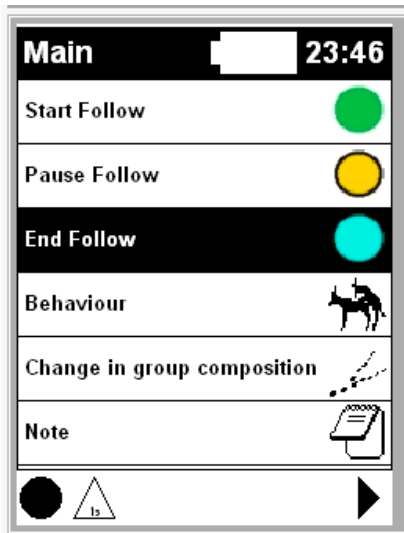


Step 25: start the GPS timer again (not that it stopped, but just because the “Change in group composition” dial resends you back to Step 6)

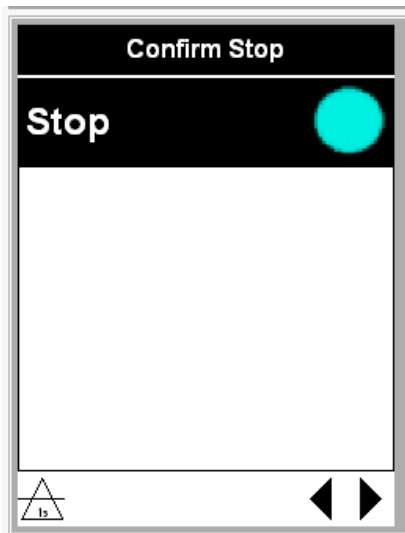


Step 26: changes saved along with GPS coordinates

To end the trailing, whether it is completed or for other reason, proceed as follows:



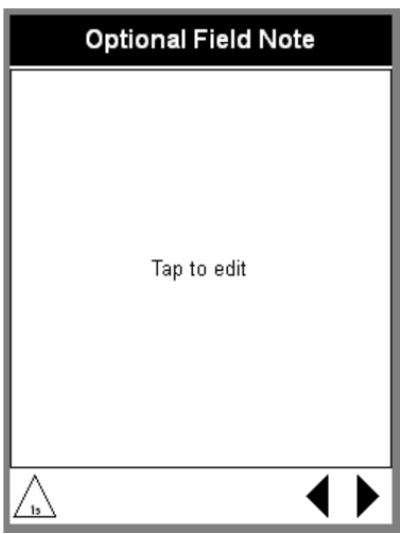
Step 27: indicate the trailing is to be ended



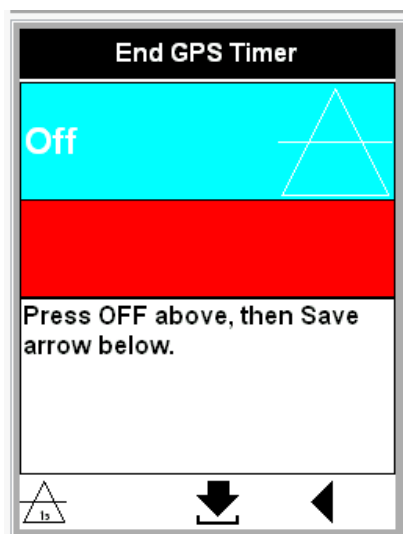
Step 28: confirm the information



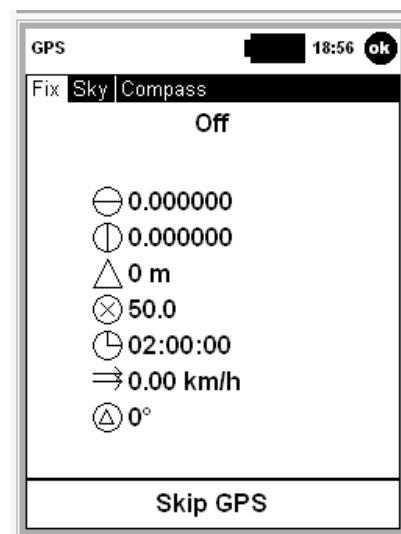
Step 29: indicate the reason for ending the trailing



Step 30: enter any important additional detail



Step 31: stop the GPS timer



Step 32: ending information saved along with GPS coordinates of the end point

Appendix 4D

Curation of trailing data

After collection, the trail was uploaded on the CyberTracker desktop application on a computer. From there, the trail was exported as a shapefile, excluding all GPS points recorded during times where the trail was suspended. Specifically, our CyberTracker application allowed the recorder to mark a pause (i.e. Stop) in the data collection when observers (trackers) needed to confirm the trail's direction, for instance. Then, the recorder indicated the trailing was resumed (i.e. Start) from the location where it was paused. During these pauses, the GPS timer continued running in the background, recording one fix per second, to avoid losing time and accuracy associated with satellite reconnection. Consequently, the stop and start points were designated as "Stop Element" and "Start Element", respectively, in the trail exportation process, with data between these points being discarded.

Then, the trail shapefile was uploaded in ArcGIS® 10.8.0 (Esri) and underwent minor cleaning to remove irrelevant GPS fixes. These typically included GPS points recorded just before a pause or behaviour recording, or while navigating across a dense ticket. In such situations, the recorder might have already significantly slowed down or briefly stopped, causing the trail to display erratic movements or a "starfish" pattern. This occurs due to GPS accuracy errors of up to 3 meters, leading to recorded coordinates rarely being identical when the recorder is stationary. Therefore, where these issues were detected, any GPS points located within 3 meters of the overall trail trajectory were removed. GPS points located beyond 3 meters were removed only if there were contextual reasons to believe there are spurious (e.g. the recorder stepped away from the trail to go around a ticket too dense to walk through). Then, if the target fled due to the spotting on day 1, the trail's starting point was effectively redefined as the location where the target resumed walking.

Once cleaned, the trails were classified as either « unbiased » or « biased ». A trail was considered as unbiased when: (1) it sampled 24 hours of the target's movements, (2) the field team presence did not alter the target's behaviour during the trailing, (3) the target was re-sighted after 24 hours, or the place where it was resting or foraging before fleeing at the approach of the field team was identified. Therefore, biased trails were those for which we sampled less than 24 hours ("Incomplete"), the field team startled the target during the trailing causing it to run away ("Running"), or the target was not located on time and trackers had to continue trailing until they estimated that 24 hours of travel distance had been sampled ("Estimation"). Trails with

bias(es) were further investigated to confirm their inclusion in the final dataset and corrected where possible (**Table 4D- 1**).

In case the trail's completion was based on estimation, trails were discarded only if the 24-hour distance was estimated to be completed more than 2 hours after the time the target should have been re-sighted (e.g. after 2pm if the spotting time on day 1 was 12am). We made this decision based on previous accuracy assessments in track ageing (Liebenberg, 1990b), assuming that the error in the 24-hour trail length potentially caused by the estimation was minimal when the trail was estimated to be less than 2 hours old. Furthermore, such error is likely much smaller than the variance associated with the choice of the target sample.

Table 4D- 1 Summary of the 71 trails collected and their classification pertaining the criteria assessed for their inclusion in the final dataset.

Species	Date of collection (dd-mm-yy)	Number of individuals trailed ^a	Initial length after cleaning	Trail (km) quality basic	Trail quality	Biased trail category	Trail length (km) after correction relevant ^b	Inclusion after in the final dataset ^c	Reason of exclusion
Eland	18-05-23	50+	10.673		Unbiased		10.673	Yes	
Eland	28-06-23	2-10	6.113		Unbiased		6.113	Yes	
Eland	11-07-23	5-40	19.832		Biased	Estimation	19.832	Yes	
Eland	12-07-23	100+	17.188		Biased	Estimation	17.188	Yes	
Eland	12-07-23	30	18.851		Biased	Incomplete, Estimation	NA	No	Contextual outlier. Third trail done during wild fires. Their lengths are particularly long. Discarded to avoid overestimation of $\bar{M}$.
Eland	21-07-23	20-30	12.890		Unbiased		12.890	Yes	
Eland	25-07-23	50+	4.856		Unbiased		4.856	Yes	
Eland	31-07-23	15	5.514		Unbiased		5.514	Yes	
Eland	01-08-23	17-30	8.298		Unbiased		8.298	Yes	
Eland	02-08-23	9	9.841		Unbiased		9.841	Yes	
Eland	03-08-23	3-30+	13.123		Biased	Estimation	13.123	Yes	
Eland	08-08-23	2	13.415		Biased	Running	12.200	Yes	
Eland	10-08-23	1	5.855		Biased	Running	5.086	Yes	
Eland	11-08-23	9	14.144		Biased	Incomplete	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.

Red hartebeest	16-05-23	12	3.217	Unbiased		3.217	Yes
Red hartebeest	23-05-23	4	5.977	Biased	Running, Estimation	5.790	Yes
Red hartebeest	26-05-23	5	10.466	Biased	Estimation	10.466	Yes
Red hartebeest	30-05-23	1-10	11.162	Unbiased		11.162	Yes
Red hartebeest	02-06-23	12	10.261	Biased	Running	9.162	Yes
Red hartebeest	08-06-23	7	6.266	Unbiased		6.266	Yes
Red hartebeest	12-06-23	12	1.881	Unbiased		1.881	Yes
Red hartebeest	13-06-23	4	9.026	Unbiased		9.026	Yes
Red hartebeest	14-06-23	7	4.774	Unbiased		4.774	Yes
Red hartebeest	23-06-23	2	4.646	Biased	Running	4.253	Yes
Red hartebeest	29-06-23	10	3.040	Biased	Running	2.933	Yes
Red hartebeest	10-07-23	4	1.124	Unbiased		1.124	Yes

Red hartebeest	13-07-23	5-12	6.166	Biased	Running	5.904	Yes	
Greater kudu	24-05-23	7	7.171	Unbiased		7.171	Yes	
Greater kudu	25-05-23	1-2	3.566	Biased	Estimation	3.566	Yes	
Greater kudu	09-06-23	3	1.299	Biased	Incomplete, Estimation	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Greater kudu	15-06-23	1-3	0.299	Biased	Incomplete, Estimation	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Greater kudu	15-06-23	1	4.390	Biased	Running	4.255	Yes	
Greater kudu	19-06-23	10-4	6.867	Biased	Running	6.510	Yes	
Greater kudu	21-06-23	3	8.177	Biased	Estimation	8.177	Yes	
Greater kudu	21-06-23	6	6.639	Unbiased ^d		6.586	Yes	
Greater kudu	22-06-23	12	4.815	Biased	Running	3.773	Yes	
Greater kudu	26-06-23	1	5.780	Unbiased		5.780	Yes	
Greater kudu	05-07-23	4	2.815	Unbiased ^d		2.752	Yes	
Greater kudu	06-07-23	3	1.504	Biased	Running	1.329	No	Corrected trail length value falls outside two SD from the mean $\bar{M}$ of unbiased trails.
Greater kudu	19-07-23	4	11.168	Unbiased		11.168	Yes	
Greater kudu	27-07-23	4	6.911	Biased	Running	6.774	Yes	
Greater kudu	29-07-23	3	5.581	Biased	Running	5.354	Yes	
Greater kudu	04-08-23	5	8.951	Unbiased		8.951	Yes	

Greater kudu	07-08-23	1-2	3.040	Unbiased ^d		2.995	Yes	
Greater kudu	09-08-23	6	7.364	Unbiased ^d		7.296	Yes	
Greater kudu	11-08-23	4	3.407	Biased	Running	3.105	Yes	
Greater kudu	14-08-23	6	7.419	Unbiased		7.419	Yes	
Greater kudu	15-08-23	6	3.720	Biased	Running	3.522	Yes	
Ostrich	19-05-23	2	2.799	Biased	Estimation	2.799	Yes	
Ostrich	29-05-23	2	3.050	Biased	Incomplete, e, Estimation	3.183	Yes	
Ostrich	01-06-23	2	3.363	Biased	Estimation	3.363	Yes	
Ostrich	05-06-23	8	1.933	Biased	Incomplete, e	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Ostrich	06-06-23	1	2.853	Biased	Incomplete, e, Estimation	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Ostrich	07-06-23	1	3.396	Biased	Incomplete, e, Estimation	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Ostrich	30-06-23	3	8.217	Biased	Incomplete, e, Estimation	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Ostrich	07-07-23	8	7.998	Unbiased		7.998	Yes	
Ostrich	24-07-23	2	8.571	Biased	Running	8.430	Yes	

Ostrich	26-07-23	2	5.361	Biased	Incomplete	NA	No	Too many missing hours, leading to too much uncertainty in extrapolating the trail length.
Springbok	17-05-23	35	2.411	Unbiased		2.411	Yes	
Springbok	22-05-23	43	1.591	Unbiased		1.591	Yes	
Springbok	31-05-23	26	2.903	Unbiased		2.903	Yes	
Springbok	05-06-23	35	2.306	Unbiased		2.306	Yes	
Springbok	09-06-23	4	2.023	Unbiased		2.023	Yes	
Springbok	20-06-23	4	1.145	Unbiased		1.145	Yes	
Springbok	27-06-23	4	1.812	Unbiased		1.812	Yes	
Springbok	04-07-23	7	1.654	Unbiased		1.654	Yes	
Springbok	06-07-23	17	1.704	Unbiased		1.704	Yes	
Springbok	10-07-23	7	0.899	Unbiased		0.899	Yes	
Springbok	20-07-23	14	1.256	Unbiased		1.256	Yes	
Springbok	20-07-23	3	1.611	Unbiased		1.611	Yes	
Springbok	26-07-23	33	1.962	Unbiased		1.962	Yes	

^aNumbers separated by a dash, i.e. “nn-NN”, indicate that the group composition fluctuated during the trailing between nn and NN individuals.

^bBiased trails for which the length was corrected are highlighted in bold. NA indicates biased trails not eligible for correction, therefore directly discarded from the final dataset. ^cDecision relative to the inclusion of biased trails in the final dataset are highlighted in bold.

^dTrails with observer-induced portions during the trailing <100m (median of 58m) were classified as ‘Unbiased’ for the data curation process. These portions were still excluded from the final trail length.

Second, portions of the trails where animals ran away after detecting the field team, if any, were removed to prevent artificially inflating the trail length. Even the longest observed running distance during trailing (i.e. 1.2 km) was presumably covered in less than 7.3 minutes at a conservative 10km/h (less at higher running speed). Therefore, removing such portions only potentially causes a small underestimation bias in the 24-hour trail length, i.e. the limited distance hypothetically covered by target, if not resting, in those few minutes if not startled. Conversely, keeping such portions would inflict a severe overestimation bias.

Finally, incomplete trails (< 24 hours) were discarded only if they had been sampled less than 22 hours and had ended before 10am. In such cases, the potentially high variability in animal behaviour during the missing hours would render any inference on the 24-hour trail length too uncertain. In particular, animals were often observed to rest for a significant amount of time during the night and be most active early in the morning. Additionally, incomplete trails of 22 hours or more must have been estimated on a trail maximum 2 hour fresh, in order to optimise the accuracy related to the trail age's estimation. If not, the trails were also discarded. Trails not discarded based on the above criteria were extrapolated to a 24-hour length using the average hourly distance covered during the sampled period of 22 hours or more.

After applying the aforementioned corrections, we investigated the probability of the remaining biased trails (i.e. not discarded, and corrected where relevant) to be statistical outliers. First, for each species but ostrich, we computed the mean $\bar{M}$ and its standard deviation (SD) from the set of unbiased trails (**Table 4D- 2**). As ostrich presented only one unbiased trail, these parameters could not be calculated for this species. We confirmed data compliance with normality by assessing it across all values, which were previously standardised within each species (**Figure 4D- 1**). Assessing normality within each species lacked reliability due to small sample size. Second, biased trails presenting a trail length value exceeding two SD from the mean of the unbiased trails were excluded from the final dataset. As two SD around the mean comprise approximately 95% of the data points, it is deemed an appropriate threshold for the purpose. Springbok trails were all unbiased, so did not have to undergo this process. In the absence of a mean $\bar{M}$ and SD for unbiased trails, biased ostrich trails could not be assessed and were all included in the final dataset. For the other three species, we combined the retained biased trails with the unbiased trails in a final dataset. Lastly, for each species, we computed a new mean $\bar{M}$ and SD from their final datasets, i.e. the average estimates of daily travel distance presented in **Table 4-2** of the

manuscript. Prior to analysis, data compliance with normality was again confirmed, following the method explained above (**Figure 4D- 2**).

Table 4D- 2 Average daily travel distance estimates ($\widehat{M}$) for each species, based exclusively on the set of unbiased trails.

Species	Number of unbiased trails	$\widehat{M}$	Standard deviation
Eland	9	10.578	5.229
Red hartebeest	7	5.350	3.717
Greater kudu	9	6.680	2.653
Ostrich	1	NA	NA
Springbok	13	1.790	0.151

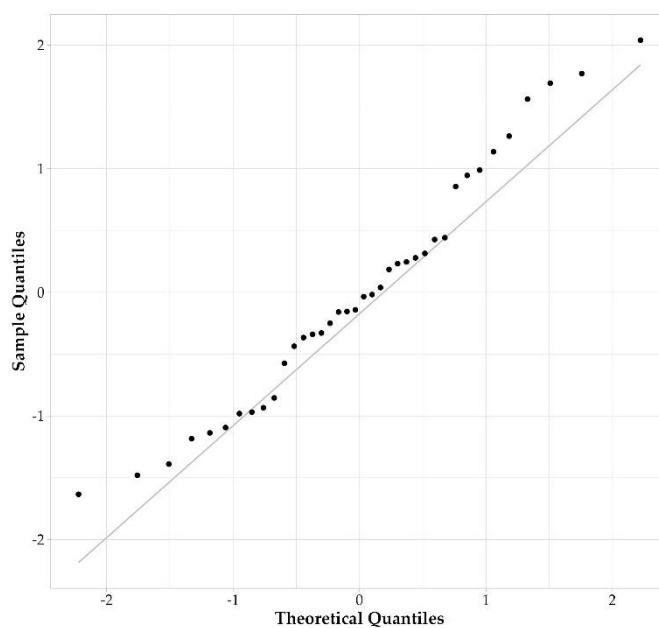


Figure 4D- 1 Q-Q plot for standardised daily travel distance values of unbiased trails.

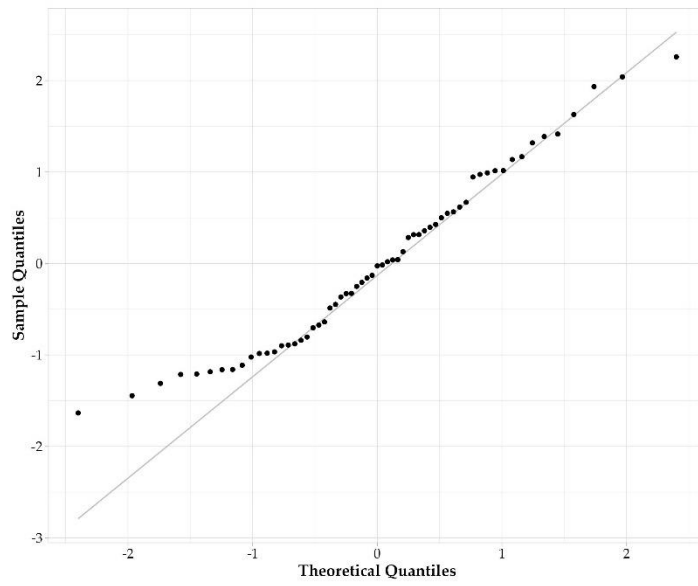


Figure 4D- 2 Q-Q plot for standardised daily travel distance values of the final trail's dataset

Appendix 4E

Detailed statistical outputs

Detailed statistical results for the linear regressions performed in this study are presented in **Table 4E- 1**, and **Table 4E- 2** below.

Table 4E- 1 Linear regression model coefficients representing the temporal variation in species' daily travel distance within the cold dry season 2023. The model was applied separately to each species

Species	Coefficient	Estimate	Std. Error	t value	p-value
Eland	Intercept	12.732	4.393	2.898	0.016*
	Day	-0.035	0.064	-0.546	0.597
Residual standard error: 5.004 on 10 degrees of freedom Multiple R-squared: 0.02891, Adjusted R-squared: -0.0682 F-statistic: 0.2977 on 1 and 10 DF, p-value: 0.5973					
Red hartebeest	Intercept	7.981	1.579	5.055	3.69e-04***
	Day	-0.079	0.049	-1.608	0.136
Residual standard error: 3.069 on 11 degrees of freedom Multiple R-squared: 0.1903, Adjusted R-squared: 0.1167 F-statistic: 2.586 on 1 and 11 DF, p-value: 0.1361					
Greater kudu	Intercept	5.659	1.312	4.312	5.37e-04***
	Day	0.003	0.021	0.155	0.879
Residual standard error: 2.428 on 16 degrees of freedom Multiple R-squared: 0.001491, Adjusted R-squared: -0.06092 F-statistic: 0.02389 on 1 and 16 DF, p-value: 0.8791					
Ostrich	Intercept	2.183	0.425	5.130	0.014*
	Day	0.097	0.011	9.074	0.003**
Residual standard error: 0.6071 on 3 degrees of freedom Multiple R-squared: 0.9648, Adjusted R-squared: 0.9531 F-statistic: 82.34 on 1 and 3 DF, p-value: 0.002827					
Springbok	Intercept	2.280	0.261	8.734	2.81e-06***
	Day	-0.013	0.006	-2.174	0.052 .
Residual standard error: 0.476 on 11 degrees of freedom Multiple R-squared: 0.301, Adjusted R-squared: 0.237 F-statistic: 4.726 on 1 and 11 DF, p-value: 0.052					

Std. error, standard error. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

Table 4E- 2 Linear regression model coefficients predicting empirical $\widehat{M}$ from allometric $\widehat{M}$ and its interaction with the foraging strategy variable. The intercept and the main foraging strategy coefficient are absent from the table as the intercept has been forced to zero. The reference foraging strategy group, represented by the “Allometric” coefficient, is “Herbivores and solitary hunters”.

Coefficient	Std.		t value	p-value
	Estimate	Error		
Allometric	1.917	0.122	15.775	5.53e-12***
Allometric:factor(`Foraging strategy`) Social hunters and scavengers	2.781	0.251	11.071	1.82e-09***

Residual standard error: 2.312 on 18 degrees of freedom

Multiple R-squared: 0.975, Adjusted R-squared: 0.972

F-statistic: 325.7 on 2 and 18 DF, p-value: 3.65e-15

Std. error, standard error. Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

Appendix 5A

Cybertracker application for track survey

The source file of this application was shared by Derek Keeping in 2018

Originally designed for illiterate trackers with multi-choice icons, the CyberTracker application interface is very user-friendly, enabling significantly faster data collection than text interfaces or written methods, while also reducing data input errors. Once the survey is completed, the smartphone is connected to a computer equipped with the CyberTracker software that downloads the data from the phone and organises them in a table that can be exported to a ready-to-use spreadsheet.

Our custom-made CyberTracker application installed on a smartphone allows to record the following information for each track data point:

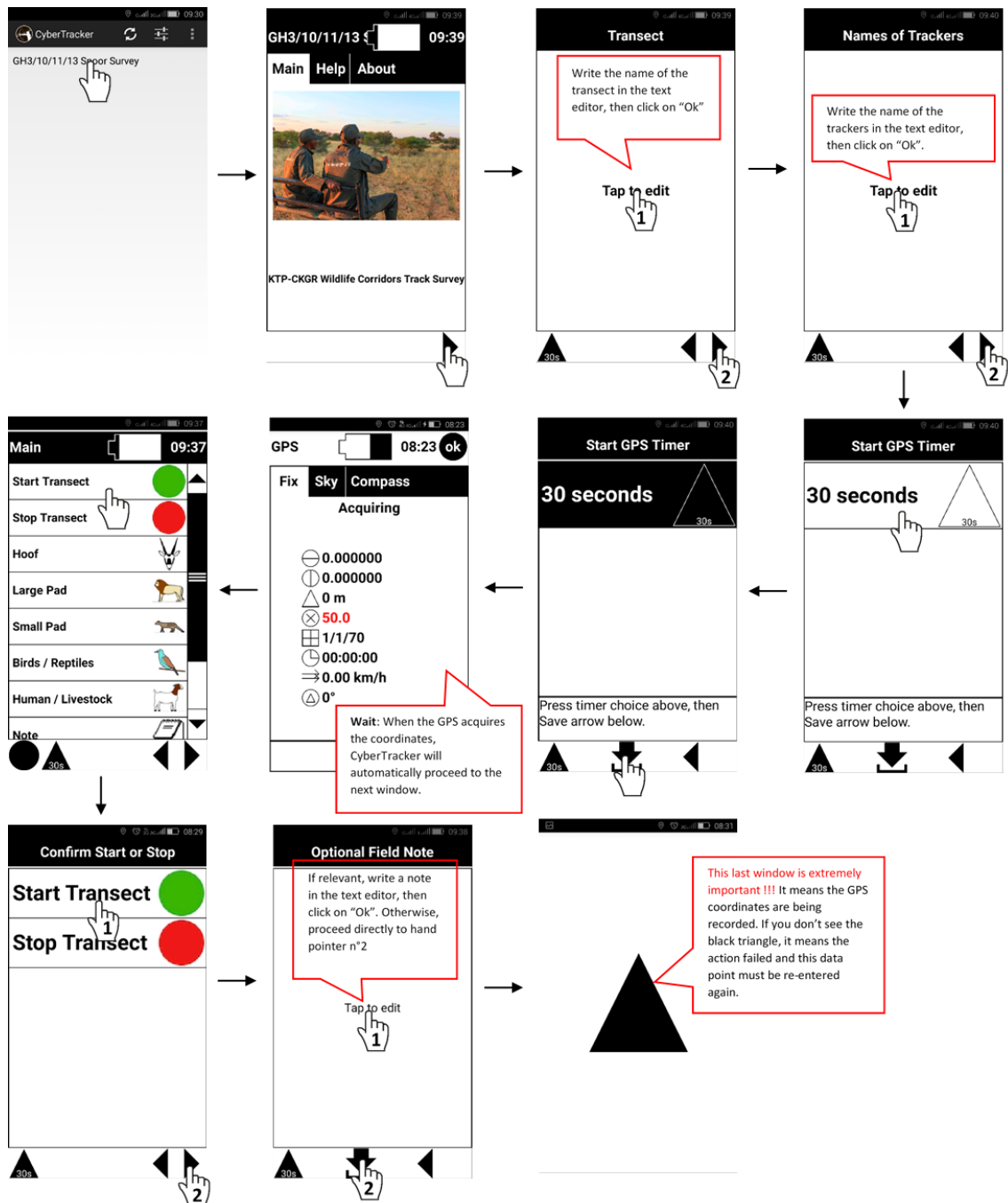
- **Name of the transect**
- **Name of the observers**
- **Name of the species**
- **Number of individual(s)**
- **Age of the species track(s) from 24h to 1 month old**
- **Optional field note**
- **GPS location**

A “Go-to” Excel file, containing the start and stop points of each transect, along with satellite background maps of the various parts within the study areas, was also loaded onto the application.

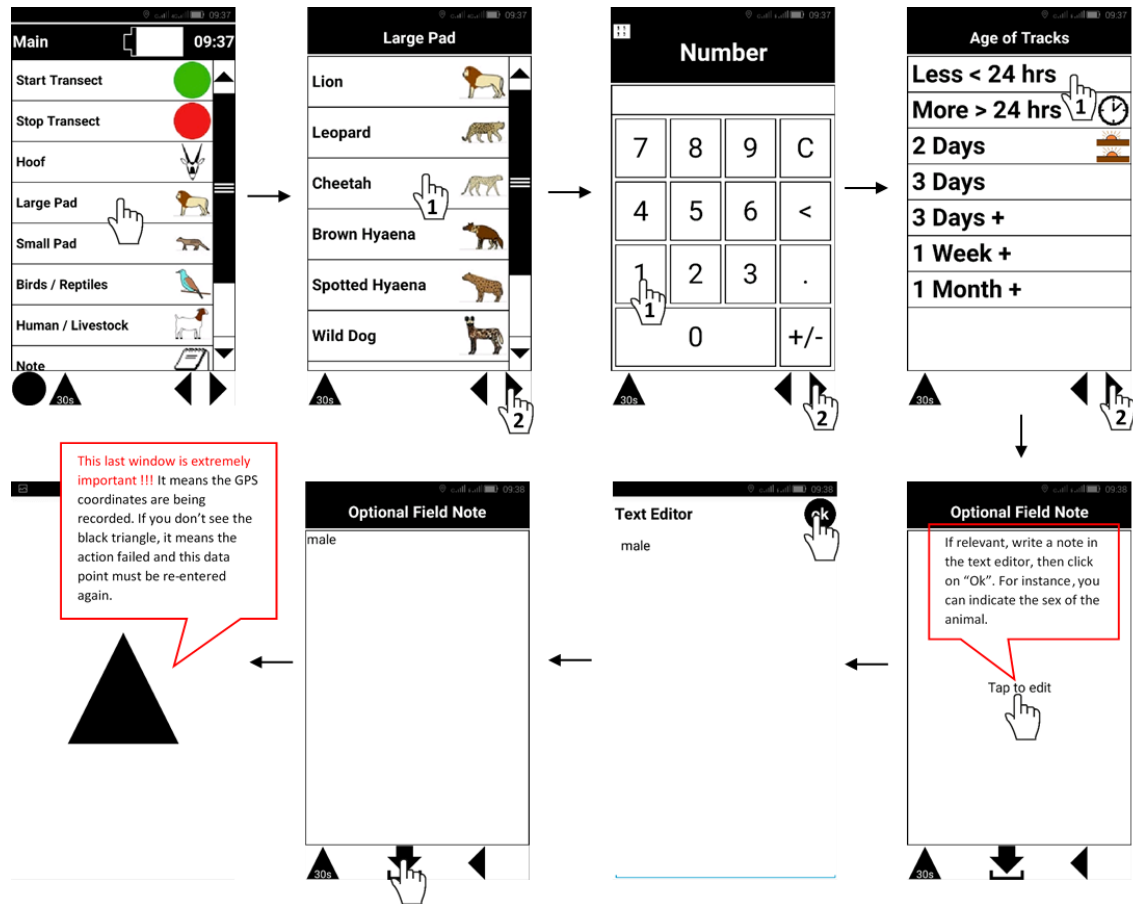
The following sections show how to perform key actions in the CyberTracker application during the track survey, supported by interface screenshots.

I. Start a transect

Click on the Cybertracker App icon installed on the smartphone and apply the following steps indicated by the white hand pointer:



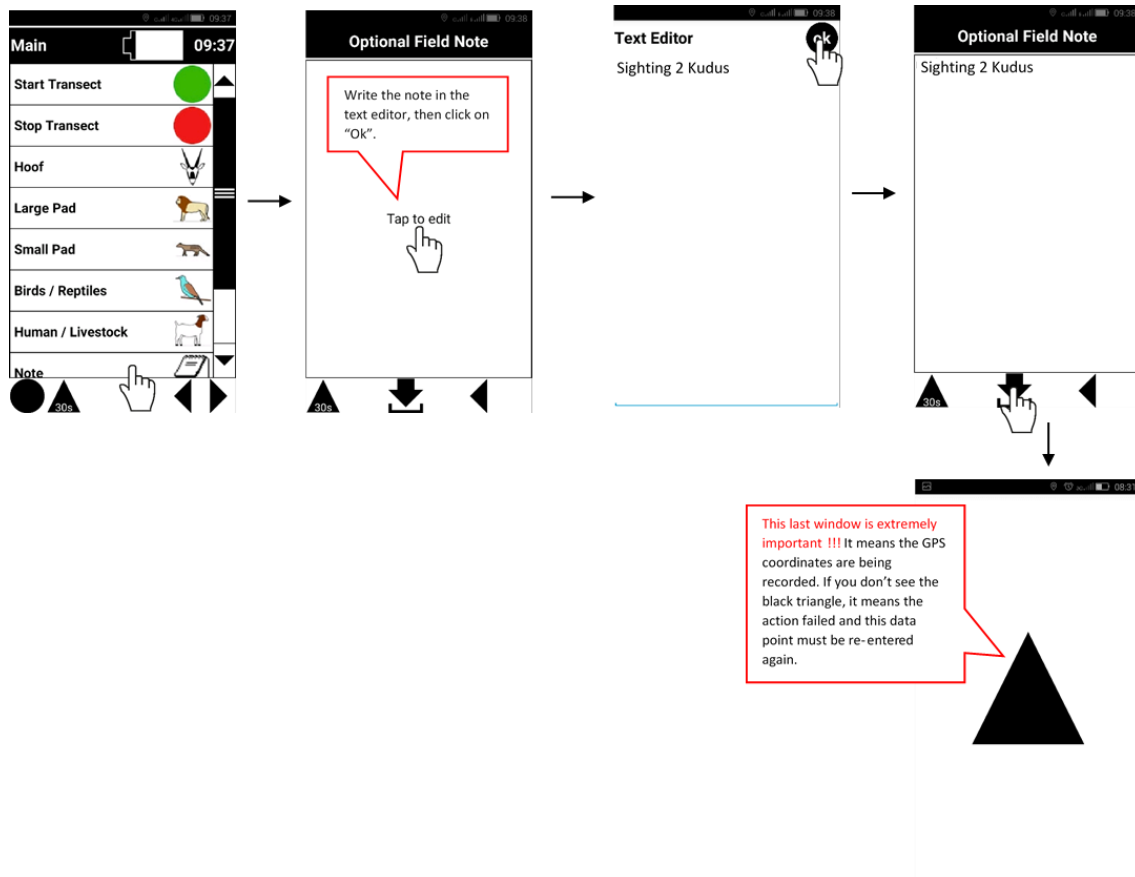
2. Record a track data point: e.g. 1 fresh male cheetah track



Note of the age of tracks:

- **Less < 24h ("Fresh"):** Tracks estimated to be less than 24 hours old, up to **1 day** old. *Example: If it is currently 10:00 AM, this includes all tracks made between 10:00 AM yesterday and now.*
- **More >24h:** Tracks older than 24 hours.
Note: This category was not used in these surveys.
- **2 Days:** Tracks estimated to have been made within the **2nd day**, so between 24h and 48h old. *Example: If it is now Wednesday 10:00 AM, this includes tracks made between Monday 10:00 AM and Tuesday 10:00 AM.*
- **3 Days:** Tracks estimated to have been made within the **3rd day**, so between 48h and 72h old.
- **3+ Days:** Tracks estimated to have been made within the **4th, 5th or 6th day**.
- **1 Week+:** Tracks estimated to have been made within the **7th day** up to **1 month** ago.
- **1 Month+:** Tracks estimated to be **1 month** old or more.

3. Record a Note only: e.g. Sighting 2 Kudus



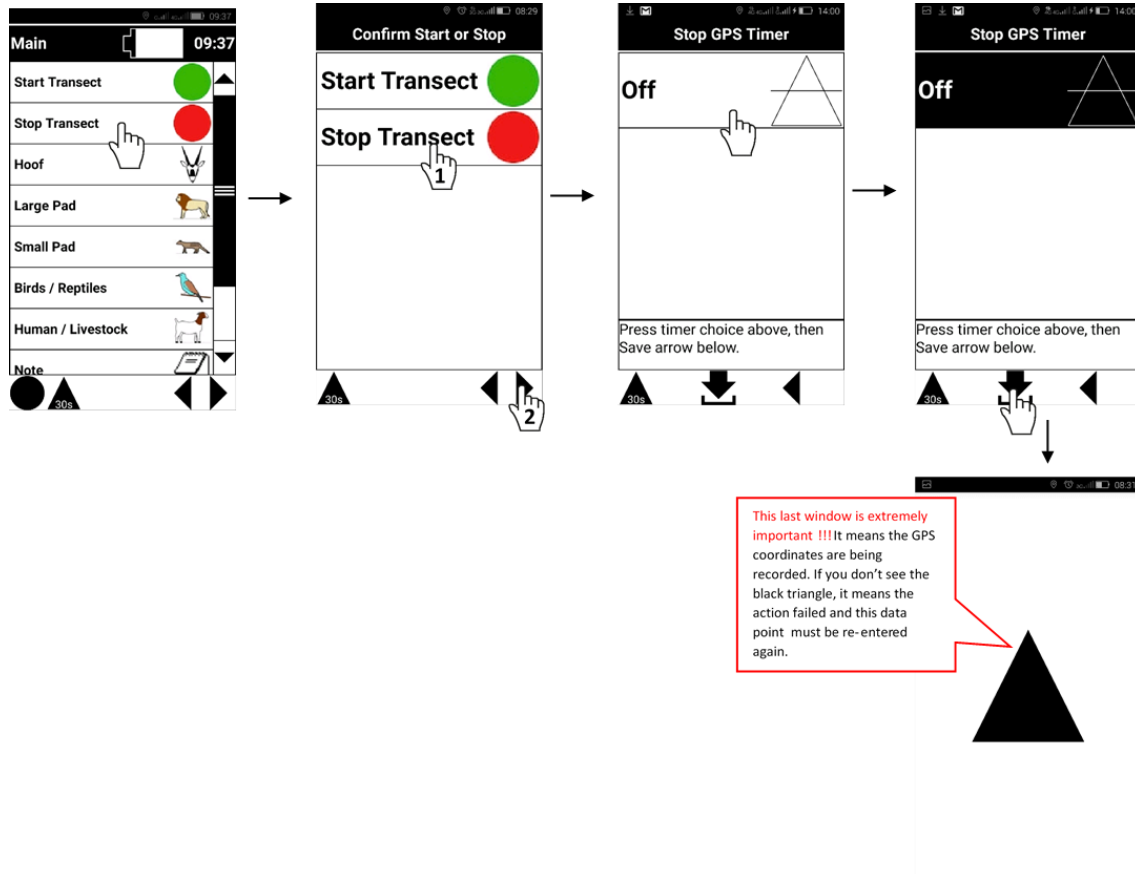
Note:

During transects, the type of data that can be entered using this “Note” section are:

- Direction of tracks
- Cattle track starts and stops along transect
- Direct sightings
- Observations relevant to the study along the transect
- Poaching evidence
- Any unusual or outstanding observation

NB: These data were not included in the analysis for the chapter to which this appendix refers. If such information becomes of primary interest, the CyberTracker application can be modified to systematically record it as dedicated screens.

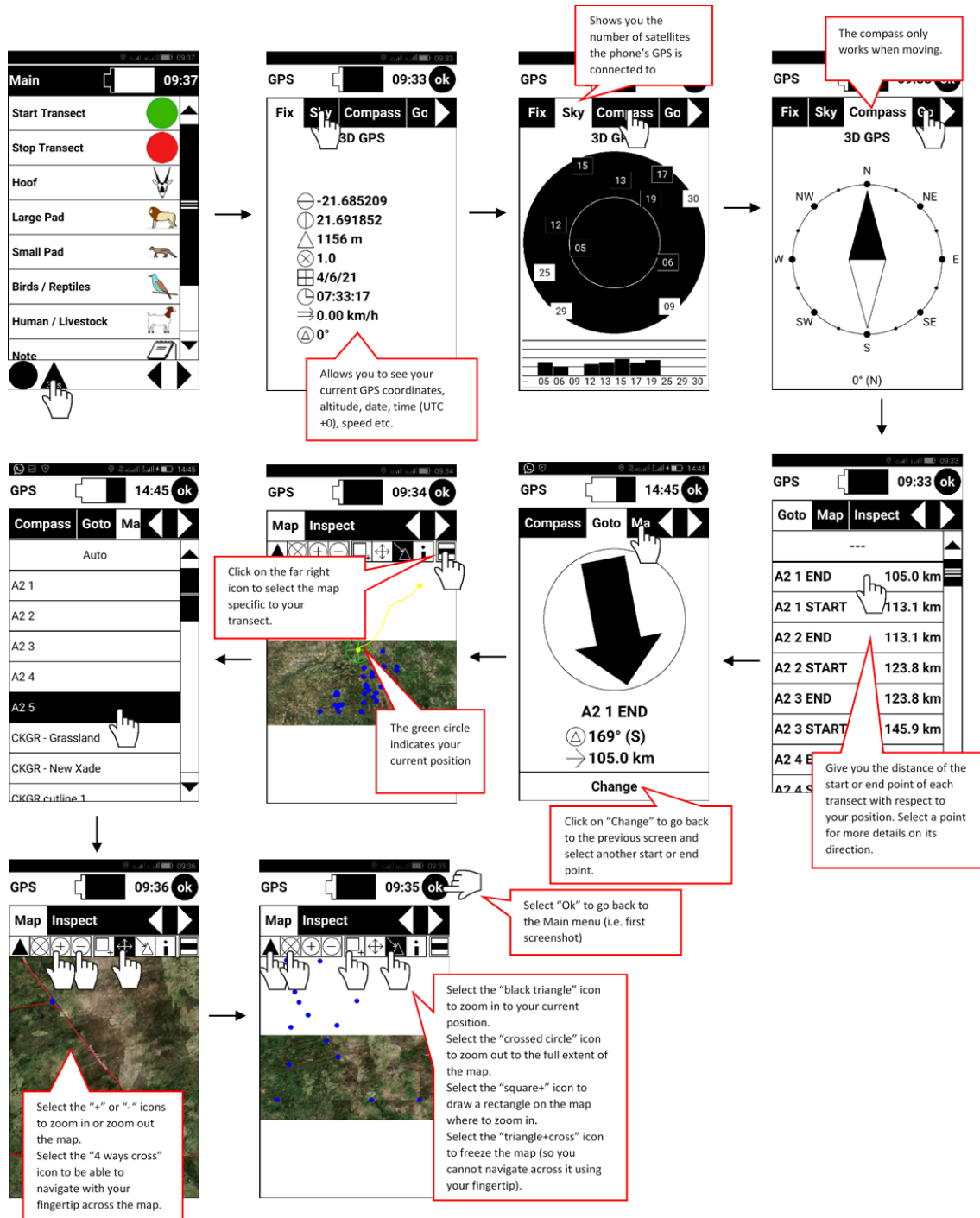
4. Stop a transect



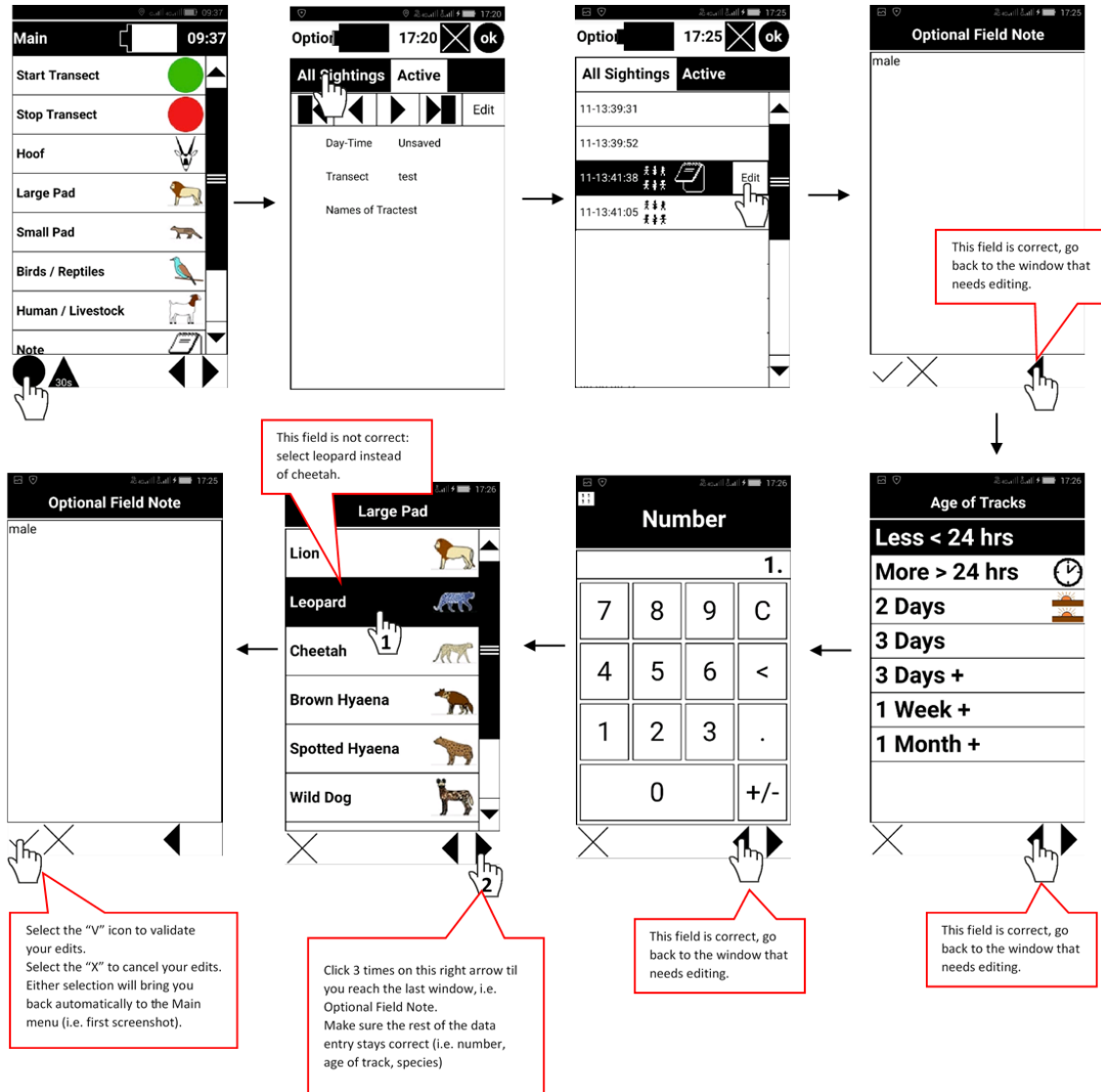
Note:

At the end of the day, you might have to stop for the night in the middle of a transect. **DO NOT STOP the transect on the CyberTracker application if you did not reach the end point of it.** Just leave it on the Main Menu page, lock the screen, and just carry on with the track collection the next morning.

5. Check the GPS features and transect maps



6. Edit a data point: e.g. correct the 1 fresh male cheetah track into 1 fresh male leopard track



Note:

- The newly edited data point will now appear as the **last data point** at the bottom of the "All Sightings" list (shown in the 3rd screenshot). This doesn't change its date and time information.
- It is **NOT possible to delete a data point**, only possible to edit it. However, one can open its editing session and **write that it needs to be deleted in the "Optional Field Note" window** and validate the edit. It can be deleted once data are uploaded on the computer.

Appendix 5B

Spatial layer creation in ArcGIS 10.8.

The document below outlines the process of generating various spatial layers in ArcMap 10.8. (ArcGIS Desktop), used to study the relationship between species relative track density and environmental variables. The document can be accessed through the following repository:

[https://docs.google.com/document/d/1a -
vivUDKrX3V4Nwoi5nGYj_Lhk7E51z/edit?usp=sharing&oid=117389582518
080036285&rtpof=true&sd=true](https://docs.google.com/document/d/1a-vivUDKrX3V4Nwoi5nGYj_Lhk7E51z/edit?usp=sharing&oid=117389582518080036285&rtpof=true&sd=true)

Appendix 5C

Google Earth Engine script for creating the vegetation cover map

The script below outlines the process of generating a vegetation cover map from Sentinel-2 10 m imagery using the Google Earth Engine Code Editor. The script can be accessed through the following repository:

https://drive.google.com/file/d/1Br-YH8iRibbUE_3uHtLoFhFwGe5JLIQU/view?usp=drive_link

Appendix 5D

Google Earth Engine script for creating the vegetation index maps

The script below outlines the process for generating a Modified Soil-Adjusted Vegetation Index (MSAVI) map from Sentinel-2 10 m imagery using the Google Earth Engine Code Editor. The example provided corresponds to the May 2019 survey. The script can be accessed through the following repository:

https://drive.google.com/file/d/17aOjHM_7729wp8pNh0CzkCxCvKbqys5kZ/view?usp=sharing

Appendix 5E

R scripts for modelling species relative track density and predicting its spatial variation

The R scripts below outline the full workflow for building sdmTMB models of relative track density, including model comparison, cross-validation, and the generation of predicted relative track density maps. Two species are used as typical examples: brown hyena using Tweedie models, and gemsbok using hurdle models. The springbok script is also provided as an example of special cases where spatial random effects were excluded from positive models, and positive model cross-validation was performed using a bootstrap approach instead of spatial clustering.

Scripts can be accessed through the following repositories:

Brown hyena:

https://drive.google.com/file/d/1UFfJ46x_ZASpHg41B04M3Kw4cZ1dJbTS/view?usp=drive_link

Gemsbok: https://drive.google.com/file/d/13_QtVTDwmZ9JGaBJ-CB5Tz5vX1z3BHs6/view?usp=drive_link

Springbok: https://drive.google.com/file/d/1-W_eyLxnI3qM6zr8HYtgV_GIgcYAXKyy/view?usp=drive_link

