Camera trap efficacy: a wider view

A study regarding the detection- and capturing abilities of camera traps in respect to their detection zone and field of view

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Summary

Camera traps are devices used to capture videos or photos of animals while minimising human presence. This research tool provides a rare insight into our natural world, whereby knowledge is increased. This knowledge can be used to face the increasing threats nature is currently facing, by determining conservation priorities and adapting management practices.

This study aimed to analyse camera traps and determine the extent to which their ability to detect and capture animal presence can be increased by expanding their detection zones and fields of view. The study seeks to broaden the understanding of these key camera trap features which are crucial for correct interpretation of camera trap data. A better understanding of the abilities of camera traps can also support future development of camera trap models.

The abilities to detect and capture animal presence was tested by comparing two camera trap models, with differences in both detection zone and field of view. A camera trap of the brand Bushnell represented a conventional camera trap of average quality, where a 360 degree modified camera trap with an enlarged detection zone was developed to be able to compare these features. To minimise biases and aid data processing, the camera traps were deployed at the same time, at the same location, while the scene was constantly monitored by another (360 degree) camera, the monitoring camera. The study was carried out over a total of 36 days, during day light. The differences in functioning of the cameras in relation to animal characteristics species was tested by targeting three animal species, differing in body mass and skin cover. These species were donkeys (*Equus africanus asinus*), sheep (*Ovis aries*), and western jackdaws (*Coloeus monedula*).

The results of this study show that the modified, 360 degree, camera trap was superior in detection, capturing and overall successful functioning (with a mean increment of 89.2% by using the modified camera trap), in relation to all target animal species. Downsides of the modified camera trap were found in a decreased reliability compared to the conventional trap, as 28 out of 31 technological errors were due to the modified trap, compared to one due to the conventional, as well as a higher rate of false triggers: 0.8 for the conventional and 8.0 for the modified trap. Therefore it is recommended to refine the rough prototype of the modified 360 camera trap to increase its reliability. Future research and camera trap modifications can focus on suspended camera trap placement, remote sensors, and the addition of an (infra-red) flash. Additionally, animals with (singular) specific characteristics could be targeted in future research as well, to gain a better understanding about the detection and capturing abilities of camera traps.

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Abbreviations

f/ : the ratio of the system's focal length to the diameter of the entrance pupil
mAh : milli Ampere-hour
TEAM : Tropical Ecology Assessment and Monitoring network

1 Introduction

See what you have been missing. Wildlife camera traps can aid in precisely that. Camera traps detect animal movement to capture them on film, minimising human presence. In cases where the presence of human beings influence animal behaviour, camera traps can provide a rare insight into the natural life of wild animals and shed light where it was not seen before.

Scientific use of camera traps have led to major discoveries. Some examples are discoveries of new species such as the grey-faced sengi (*Rhynchocyon udzungwensis*) and the Annamite striped rabbit (*Nesolagus timminsi*) (Hance, 2011) or the discovery of species that were thought to be extinct, such as an Armoured leopard *(Panthera pardus orientalis*). It is assumed that these discoveries would not have been made without the use of camera traps.

Environmental scientists all over the world, in a wide range of fields, use wildlife camera traps to fill gaps in knowledge. Camera traps can be used to collect a wide range of information. Currently, most studies focus on species presence, relative abundance (how common or rare a species is relative to other species in a defined location), behaviour, occupancy (distribution of the numbers of species occupying different numbers of areas) and density (population per unit area) [e.g. Burton *et al.,* 2015, Magle *et al.*, 2015, Allen *et al.*, 2016a, b]. Camera traps can also monitor changes in animal communities, for example related to human presence, predator control measures, forestry practices or climate change [e.g. Muhly *et al.*, 2011, Samejima *et al*., 2012).

In a time when nature is facing major challenges in relation to habitat loss, degradation and climate change, camera traps can play an important role in monitoring the changes that occur and how wildlife communities react to this. Many studies use the information provided by camera trapping studies to adapt management practices, determine conservation priorities, or apply for subsidies. Others aim for data that provides new insights in wild animal behaviour (Mccallum *et al.*, 2012). It is particularly important to study the wildlife communities of tropical regions, as these areas harbour nearly half the species on the planet, while covering less than 5% of Earth´s surface (TEAM website, 2019). The most extensive tropical camera trap monitoring programme is the TEAM (Tropical Ecology Assessment and Monitoring) network (Beaudrot *et al.*, 2018). The aim is to gain a better understanding on how tropical forests are responding to changing climates and disturbed landscapes by using an extensive network of camera traps, thereby creating an early warning system.

Using camera traps as research tool is considered to be a less-invasive method of wildlife research, as it reduces animal disturbance and eliminates the need for animal handling (live trapping). High quality camera traps are often rather expensive pieces of equipment. However, compared to other types of research such as live trapping, faeces identification, track surveys, and interviewing local residents, the use of camera traps can be relatively inexpensive in the long-term and reasonably simple to implement (Tobler *et al*., 2008a, b, Welbourne *et* al., 2015). The advantages of using camera traps in research compared to other survey methods are especially clear when looking at the amount of effort and time, and thus money, involved in fieldwork that is necessary to gather sufficient amounts of data to address the same issues (Silveira, 2003, Hance, 2011).

Camera trap functioning

In order to successfully detect animal presence and capture this animal on film (resulting in an animal on photo or video), the ability to detect, the speed of processing (from detection to capturing), and related to that, the field of view of the camera, are of great importance. For a better understanding of the main features of camera traps, a schematic representation of the successful functioning of a camera trap is given in figure 1.

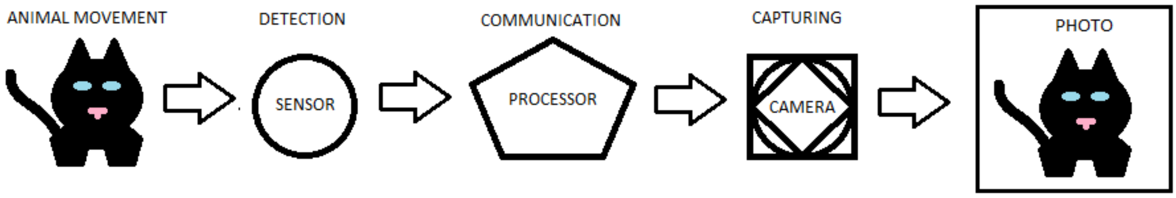

Figure 1. A schematic representation of the functioning of a camera trap

As shown in figure 1, the sensor determines the ability of the camera trap to detect animal presence (i.e. movement), while the camera (lens), together with the processor, determines the ability to capture the scene. A perfect camera trap would capture all animal presence on photo or video, thus never fail to detect them, and never take a photo when no animal is present.

Camera trap limitations

Two limitations of camera traps are 1) their detection ability, in order to activate the camera, and 2) their limited field of view, in order to capture the animal on photo or video after camera activation by detection. The detection ability is dependent on the detection zone of the sensors, i.e. the area within the range of the sensor, while the field of view, i.e. the area of which a photo or video is taken, is dependent on the camera lens(es). Related to the latter, the need for fast processing decreases when the field of view increases, since it is more likely that the animal would still be within (the increased) sight. As Arnaud Desbiez states clearly in the Guardian (Hance, 2011): "Camera traps are limited in space. They can only gather information in the tiny area where their sensors are positioned. Therefore animals can easily go undetected, and you need a lot of cameras to properly survey an area."

To enable the detection of animal presence, most camera trap models are equipped with passive infrared sensors. In cheaper camera trap models, the quality of the sensors is often reduced. The detection angles differ between models, and the sensitivity of the sensor may differ substantially (Rowcliffe *et al*. 2011). Passive infrared sensors respond to the movement of infrared radiation that is emitted by the surface of an object, or animal, in the case of a camera trap. Both the animal's body mass and the temperature signature of an animal, i.e. the amount of infrared radiation that is emitted, influences the ability of the sensors to detect them. The temperature signature is related to the degree of emitting obstructing cover (fur, feathers, wool, or scales) that effect the level of infrared emission. Since water also decreases the emission of infrared, rain (i.e. wet animals) alters the detection ability of sensors as well (Welbourne *et al.*, 2016).

To be able to capture the detected animal on photo or film, a camera trap is usually equipped with a lens with a view of about 40 to 50 degrees. If either the processing time takes too long, or the positioning of the camera trap is off, a passing animal may not be in view when the camera starts capturing. These events would result in a photo or video without an animal on it. When a researcher is processing the data of a camera trap, these events would typically be considered a 'false trigger', i.e. the camera trap was activated by something other than the presence of an animal. However, without any person or camera present to contradict this, this is merely an assumption, since it is known to happen that when animals move at high speed or are at close proximity to the camera trap (Glen *et al.*, 2013), they will be out of the camera trap's field view.

The detection- and capturing ability of a camera trap is also related to its positioning (Smith&Coulson, 2012). Both vertical and horizontal positioning determines the sensor detection zone and field of view of the camera, and aiming too high or low (depending on the research goal and/ or target species) will influence the ability to detect and/ or capture animal movement.

Other factors that are of influence to the functioning of camera traps are environmental factors, and animal behaviour. Vegetation that obstruct the sensors and/ or lens of the camera trap, decreases its ability to function as well. There is also a chance that that vegetation is sun-heated and moves in front of the sensor, which could 'falsely' activate the camera, resulting in actual false triggers (Rowcliffe *et al*., 2011). Likewise, the reaction of an animal to the camera trap can be of influence (Schipper, 2007, Meek *et al.*, 2014, Meek *et al.*, 2016). When an animal notices an camera trap, and runs from it before or right after the animal is detected by that trap, this animal will either not be detected or not captured by that trap. This means that animals might be around, but the collected data shows otherwise.

To provide an overview of factors influencing detection- and capturing abilities of camera traps, table 1 is given.

Table 1. *Factors influencing detection- and capturing abilities of camera traps*

Factors influencing detection ability	Factors influencing capturing ability
Sensitivity (quality) of the sensor(s)	Speed of processing (detection to capturing)
Detection zone/ camera trap positioning	Field of view/ camera trap positioning
Animal characteristics -Body size/ distance to camera trap -Temperature signature -Responses to camera trap	Animal characteristics -Body size/ distance to camera trap -Speed of movement -Responses to camera trap
Environmental factors -Obstruction by vegetation -False triggers due to sun-heated vegetation	Environmental factors -Obstruction by vegetation
	Quality of the camera -Amount of pixels -Lens quality

Problem statement

Data that is collected by studies using camera traps is often analysed as if there were no ability-affecting factors, thus without taking these important influences into account. The generally accepted assumptions concerning the efficacy (adequate to accomplish a purpose; producing the intended or expected result) of camera traps can threaten the accurate analysis of the collected data. These assumptions are mostly related to the ability of camera traps to detect animal presence, and subsequently capture this animal on photo or video. Therefore it is difficult to draw conclusions of data based on camera trapping, as it is unknown what the camera misses. This is especially true for studies highly relying on camera trap efficacy, to, for example, calculate relative abundance and density. The assumptions can subsequently result in ineffective or even harmful implementation of research outcomes.

Rigorous testing of camera trap models should be an important step into adopting research tools (e.g. Swann *et al.*, 2004, Weingarth *et* al., 2013, Meek *et* al., 2015). Testing of camera trap efficacy, per model and target species is important to generate comparable and reliable data (Newey *et al*., 2015). Because of this lack of testing, not much is known about the actual abilities of currently used camera trap models.

In response to the abilities and limitations of currently available camera trap models, and to make an effort to overcome some of the restrictions, this current study took place. It is initiated to increase our understanding of the current capabilities, and future possibilities of camera traps. The focus of this study is to examine to what extent modification to the camera trap detection and capturing features (sensor and camera) improve the ability of these traps to successfully detect and capture target animal presence. If it is known what exactly the efficacy is for the specific animals, future camera trap designing efforts and camera trap studies can benefit from this, which can ultimately be of great value to wildlife conservation efforts.

Objective

The objective of this study is to examine whether the ability of camera traps to detect- and capture specific animal presence on film, can be increased by using a modified camera trap with and widened detection zone and enlarged field of view. Hereby the reliability of the collected data from camera traps can be determined. The results of this study can increase awareness for biases with regard to the abilities of different camera trap models, in relation to animal species characteristics, thus increase awareness of the reliability of the collected data from those traps. If it is known what exactly the efficacy is, future camera trap development efforts and camera trap studies can benefit from this, which can ultimately be of great value to wildlife conservation efforts.

<u>Main research question</u>
To what extent will the ability of camera traps to capture animal presence on photo improve by a) a widened detection zone, and b) an enlarged field of view?

<u>Sub question 1</u>
To what extent will the detection success of a camera trap increase when its sensor detection zone is widened from 40 degrees to 240 degrees?

a)To what extend do differences between animal species have effect on the detection success?

b) Does a wider detection zone increase the false trigger rate?

<u>Sub question 2</u>
To what extent will the capturing success of a camera trap increase when its field of view is enlarged from 45 degree to 360 degree?

a) To what extend do differences between animal species have an effect on the capturing success?

To address these questions, the performance of two camera trap models were compared. One of these camera traps was a commercially available 'conventional camera trap', i.e. one of average quality, with average features. The other camera trap was a prototype of a modified camera trap. Three animal species were used as target animals, to get examine whether the characteristics of these animals were of influence on the camera trap's abilities.

Commissioning party

Dr. Andrew Quitmeyer, founder of Digital Naturalism Laboratories, commissioned this research. For his project concerning the testing and exploration of the abilities of an modified 360 degree camera trap, he found himself in need of specified input. As I have extensive experience with camera trapping, Quitmeyer contacted me to work with him on this project. Quitmeyer is dedicated to 'investigate the boundless potential that digital media can plan in biological field work' [13] and has extensive experience with creating digital tools to aid field research. Digital Naturalism Laboratories is an organisation which focuses on combining field biology, interaction design and wild hacking.

Structure of this report

After the introduction, the methodology can be found in chapter 2. This chapter first describes the study setting and research materials. Then, the preparation and data collection, and its processing and analysis is clarified. The next chapter, chapter 3, shows the results derived from the data, where the subchapters provide answers to the research questions and their sub questions. In the 4th chapter, conclusion and discussion, a more broad interpretation of the research results is given and discussed, followed by the recommendations in the final chapter, number 5. Finally, the references and annex are provided.

2 Methodology and materials

2.1 Study setting

The study area of this research was located at the petting zoo 'Kinderboerderij en Hertenkamp de Goffert' in the Netherlands, which has a temperate climate. Although most scientific studies using camera traps are carried out in the tropics with wild animals (Trolliet *et al*., 2014, TEAM website, 2019), initial testing of such research equipment is often conducted in a (semi) controlled environment. The tested modified camera trap is the first prototype, hence the choice of this location as study area. The main advantages of this zoo lay in the (semi) domestication of the animals so they do not react to the camera traps, the equipment safety, and the clear, open fields they are kept in. The fields at which the study took place are absent of most vegetation other than low grass, and a few trees and shrubs. It was made sure that around the actual location of the camera trap set-up, only grass was present. This openness prevents detection and capturing obstruction by vegetation, and false triggers due to movement of, for example, sun-heated vegetation [Rowcliffe *et al.*, 2011, Meek et al. 2015).

To test the effect of a variety of animal characteristics, three target animal species were selected. As mentioned in the introduction, the passive infrared sensors respond to the emission of infrared, and for animals this is mostly dependent on body size (mass), and skin cover. Therefore, the three target animals that were selected for this study, vary in both body mass, and skin cover. The largest of the animals are donkeys (*Equus africanus asinus*), followed by sheep (*Ovis aries*) and finally western jackdaws (*Coloeus monedula*). These species have different skin cover: the donkey has fur, the sheep has wool, and the jackdaw has feathers. Even though wool officially is a kind of fur, the insulating properties are higher than those of regular fur, thus for this study regarded as a separate skin cover. Table 2 shows the differences in target animal characteristics.

Table 2. *Target animal species characteristic in relation to body mass and skin cover*

Species	**Approximate weight**	**Skin cover**
Donkey (*E. africanus asinus*)	180 KG	Fur
Sheep (*O. aries*)	55 KG	Wool
Western jackdaw (*C. monedula)*	0.25 KG	Feathers

Note: weights derived from Rousseeuw&Leroy, 1987

Two deployment sites were selected, one accommodating sheep, and the other one donkeys. At both deployment sites, the third target animals were present, the free-roaming jackdaws. The set-up was deployed for 18 days at each deployment site during the spring of 2019, and collected data between 7AM and 8PM (during daylight). The reason behind these deployment times was that two out of 3 used cameras did not have light sources to facilitate night-time recording. Also, the target animal species were diurnal, which means they would be most active between sunrise and sunset. The set-up has resulted in a total of 208 hours of video, and 3549 photos.

2.2 Research materials

In order to execute the study, the functioning of two camera traps were compared:
1) a conventional camera trap, the Bushnell Trophy Camera HD, and
2) a modified camera trap prototype, based on a Ricoh Theta S.

To be able to verify what is in reality happening at the deployment site during the deployment period, a Maginon camera was used.

The two camera traps and the monitoring camera were deployed for a total of 36 days, 18 days on each deployment site, during daylight. The main specifications of these cameras, in relation to detection and capturing, are shown in table 3. Figure 2 contains photos of all three cameras.

Table 3. *Camera trap specifications in relation to detection and capturing features*

Camera model	Conventional camera trap	Modified camera trap
Detection angle	40 degree	240 degree (2* 120)
Field of view	45 degree	360 degree (panoramic)
Camera quality	Pixels: 16MP Lens, diaphragm: f/3.1	Pixels: 12MP Lens, diaphragm: f/2.0
Processing time	0.2 seconds	2.2 seconds

The conventional camera trap

As conventional camera trap, a model of the brand Bushnell was chosen. The reasoning behind this, is that Bushnell is one of the most well-known and popular brands on the market. The model, Trophy Cam, is known to have one of the fastest processing times. The brand, and model, are used throughout the scientific research world (Newey, *et al.,* 2015) and is thus considered to be representable for a conventional camera trap within the mid-range price class. This camera trap has the option to either record video or take (one or more) photos. for this study, it was set to take 3 pictures in a row after each detection, after which it would go back into stand-by mode. This camera runs on 8 AA batteries. Specific features of this camera can be found in table 3.

The modified camera trap

The modified 360 degree camera trap was open-sourced arduino-based (i.e. small processing computer), which facilitated the attachment of a multitude and diversity of for example sensors, cameras, lights, and external energy sources. For this study two opportunities were used: to attach 1) multiple sensors and 2) an external power supply. The camera trap is fully programmable, which provides a broad variety of opportunities. This was used to program the adruino in such a way, that it acted the same as the conventional camera trap: after detection it would turn on the camera and take 3 pictures in a row, and then enter into stand-by mode.

The monitoring camera

This camera, of the brand Maginon, was also a 360 degree one, so all sides of the camera trap set-up were constantly monitored. Since it was running constantly, this camera used an additional external power supply.

Figure 2. Photos of the cameras

From left to right: The conventional camera trap, the modified camera trap, the monitoring camera, and the modified camera trap's lenses (enabling a 360 degree field of view) from above.

Additional materials

For supplying power to the cameras, two power banks of the brand Silicon Power were used, one for the modified camera trap and one for the monitoring camera. Both had a capacity of 10.000 mAh and were charged overnight. Except for the modified camera trap, which had sufficient internal storage (16 GB), external SD cards were used. The conventional camera trap used a 16 GB card and the monitoring camera a 32 GB card. To protect the cameras against the animals, a fence was built. In the field with the sheep, a simple mesh-wire -with-pole construction was sufficient, for the donkeys a sturdier, metal fence was placed.

2.3 Preparation and data collection

The first step was to modify a 360 degree camera into a 360 degree camera trap. Where the camera originally functioned by manually pushing a button, this was changed into activation by a change in current. For this, an arduino (small processing computer) was used. The arduino enabled sensor attachment and communication between these sensors and the camera. In the field, this arduino was active day-long in order to obtain input by the sensors and communicate this to the camera. Once the camera trap was functional the arduino was programmed. The inserted instructions were specific input (triggering of the sensor) and output (activate the camera, take photos, and turn off). The trigger ability of the sensors were tested and the modified camera trap was deployed for trial testing. The trap was programmed for taking 3 consecutive photos per trigger, in line with the settings of the conventional camera trap.

To aid data processing and analysis, a potential detection zone was indicated, of which the boundary was indicated with coloured bamboo sticks. The radius of this round zone was set at 8 meter, which was about the maximum detection distance of the modified camera trap's sensors. Only when a target animal would enter the potential detection zone, which was recorded by the monitoring camera, this would be considered a potential detection event. For the potential detection zone, a radius of 8 meters was chosen because of the maximum detection distance of the sensors was indicated.

In order to keep as many factors that could possibly influence camera trap functioning, the two traps and the monitoring camera were positioned at the same, central, location within the potential detection zone, located more or less in the middle of the animal's field, running simultaneously. All 3 cameras were placed onto a sturdy tripod. The modifying camera was placed on top of the tripod, while both camera traps were placed with the sensors at 30cm from the ground. The conventional trap faced north in order to prevent direct sunlight onto the lens, which could negatively influence picture quality. The external power supplies (power banks) were placed underneath the tripod. Figure 3 shows a schematic representation of the camera trap set-up, and figure 4 a picture. To protect the camera trap set-up from weather conditions, every piece of equipment was placed in waterproof housing, including silica bags. To shield the material against overheating, a shade cloth was installed above the set-up. A clock was added to the set-up, so precise timestamps were added to each video and photo.

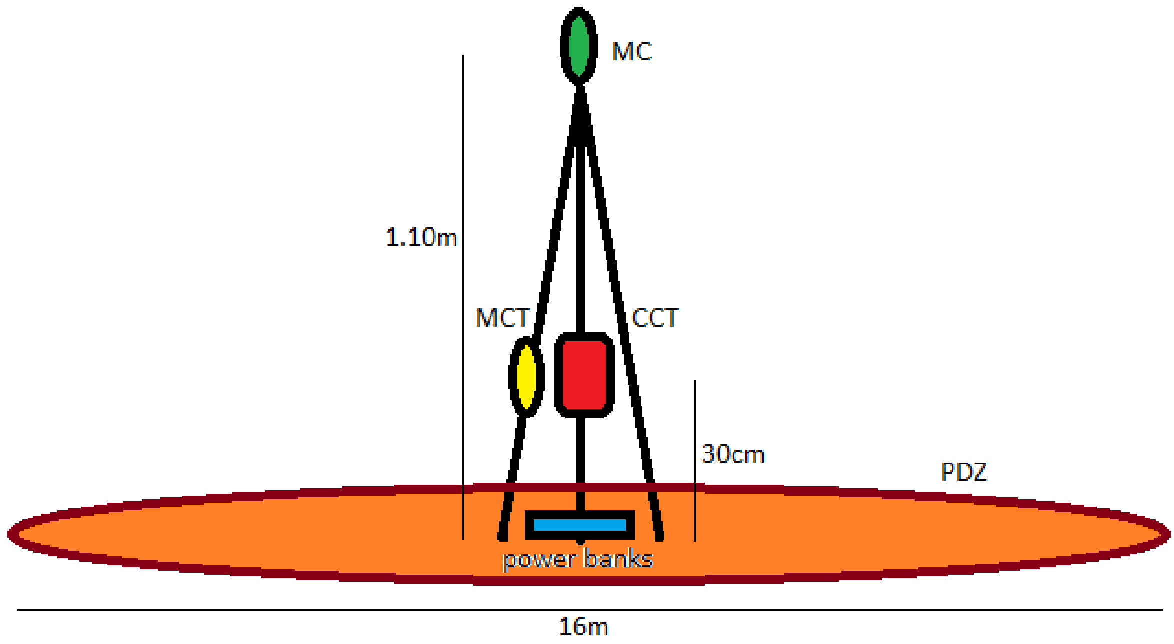

Figure 3. A schematic representation of the camera trap set-up
The monitoring camera (MC) is on top, the modified camera trap (MCT) is on the left, and the conventional camera trap (CCT) right next to the modified trap. Underneath the tripod are the power banks. The circle is a representation of the potential detection zone (PDZ) and had in reality a radius of 8 meters.

Figure 4. A photo of the camera trap set-up
The weather protection is taken off for a clearer view.

2.4 Data processing

The footage from each camera was collected daily throughout the deployment period. If one of the three cameras showed any defects, or failed to record completely, this data was left out of the analysis. The reasoning behind this was, that if the monitoring camera failed, there was no data available for determining whether there was a target animal to be detected or not. If one of the camera traps had a defect, there was no data available to compare the data of the remaining trap to. For each camera, a digital data folder was created, indicating the deployment date. The videos of the monitoring camera were processed by using Windows Media Player, playing at triple speed. The photos of both camera traps were viewed using Windows Photo Viewer. When necessary to get a closer view, the program Ricoh Theta was used to get a detailed 360 degree view.

Monitoring camera → potential detection events

First, the footage of the monitoring camera was processed. The previously indicated potential detection zone was used to determine whether the movement of an animal had the potential of being detected, which was considered a potential detection event. Each of these potential detection events, including the species of animal and the timestamp, was entered on a separate line in a spread sheet. This process resulted in a list of events which could have resulted in footage from the camera traps. A schematic representation of this is given in figure 5.

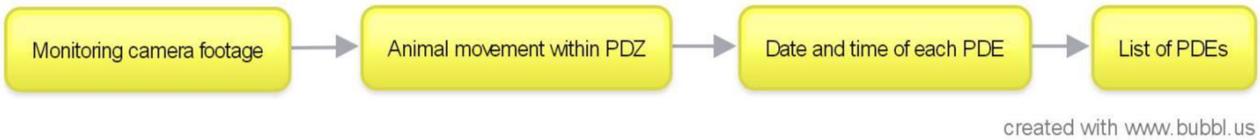

Figure 5. A schematic representation of the process from date to a list of potential detection events
PDZ meaning the potential detection zone, and PDE a potential detection event.

Camera trap footage → photo events (photo events)

Every first photo that was taken within 10 seconds after each potential detection zone by either one of the camera trap is considered a photo event, including photos with the absence of animals. Only after all animals left the potential detection zone, new photo events would be determined. The photo events, with timestamp, were noted down for each camera trap, in the same spread sheet as the potential detection events. These photo events were categorised into 3 photo event groups:

'SHOW'	there was an animal captured on film within 10 seconds of a potential detection event
'NO SHOW'	there was no animal captured on film within 10 seconds of a potential detection event
'NO DETECTION'	there was a potential detection event at a certain time, but no photo event within 10 seconds

Since the monitoring camera showed all activity around the camera set-up, there were no cases of 'show' photo events without a potential detection event. This analysis of the footage resulted in a spread sheet with a list of potential detection events and photo events, indicating the photo event group, including timestamps.

Camera trap footage → false triggers
Blanc photos (with no animals) that were taken at a time that no animal, target animal species or other, was present according to the monitoring camera, were considered to be a false trigger. This data was noted down in a second spread sheet, including date and timestamp of the false trigger.

2.5 Data analysis

For further analysis, both spread sheets were transferred to a Microsoft Access 2010 database. This resulted in two database tables: one containing all the information about the potential detection events, containing these events, dates, time stamps, species, and the detection events of each camera trap. The other table consisted of information about the false triggers, containing the date, hours of camera activity and the amount of false triggers of each camera trap.

In Access, the data was analysed by creating queries. Queries pull information from various tables, collects and/ or performs calculations to this data, and displays them in a clear and understandable manner. Since this study is focused on the detection- and capturing abilities of the camera traps in relation to the specific target animal species, other species than these were excluded from further analysis, except for the calculation of the false trigger rate. The database list containing the detection- and capturing results for each camera trap, specified to the target animal species, can be found in the annex.

In order to calculate the detection- and capturing success of a camera trap in relation to these target animal species, the photo event groups were used. The sum of the ‘show’ and ‘no show’ groups was the number of detections, and the ‘no detection’ group was used to calculate the number of misses. Per potential detection event, the detection results of the cameras were verified to find overlapping detections and –misses, and events which were exclusively detected by either one of the traps. The capture success was determined based on the successful detections of each camera trap. Overall successful camera traps functioning was calculated by using the number of potential detection events in relation to the number of captures of each camera trap. For every result, the relationship with the target animal species was made to determine the effect of animal characteristics to the abilities of each camera trap. For the false trigger rate, the total of all photo events was used, including those after the initial potential detection zone entry. The false trigger rate, per camera trap, was calculated by dividing the total number of false triggers by the total number of photo events.

3 Results

3.1 Differences between the camera trap models in relation to their detection ability

The test indicates that widening the detection zone of a camera trap from 40 to 240 degrees increases the ability of animal presence detection by 65.0% when comparing the data that was collected by the monitoring camera and those of both camera trap models. The conventional camera trap's ability to detect animal movement of the proved to be 44.4% (180 photo events out of 405 potential detection events), where the modified camera trap detected 73.3% (297 photo events out of 405 potential detection events). Table 4 shows the detection performances of both camera traps, including the degree of increment by using the modified camera trap compared to the conventional camera trap.

Table 4. *The detection performances of both camera traps*
Including the degree of increment by using the modified camera trap compared to the conventional camera trap.

Target animal species	Conventional trap	Modified trap	Increment
Donkey (87)	52.9% (46)	79.3% (69)	50.0%
Sheep (152)	50.0% (76)	76.3% (116)	52.6%
Jackdaw (166)	34.9% (58)	67.5% (112)	93.0%
Total (405)	44.4% (180)	73.3% (297)	65.0%

Note. The number of potential detection events for each target animal species are between brackets behind these species. The number of detection events are between brackets behind each detection percentage.

3.1.1 The effect of target animal species on the detection ability

The test indicates that the differences between animals species has quite some effect on the ability of camera traps to detect their movement. By using the modified camera trap instead of the conventional trap, the detection ability increased with 50% for the donkeys, 52.6% for the sheep, and peaked for the jackdaw detection at 93%.

For both camera traps, the donkeys were the easiest target animal species to detect. The modified camera trap detected 79.3% (69) of the 87 potential detection event for that species, while the conventional camera trap detected 52.9% (46). Next in line were the sheep with a detection of 50% (76) out of 152 potential detection events for the conventional camera trap and 76.3% (116) for the modified camera trap. The jackdaws proved to be the most difficult target animal species to be detected by the camera traps with a percentage of 34.9 (58) for the conventional camera trap and 67.5% (112) out of 166 potential detection events for the modified camera trap. Table ...# shows the detection successes with the specific results for each target animal species.

3.1.2 Exclusive and overlapping detections or misses

Although the modified camera trap detected more potential detection events, the test indicates that this modified camera trap also missed movement of which some were detected by the conventional camera trap and vice versa. Other potential detection events were detected or missed by both traps. In case both cameras missed the animal movement, this could indicate that this animal was more likely that it was difficult to detect due to factors in relation to other factors, such as animals characteristics, instead of failure of the sensors.

The test indicates that the modified camera trap has the most exclusive detections with a percentage of 35.6 (144) where the conventional camera trap has 6.7% (27) exclusive detections. 37.8% (153) of the potential detection events was detected by both traps, and 20.0% (81) was missed by both. The test also showed seemingly irregular variations between the target animal species in regard to exclusive and overlapping detections or misses. The total, exclusive and overlapping detection performances of the camera traps are shown in table 5, specified with the results for each target animal species.

Table 5. *The exclusive and overlapping detections or misses of the camera trap*
Specified with the results for each target animal species.

Target animal species	Exclusively by conventional trap	Exclusively by modified trap	Overlapping detections	Overlapping misses
Donkey (87)	5.7% (5)	35.9% (28)	47.1% (41)	14.9% (13)
Sheep (152)	7.9% (12)	34.2% (52)	42.1% (64)	15.8% (24)
Jackdaw (166)	6.0% (10)	38.6% (64)	28.9% (48)	26.5% (44)
Total (405)	6.7% (27)	35.6% (144)	37.8% (153)	20.0% (81)

Note. The number of potential detection events for each target animal species are between brackets behind these species. The number of detection events are between brackets behind each detection percentage.

3.1.3 The effect of the widened detection zone on the false trigger rate

When comparing the data of the monitoring camera and the camera traps, it appeared that false triggers occur about ten times as often for the modified camera trap as for the conventional camera trap. In total, 397 photos were captured by the conventional camera trap, and 786 by the modified camera trap. Of these photos, 0.8% (3) was considered to be a false trigger for the conventional camera trap, and 8.0% (63) of the photos of the modified camera trap.

3.2 Differences between the camera trap models in relation to their capturing ability

The test indicates that an enlarged field of view of a camera trap increases the success of capturing animal presence on photo. Of the 297 detection event of the modified camera trap, all target animal species (100%) were captured, while the conventional camera trap failed to capture 12.8% (23) of its 180 detection events. Table 6 shows the capturing performances of each camera trap, specified for each target animal species.

Table 6. *The capture abilities of each camera trap*
Specified with the results for each target animal species.

Target animal species	Conventional captured (#)	Conventional captured (%)	Target animal species	Modified captured (#)	Modified captured (#)
Donkey (46)	42	91.3	Donkey (69)	69	100
Sheep (76)	58	76.3	Sheep (116)	116	100
Jackdaw (58)	57	98.3	Jackdaw (112)	112	100
Total (180)	157	87.2	Total (297)	297	100

Note. The number of potential detection events, for each target animal species are between brackets behind these species.

3.2.1 The effect of target animal species on the detection ability

Of the 23 failed capturing events of the conventional camera trap, 4 were donkeys, 18 sheep, and 1 was a jackdaw. Percentage wise this means that 91.3% of the donkey detection events, 76.3% of the sheep detection events, and finally 98.3% of the jackdaw detection events were captured successfully by the conventional camera trap. For the modified camera trap these percentages are all 100%. Table 6 shows the capturing abilities of each camera trap, specified for each target animal species.

3.3 The extent of ability increment by using the modified camera trap

As a reminder, successful camera trap recordings are those potential detection events that have resulted in a photo of an animal. This is dependent of both the detection and capturing abilities of the camera traps.

The results of the study showed that the modified camera trap was superior in both detecting and capturing. This was true for all target animal species, though in different degrees. The extent to which the modified camera trap was able to capture animal presence on photo improved by a mean of 89.2% compared to the ability of the conventional camera trap. The effect was most apparent for capturing sheep, with an increase of 100%, and least for donkeys, with an increase of 64.3%. As a drawback, the modified camera trap experienced a ten-fold increase of false triggers, 0.8% for the conventional camera trap, and 8.0% for the modified camera trap. Table 7 shows the extend of increment of the modified camera trap's ability to capture animal presence on film, compared to that of the conventional camera trap, with specifications to the target animal species.

Table 7. *The extent of ability increment by using the modified camera trap*
Compared to that of the conventional camera trap, with specifications to the target animal species.

Target animal species	Successful functioning conventional (#)	Successful functioning conventional l (%)	Successful functioning modified (#)	Successful functioning modified (%)	Increment
Donkey (87)	42	48.3	69	79.3	64.3%
Sheep (152)	58	38.2	116	76.3	100.0%
Jackdaw (166)	57	34.3	112	67.5	96.5%
Total (405)	157	38.8	297	73.3	89.2%

Note. The number of potential detection events for each target animal species are between brackets behind these species.

4 Conclusion and discussion

The results of this study show that the adaptations to the detection zone and field of view of the modified camera trap, increase the ability of the camera trap to successfully capture animal presence on film. The difference in overall successful recording of animal movement is at the first place a result of the widening of the detection zone and secondly the enlargement of the field of view of the camera trap. This is true for all three target animal species.

The total detection ability increased by 65.0% by using the modified camera trap instead of the conventional camera trap. Since the sensitivity of the sensors that were used for the modified camera trap were very similar to the sensor of the conventional camera trap, the widening of the detection zone from 40 to 240 degrees should account for the differences in mean detection abilities of the camera traps. The positioning of the trap could in part account for a higher detection success of the modified camera trap, since the sensor detection zone of this camera trap is spherical instead of the horizontal zone of the conventional camera trap. The lower photo quality of the modified trap, compared to that of the conventional camera trap, proved to make identification onto individual level more difficult, but is assumed to be sufficient for species identification.

The study shows a differences in detection success between the target animal species for both traps. Donkeys were easiest to detect, with 52.9% for the conventional trap to 79.3% detection for the modified, followed by sheep, with 50.0 (conventional) to 76.3% (modified) detection, and at a larger distance, the jackdaw, with 34.9% (conventional) to 67.5% (modified) detection. Both the large body size and least amount of skin cover of the donkey can he the reason behind the detection successes. Sheep's wool, and thus more radiation obstructing skin cover, and smaller size compared to the donkeys, can account for the second position in the detection likelihood. Sheep have a much larger body size than the jackdaw, but feathers are better heat insulators than wool (Dawson *et al.*, 2004). Thus it is unknown whether the size difference or skin cover is the defining factor for an greater detection success for the sheep compared to the jackdaw.

Even though differences in detection ability of the camera traps in relation to the target animal species were observed, it remains largely unclear whether the body sizes or the skin covers of the species were the defining factor for these differences. The chosen methods of this study were not specific enough to determine these causes…

Because the target animal species had the option to find cover when it rained, the differences between the abilities of the camera traps in regard to the detection of wet animals could not be observed. In a more natural environment, with a variety of animal species and wet animals do occur, it is assumed that (a combination of) small size, thick skin cover and increased humidity negatively effects the ability of the camera trap to detect their movement. Camera traps with both passive infrared sensors and other types of sensors could be a solution to this.

The detection success differences between the target animal species were similar for both camera traps. Both traps had the highest success with detecting donkeys, less with sheep and lowest with jackdaw. The increase of detection ability by using the modified camera trap instead of the conventional trap is quite similar for the donkey and sheep, 50.0% and 52.6% respectively, and most obvious for the jackdaw, with a percentage of 93.0%. It is assumed that the variance in the shape of the traps' sensors largely account for this difference as the spherical shape of those of the modified trap opposed to the horizontal shape of the conventional trap sensor would be more fitting for flying animals.

The increased detection zone of the modified camera trap accounted for a ten-fold increase of false triggers. Even though a false trigger percentage of 8 is not that high compared to the outcomes of other studies with one sensor-traps, ranging between 0.2% and approximately 10% (even up to 91%) (e.g. Glen *et al.* 2013), the open area of the study sites used for this study should be taken into account. Therefore it is assumed that when the modified camera trap would be deployed in more vegetated environment, where moving sun-heated vegetation can falsely trigger the sensors, the false trigger rate is likely to increase, depending on the local environmental factors.

The result of false triggers is the collection of 'useless' data. This increases the time needed for data processing as well, and the battery will be drained faster when the camera is activated more often. These could be reasons not to increase the detection zone, depending on the type and length of study conducted, and manner of data processing. When data processing would be done with automated species identification software, an increase of false triggers should be less of a problem. These programs first crop images out of the background of the photo, and then uses known species distinguishing features to compare these to the photo, thereby identifying the animal onto species level. Currently, up to 90% correct classification is reached, and reduced manual review (checking photos that the program is unsure of) by approximately 40% (Tack *et al.*, 2016). Since this software is into development, more sophisticated photo reviewing programs will be developed over time (Yu *et al.*, 2013).

The modified camera trap has captured 100% of all detected animals, while the conventional camera trap failed to capture the animals in 23 photo events. This difference is most obvious with the sheep, which is the least-captured target animal species by the conventional camera trap; the modified camera trap captured 23.7% more of these target animal species detections. The monitoring camera data showed that animals moving outside of the field of view of the conventional trap during the processing time (from detection to capturing) was the main reason for failed capturing. This mostly happened when an animal was too close to the camera trap.

A plausible reason for a relatively high capture success of the donkey detections (91.3%) compared to the sheep, could be the increased distance between the protective fence and the camera trap set-up at that deployment site, in a way that the animals could not be too close to the camera to disappear from its field of view. This, in combination with a correct height of the camera trap for this animal. Another factor that could be resulting in a difference between the donkey and sheep detections, are external factors like the weather.

Even though the two cameras were deployed at the same time at each deployment site, whereby external factors were the same for both traps, this study did not take into account that these factors would differ when comparing the two separate sites. This study setting error should be taken into account when comparing the data of these two target animal species.

The near-perfect capture success rate (98.3%) of the jackdaw could not be explained by the results of this research. One idea would be that the natural grouping behaviour of these species is of influence; it probably happened more than once that one of the jackdaws was detected, while another individual was captured on film. Since the modified camera trap had a 100% capturing success, the field of view of the camera seemed to have nullified the longer processing time of the modified camera trap compared to that of the conventional camera trap.

The abilities of a modified camera trap to record animals during night-time remains to be investigated, since no light sources to facilitate such recordings were attached to this trap. When testing camera traps during night-time, the monitoring camera should be equipped with light sources as well, which means that these would be active night-long, which would most probably influence animal presence and behaviour.

The lower quality of the camera of the modified camera trap, compared to that of the conventional camera trap, decreased individual identification possibilities when the subject is further away, but is assumed to be sufficient for identifying onto species level. This is, as it is for the conventional camera trap, dependent on other factors, such as obstruction by vegetation, speed of the animal, distance to the camera, as well. However, the 360 degree field of view of the modified camera trap, when programmed to take a series of photos, is more likely to capture a good photo than the conventional camera trap with a 40 degree field of view and thus more chance of the animal to move out of the field of view of the camera trap before capturing.

For this study the data processing of both standard and panoramic photos was performed with the same software (Windows Photo Viewer). It is not sure whether automated review software for species identification can currently deal with panoramic photos as well, though adaptations for this should be only a matter of time, when proven necessary.

Since the target animal species in this study were used to human presence in an urban setting, responses to sound- and/ or light emission, scent, and visibility of the camera trap were of neglectable influence. Wild animals could respond to the presence of a camera trap and would be more likely to move at a faster pace than in a petting zoo. A divergent body mass from the targeted animals in this study, can influence the detection and capturing abilities of camera traps. For this study the camera traps were only deployed during daylight, therefore it remains to be examined what the performances of these traps are in low-light situations. The open fields at the study site were not representable for natural environments. More natural environments, such as wet tropical regions, would challenge the camera traps to both detect and capture animals, due to thigh level of humidity typical to wet tropical areas. Also, more vegetation would be likely, which would be negatively influencing the detection and capturing abilities of a camera trap, since this vegetation could obstruct both its sensors and field of view.

The modified camera trap proved to be prone to technical error, during the 36 deployment days, 28 times this trap was responsible for data loss because it had stopped functioning. Three times the monitoring camera experienced this problem, the conventional trap never experienced a technical error during this study. The origins of technical error of the modified camera trap could be found in problems with overheating caused by direct sunlight in combination with the rain protection.

The future value of the professional implementation of camera traps depends on the acknowledgement, and tackling the detection- and capturing limitations of these traps. in the meantime, scientists should take caution when interpreting and comparing study results (Larrucea *et al.*, 2007, Smith&Coulson, 2012, Taylor *et al.* 2014). Using camera traps to see what we have been missing, or will be missing forever if degradation of the natural world continues. It will be a sad, desolate state if only photos will remain of all the beautiful creatures.

5 Recommendations

Current significance to research

The outcomes of this study highly recommend scientists to be very careful with the interpretation of data that was and will be collected using camera traps, since their abilities are not as reliable as they were assumed to be. As mentioned in the introduction, this is especially true for studies using camera trap data to determine (relative) abundance, density and occupancy. When, for example, the data for an abundance study suggests that there are a certain number of great cats, but the camera trap missed 30% of the passing individuals, the interpretation of the results is way off. This can subsequently result in an ineffective or even harmful implementation of this data. As long as the actual, instead of the assumed, reliability of camera traps is taken into account, the outcomes of these studies are, at least, debatable. If future tests indicate that for a certain animal species, while observed with a specific camera trap, in certain environmental circumstances, a mean of 30% is missed, this can be taken into account by adapting the formulas used to analyse the data. In this way, a more accurate assumption in relation to the abundance of this animal.

The interpretation of data collected in tropical areas, where most camera trap studies take place, deserve extra attention. As shown in this study, differences in animal species characteristics are of influence to the detection ability of camera traps. Higher temperatures of the environment would decrease the difference between the animals and its surrounding, which would decrease the ability of the traps to detect their presence.

Future research

Further research, in specific to the testing of camera trap abilities, will increase the level of understanding, which makes data interpretation more accurate. When testing the abilities, and thus the reliability of camera traps, the use of a monitoring camera is highly recommended, since it is of vital importance to record the actual scene during the deployment. This is especially true for the use of camera traps in more challenging environments such as wet tropical areas, where even less is known about the efficacy of camera traps. It is recommended to carry out tests in wild environments, where a wide variety of animals is present, to be able to increase knowledge about camera trap’s reliability in regard to other animal species.

As the modified camera trap can be placed in nearly every position, it would be interesting to experiment with suspended placement, possibly in combination with remote sensors. The study of Smith and Coulson (2012) showed that vertical placement of conventional camera traps is often superior to the general implemented horizontal placement. Suspended placement could decrease camera trap sensing by animals as well, an important factor influencing both detection and capturing abilities of camera traps.

Recommendations for camera trap developers

First of all, the next generation 360 degree camera traps should be made of high quality components, while keeping the costs of the devices low. The (professional) do-it-yourself movement could be a means of doing so, since this movement is much less inclined to be profit-oriented, and is very resourceful in terms of working with affordable components of high quality (e.g. Rico-Guevara&Kickley, 2017). This would make the traps both more reliable, and affordable for low-budget studies as well as the general public.

Since the widening of the detection zone seems to positively influence the ability of a camera trap to detect animal movement, camera traps with multiple sensors is preferred over single-sensor traps. The same applies to the enlargement of the field of view of the trap, though the quality of this camera (lens) should be increased to facilitate individual animal recognition.

Since the experienced technical errors seemed to be linked to overheating, special attention should be given to the camera trap’s housing. These modifications should increase the reliability of a modified camera trap, which proved to be the major down-side of the current modified camera trap. The high level of humidity in other environments, for example wet tropical areas, requires a robust camera trap housing as well.

The addition of a (infra-red) flash would make it possible to capture animals in low light as well, though it would be a challenge to illuminate a 360 degree area. An option would be that multiple lights would face out from the centre into different directions, and when triggered, the light corresponding to the sensor would go off.

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Appendix 1. Table with the processed data

The conventional camera trap is abbreviated with ‘CCT’, and the modified camera trap with ‘ MCT’. This list contains the data after animals species other than targeted ones were excluded from the database.

Date	Hours active	Species	CCT show	CCT no show	CCT no detection	MCT show	MCT no show	MCT no detection
20-4	8	C. monedula	3	0	8	7	0	4
		O. aries	5	1	5	10	0	1
21-4	7	C. monedula	5	0	10	14	0	1
		O. aries	3	1	7	9	0	2
22-4	2	C. monedula	1	0	3	2	0	2
		O. aries	2	0	5	5	0	2
23-4	13	C. monedula	7	1	9	13	0	4
		O. aries	8	3	12	17	0	6
24-4	7	C. monedula	2	0	5	5	0	2
		O. aries	3	1	6	9	0	1
26-4	8	C. monedula	4	0	6	6	0	4
		O. aries	5	1	4	8	0	2
27-4	5	C. monedula	2	0	3	3	0	2
		O. aries	2	1	5	6	0	2
28-4	13	C. monedula	4	0	13	11	0	6
		O. aries	6	2	7	12	0	3
29-4	6	C. monedula	2	0	11	8	0	5
		O. aries	3	0	4	5	0	2
1-5	9	C. monedula	0	0	2	1	0	1
		O. aries	2	2	3	5	0	2
2-5	1	C. monedula	1	0	0	1	0	0
		O. aries	2	0	0	2	0	0
3-5	6	C. monedula	1	0	2	2	0	1
		O. aries	2	1	2	3	0	2
4-5	7	C. monedula	1	0	2	2	0	1
		O. aries	4	2	3	6	0	3
5-5	3	C. monedula	1	0	2	2	0	1
		O. aries	3	0	3	5	0	1
6-5	13	C. monedula	2	0	4	3	0	3
		O. aries	5	1	7	8	0	5
7-5	6	C. monedula	3	0	4	5	0	2
		O. aries	3	2	3	6	0	2
8-5	1	E. africanus	1	0	0	1	0	0
9-5	4	C. monedula	1	0	1	2	0	0
		E. africanus	3	0	3	4	0	2
10-5	13	C. monedula	2	0	4	3	0	3
		E. africanus	4	1	5	8	0	2
11-5	8	C. monedula	1	0	1	1	0	1
		E. africanus	4	0	3	6	0	1

12-5	9	C. monedula	2	0	1	2	0	1
		E. africanus	3	0	2	4	0	1
13-5	11	C. monedula	1	0	4	3	0	2
		E. africanus	2	0	4	3	0	3
14-5	6	C. monedula	1	0	0	1	0	0
		E. africanus	3	0	5	6	0	2
16-5	2	C. monedula	0	0	1	0	0	1
		E. africanus	1	0	1	1	0	1
17-5	1	C. monedula	1	0	0	1	0	0
		E. africanus	1	0	1	2	0	0
18-5	5	C. monedula	1	0	2	1	0	2
		E. africanus	3	1	1	5	0	0
19-5	7	C. monedula	2	0	3	4	0	1
		E. africanus	4	0	2	5	0	1
20-5	2	C. monedula	1	0	0	1	0	0
		E. africanus	1	0	2	2	0	1
21-5	1	C. monedula	0	0	1	1	0	0
		E. africanus	1	0	0	1	0	0
22-5	4	C. monedula	1	0	0	1	0	0
		E. africanus	2	1	2	4	0	1
23-5	13	C. monedula	2	0	3	3	0	2
		E. africanus	5	1	5	10	0	1
24-5	3	C. monedula	2	0	3	3	0	2
		E. africanus	3	0	3	5	0	1
25-5	4	E. africanus	1	0	2	2	0	1
Sum	**208**		**157**	**23**	**225**	**297**	**0**	**108**