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Camera traps as a research method for carnivore population estimation: Strength, weaknesses, opportunities and threats, analysis and improvements

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Abstract: Camera traps have been gaining popularity in population estimation studies. Based on 60 scientific journals, we evaluated the strengths, weaknesses and improvements of the camera trap method to better understand its effectiveness for studying population parameters. Camera traps have a strong advantage of being a non-invasive method, requiring minimal labor and because of its ability to detect multiple species per sampling effort. However, theft and time-consuming data analyses, poor sensor performance and potential behavioral changes of wildlife due to noise and flashlights, prevent the camera traps from being the optimal population estimation method. The population parameter studied depends strongly on the behavior and biology of the target species, although the most common opportunity for development is all related to sensor performance (better triggering response and higher sensitivity) as well as extreme weather condition resistance.

Keywords: Monitoring, Research methods, Large carnivores, Method analysis

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Introduction

Estimating carnivore population abundance is an active challenge, nevertheless, obtaining such information as accurately as possible is critical (Nichols & Williams, 2006). Camera trapping has emerged as a powerful tool that allows for non-invasive data collection to study behavioral and ecological aspects of target species (Delisle et al., 2021). Information from camera traps allow unambiguous individual identification making its data useful for generating accurate population estimates from capture-recapture analysis (Joubert et al., 2020; Macdonald et al., 2020).

Camera traps are being actively used to study carnivore population diversity and evaluate their abundance and in recent years cameras have been used to study more complex elements of carnivore populations such as age structures, predatory behavior, and daily activities (Joubert et al., 2020; Miyamoto et al., 2018; Thornton et al., 2018). However, there are several factors that may impact the overall performance of the camera traps: users' expertise, the condition of the study area, the quality of the equipment, and bias due to systematic error. Certain limitations – technical, user or otherwise are further limited by great differences among the cameras themselves, namely in their sensitivity, detection zones and performance under variable environmental conditions.

Comparative tests of the applicability and effectiveness of camera raps are rarely conducted, although it is important to know the potential issues in terms of the strengths and weaknesses and select traps suitable for local application. In this paper, we aim to conduct a systematic literature review and analyze camera trapping as the method to estimate wildlife populations using a known method of SWOT analysis (strength, weaknesses, opportunities, and threats).

Materials and Methods

We used the Scopus as our database to gather publications. The keywords that we combined included "camera trap" OR "photo trap" OR "remote camera" AND "effectiveness" OR "Practicality" AND "Carnivores" OR "Predators". The search for scientific papers was filtered by keywords which were included in the title, abstract and/or keywords. To perform the SWOT analysis, we used the following definitions to extract information from the scientific papers and classify them accordingly. *Strength* in this case is defined as attributes of the camera trap methodology that benefits the study at hand and makes it easier and more practical to execute. In other words, characteristics that are absent in other more traditional methods and that separate camera trapping from other methods. *Weaknesses* are defined by attributes that hinder the method to perform at its optimal level and attributes that are likely to lead to biased or imprecise results. We defined the *Opportunities* as potential external factors that are not part of the method but could potentially give a method an additional advantage. Finally, we defined *Threats* as factors that have the potential to harm the final outcome of the study.

Results

In total 60 articles were generated as a result of the search. The list of the scientific publications that were collected does not include all papers that were published on the topic of camera trapping, nevertheless, the list acquired enables us to have a good overall understanding of the limitations and advantages of the camera traps as a population estimation method. The strengths, weaknesses, opportunities and threats of the camera trap method based on the analyzed papers are summarized in Table 1.

Discussion

Strengths and Weaknesses

We investigated the strengths and weaknesses of camera trapping as a first part of the study. Camera trapping is relatively low cost in the long term compared to other methods of population estimation, it is non-invasive, and makes it possible to obtain information on trap-shy species in a wide range of habitats (Table 1 Strength 1 & 5). It is a great tool that replaces traditional methods especially in areas that are remote and hard to access (Table 1 Strength 4) while producing data on multiple species simultaneously (Table 1 Strength 6). Steinbeiser et al. (2019) demonstrated the substantial underestimation of species richness using transect surveys in comparison to camera traps in a savanna ecosystem.

Recorded photos permanently document multiple types of information. Camera-traps are now being more frequently used to study behaviors of species such as unique behavioral associations among and between different trophic levels (Table 1 Strength 7). For example, Burton et al. (2012) modeled the responses of carnivores to hunting, habitat and prey in western African protected areas, while Thornton et al. (2018) managed to document two spatial hotspots of probable hunting association between badgers and coyotes in north-central Washington which suggests a large role of environmental characteristics in shaping foraging associations.

Camera traps are specifically effective methods for mid-sized and large carnivore species

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Table 1: SWOT analysis of the camera trapping as a method for population estimation.

Strengths
1. Not invasive method of data collection (Gompper et al., 2006; Joubert et al., 2020) 2. Effective monitoring method for mid-sized and large carnivore species (Avrin et al., 2021; Balme, Slotow, & Hunter, 2009; Gompper et al., 2006; Joubert et al., 2020; Kämmerle et al., 2019; Rogan et al., 2022; Shamoon et al., 2017; Strampelli et al., 2020; Stobo-Wilson et al., 2020; Sunarto et al., 2015) 3. Most optimal choice for the the studies focusing on population diversity and abundance evaluation (Balme, Slotow, & Hunter, 2009; Beirne et al., 2021; Burgar et al., 2019; Farris et al., 2014; Kluever et al., 2013; Lazenby et al., 2015; Macdonald et al., 2020; Muench & Martínez-Ramos, 2016; O'Brien & Kinnaird, 2011; Palencia et al., 2021; Rogan et al., 2022; Shamoon et al., 2017; Silveira et al., 2003; Steinbeiser et al., 2019; Xiao et al., 2016) 4. Great replacement for traditional methods when working in remote, hard to access areas (Bernard et al., 2022; Silveira et al., 2003; Steinbeiser et al., 2019) 5. Minimal labor and cost effective on a long term (Delisle et al., 2021; Foresman & Pearson, 1998; Steinbeiser et al., 2019) 6. Ability to detect multiple species and Species detection is usually unambiguous (Burgar et al., 2019; Farris et al., 2014; Foresman & Pearson, 1998; Joubert et al., 2020; Macdonald et al., 2020; O'Connell et al., 2011) 7. Recorded photos are permanent and document multiple types of information (age, behavior, predation, daily activity) (Comer et al., 2018; Joubert et al., 2020; Lazenby et al., 2015; Miyamoto et al., 2018; O'Connell et al., 2011; Srbek-Araujo et al., 2017; Thornton et al., 2018)
Weaknesses
1. Behavior changes of wildlife (Meek et al., 2016; Selonen et al., 2022) 2. Ineffective for small carnivores (Gompper et al., 2006; Pirie et al., 2016) 3. Needs to be accompanied with other methods for accuracy (Balme, Hunter, & Slotow, 2009; Engeman & Witmer, 2000; Gompper et al., 2006; Pirie et al., 2016) 4. Time-consuming data analyses and expensive equipment (Foresman & Pearson, 1998; Glover-Kapfer et al., 2019; Kelly et al., 2012; O'Connell et al., 2011; Palencia et al., 2021; Steinbeiser et al., 2019) 5. Battery and memory limitations (O'Connell et al., 2011) 6. High risk of theft and wildlife damage (Glover-Kapfer et al., 2019; Kelly et al., 2012; Steinbeiser et al., 2019) 7. Camera traps have limitations for estimating population parameters, especially if individuals cannot be identified (Jordan et al., 2011; Joubert et al., 2020; Kelly et al., 2012; Larrucea, Brussard, et al., 2007; Larrucea, Serra, et al., 2007; Negrões et al., 2010)

Table 1: SWOT analysis of the camera trapping as a method for population estimation (continued).

Opportunities
1. Allows for complex sampling design for studies on a population level (Burton et al., 2012; Farris et al., 2014; Kämmerle et al., 2019; Kelly, 2001; Kluever et al., 2013; Mendoza et al., 2011; Rogan et al., 2022; Sunarto et al., 2015; Thornton et al., 2018)
2. Can be used with or without bait/lure (Barcelos et al., 2023; Buyaskas et al., 2020; Comer et al., 2018; Joubert et al., 2020; Dri et al., 2022; Palmer et al., 2021; Stobo-Wilson et al., 2020; Thorn et al., 2009)
3. Can be paired with other software and give more diverse results (Mendoza et al., 2011)
4. Camera traps are used to generate abundance indices (Beirne et al., 2021; Burton et al., 2012; Farris et al., 2014; Muench & Martínez-Ramos, 2016; Sollmann et al., 2013; Strampelli et al., 2020; Windell et al., 2022)
5. Pictures produced are aesthetically pleasing and can be used in research fundraising and awareness raising (O'Connell et al., 2011)
6. Can be used to evaluate other monitoring measures (Avrin et al., 2021; Comer et al., 2018; Nekaris et al., 2020; Palmer et al., 2021; Windell et al., 2022)
Threats
1. Capturing non-target species (Kelly et al., 2012)
2. Human scent may cause the animals to avert the camera device (Buyaskas et al., 2020)
3. Bias due to under-recording. misidentification of the species and/or translating the data (Borah et al., 2014; Joubert et al., 2020; Mendoza et al., 2011; Pirie et al., 2016)
4. Data can be lost due to equipment failure (O'Connell et al., 2011)
5. Technology is changing rapidly and software needs to be constantly updated (Mendoza et al., 2011)

(Table 1 Strength 2). While some authors like Gompper et al. (2006) and Pirie et al. (2016) argue that camera traps are ineffective for observe and study small mammal, Srbek-Araujo et al. (2017) successfully investigated squirrel preys on seeds defecated by lowland tapirs in the Atlantic Forest, southeastern Brazil.

There are two parameters to assess the effectiveness of a method: latency to initial detection (LTD) and probability of detection (POD). LTD measures the time it takes for the first detection of a species at a survey site to be documented. POD looks at the probability of detecting a species with a specific technique. In an ideal scenario, more efficient survey methodologies should result in a low LTD and high POD.

Gompper et al. (2006) found that the value for each of those parameters varies depending on the target species and concluded that for mid-sized carnivores, for example, raccoon, fisher, opossum, and domestic cat, camera traps and plate tracks had a very similar detection efficiency, this is also confirmed by the study done by Shamoon et al. (2017) that investigated medium-sized carnivores in Mediterranean agricultural areas. At the same time, the wariness and aversion to foreign equipment by the animals showed

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higher LTD for track plates compared to camera tramps (Gompper et al., 2006).

LTD can be manipulated through a combination of bait and lure on the site (Table 1 Opportunities 2). Buyaskas et al. (2020) finds that the combination of bait and lure as an attractant was particularly effective for all mustelid species, especially American marten and fisher, and slightly less effective than bait for short-tailed weasel. Opossum records in lured stations were almost three times higher than in non-lured stations Barcelos et al. (2023). Lure has proved comparatively more effective than bait for American black bear and bait was notably more effective than lure for mustelids, which also had a much greater chance of being detected with attractive use than other carnivores (Buyaskas et al., 2020).

For smaller mammals like martens and weasels, track plates had higher POD compared to camera traps, however, camera traps proved to be a useful method to survey the bears showing low LTD and high POD (Gompper et al., 2006). On the other hand, because coyotes are more warry, cameras proved ineffective as shown by the high LTD and low POD. For coyotes, the best method for surveying remains to be snow tracking (Gompper et al., 2006). Buyaskas et al. (2020) also confirms this by concluding that compared to mustelids, the use of attractants for eastern coyote and American black bear was less successful in maximizing detection probability, despite increases in detection probability for both species, suggesting that the eastern coyote is wary of human scent at bait stations.

Buyaskas et al. (2020) found that except for coyotes and red foxes, the faecal surveys proved inefficient to detect the presence of the species. Genetic tests of the fecal and snow tracking confirmed the presence of red foxes in areas where other methods were unable to document them. As a result, Gompper et al. (2006) argue that cameras and track-plates are inefficient for surveying small canids in some harder-reaching regions. The high POD indicated that snow tracking surveys were highly effective for detecting species that are normally active in winter, and this method may be more effective than both cameras and track plates given that the conditions are suitable.

Behavior changes of wildlife as a result of camera traps was also observed by Meek et al. (2016) and Selonen et al. (2022) who argue that the flash light causes animals to avoid the camera stations (Table 1 Weakness 1). Dealing with these changed reactions is critical as this will influence time spent in front of the camera, and can therefore result in bias. As a result, some authors proposed to disregard the first period of the survey to allow animals to become used to the equipment (Howe et al., 2017); while others discarded all the observations where animal behavior indicated a slight change in reaction to the camera traps (Bessone et al., 2020). while others discarded some data to obtain a reasonable detection function fit-ting (Cappelle et al., 2019). This all points to the fact that different methods need to be used when trying to examine different species in the carnivore community.

Those studies that set out to report on wildlife species on a population or community level require a much more intense sampling effort and a more complex design of the sampling technique. Camera traps have been actively used in that regard, as they are said to offer a better alternative to the so-called traditional methods that focus on population diversity and abundance evaluation (Table 1 Strength 3). However, camera traps have limitations for estimating population parameters especially if individuals cannot be individually identified and this is only possible for species with distinctive markings, (Table 1 Weakness 7).

Moreover, analyzing the data from the camera traps is extremely time consuming and requires purchasing of rather expensive equipment (Table 1 Weakness 4) which are in themselves limited by battery life and memory, thus in need constant monitoring (Table 1 Weakness 5). Cameras being an expensive and a valuable tool are often at risk of theft or damage by wildlife resulting in both financial and experimental losses (Table 1 Weakness 6), although this is easy to prevent by use of locks, camouflage, or security cases.

Nevertheless, Silveira et al. (2003) mentions that when it comes to comparing different methods and choosing one for the population diversity and abundance evaluation, camera traps are the better choice, primarily because camera traps are most useful and appropriate in remote areas that are difficult to access and where conducting traditional methods like line transects and/or animal track-/scat surveys are rather impossible (Table 1 Strength 4). Contrary to Silveira et al. (2003), Gompper et al. (2006) and Pirie et al. (2016) argue that camera traps are quite incapable to identify small canids that would otherwise be easily detected by more traditional methods for example by scat or track surveys and/or DNA analysis (Gompper et al., 2006; Silveira et al., 2003). Interestingly, Pirie et al. (2016) similarly found that in South Africa camera traps largely under-recorded the number of animals that were passing a trapping area compared to those identified using traditional traps, especially the smaller species. The study effectively demonstrated that the track plates can provide us with an opportunity to advance the success of the camera traps. In order to avoid under-recording of the species Engeman and Witmer (2000); Gompper et al. (2006); Balme, Hunter, and Slotow (2009); Pirie et al. (2016) argue that camera trapping stations need to be accompanied by other methods to improve accuracy of species recording (Table 1 Weakness 3).

Threats and Opportunities

It is true that camera traps allow for complex sampling design for studies that focus on population level. For example, using camera traps as the main method, Sunarto et al. (2015) successfully addressed knowledge gaps on the topic of cat coexistence in central Sumatra by investigating general ecological characteristics of each cat species in relation to geographic location and site conditions; factors affecting probability of site use by each cat species; and the extent of interactions between cat species pairs as indicated by spatial and temporal co-occurrence. However, it is important to consider the bias of the camera trapping for the population estimation studies and account for that bias. Bias due to under-recording. misidentification of the species and/or translating the data (Table 1 Threats 3).

Consideration of human presence at the monitoring site should also be taken into account in the initial study design. If the study design protocol requires frequent site visits for rebating as concluded by Barcelos et al. (2023), care must be taken to assure that the species of study is known to be resilient to effects of human presence; otherwise, such a protocol may not be suitable as human scent may cause the animals to avert the camera device (Buyaskas et al., 2020). Lure renewing will in itself imply a significant increase in field-related costs and it’s likely to bias other species studies.

Camera traps are used to generate abundance indices as well, to get a quick insight into population size (Table 1 Opportunities 4). However, it is important to note that the indices are in themselves limited and biased compared to actual population density. It is important to note that differences and variations in indices are not directly proportionate to variations in the actual population size. However, the very nature of using the indices requires the researcher to establish certain assumptions. For example, one such assumption is that wildlife detectability is constant in both dimensions of space and time as

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well as among species which in itself is questionable (Sollmann et al., 2013). Moreover, indices are not often corrected to the actual population dynamics, this leads to the indices being unable to give insight into the true population dynamics (Sollmann et al., 2013).

Nonetheless, the information gathered from camera traps can prove a great use in the occupancy model which aims to study species occurrence and absence from the area in order to outline certain population dynamic parameters. This has very helpful implications for monitoring elusive species for which observations are scarce (Trolliet et al., 2014). Once the information is gathered from the cameras, researchers must realize that data processing often takes more time than deploying and monitoring cameras in the field (Table 1 Weakness 4). Considerable data management is required in any camera-trapping study such as sifting through photographs and entering them into a relevant database. In addition, other than target species, cameras also capture nontarget species which also need to be entered into the database (Kelly et al., 2012). While it may seem like nontarget species are an unimportant part of the study at hand, they can also provide some important information, for example, nontarget species can give a great idea about potential competitors, and the distribution of prey. It is also a possibility to link the trapping rates of the target carnivores to the trapping rates of prey (Kelly et al., 2012).

Individual animals are identified by natural fur marks, injuries, and coloration patterns. While the differences in the individual markings may be obvious, these types of identifications are always subjective and will vary depending on the individual observer. This also affects the precision of the estimation outcome. In order to minimize the possibility to misidentify an individual, a number of computer models have been developed for this specific reason - to help identify the pictures of marked animals (Kelly, 2001; Mendoza et al., 2011). These tools significantly improve the researchers' ability to recognize and identify individuals and ultimately make population density estimates more accurate.

Improvements

In their review of 2,167 papers, Delisle et al. (2021) observed that there is a significant decline in studies published since 2005 that used capture-recapture camera trap methodology as the main study method. One of the most common reasons for these declines in camera trap use is researchers' inability to effectively identify individuals. As a result, many researchers who are unable to identify individuals either shifted their focus to estimates of occupancy or switched to using abundance indexes. Both alternatives are less costly choices (Delisle et al., 2021).

To tackle the issue of identification, Joubert et al. (2020) designed an study site arrangement by strategically positioned baits to enhance the identification of individually marked carnivores, ensuring optimal scrutiny of the right side for species with distinct coat patterns like leopards, jaguars, ocelots, and clouded leopards. This approach facilitates precise measurement of body dimensions, as well as more accurate determination of an individual's age and sex from photographs. However, a potential limitation lies in the methodology favoring the recording of individuals attracted to bait, potentially introducing bias by not capturing bait-shy individuals. Moreover, the use of baits at camera stations may influence the ranging behavior of the target species, potentially conditioning them to bait presence and affecting their movement patterns during sampling.

In order to have more efficient camera trap data that leads to unbiased population estimations, it is important to consider the distribution of cameras around the study site depending on the habitat use, compliance with the assumptions of mark-recapture models, sampling frequency, and the adequate selection of individual animal characteristics to be used to distinguish between different individuals (Mendoza et al., 2011). However, one other methodological aspect that needs to be given significant attention is the reduction of subjectivity during individual identification.

Mendoza et al. (2011) suggested two ways in which misidentification and its potential bias can impact population size estimates. First, in case the misidentification cannot be improved, models can be composed that would account for the misidentification and include its possible effects in the final population estimations (Mendoza et al., 2011). Yoshizaki et al. (2009) modeled the possible effect that miscounting would have on the population estimates due to natural marks on a single individual changing over time, for example, evolving markings over time contributed to a significant bias and often overestimated the population size (Yoshizaki et al., 2009). The second way to prevent misidentification bias is to digitalize the identification process. This is primarily important when a researcher works with exceptionally large picture databases which are repetitive, and time-consuming, therefore, easily susceptible to identification error. Kelly (2001), used a 3-dimensional computer-matching system to assist to classify close to 10,000 images of Serengeti cheetahs. While the speed of identification increased dramatically as well as identification accuracy, the effectiveness of the method highly depends on the quality of the image and the angle at which the compared pictures have been captured (Kelly, 2001).

These models, while theoretically viable, have two practical shortcomings when identifying species. The first shortcoming is the rather poor performance of the camera traps for rare species, and the second shortcoming is the overall poor transferability. This is typical for the case scenarios when classifying pictures from the cameras that are not in the model training set (Delisle et al., 2021). Poor detection of rare species is a cause for actual concern as the rare species are of greater conservation interest. However, the poor transferability is a significantly bigger issue as it in turn limits the effective classification performance for rare species. Tabak et al. (2020) suggest increasing the diversity of the camera trap sites and therefore the backgrounds on which to train the models (Tabak et al., 2020).

Mendoza et al. (2011) proposed a new method to help reduce individual identification bias. For this, an online web interface was constructed that allows first to classify all the pictures captured by camera traps into time-related clusters and then allows the classifiers to independently name the target species of bobcats simultaneously, in a mutually blind procedure. The picture identification tool significantly decreased the differences between the classifiers as shown by the Adjusted Rand Index (ARI) (Mendoza et al., 2011).

Delisle et al. (2021) predict that the number of studies that set out to examine unmarked populations will grow, these studies will highly rely on modern technology and relatively newly developed methods, especially for population abundance estimations (Delisle et al., 2021). Delisle et al. (2021) suggest that improved accessibility of software and continued methodological refinement should result in better decision-making and greater adoption by future camera trap studies focused on abundance estimation (Delisle et al., 2021).

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