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Camera Traps in Wildlife Research: Through my Lens

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I remember the first time that I set a camera trap for a wildlife study. My coworkers and I, in collaboration between MPG Ranch and the Defenders of Wildlife, were to set camera traps, bait and hair snags as part of a wolverine monitoring study. On the first day, the sky was clear, the air was cold, and my hands froze as I tied elk ribs to the tree in front of our camera. The concentrated scent bait we used clung to my nostrils for days. But all that discomfort was worth it, when weeks later we took the camera from its tree. On the ride home, I slid the memory card into my laptop. When the images loaded I was delighted by what I saw: the screen was suddenly full of moose, fisher, coyotes, and other animals large and small, all of which had come within feet of the camera I helped set. It was thrilling to see this activity and get a sense of how much wildlife surrounds me every time I walk in the woods. I was hooked. The following winter I returned to the Bitterroot to help continue this study with Defenders of Wildlife. Two years later I helped a graduate student set camera traps near the Blackfoot River, and that spring I classified photos from northern Idaho for another graduate student. This last experience was wonderful, because I saw just how large, spatially and temporally, camera trapping studies can be. Researchers can easily cover the forest in traps and observe their target species silently. It left me wondering: how is camera trapping technology changing how researchers study wildlife?

Camera trapping was pioneered over a century ago, by photographer and politician George Shiras III (Wender 2015). The former congressman wrote to National Geographic Magazine in 1906 about the new sport of wildlife photography, as well as how he could get the animals to take pictures of themselves. He may have even coined the term camera trap when he invited the reader to "string [their] cameras out like traps with a thread across the runway, and gather in the exposed game laden plates at nightfall" (Shiras 1906). These homemade traps had to be reset every time they were triggered, which in Shiras' time was no easy task, he was using glass plate cameras (Shiras 1906, Shiras 1913). But by the 1950s film had improved to professional quality, and camera trapping was starting to be considered as a non-invasive way to observe wildlife behavior (Gysel and Davis 1956). The first commercially made traps came four decades later. The user had to insert a camera made for everyday use, but the traps were finally able to advance the film on their own and take consecutive shots (Kucera and Barrett 1993). This crucial development allowed cameras to be set out for weeks or even months, depending on battery life, storage capacity and the rate at which they were triggered. Finally, camera traps came into their own, as a method for landscape-level monitoring that was less labor-intensive than others. In the 1990s we also saw the first camera-driven studies of wildlife abundance, when Karanth et al. started using cameras to observe tigers (*Panthera tigris*) (1995). They used the tigers' stripes, which are unique to individuals, to pioneer mark-resight studies that didn't require touching a single animal (Dorazio and Karanth 2017).

Today, camera traps are cheap enough for wildlife enthusiasts to buy, and are popular with hunters for determining where their targets are on the landscape. Aided by this wide market popularity, camera makers have made strides in their functionality and simplicity of use over the last two decades. Most are self-contained - their sensors, cameras, flashes, and controls are all in one package, which simplifies deployment and makes them weatherproof and durable. Instead of trip-wires, most use passive infrared sensors to detect when something warmer than the surrounding environment is moving past the camera. Their flashes can be white, to produce clear images of wildlife markings, or infrared, which can only be seen by some mammals, to reduce disturbance. Some can even record video to capture behavior, but this drains batteries and fills memory cards quicker than photos (Rovero et al. 2013). While the first commercial systems cost more than $850 adjusted for inflation, researchers can now buy fully functional traps for less than $250 dollars depending on the specific features that their study requires (Kucera and Barrett 1993, bls.gov, Rovero et al. 2013). This relatively affordable package means that more researchers are able to monitor wildlife populations over more of their range.

Biologists often use camera traps to estimate the abundance or density of wildlife populations. Usually this is achieved by mark-resight study designs. The fundamentals of mark-resight methods for estimating abundance are summarized well by Whittington et al. (2018):

> population N can be estimated as $\widehat{N} = m + \frac{u}{\widehat{P}}$ where m is the number of marked animals, u is the number of observed unmarked animals and $\widehat{P}$ is the estimated probability of encountering a marked individual during a resight survey.

Karanth et al., didn't have to mark tigers with tags or collars. They used natural markings (stripes) instead, and simply recorded these patterns so they could be recognized by experts in subsequent photos Karanth et al. (1995). This type of mark-resight study that uses natural markings can be useful for many cryptic species that are otherwise wary of trapping, and for researchers who want to avoid disturbance of wildlife. Unnatural markings like ear tags or collars can also be used and detected with cameras. Then all researchers must do is analyze images from camera traps and determine how likely it is that a given animal in the study area is observed.

Camera traps offer a way to answer many questions about wildlife populations besides population density. One of the first uses of a camera trap for wildlife research looked at which animals ate seeds on the forest floor (Gysel and Davis 1956). Since this pilot study, there have been numerous studies of wildlife behavior using camera traps, comparing what time of day meadow mice and harvest mice (*Microtus californicus*, *Reithrodontomys megalotis*) are active, or characterizing puma (*Puma concolor*) scavenging activity for example (Pearson 1959, Bauer et al. 2005). Behavioral studies like these can help us understand how species are using habitat, rather than simply identifying where they spend their time. Other studies have answered questions about whole communities, including species richness and diversity (e.g. Mohd 2006, Tobler et al. 2008). These inventory studies can help develop a trend of how diversity changes in an area through time and help focus broad scale conservation efforts (Tobler et al. 2008).

Despite the efficiency and flexibility of modern camera traps, they cannot answer every question a wildlife manager might have, and they can't observe every species with equal precision. For one, it can be difficult to get an accurate count of population abundance. When researchers use the basic capture-mark-resight models described above, they make two important assumptions. The first is that the population is geographically closed, meaning no individuals are moving into or out of a population during the study period (Andrew et al. 2008). Because there are often no physical barriers keeping wildlife entrained, researchers tend to under-estimate abundance. The other key assumption is that marked individuals are no more likely than unmarked individuals to be viewed by cameras (Whittington et al. 2018). This assumption is often not valid because marked individuals are more likely to be sighted in areas where they were marked than unmarked individuals (Whittington et al. 2018). Researchers must add in some understanding of the species' home range, generally from telemetry data, and add parameters to their models to relax these assumptions (Karanth 1995, Andrew et al. 2008, Rowcliffe et al. 2008, Whittington et al. 2018).

To make camera trap study design even more complicated, wildlife species can have different probabilities of detection. Smaller species can often be overlooked, either because they don't trigger the camera's infrared sensor, or aren't seen by the technicians that classify images (Silveira et al. 2003, Harmsen et al. 2010, Sirén et al. 2016). One study was able to record marten (*Martes americana*) density using a novel approach. Sirén et al. placed partially-opened cans of sardines above a platform, which meant that martens had to climb up to the can, exposing their unique ventral patches, or the id code on their radio-collar, to the camera. (2010). Species also differentially use parts of the landscape. Harmsen et al. found that predators in Belize, like jaguars (*Panthera onca*) and pumas (*Puma concolor*) used trails more than their medium sized prey species like paca (*Agouti paca*), who tend to cross trails, and wouldn't be detected by trail-facing cameras unless they were placed at crossings (2010). To get accurate measures of abundance or density, researchers will need to tailor both their study design (i.e. where to place cameras) and their analysis, to their specific study system. Some species will be better sampled by other techniques like track plates or snow tracking (Gompper et al. 2006).

While I classified photos, counting and recording wildlife numbers and species, I wondered: how can researchers be sure that the volunteers who analyze their images, are accurately identifying wildlife? Most researchers with large study areas and many cameras can't hire expert biologists to do this time-intensive work, so they enlist the help of volunteers like me. This collaboration has been made easier by online programs like TRAPPER, where volunteers simply log in and start classifying or commenting on pictures or video. Developments like this widen the possibilities for crowd-sourcing photo analysis (Bubnicki et al. 2016). Citizen science methods have been used in many fields, but many are wary of the data they produce, and inaccurate reporting has been handled in different ways by researchers (Alexandra et al. 2016). Some require volunteers to pass competency exams, while others flag outliers in the data to be verified by later experts (Bonter and Cooper 2012). Alexandra et al. had volunteers classify the same set of images, and then compared their work to that of experts (2016). They found that by pooling the answers of just 5 untrained, untested volunteers, they were able to correctly identify more than 90% of the animals, and that 20 volunteers were more accurate than the experts themselves (Alexandra et al. 2016). This work can often be tiring and banal, but there are redeeming moments, where you glimpse an interesting wildlife species or behavior. I also found it to be a great way to improve my ability to recognize species, and I think many aspiring biologists and naturalists would get something from the experience. There's a lot of promise for camera trapping in outsourcing data categorization to enthusiasts over the internet. We may even be able to one day have computers classify data for us as artificial intelligence improves, but it's difficult to know how long it will be before algorithms are comparable to humans when it comes to pattern and context recognition, especially in low light, grainy pictures.

Camera trapping systems are not the panacea to wildlife research's scale and uncertainty, but they are a useful tool in our kit that, paired with careful and purposeful study designs, will continue to answer many questions about our natural world. As in many fields of technology, camera traps will likely continue to improve and get cheaper, and as our ability to model the data we get from them improves we might see their popularity and utility get even broader. One thing that seems clear is that as wildlife biology continues to move toward management based on quantitative analysis, photo trapping will continue to be an invaluable tool.

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