Chapter 2
A History of Camera Trapping

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2.1 Introduction

The human desire to observe wild animals without disturbing them goes back at least to hunter-gatherers who constructed blinds. Our ability to do so was greatly enhanced with the development of photography and other, even more recent, innovations such as small, portable batteries, electric lights, and digital equipment. These technologies allow us to make undisturbed observations on a wide variety of wildlife, in a wide variety of habitats, at all hours, and under the most challenging of conditions. Our early ancestors were motivated by a desire for animal products. Today, desires for undisturbed observations of wildlife range from recreation and an aesthetic appreciation of nature to increasing our scientific understanding of animal populations and their relationship to their environment.

Modern photographic equipment, camera-triggering devices, and compact power sources allow us unprecedented, unobtrusive access into wildlife habitats using automated camera traps. Even people with no scientific training can now address simple questions such as "What animal is in my backyard at night?" Wildlife scientists are using modern remote camera equipment to answer more sophisticated questions such as "What animal species occur in a certain area?", "What are they doing?", and even "How many are there?" Detecting cryptic or rare species, delineating species distributions, documenting predation, monitoring animal behavior, and estimating population size and even vital rates are topics that are now being addressed by scientists using remote photography. Such pictures can be worth much more than words alone. This review will briefly describe the development and use of remote photographic equipment up to the refinement of techniques for quantitatively assessing the demographics of wildlife. This last topic is treated in various chapters in the current volume.

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2.2 Early Developments

Photography was invented and refined in the Nineteenth Century (Newhall 1982). Heavy, bulky equipment and slow film and lenses notwithstanding, the new technique was soon applied to photographing nature. Guggisberg (1977) described one of the first successful attempts to photograph wild animals by Professor G. Fritsch, a German explorer in South Africa in 1863. In another instance, one of the earliest examples of "endangered species" photography, a captive quagga *Equus quagga* was photographed at the London Zoo in the early 1870s; by that time it had already become extinct in the wild. In 1870, Charles A. Hewins of Boston produced a photo of a white stork *Ciconia ciconia* on a nest at Strassburg. One of the earliest uses of wildlife photography for scientific purposes was during 1872–1876 on an oceanographic voyage by the English vessel *HMS Challenger*. On this expedition, C. Newbold, a corporal with the Royal Engineers, photographed rookeries of rockhopper penguins *Eudyptes chrysocome* and breeding albatrosses *Diomedia* spp.

Wildlife photography became popular in the late Nineteenth Century. According to Guggisberg (1977), by the year 1900 there were four million camera owners in Britain; the Zoological Photographic Club was founded in 1899. Technological advances resulted in smaller, more portable cameras. The "Bird-land Camera" was a type of reflex camera developed by English bird photographer Oliver Pike in the early 1900s and marketed as "Specially designed for Natural History Photography". In the United States, A. G. Wallihan (1906) published "Camera shots at Big Game," a collection of photographs of elk *Cervus elaphus*, mule deer *Odocoileus hemionus*, pronghorn *Antilocapra americana*, mountain lions *Felis concolor*, bobcats *Lynx rufus*, and other wildlife taken in the Rocky Mountains; the book's introduction was by Theodore Roosevelt.

These early wildlife photographs were taken by the photographer manually releasing a shutter. Technological developments that produced much faster shutter speeds allowed Eadweard James Muybridge in 1878 to line up a dozen cameras and have them triggered by a horse breaking strings as it galloped past. This not only demonstrated that all four feet of a horse are off the ground at certain points in a gallop, but was the beginning of a rigorous understanding of animal locomotion, and ultimately led to the development of motion pictures (Guggisberg 1977; Newhall 1982). This was also one of the first examples of an animal taking its own picture.

George Shiras in the 1890s was the first to develop a method using a trip wire and a flash system in which wild animals photographed themselves. His "flashlight" photographs won a gold medal at the 1900 Paris World Exhibition and were published in National Geographic Magazine (Guggisberg 1977; Shiras 1906, 1908, 1913. Shiras recorded numerous wildlife species with trip wires, including American mink *Mustela vison*, raccoons *Procyon lotor*, white-tailed deer *O. virginianus*, North American porcupines *Erithizon dorsatum*, muskrats *Ondatra zibethicus*, snowshoe hares *Lepus americanus*, striped skunks *Mephitis mephitis*, American beavers *Castor canadensis*, black and turkey vultures *Coragyps atratus* and *Cathartes aura*, northern bobwhite quail *Colinus virginianus*, cardinals *Cardinalis cardinalis*, Eastern gray squirrels *Sciurus carolinensis*, Virginia opossums *Didelphis virginiana*, gopher tortoises *Gopherus polyphemus*, caribou *Rangifer tarandus*, moose *Alces alces*, grizzly bears *Ursus arctos*, and elk. Shiras was successful in photographing so many wild species in part because of the variety of methods he developed to induce the animal to pull the trip wire. For example, he often used bait tied to the trip wire that attracted animals and induced them to pull on it, such as cheese for photographing raccoons and carrion for vultures. He also placed the wire across likely travel routes to photograph elk. Shiras used a particularly clever way to photograph a beaver. He tied the trip wire to a dislodged stick in the beaver's dam; at night, when the beaver repaired the dam, it took its own picture.

In the early decades of the Twentieth Century, there were several other successful attempts around the world to have animals to take their own pictures. The German sportsman and photographer Carl Georg Schillings adapted Shiras' methods to the wildlife of East Africa in 1903 and 1904. Using bait such as a live donkey, and photographing at waterholes, Schillings (1905, 1907a, b) produced spectacular photographs of many wildlife species including African lions *Panthera leo*, leopards *P. pardus*, spotted hyenas *Crocuta crocuta*, and jackals *Canis* sp., all taken by the subjects themselves. William Nesbit (1926) published the first detailed guide to outdoor photography, and stated that "flashlight trap photography," where a wild animal takes its own picture by tripping a wire, "is a most fascinating sport and is deservedly becoming more and more popular" (Nesbit 1926:62). He acknowledged the assistance of and included photos by Frank Chapman, William T. Hornaday, and George Shiras, the last of whom he described as "the father of this class of animal photography" (Nesbit 1926:303), and included brief biographies and literature citations of a "Who's who in nature photography." The book provided detailed descriptions of camera equipment, baits to attract different animals, high-speed flash apparatus, and trip wires to release the shutter. Nesbit also published a photo of the first wild tiger *P. tigris* taken with this apparatus, by F. W. Champion of the Indian Forest Service. Champion (1928, 1933) subsequently published several books describing his experiences and including many photographs of tigers and other animals such as leopards *P. pardus*, leopard cats *Felis bengalensis*, jungle cats *F. chaus*, fishing cats *F. viverrinus*, striped hyenas *H. hyaena*, sloth bears *U. ursinus*, and ratels *Mellivora capensis*. In Michigan, Harris and DuCharme (1928) used Nesbit's apparatus, and some they made themselves, to photograph beavers and other animals using trails made by beavers.

In a purely scientific context, Frank M. Chapman, Curator of Ornithology at The American Museum of Natural History in New York, worked with trip wires and bait to document the species present on the then-recently established research island of Barro Colorado in Panama. In his "census of the living" (Chapman 1927:332), using Nesbit's apparatus, he successfully photographed mountain lions, ocelots *Leopardus pardalis*, white-lipped peccaries *Tayassu pecari*, Baird's tapirs *Tapirus bairdii*, and coatimundis *Nasua* sp. in the tropical forest. This is likely the first explicit attempt to document the species present in an area with remote photography. Chapman also discussed distinguishing individual animals in the photographs;

based on one animal's markings, he concluded that he had several photographs of the same mountain lion and at least one different individual in another photograph. He also made inferences about the animals' behavior. For example, he noted that several of the cats seemed to be aware of the trip wire and attempted to step over it; the peccaries showed no such awareness. These themes of recognizing individuals and observing animal behavior have been developed greatly in more recent years.

Another early developer of the animal-triggered remote camera was Tappan Gregory, an attorney from Chicago. Gregory (1927) described taking remote photographs of a porcupine and a white-footed mouse *Peromyscus leucopus*, using a trip wire to discharge a flash. He subsequently developed more sophisticated methods with which he successfully recorded photographic images of a wide variety of North American wildlife (Gregory 1930), and worked on scientific endeavors with the U. S. Bureau of Biological Survey, Chicago Academy of Sciences, Smithsonian Institution, and the National Zoo. On scientific expeditions, using the camera traps he developed, he obtained photographs of wolves *Canis lupus* in Louisiana in 1934 and mountain lions in northern Mexico in 1937. Gregory (1939) published detailed plans of his camera traps, and discussed at length their operation, including mounting them on a tree, setting up a field darkroom, and safety issues regarding the use of magnesium flash powder. Stanley P. Young (1946) of the Bureau of Biological Survey, who lead the expedition to Mexico, used several of the mountain lion photographs in his book, and discussed the use of catnip oil to attract the animals to a treadle that, when stepped on, operated the camera.

2.3 The Modern Era

By the mid-Twentieth Century, smaller photographic equipment and the replacement of the clumsy and dangerous magnesium flash powder with flash bulbs allowed further refinement of remote wildlife photography. Several plans for remote cameras to record wildlife activity were published during this time. Gysel and Davis (1956) described an inexpensive photographic unit powered by a 6-V battery that operated when an animal pulled on bait attached to a string. In a somewhat cumbersome sequence of events involving two knife switches, a solenoid, and a modified mouse trap, a single photo was taken by a camera with a synchronized-flash unit. Designed to be housed in a wooden box, this system reportedly performed well in all seasons in Michigan. Gysel and Davis (1956) photographed eastern fox squirrels *Sciurus niger* taking seeds in a study of forest trees, a striped skunk taking a dead rabbit from a trap, and red squirrels *Tamiasciurus hudsonicus* and blue jays *Cyanocitta cristata* taking mourning dove *Zenaida macroura* eggs in a nest predation study. By placing the trip wires across den entrances, they identified the size of foxes using den sites, and determined which species used different kinds of ground dens.

Pearson (1959, 1960) designed a photographic system to monitor the activity patterns of small mammals, particularly California voles *Microtus californicus*, in runways in California. His system employed a 16-mm movie camera, operated one frame at a time so that several hundred exposures could be made without resetting the system. Pearson (1959) described two triggering systems for his cameras, neither of which used a trip wire. In one system, a treadle placed in the runway closed an electric switch when a mouse ran across it and caused a photograph to be taken. The other used a beam of deep red light that was positioned across the runway such that when interrupted by an animal, an exposure was made. He included a clock, ruler, thermometer, and hygrometer in the field of view of the camera. By using ear-tags and patterns of clipping fur, Pearson (1959) was able to recognize individual mice over time. Most photographs were of voles and western harvest mice *Reithrodontomys megalotis*, but he also identified 26 other species of mammals, birds, and lizards in his photographs. He was able to go beyond simple species identification, however, and described daily and annual activity patterns of the two mouse species as well those of brush rabbits *Sylvilagus bachmani* and shrews *Sorex* spp., and he described effects of temperature and relative humidity on the activity of shrews and western fence lizards *Sceloporus occidentalis*.

Other investigators used equipment based on that described by Pearson (1959). Using the treadle placed in runways, Osterberg (1962) studied the activity patterns of northern short-tailed shrews *Blarina brevicauda* and meadow voles *M. pennsylvanicus* in Michigan, and related them to weather, time of day, and season. Buckner (1964) used the design employing the light beam positioned across the runway to release the shutter. Working in a tamarack *Larix laricina* bog in Manitoba, he photographed nine small mammal species, and contrasted the daily activity patterns of snowshoe hare, red squirrel, and red-backed vole *Clethrionomys gapperi*. He adapted the system to operate from a 6-V car battery, increasing its portability, and suggested that the system might be of use in "…obtaining seasonal population estimates of small mammals" (Buckner 1964:79).

Dodge and Snyder (1960) presented detailed plans for a more portable remote camera system that, unlike the one described by Pearson (1959), did not require 110-V A.C. power but operated off a 6-V car battery and allowed multiple exposures without resetting the apparatus. Their design incorporated a light beam that when broken by the body of an animal activated a solenoid connected to the camera's shutter. They also used a movie camera that advanced one frame each time the shutter was activated, thus allowing a series of pictures to be taken. Abbott and Dodge (1961) used a similar apparatus in a study of forest seed predation. Abbott and Coombs (1964) described an even more portable device that used a 35-mm camera with a bulk film magazine that allowed up to 420 exposures, rather than the usual 36, and thus could be left in the field longer without changing film. The 35-mm film produced larger negatives than the 16-mm movie cameras used in the earlier designs. Powered by 6-V motorcycle batteries, this unit weighed 22 kg. Winkler and Adams (1968) developed a movie camera system to study the activity of terrestrial carnivores around bat caves. This system employed an automobile battery, four 100-W aircraft landing lamps, and a photoelectric-cell trigger.

Winkler and Adams (1968) were able to photograph 31 separate 2-sec movie sequences per roll of film, and identified raccoons and striped skunks as they entered and exited bat caves.

Although much of this earlier work focused on mammals, remote camera systems were also developed for avian research. Cowardin and Ashe (1965) described a system to count waterfowl that employed a 35-mm half-frame camera that took 72 exposures. It was controlled by a timer that took pictures every 15 min. They placed the cameras in randomly selected quadrats in different marsh habitats to estimate waterfowl use. Temple (1972) developed a time-lapse photographic system to observe the nesting behavior of peregrine falcons *Falco peregrinus*. He used an inexpensive Super-8 movie camera attached to an electronic timer. With a capacity of 3,600 frames on a roll of Super-8 film, the camera could be left in place for days without changing film. Because this system did not function at night, no flash capability was required, and thus battery requirements were minimal. The system weighed 4 kg. Diem et al. (1973) described camera systems using either a Super-8 or 35-mm camera that could withstand the rigors of a Wyoming winter. Although more expensive than the Super-8 cameras, the 35-mm cameras allowed the use of telephoto and wide-angle lenses. The cameras were attached to an intervalometer and took a picture at intervals from 5 to 15 min. They were used in studies of breeding colonies of California gulls *Larus californicus* and American white pelicans *Pelecanus erythrorhynchos*, as well as big game and livestock grazing and large-mammal movements across highways. Powered by a 6-V battery, the systems weighed between 2.2 and 5.8 kg, and thus were substantially more portable than earlier designs, and operated in temperatures as low as −35°C. Goetz (1981) developed a remote photographic system to study predation on wild turkey *Meleagris gallopavo* nests using a Polaroid camera that had an automatic flash, exposure control, and film advance and contained its own power supply in the film pack. He modified the camera to be triggered through a microswitch beneath the nest platform, and reported excellent results under all light conditions. An obvious advantage of such a system is that the exposed film is available immediately. The system as described was limited to ten pictures using flash. An inherent limitation on using Polaroid film is low temperature inhibiting the chemical developing process; it would have unlikely been useful in winter temperatures below freezing.

Echoing the work of Chapman (1927) in the Neotropics, Seydack (1984) described the operation of a 35-mm camera system to census rainforest mammals in South Africa. He connected a trip plate placed on a trail to an autowinding camera and flash; a photo was taken when an animal weighing 2 kg or more stepped on the plate. The camera was powered by a 6-V battery and had a flash capacity of 16 bulbs. He deployed six camera systems systematically along paths within 100-ha survey blocks. Seydack (1984) left the cameras out for 1 month, and then moved them to the next survey block. He repeated this procedure six times over 3 years. He detected 14 species, and made estimates of population density for bushbuck *Tragelaphus scriptus*, identifying at least 61 individuals by coat pattern and, in males, horn morphology. He could also recognize individual leopards by their patterns of spots and honey badgers *Mellivora capensis* by differences in their white lateral stripe. Seydack (1984) grouped the species he detected into: (1) those that are individually recognizable and thus for which a density estimate may be calculated; (2) those not individually recognizable but, like the African porcupine *Hystrix cristata* and large-spotted genet *Genetta trigrina*, are relatively abundant, and (3) those not individually recognizable but are either rare or difficult to detect due to a behavioral characteristic. He concluded that there is "…a great potential for the photo-recording census technique as a versatile tool of quantitative research and general wildlife censusing" (Seydack 1984:14).

Hiby and Jeffery (1987) and Nicholas et al. (1991) used remote photographic systems to record the presence of Mediterranean monk seals *Monachus monachus* at haul-out sites in caves on the Greek island of Kefallinia. Because these rare seals are particularly sensitive to human disturbance, remote photography seemed appropriate to detect seals' use of caves. They used automatic 35-mm cameras, operated by a trip wire made of fishing line, attached to the walls of suspected haul-out caves. They identified four individual Mediterranean monk seals using the caves.

Carthew and Slater (1991) described an automatic photographic system that employed a pulsed infrared beam as a triggering device. When the beam is intercepted by an animal, the infrared sensor sends a signal to a modified automatic, 35-mm camera with a dedicated flash, automatic exposure control, and a quartz data-back to record date and time on each frame. They used this system to observe animals passing along trails or the tops of logs, and to identify diurnal and nocturnal pollinators visiting flowering plants in Australia. Griffiths and Van Schaik (1993a) noted the utility of remote cameras in studying rainforest animals. They used remote photography to document the changed activity patterns and avoidance of areas used by humans by a variety of larger mammals in Sumatra (Griffiths and Van Schaik 1993b).

Mace et al. (1994) devised a remote photographic system for use in a systematic survey of grizzly bears in Montana. They adapted an automatic, 35-mm camera to be activated by a microwave motion and a passive infrared heat sensor. Using blood as an attractant at systematically deployed survey stations over 817 km^2, they photographed grizzly and black bears *U. americana* as well as 21 other species of wildlife, documented grizzly bear distribution, and ultimately were able to generate estimates of the abundance of grizzly bears in their study area.

2.4 Forest Carnivores

In the early 1990s there was an increasing awareness among wildlife managers in the United States that the conservation status of a suite of small and mid-sized carnivores, including the American marten *Martes americana*, fisher *M. pennanti*, wolverine, and lynx, was of concern. An ad hoc group of federal and state agency biologists and university researchers formed the Western Forest Carnivore Committee to gather what information existed on these species and to develop reliable, non-lethal methods to detect their presence. One issue that immediately presented itself was assessing the distribution of these shy, low density species. Because trapping them had been illegal for decades in most states, there was no recent reliable information on their occurrence throughout most of their historic range. During this period, Fowler and Golightly (1993) and Jones and Raphael (1993) developed and deployed inexpensive, 110-size cameras for field surveys of forest carnivores. Reminiscent of the system deployed by Shiras and Champion nearly a century earlier, these cameras operated when an animal pulled on bait attached by a line to the camera's shutter release. They allow only one photograph to be taken without resetting the camera, and their utility is limited by severe weather and snow. Kucera and Barrett (1993) described the use of the commercially available Trailmaster® remote camera systems for detecting wildlife. With features similar to those described by Carthew and Slater (1991), the Trailmaster® comprises an automatic, 35-mm camera triggered when a pulsed infrared beam deployed over bait or across a trail is broken (see Swann et al., Chap. 3). Kucera and Barrett (1993) and Kucera (1993) used these systems to document the contemporary distribution of rare and shy carnivores in remote areas of California. Data from these remote camera stations combined with those from sooted-track-plate surveys formed the basis for describing the first contemporary distribution of fishers (Zielinski et al. 1995) and American martens (Kucera et al. 1995) in California since the work of Grinnell et al. (1937).

Remote photographic techniques also played a large part in describing non-lethal methods to generate reliable distribution data on a variety of rare carnivores, which was developed from efforts of the Western Forest Carnivore Committee (Zielinski and Kucera 1995) These authors also discussed the strategy behind designing surveys for rare carnivores at both relatively small and larger regional levels, and provided guidelines for conducting such surveys and detailed instructions for using the equipment. This document provided general guidance for developing survey protocols for carnivore surveys throughout western North America and served as a guide for practitioners everywhere attempting to use cameras in the study of wildlife populations.

2.5 Expanding Applications

Several investigators since Goetz (1981) have employed remote photography to investigate avian nest predation. Laurance and Grant (1994) and Major and Gowing (1994) identified nest predators of birds in Australia using different designs of remote cameras built specifically for them. Laurance and Grant (1994) identified nine species, including mammals, birds, and reptiles, visiting the artificial ground nests, and concluded that white-tailed rats *Uromys caudimaculatus* were the most common predator. Major and Gowing (1994), using a somewhat different apparatus to study predation on the nests of a tree-nesting passerine, identified the most important predator as the black rat *Rattus rattus*. Leimgruber et al. (1994) studied nest predation with infrared-triggered cameras at artificial nests in forests blocks of different size in Virginia. They found 13 species preying on nests, and related predation rates more to vegetation structure than to the size of the block of forest. They also suggested that simply removing a few larger predators such as striped skunks and raccoons from a diverse predator community would have little effect on nest predation. Danielson et al. (1996) described another design for a remote camera to photograph nest predation events. They constructed a system in which an egg was placed on a microswitch; a photograph was taken when the egg was moved.

Through the 1990s, remote photography was being used in an increasing variety of studies. Sadighi et al. (1995) used the Trailmaster® system to monitor timber rattlesnakes *Crotalis horridis* in Massachusetts. They were able to recognize one individual through a scar on its head, and to count rattle segments as an indication of age on another. They used black and white film, but noted that by using color film, more individuals could probably be recognized by unique coloration and patterning. They also noted that the cameras documented the presence of a snake with much less human effort involved than did an active search effort. Browder et al. (1995) presented a design for an automatic, 35-mm camera; they used it in an investigation of the scavengers of carcasses of migratory fishes, identifying mammal, bird, and reptile scavengers. Pei (1995) used remote photography to study activity patterns of the spinous country rat *Niviventer coxingi* in Taiwan. Foster and Humphrey (1995) employed automatic camera units to document wildlife use of highway underpasses in southern Florida. They documented mountain lion, bobcat, white-tailed deer, raccoons, alligators *Alligator mississipiensis*, and black bears using the underpasses, and based on their data discussed implications for planning and designing such structures to reduce collisions with vehicles while allowing animal movement. Jacobson et al. (1997) used an infrared-triggered remote camera to census white-tailed deer at bait stations. They identified individual male deer by antler and other morphological characteristics and estimated population size over several years.

Karanth (1995) used automated camera traps to individually identify tigers in Nagarahole, India, and then estimate their numbers using photographic captures under a formal capture–recapture (CR) modeling. His work was subsequently extended to several sites across India to estimate tiger densities (Karanth and Nichols 1998; Karanth et al. 2004). Densities of tigers (O'Brien et al. 2003; Kawanishi and Sunquist 2004), jaguars *P. onca* (Silver et al. 2004; Silver 2004; Soisalo and Cavalcanti 2006), leopards (Henschel and Ray 2003) and ocelots (Trolle and Kéry 2005) have been estimated using similar methods by other workers. More recently, application of CR models to camera trap data was further extended by a 9-year study that estimated survival, recruitment, temporary emigration, transience, and rates of population change in a tiger population in Nagarahole (Karanth et al. 2006).

In their review of the primary literature, Cutler and Swan (1999) reported that the topics of published research using remote photography in wildlife ecology most frequently comprised nest predation, feeding ecology, nesting behavior, and evaluation of photographic equipment. Activity patterns, population parameters, and species detections were less common themes. Although researchers continue to investigate these topics with remote photography, the pattern may have changed. The more recent literature reveals a widening array of topics being investigated using camera traps in a truly impressive variety of habitats and locations. Fedriani et al. (2000) employed camera trapping and leg-hold trapping to assess habitat relations and relative abundance of coyotes *C. latrans*, gray foxes *Urocyon cinereoargenteus*, and bobcats in southern California. Somewhat similarly, Jacamo et al. (2004) studied niche relations among the maned wolf *Chrysocyon brachyurus*, crab-eating fox *Dusicyon thous*, and hoary fox *D. vetulus* in central Brazil using camera traps to assess habitat and activity patterns. McCullough et al. (2000) used camera traps along with radiotelemetry to investigate the ecology of the small, forest-dwelling Reeves' muntjac *Muntiacus reevesi* in Taiwan. They also produced population estimates based on CR models. By placing remote cameras in fig trees, Otani (2001) quantified the foraging frequency of Japanese macaques *Macaca fuscata* on figs and discussed the implications for seed dispersal in the forest. Beck and Terborg (2002) studied seed predation on palm *Astrocaryum murumuru* var. *macrocalyx* seeds under solitary trees versus dense groves in eastern Peru, and photographically identified several unexpected predators on the seeds. Kitamura et al. (2004) used remote photography to study seed dispersal and seed predation in forests in Thailand.

DeVault and Rhodes (2002) and DeVault et al. (2004) identified 17 species of vertebrates, including mammals, birds, and reptiles, scavenging on carcasses of small mammals in the eastern U.S. and suggested that scavenging may provide a larger component of the diet of some species than was previously thought. Main and Richardson (2002) assessed wildlife response to prescribed burning of forests in southwest Florida using camera traps distributed within forests before and after burning. Sequin et al. (2003) found that social and territorial status greatly affected the likelihood that a coyote would be captured by a remote camera. The dominant territory holders were most wary and rarely photographed; lower-status individuals and transients were detected on film much more often. Bridges et al. (2004) used remote cameras to monitor the denning behavior of black bears. Such cameras produced minimal disturbance to the animals, and provided insights into den emergence, behavior around the dens, and ages of cubs when they emerged (see Bridges and Noss, Chap. 5).

A particularly dramatic and valuable recent use of remote photography has been to document the presence of rare or presumed-extinct animals. For example, Surridge et al. (1999) documented a previously undescribed species of striped rabbit *Nesolagus timminsi* on the Southeast Asian mainland some 1,500 km north of the known range of the critically endangered Sumatran striped rabbit *N. netscheri* on the Island of Sumatra. Jeganathan et al. (2002) documented the presence of Jerdon's coursers *Rhinoptilus bitorquatus*, a critically endangered, poorly known, nocturnal, cursorial bird inhabiting scrub jungle in India, using both camera traps and track surveys . They recommend that relatively inexpensive and rapid track surveys be conducted for the bird, and that camera traps be used to confirm any suspected tracks. Holden et al. (2003) documented the presence and distribution of the endangered Asian tapir *T. indicus* in a national park in Sumatra, in an area where neither they nor park rangers ever saw the animals. Using camera traps, these investigators not only documented a surprisingly widespread distribution of the tapirs in the park, but discovered that they often occurred in pairs, and were found in a variety of habitat types in addition to primary forest. Lee et al. (2003) documented an expanded range of the Sulawesi palm civet *Macrogalidia musschenbroekii*, a little-known and endemic viverid, with the use of camera traps. Gonzalez-Esteban et al. (2004) documented the distribution of the European mink *Mustela lutreola* in northern Spain with remote photography, and recommended this method over live-trapping on the bases of cost and effort. In the Atlantic Forest of eastern Brazil, Kierulff et al. (2004) documented the distribution of the highly endangered buff-headed capuchin monkey *Cebus xanthosternos* in 13 forest fragments using camera traps baited with bananas. They also documented the presence of four other primate species, and gathered data such as the minimum number of individuals present, and number of infants. Recently, during an effort using camera traps to assess changes in the distribution of American martens over time in a study area in California's Sierra Nevada, Moriarty et al. (2009) produced photographs of a wolverine, the first documented in California since 1922. Subsequent genetic studies indicated that it was probably a dispersing male from the northern Rocky Mountains.

Mammals are not the only targets of detection using remote cameras. Lok et al. (2005) used camera traps to supplement other survey techniques to document the avifauna of Bawangling Nature Reserve, on the tropical island of Hainan in the South China Sea. Some of the bird species captured on film were classified as Vulnerable or Near Threatened, several considered very rare, and some had never before been captured on film.

The results of other remote camera surveys have been less encouraging from a conservation standpoint. Tilson et al. (2004) surveyed an area of southern China comprising eight reserves in five provinces for the presence of the south China tiger *P. t. amoyensis*. They found no evidence of tigers and little potential prey. The absence of photographic detections mirrored the absence of reported livestock depredations, and the authors conclude that it is likely that no tigers remain in this area. Numata et al. (2005) detected 18 species of mammals with camera traps with in and adjacent to a forest reserve in peninsular Malaysia, but these did not include the Asian elephant *Elephas maximus*, tiger, or sun bear *Helarctos malayanus*, and the authors concluded they are locally extinct. Among the species detected were domestic dogs used for poaching and hunting, and domestic cattle. Numata et al. (2005) did, however, confirm the presence of the Asian tapir in primary forest on the reserve; there is little published information on the current status and distribution of this species. In a forest reserve on Malaysian Borneo, Wong et al. (2005) used remote photography to monitor the physical condition, and document the starvation, of radiocollared sun bears and bearded pigs *Sus barbatus*. This occurred during a period of famine resulting from a fruit scarcity in the lowland tropical rainforest during a periodic, intermast interval.

Silveira et al. (2003) concluded that, despite relatively high initial costs, camera trapping was preferred over track surveys and direct counts in conducting rapid faunal assessments of mammals for conservation purposes. Similarly, Srbek-Araujo and Chiarello (2005) concluded that camera traps were an efficient way to inventory medium- and large-sized mammals in neotropical forests. Trolle (2003) used camera trapping and other methods to survey mammals in the Rio Japuri region of Brazil, and detected 13 of 41 mammal species using both baited and unbaited camera traps. In northern Mexico, Lorenzana-Pina et al. (2004) used camera traps to inventory medium and large mammals. They detected 18 wild mammal species, an estimated 80% of the medium- and large-sized mammals in their study area. Yasuda (2004) conducted a camera trap study of mammal diversity and abundance in central Japan, and developed guidelines for a minimum trapping effort to detect several species. Hirakawa (2005) developed a novel camera trap technique to detect bats. Knowing that insectivorous bats are attracted to any moving object of an appropriate size, he attached a pencil eraser to a line connected to a camera; when bats attacked the eraser, apparently mistaking it for insect prey, a photograph was taken. Research also confirms that remote photography is not the best tool for every job. In comparing survey methods for bobcats, Harrison (2006) found that detector dogs produced many more detections than did remote cameras, hair snares, or scent stations.

Conservation organizations now routinely incorporate the use of remote photography in their efforts to document and preserve biodiversity around the world (Henschel and Ray 2003; Sanderson and Trolle 2005). The Wildlife Conservation Society produced the first-ever photograph of the rare servaline genet *G. servalina* in Tanzania (Brink et al. 2002; Anonymous 2002). Sanderson and Trolle (2005) of Conservation International presented a photograph of the Siamese crocodile *Crocodylus siamensis* in Cambodia, previously thought to have been extirpated throughout much of its range. Staff of the World Wildlife Fund recently documented a rhinoceros on the island of Borneo, one of the last of a subspecies of the critically endangered Sumatran rhino *Dicerorhinus sumatrensis* (Anonymous 2006). The World Wildlife Fund has an online posting (http://worldwildlife.org/cameratrap/) of photographs taken at camera traps from remote places around the world.

Other novel uses of remote photography continue to be reported. In Australia, Glen and Dickman (2003a) used remote cameras to evaluate the possibility that poisoned baits set out to kill European red foxes *Vulpes vulpes* and wild dogs as part of a program to protect the spotted-tailed quoll *Dasyurus maculatus*, an endangered marsupial carnivore, would be taken by native, non-target species. As part of this research, Glen and Dickman (2003b) compared animal identifications from tracks left near baits to those from photographs taken of animals visiting the baits and found the track identifications inaccurate and unreliable, especially in unfavorable weather conditions. Following this, Claridge et al. (2004) investigated the behavior of the spotted-tailed quoll with the use of a remote, digital camera, alleviating the need to process film and getting results immediately in the field. Hegglin et al. (2004) used camera traps to document the uptake of bait laced with a rabies vaccine by red foxes in Zurich, Switzerland. With the data they gathered, they were able to recommend designs of bait stations to facilitate vaccination efficiency and reduce loss of such baits to non-target species. Using remote cameras in addition to other sampling techniques, Mazurek and Zielinski (2004) investigated the value to wildlife of legacy trees, those old trees left in an otherwise commercially harvested redwood *Sequoia sempervirens* forest in northwestern California. Using the cameras, they detected 13 species not detected by other survey methods. Rao et al. (2005) used camera traps to document the effect of hunting on the distribution and relative abundance of wildlife near a National Park in Myanmar. O'Connell et al. (2006) developed models of site occupancy to be used in large-scale monitoring programs for medium-sized and large mammals from detection data generated at an array of sampling techniques that included camera traps.

Other important topics of wildlife conservation have been studied using camera traps. Staller et al. (2005) used remote video photography to document predation on northern bobwhite *Colinus virginianus* nests. Nest predation was attributed to many more predator species than anticipated, and included nine-banded armadillos *Dasypus novemcinctus* and bobcats. This work also verified the inaccuracy of using of only nest remains to make identifications of nest predators. The use of remote photography for fixed-place monitoring, notably in studies of highways and wildlife, is common. Ng et al. (2004) documented the use of highway undercrossings by wildlife in southern California using remote photography. Goosem (2005) incorporated remote photography into a multifaceted scheme of monitoring wildlife use of crossing structures designed for a highway in Brisbane, Australia.

From the early work of Muybridge, Shiras, Nesbit, and Chapman, remote wildlife photography has developed into a modern, high-tech field, and is being used to address an increasing variety of scientific and conservation issues. Combining human curiosity and ingenuity, these remote camera techniques have allowed previously unimaginable access into the lives of many wildlife species. Developments have been driven by advances in technology such as the electronic flash, smaller batteries, and, most recently, digital and web-based photography. Yasuda and Kawakame (2002) described an "online" remote video system that streamed video images from a digital camera through a server to a computer. This provided real-time monitoring of wildlife and automatic storage of the digital images on the computer. Locke et al. (2005) described a web-based digital photographic system that could be used in remote areas. Triggered by a motion and heat sensor and with batteries that are continuously recharged with solar panels, the system can monitor wildlife at a remote site indefinitely, providing essentially real-time photographs without visits by humans to change film or batteries. Photographic results from this system can be seen at http://www.video-monitoring.com/wtek/.

A variety of commercially produced models are now available through outdoor and equipment suppliers and their internet outlets (e.g., www.cabelas.com). For example we have used RECONYX™ camera traps at all the water sources on a research station in central California to monitor wildlife on the 10 km^2 property. We have obtained nearly two million photos of terrestrial vertebrates ranging from western toads *Bufo* boreas to rattlesnakes to mountain lions to California condors *Gymnogis californianus*. These systems can be left in the field for up to 4 months at a time, during which as many as 20,000 photos are collected, documenting the presence of wildlife every second an animal is within range. We have even "captured" poachers. In another ongoing project we deploy the same camera systems on a rotating basis every square kilometer over a 300 km^2 region of the southern Sierra Nevada. The sites are baited for carnivores and checked weekly. Results are collected on site by reading compact flash cards with card readers. These major advances in technology now allow monitoring of wilderness wildlife at a very reasonable cost.

More than 100 years ago, the pioneering remote photographer Carl Georg Schillings recognized the effect of the modern world on its wild inhabitants. In passages that seem prescient, Schillings bemoaned the destruction of native fauna and flora, and observed that "Civilized man will destroy all that appears to him harmful or valueless, and will try to preserve only those animals and plants which he deems useful or ornamental" (Schillings 1905:2). He placed his photography and specimen collecting in the explicit context of increasing "…the pleasure and education of young and old" (Schillings 1905:10). We are confident that technological advances in remote photography will continue, at least in part as a spinoff from security concerns. We hope that developments in the field of remote wildlife photography continue to satisfy and pique human curiosity, increase scientific understanding, and promote the conservation of wild species and their habitats.

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