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Use of Remote Cameras in Wildlife Ecology

SHAWN L. LOCKE,
ISRAEL D. PARKER, AND
ROEL R. LOPEZ

INTRODUCTION

USE OF CAMERA TECHNOLOGY is deeply rooted in wildlife research and management. It includes remote monitoring, real-time observations, infrared and ultraviolet analysis, and many other technologies (Fig. 12.1). Perhaps the most familiar use of cameras in wildlife research and management is that of remote cameras. **Remote cameras** (commonly known as game cameras, trail cameras, infrared-triggered cameras, or by trade names) have recently become readily available and popular among hunters and other wildlife enthusiasts. However, remote cameras have been used in ecological research for more than 50 years (Kucera and Barrett 1993). Early remote cameras were custom-built by researchers to record various types of wildlife activities (Gysel and Davis 1956, Dodge and Snyder 1960, Cowardin and Ashe 1965). These rudimentary remote cameras were the precursor to a burgeoning industry of commercially available remote cameras with a variety of field applications in wildlife research and management (Kucera and Barrett 1993) that includes identifying nest predators (e.g., Hernandez et al. 1997, Dreibelbis et al. 2008); studying animal activity and behavior (e.g., Foster and Humphrey 1995, Main and Richardson 2002); estimating animal abundance (e.g, Jacobson et al. 1997, Roberts et al. 2006); and monitoring species occurrence, including rare and endangered species (e.g., Karanth and Nichols 1998, Watts et al. 2008, O'Connell et al. 2011).

Camera technology extends beyond solely remote, illustrating the breadth of its application to wildlife research and management. For example, camera equipment orbits Earth, collecting remote sensing data; records habitat and species data in oceans and freshwater bodies; monitors wildlife behavior in real time; reveals the reflective properties of wildlife pelages; monitors zooplankton and invertebrates; and brings nature to citizen scientists via Internet connections. Cameras in wildlife management and research have advantages and disadvantages that researchers should be aware of prior to starting a project (Table 12.1).

The goal of this chapter is to describe different camera systems and their applications in wildlife ecology. Specifically, we discuss aspects of camera equipment, data storage, and use of various camera systems in wildlife research and management. We include the strengths and weakness of different systems and techniques.

EQUIPMENT AND DATA MANAGEMENT

Data collection using camera systems is dependent on the quality of the equipment and ability of the operator(s). The operator must correctly determine the appropriate

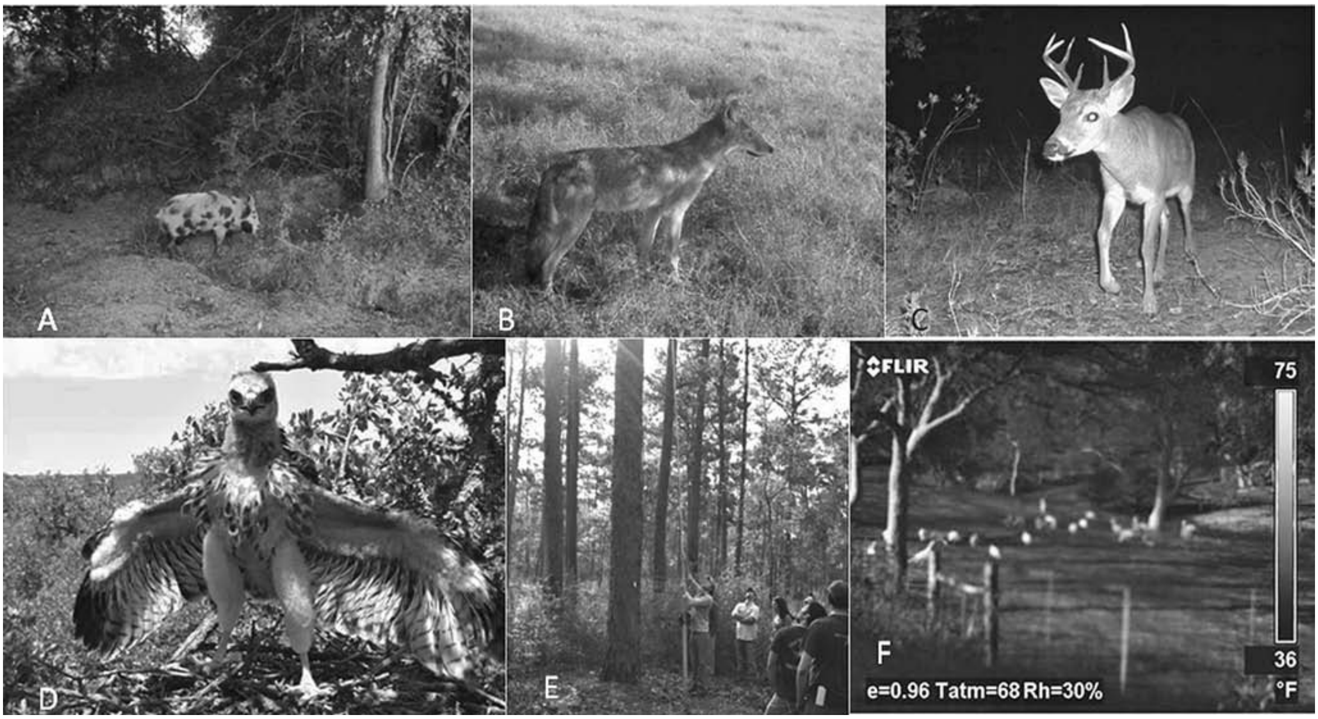

Fig. 12.1. Results from the use of cameras in wildlife research and management. (A–C) Infrared-triggered camera photos. (D) Hawk nest monitoring. (E) Using a peep camera to monitor red-cockaded woodpecker nest. (F) Thermal infrared image of Rio Grande wild turkeys foraging. *(A–C) Photos courtesy of I. Parker; (D) photo courtesy of K. Melton; (E, F) photo courtesy of S. Locke.*

use of and need for camera systems, set up the camera systems for optimal data collection, and adequately maintain the equipment. Additionally, the **effectiveness** of camera system equipment is dependent on one or more of the following: (1) battery life, (2) data storage capacity, and (3) picture quality (i.e., resolution). As technology has improved, cameras have become more efficient, more affordable, and easier to use. A brief review of each of these factors is provided here.

In general, **battery longevity** is a product of multiple factors (e.g., temperature, age, number of pictures taken, flash configuration or presence, and battery quality). These are especially salient factors for remote cameras that are left unattended in the field. Jackson et al. (2005) found that battery life for their film-based remote camera systems exceeded 3 months in the harsh winter conditions of snow leopard (*Uncia uncia*) habitats. Battery life that once limited remote cameras has significantly advanced, and current models can remain operational for up to 150 days or ≥1,000 photos using battery-saving technology. Users can opt for higher capacity batteries (e.g., NiMH or lithium), solar chargers, or additional batteries (i.e., external battery packs) to dramatically increase battery life (Brown and Gehrt 2009).

Data storage continues to improve. Relatively inexpensive storage units hold thousands of pictures and videos, with exact numbers depending on image quality and compression (Newbery and Southwell 2009). This capacity is a vast improvement over film-based cameras, which are generally limited to a maximum of 36 images before film replacement (Parker et al. 2008). Additionally, development costs and storage concerns are virtually nonexistent for digital images. Most costs are incurred during start-up in the form of equipment purchases.

Images recorded by cameras can vary in quality and size, depending on equipment specifications, thereby impacting storage capabilities and data collection opportunities from the images. Low resolution (e.g., insufficient pixel count) and videos require less storage space, but researchers must balance resolution requirements with storage capabilities. Image quality is an important consideration for real-time observation (e.g., peep cameras), data transmission via the Internet (e.g., web-based remote cameras), and infrared cameras. Researchers should determine storage and resolution requirements prior to beginning research or management activities.

It also is important to have a data management plan prior to the initiation of a camera project. Some camera companies have **data management** software that is included with purchase. Photo and video management software also can be purchased separately. However one chooses to organize camera data, it should be done such that collection and retrieval of media are quick and easy. When analyzing media from cameras, it is helpful to have a software package with image enhancement tools that allow the user to zoom in or

Table 12.1. Advantages and disadvantages of cameras in general and of remote and thermal infrared cameras specifically

Camera type	Advantages	Disadvantages
General[a]	Declining costs	Dependent on operator skill
	Miniaturization	Maintenance and repair
	Increased usability	Rapid obsolescence
	Increased build quality	Replacement expensive
	Uniform data storage	Equipment storage difficult
	Flexibility	Subject to environment
Remote	Invasiveness reduced	Dependent on human placement
	Consistent monitoring	May disrupt behavior
	Photo/video evidence	Subject to failure
	Simultaneous observation	Subject to environment
	Observer bias reduced	Maintenance and repair
	Declining costs	Vandalism
	Increasing capabilities	Limitations of photographic data
	Consistent observation in rough, inclement, or dangerous areas	
	Observe secretive or aggressive animals	
Thermal infrared	Works well in optimal conditions	Cost
	Declining costs	Detection varies among vegetation structure
	Detects spectrum outside of human vision	Animal size impacts detectability
	Increasing utility in wildlife disease study and management	Poikilothermic organisms problematic
		Seasonally dependent

[a] Single lens reflex and digital single lens reflex cameras.

adjust brightness, color, and contrast for optimal picture quality and clarity to aid in photograph interpretation.

REMOTE CAMERAS

Remote cameras are often referred to as game cameras, trail cameras, or infrared-triggered cameras and are widely available and affordable. Remote cameras can be categorized into 2 types: active infrared (AIR) and passive infrared (PIR). **Active infrared** or beam-break sensors use an infrared emitter and receiver, creating a beam of infrared light or trip line. When this beam is broken or tripped, the camera takes a picture or video of the intended target area. Currently, AIR camera systems are manufactured by TrailMaster® (Goodson & Associates, Lenexa, KS; Kays and Slauson 2008). **Passive infrared** sensors detect movement and radiation emitted by animals within a field of view (Kays and Slauson 2008). Therefore, when the sensor detects a moving object with a surface temperature different from its surroundings, the object is captured by photo and/or video (Table 12.2). Both AIR and PIR sensors have advantages and disadvantages that should be acknowledged prior to the start of a project (Table 12.3).

Occupancy and Distribution

Documenting the occupancy and distribution of species—particularly rare, endangered, or elusive species—can be difficult (Moruzzi et al. 2002). Traditional methods for documenting species presence include visual surveys, auditory surveys, track counts, scat identification, hair analysis, detection dogs, drive counts, and trapping. Watts et al. (2008) used remote cameras to document the presence and distribution of endangered Florida Key deer (*Odocoileus virginianus clavium*) on outer islands. Watts et al. (2008) suggested that cameras were a practical method for monitoring Key deer on outer islands. Long et al. (2007*b*) compared remote cameras, hair snares, and detection dogs for detecting black bears (*Ursus americanus*), fishers (*Martes pennanti*), and bobcats (*Lynx rufus*) in Vermont. Detection dogs were the most effective method for detecting the 3 carnivores, with remote cameras less effective than dogs, but more effective than hair snares. Detection dogs were more costly than the other methods on a per site basis. Remote cameras are an effective means for evaluating the presence of wildlife after a treatment, and they can be used to identify the potential for disease transmission or vaccine delivery.

Wildlife-Crossing Structures

Interactions between vehicles and wildlife pose significant problems. Wildlife–vehicle collisions represent significant physical and monetary dangers to wildlife and drivers. Wildlife–vehicle collisions also can be considered take of threatened or endangered species and thus impact road construction projects and development strategies (Lopez et al. 2003). Additionally, roadways can negatively impact wildlife movement patterns, including dispersal, migration, and corridor connectivity (Jackson 2000). One strategy for reducing such problems is construction of **wildlife-crossing structures** (e.g., overpasses, underpasses, or exclusion fencing) to reconnect areas bisected by roadways and provide safe alternative movement corridors for wildlife (Foster and Humphrey 1995, Ng et al. 2004). These structures must fit in a larger mitigation effort that generally includes exclusion fencing, speed limit alterations, and warning signs. Wildlife crossing structures also must undergo rigorous and sustained monitoring over (possibly) many years to ensure proper function (e.g., wildlife acceptance and use; Hardy et al. 2003, Braden et al. 2008). A popular method for monitoring wildlife crossing structures is remote cameras (Ford et al. 2009). Advantages of remote cameras include continuous operation, full coverage of crossing structure, and minimal intrusion by researchers. Given the extended time periods required for appropriate monitoring, remote cameras are often the preferred method for data collection. Disadvantages include risk of vandalism and natural hazards (e.g., flooding; Box 12.1).

Table 12.2. Specifications for commercially available, passive infrared remote cameras[a]

Brand	Capacity (megapixel)	Flash range (m)	Flash type	Video	Expandable memory	Delays	Sensitivity adjustment	Password protection	MSRP (US$)
BuckEye									
Apollo	0.3–3.1	15+	Both	Yes	SD	0.02–120 min	Yes	N/A	595
Orion	0.3–3.1	15+	IR	Yes	SD	0.02–120 min	Yes	N/A	999
Bushnell									
Trophy Cam	3–5	14	IR	Yes	SD	0–1 min	Yes	N/A	260
Trail Scout	2–5	14	White	Yes	SD	0.5 min	No	Yes	326
Trail Scout Pro	3–7	14	IR	Yes	SD	1 min	Yes	Yes	456
Trail Sentry	2–5	14	IR	No	SD	N/A	No	Yes	140
Camtrakker									
MK-8	1.3–3.2	N/A	Both	No	SD	Yes	N/A	No	430
Cuddeback									
Capture	3	15	White	No	SD	0.5–30 min	No	No	200
Capture IR	1.3–5.0	12	IR	No	SD	0.5–30 min	No	No	250
NoFlash	1.3–3.0	12–18	IR	Yes	CF	1–60 min	Yes	Yes	399
ExPert	3.0	18	White	Yes	CF	1–60 min	Yes	Yes	349
ExCite	2.0	12	White	No	CF	1–60 min	Yes	No	249
Leaf River									
DV-5	5.0	N/A	White	Yes	SD	1–90 min	Yes	No	300
IR-5	5.0	N/A	IR	Yes	SD	1–90 min	Yes	No	330
DV-7SS	7.0	N/A	White	Yes	SD	1–90 min	Yes	No	350
IR-7SS	7.0	N/A	IR	Yes	SD	1–90 min	Yes	No	380
Moultrie									
D-40	4.0	14	White	Yes	SD	1–60 min	N/A	No	120
M-45	4.0	15	White	Yes	SD	1–60 min	N/A	No	290
M-65	6.0	15	White	Yes	SD	1–60 min	N/A	Yes	390
I-40	4.0	15	IR	Yes	SD	1–60 min	N/A	No	216
I-45	4.0	15	IR	Yes	SD	1–60 min	N/A	No	290
I-60	6.0	15	IR	Yes	SD	1–60 min	N/A	Yes	320
I-65	6.0	15	IR	Yes	SD	1–60 min	N/A	Yes	390
Recon Outdoors									
Viper	2.1	N/A	IR	Yes	CF	N/A	N/A	No	230
Extreme	3.0	N/A	IR	Yes	CF	30 sec–60 min	Yes	No	350
Extreme	5.0	N/A	IR	Yes	CF	30 sec–60 min	Yes	No	400
Reconyx									
PC90	3.1	11	IR	Yes	CF	0–60 min	Yes	Yes	800
PC85	3.1	18	IR	Yes	CF	0–60 min	Yes	Yes	700
PM75	1.3	15	IR	Yes	CF	0–60 min	Yes	Yes	600
MC65	3.1	15	IR	Yes	CF	0–5 min	Yes	Yes	550
RC60	3.1	11	IR	Yes	CF	0–5 min	Yes	Yes	600
RC55	3.1	18	IR	Yes	CF	0–5 min	Yes	Yes	550
RC45	1.3	15	IR	Yes	CF	0–5 min	Yes	Yes	450
Stealthcam									
Prowler HD	1.3–8.0	12	IR	Yes	SD	1–59 min	No	No	310
Sniper Pro	1.3–8.0	15	White	Yes	SD	1–59 min	No	No	170
Sniper IR	1.3–5.0	9	IR	Yes	SD	1–59 min	Yes	No	230
Rouge IR	1.3–5.0	12	IR	Yes	SD	1–59 min	Yes	No	160
Nomad IR	1.3–5.0	9	IR	Yes	SD	1–59 min	No	No	180
Wildview									
EZ-Cam	1.3	9	White	No	SD	NA	N/A	No	75
Xtreme 2	2.0	9	White	Yes	SD	1–20 min	N/A	No	90
Xtreme 5	5.0	9	White	Yes	SD	1–20 min	N/A	No	150
Infrared	5.0	N/A	IR	Yes	SD	1–20 min	N/A	No	120

[a] CF = compactflash; IR = infrared; MSRP = manufacturer's suggested retail price; N/A = not available; SD = secure digital.

Table 12.3. Comparisons of active infrared and passive infrared camera systems

Feature	Active infrared	Passive infrared
Size	Two larger units (separate from camera)	One smaller unit (housed with camera)
Models	One company	Many companies
Price	Higher	Lower
Ease of use	More complicated	Simpler
Sensitivity	High (but flexible)	Medium (can be flexible)
Detection beam width	Narrow	Narrow or wide
False triggers	Usually fewer	Usually more
Sensitivity in tropical climates	Not affected by temperature	May be lower
Damage by wildlife	Highly susceptible	Lower risk

Adapted from Kays and Slauson (2008).

Disease Transmission and Vaccine Delivery

Issues of wildlife disease transmission and vaccine delivery are important, but difficult to evaluate. Intra- or inter-species disease transmission studies would benefit from increased knowledge of indirect or direct individual contact (e.g., nuzzling, fecal-oral contact, and site visitation). Vaccine delivery studies often provide vaccines to free-ranging species, but they lack direct knowledge of species visitation rates to the baits or individual bait consumption. Filling in these knowledge deficits would aid disease mitigation strategies and vaccine delivery methods, thus lowering costs and increasing effectiveness. Some of these issues can be addressed with the application of remote camera technology. Although remote cameras cannot always provide the clear evidence demonstrating transmission of disease or uptake of vaccine, they can add data critical for inference. For instance, VerCauteren et. al. (2007*a, b*) provided moment of contact pictures between farmed and wild cervids, demonstrating possible transmission routes for bovine tuberculosis and chronic wasting disease. Garnett et al. (2002) showed badger (*Taxidea taxus*) visits to feed lots, thus providing the possible bovine tuberculosis connection between domestic animals and wildlife species. Several studies (Gortázar et al. 2008, Jennelle et al. 2009) monitored cervid carcasses for possible conduits of bovine tuberculosis and chronic wasting disease transmission from dead wildlife to scavengers.

The delivery of vaccines to wildlife is often complicated by the presence of multiple species in the focal area, vaccine delivery over very large areas (e.g., air drops), and difficulty assessing success of vaccine delivery. Remote cameras are often used to monitor vaccine delivery systems for species visitation. Wolf et al. (2003) and Campbell and Long (2007) placed remote cameras on baits containing vaccines for rabies. Boulanger et al. (2006) used remote cameras to monitor the effectiveness of a new technique to dispense rabies vaccines to raccoons (*Procyon lotor*).

Estimating Abundance

Reliable **population estimates** are vital in the field of wildlife research and management (Jenkins and Marchington 1969) and require cost-effective and accurate methods (Rob-

Box 12.1. Pitfalls of camera use in wildlife research and management

1. **Security:** To avoid vandalism by humans and damage by wildlife, researchers and managers should ensure that cameras are concealed and securely attached to a solid substrate. Some manufacturers provide additional security options, such as strong boxes and digital security codes.
2. **Invertebrates:** Invertebrates are often attracted to camera housings for shelter, thus exposing researchers and managers to unexpected bites and stings. Invertebrates also can negatively impact camera electronics. Methods of addressing these concerns include sealing openings (e.g., with tape) and using insecticides or repellants.
3. **Environmental conditions:** Moisture intrusion (e.g., hurricanes or high humidity), fire (e.g., prescribed or wild), and sand intrusion (e.g., dust devils) can damage equipment and data. Camera openings should be sealed or equipment removed from the field prior to storms or fires.
4. **Camera placement:** Shadows, movement of vegetation, and sun-facing cameras are often the cause of misfires. Researchers and managers should face cameras in a northern or southern direction and trim problematic vegetation to avoid misfires.
5. **Nontarget species:** To minimize photographs of nontarget species and maximize those of target species, researchers and managers can use exclusion structures (e.g., fencing), species specific baits, nonconsumable baits (e.g., aromatic baits), or repellants. Additionally, researchers and managers can adjust the sensitivity of cameras to better capture the target species.

erts et al. 2006). Traditional methods for estimating abundance include drive counts, strip counts, line transects, removal methods, and mark–recapture techniques (Chapter 11, This Volume). The use of remote cameras for estimating abundance is based on mark–recapture techniques using Lincoln–Petersen estimators (Sweitzer et al. 2000), although there is increasing use of other techniques (Amstrup et al. 2005). Initial and/or subsequent "captures" are conducted via photographs, and individuals may be marked from initial capture or marked based on physical characteristics (e.g., branched antlers, pelage, or other visible markings or features). Remote cameras have been used to estimate abundance for white-tailed deer (*Odocoileus virginianus;* e.g., Jacobson et al. 1997, Koerth et al. 1997, Roberts et al. 2006), bighorn sheep (*Ovis canadensis;* Jaeger et al. 1991), feral hogs (*Sus scrofa;* Sweitzer et al. 2000), bears (*Ursus* spp.; Mace et al. 1994, Matthews et al. 2008), red fox (*Vulpes vulpes;* Sarmento et al. 2009), and felines (Felidae; e.g., Karanth and Nichols 1998, Heilbrun et al. 2006, Jackson et al. 2006, Dillon and Kelly 2007, Larrucea et al. 2007*a*), among other species.

Demographic and geographic closure is often difficult to attain with highly mobile, wide ranging species. Difficulties with closure can be overcome with remote cameras by using short duration surveys; timing surveys to take advantage of animal behavior; or integrating other technologies, such as radiotelemetry, into the survey. Remote camera studies often use baited stations to maximize photographic captures. Baited camera stations (i.e., convenience sampling) may violate the equal catchability assumption, thereby affecting the accuracy and precision of the estimate (White et al. 1982). Watts et al. (2008) suggested that baiting should be avoided when trying to estimate abundance or the time period when baiting was most significant should be excluded from the survey. Larrucea et al. (2007*b*) concluded that due to animal behavior, remote cameras do not always provide unbiased estimates, and camera placement is important to consider to reduce bias.

Compared to other methods of abundance estimation, remote cameras are attractive. Jacobson et al. (1997) concluded that estimates of adult white-tailed deer bucks could be reliably and accurately estimated using remote cameras, and remote cameras may at least provide managers with a minimum population estimate.

Nest Predation

Remote cameras have become a valuable tool for identifying nest predators in many wildlife studies and applications. Nest predation is an extremely influential aspect of nest survival, particularly among ground nesting birds (Rollins and Carroll 2001, Stephens et al. 2005). Traditional methods for identifying nest predators include physical evidence, such as eggshell fragments or animal sign (e.g., hair, scat, or tracks) recovered at the nest site (Major 1991, Larivière 1999). Physical evidence, however, can be subjective and time sensitive, and it also fails to account for multiple predator events or partial predation events (Leimgruber et al. 1994).

Cutler and Swann (1999) suggested that many researchers preferred remote cameras over traditional methods because photographs provided verifiable evidence of predation events, predator identification, and timing of predation. Using remote cameras, Dreibelbis et al. (2008) determined that multiple predator events were common at Rio Grande wild turkey (*Meleagris gallopavo intermedia*) nests. Little research has been conducted to determine the impact of the presence of remote cameras on nests. The increase of human activity around a nest may disrupt normal nesting patterns or attract or deter certain predators. Leimgruber et al. (1994) found that remote cameras had little impact on artificial ground nests. In contrast, Richardson et al. (2009) found that on average, camera equipment reduced nest predation rates, and they provided several recommendations to minimize the potential bias of remote cameras.

Animal Activity

Complex wildlife activity is difficult to observe and is often influenced by the presence of humans. Remote cameras provide sustained monitoring of wildlife behavior that would be impractical for human observers. Researchers and managers use remote cameras to investigate daily and seasonal **wildlife activity patterns** and use of specific resources (e.g., water sources). Larrucea and Brussard (2009) documented activity patterns of pygmy rabbits (*Brachylagus idahoensis*) and found a bimodal daily activity pattern impacted by season. Several studies have evaluated wildlife use of natural and manmade water sources in arid environments by using remote cameras (Morgart et al. 2005, Whiting et al. 2009).

Diet

Wildlife diets are often measured directly via observation or indirectly via scat analysis, prey remains, or animal harvest (i.e., stomach or crop analysis). Remote cameras offer an alternative form of direct observation with the added advantages of being able to monitor multiple sites simultaneously as well as providing photographic evidence that can be scrutinized at a later date. Franzreb and Hanula (1995) evaluated Trailmaster cameras to quantify the diet of nestling red-cockaded woodpeckers (*Picoides borealis*). Using photographs from the cameras, the researchers were able to identify 65% of the arthropods that adults brought to the nestlings.

THERMAL INFRARED CAMERAS

A limiting factor in studying mammals is observing them (Boonstra et al. 1998). Mammals often can be cryptic or nocturnal, making them difficult to see using only human vision. The use of **thermal infrared imagery** devices can aid researchers by converting the invisible infrared spectrum (0.8–14.0 μm) into a visible spectrum. Essentially, these devices convert surface temperatures of objects into an image visible to the human eye. For several decades, researchers have speculated the use of thermal infrared imagery would aid in detecting and observing mammals. Croon et al. (1968) and Graves et al. (1972) were among the first to use aerial thermal infrared imagery to detect large mammals (e.g., white-tailed deer). Both authors noted that thermal infrared imagery had great potential, but was not without significant limitations, such as the difficulty differentiating the thermal signatures of dense vegetation from wildlife.

More recently, thermal cameras have become more accessible; less costly (although cost is still a limiting factor); and smaller, making them highly portable. They have been used primarily to aid in the detection of large mammals, although several studies have evaluated their use for smaller mammals, such as wild boars (*Sus scrofa*), red foxes, European rabbits (*Oryctolagus cuniculu;* Focardi et al. 2001), and bats (Betke et al. 2008, Horn et al. 2008), as well as Rio Grande wild turkeys (Locke et al. 2006).

Thermal infrared cameras are largely thought to assist in detecting more individuals than do standard techniques, thereby improving estimates of density. However, the uses of thermal infrared cameras have expanded beyond density estimation. Infrared cameras have been used as a noninvasive method for detecting diseased mammals. Dunbar and MacCarthy (2006) were able to experimentally detect clinical signs of rabies in raccoons using this technology. Infrared cameras also were used to identify mule deer (*Odocoileus hemionus*) suspected of being infected with foot-and-mouth disease (Dunbar et al. 2009). Researchers have used infrared cameras to better understand thermoregulatory processes via thermal windows in the world's largest terrestrial animal, the African elephant (*Loxodonta africana*).

INNOVATIVE CAMERA TECHNIQUES

Improvements in component miniaturization and capability, storage capacity, build quality, and price have spurred the use of cameras (both still and video) in ecology in a variety of new directions. Cameras are increasingly common in habitat monitoring studies, Internet-based research and outreach, and evaluation of management activities.

Companies are now designing camera (both still and video) systems to answer specific questions. For example, Fuhrman Diversified (Seabrook, TX; R. Fuhrman, Fuhrman Diversified, personal communication) has designed and manufactured 850 video systems for various field, laboratory, educational, interactive, industrial, and scientific applications throughout the world. Rather than using existing cameras systems, many researchers are opting to have custom camera systems designed and manufactured to answer their specific research needs.

Camera monitoring now provides data from a variety of perspectives. Some of these cameras are becoming increasingly interactive and have the ability to disseminate real-time information to classrooms, researchers, and the general public over the Internet, with some providing the ability to tilt, pan, zoom, and otherwise control the cameras (Connolly 2007). State and federal natural resource agencies and nongovernmental conservation organizations provide **live streaming video** and photographs of a variety of wildlife species (e.g., bald eagles [*Haliaeetus leucocephalus*], grizzly bears [*Ursus arctos horribilis*], and barn owls [*Tyto alba*]).

Even as these broad-based initiatives expand the use of cameras beyond traditional wildlife monitoring, the technology continues to evolve and allows researchers to think outside the normal technological paradigm. For example, researchers have mounted cameras on remotely controlled model airplanes (Thome and Thome 2000, Jones 2003), on flexible tubing for burrow and den monitoring (VerCauteren et al. 2002), on blimps (Murden and Risenhower 2000), on floating platforms (Lopez and Silvy 1999), and on satellites (Mehner et al. 2004). Researcher innovations can serve to expand the range of observations, save money, and decrease disturbance of target wildlife species. They also are expanding observation into alternative wavelengths (e.g., infrared or ultraviolet) outside the normal visible spectrum using new types of detectors. For instance, many avian species reflect ultraviolet radiation (Keyser and Hill 1999). Without specialized equipment (i.e., spectrometer), this type of information remained unknown. Alternatives to these technologies have historically required the use of expensive fixed-wing aircraft or helicopters, loud and destructive excavations or intrusions, or the reduction of available data. Limitations inherent to emerging civilian (i.e., nonmilitary) technologies (e.g., relatively short transmission distance for radiocontrolled airplanes or high monetary cost) prevent these techniques from gaining wide use; however, researchers continue to explore these and other methodologies.

Cameras are often used to monitor wildlife when the physical presence of a human would disrupt behavior or prove impractical or dangerous. For instance, **peep cameras** (closed circuit cameras on extendable poles) are commonly used to view the interior of red-cockaded woodpecker nest cavities as the viewer stays safely on the ground (Richardson et al. 1999). These cameras obviate the need to climb the tree, thereby minimizing impacts on bird behavior and exposure of personnel to dangerous conditions. Additionally, cameras have been modified to enter burrows and in some cases are coupled with grappling devices to manipulate objects inside (VerCauteren et al. 2002).

SUMMARY

As cameras and camera equipment become less expensive, better built, increasingly capable, and more user friendly, they are more common and valuable in wildlife research and management. Cameras are a useful tool in wildlife ecology, but their usefulness depends on the quality of the study design and capabilities of the operator. Cameras are appropriate in research where: (1) humans would cause disturbance to wildlife behavior; (2) extended observational periods are required; (3) observation must take place in dangerous, inclement, or remote areas; (4) permanent and verifiable data are needed; or (5) different capabilities from those of the human eye are required. The heterogeneity of ecological research is reflected in its varied uses of cameras and continues to evolve to meet new research challenges.