FINDING MAMMALS USING FAR-INFRARED THERMAL IMAGING

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We examined the utility of far-infrared thermal imaging devices to detect and census mammals in the field. We used a Thermovision 210© to survey individuals, nests, or burrows of red squirrels (*Tamiasciurus hudsonicus*), Arctic ground squirrels (*Spermophilus parryii*), snowshoe hares (*Lepus americanus*), and meadow jumping mice (*Zapus hudsonius*). Using far-infrared thermal imaging, we successfully detected free-ranging red squirrels, snowshoe hares, and meadow jumping mice. Thermal imaging also was highly successful in determining activity at nests or burrows of Arctic ground squirrels. Far-infrared thermal imaging, however, was not useful in detecting active nests of red squirrels. These differences are largely attributable to variation among species in the insulative property of nests or fur. We review some of the limitations of far-infrared thermal imaging and conclude that it may provide a useful tool for certain ecological field studies.

Key words: Infrared thermal imaging, locating mammals, census and tracking, *Lepus americanus, Spermophilus parryii, Tamiasciurus hudsonicus, Zapus hudsonius,* Ontario, Yukon Territory

A major problem in studying mammals in the field is finding them. Trapping and marking techniques frequently are employed (Day et al., 1980; Seber, 1982); yet, these methods are time consuming and possibly disruptive. Krebs (1989) discusses problems associated with unequal catchability. Alternatively, researchers may rely on visual sightings of study animals or their sign (e.g., tracks, nests, and feces). Techniques for visual censusing, however, are severely constrained by the limits of human vision, which is restricted to objects emitting or reflecting light in the visible band (0.4–0.7 μm); this range represents only a small fraction of the total electromagnetic spectrum. Visual censusing can be enhanced, however, through the use of devices that convert the nonvisible to the visible spectrum of light.

The infrared spectrum can be divided into near- (0.8–1.2 μm) and far-infrared (3–14 μm). Until recently, only near-infrared image sensors have been used in studies of wildlife at ground level (Collins et al., 1991; Kruuk, 1978; Townsend and Risebrow, 1982). The main drawback of such systems is that they require an external light source, such as an infrared lamp, which emits light that is reflected from the subject, focused by the converter onto an infrared photocathode, and, through a series of steps, is converted to a visible image (Hill and Clayton, 1985). Because this light must be either mounted on or near the image converter, it limits the range of the converter and the viewing angle. In addition, the light requires a separate source of power to operate, increasing the weight of the system (Hill and Clayton, 1985). Nonetheless, where portability is not required, such as in the laboratory or in stationary field situations, near-infrared video equipment coupled with infrared illumination has proved useful (Hill and Clayton, 1985).

Far-infrared sensors operate in a different

manner. All objects with temperatures above absolute zero emit radiation at the far-infrared end of the spectrum, with the intensity varying with the temperature of the source (Hill and Clayton, 1985). Far-infrared sensors convert far-infrared energy into visible images by focusing thermal radiation onto an array of supercooled detectors. Each detector emits a voltage signal proportional to the temperature it perceives, and these signals then are amplified and transmitted to an array of light-emitting diodes that create a visible image (Hill and Clayton, 1985). Objects that are warmer than adjacent objects by ≥0.1°C can be detected at distances of ≤500 m.

There are two main types of far-infrared image-forming sensors that can be used in wildlife research, infrared linescanning devices and thermal imaging systems (Barrett and Curtis, 1992). Infrared linescanners have been used in studies of wildlife to census large mammals from aircraft (Croon et al., 1968; Graves et al., 1972; McCullough, 1979; Wiggers and Beckerman, 1993). Linescanners have an array of detectors that scan a series of narrow strips perpendicular to the direction of flight to build an image as the instrument is moved over a specific area. Thermal imagers, in contrast, produce images similar to those obtained by linescanners, but the sensors scan both horizontally and vertically, resulting in a higher quality image (Barrett and Curtis, 1992).

Far-infrared thermal imagers have been used extensively in industry (e.g., to detect electrically-defective computer chips and circuit boards, hot spots in electrical breaker boxes, and problem areas in distillation towers) and, in physiological studies on thermography, to detect heat differentials on the body (Klir and Heath, 1992). To our knowledge, no one has used this technology to locate animals or their sign. C. P. Reynolds et al. (in litt.), however, indicate that they used some form of thermal imaging to assess populations of red deer (*Cervus elaphus*). We test the potential utility of infrared thermal sensors in detecting mammals in the wild.

Materials and Methods

We initially considered three devices and field-tested two of these. The PyroViewer 5400 (manufactured by Electrophysics, Nutley, NJ) was inadequate for our purposes because it required continuous movement to detect thermal differentials. The Inframetrics 522L (manufactured by Inframetrics, Bedford, MA) gave a clear image, but was bulky (11 kg) and required liquid nitrogen as a coolant (newer versions, however, are thermoelectrically cooled). This was the first device we used in a field test in the Yukon Territory, Canada, in a variety of situations. We discontinued using it because it was awkward and heavy in the field. The Thermovision 210 cost $29,950 (manufactured in Sweden by Agema Infrared Systems, Danderyd, Sweden; distributors in Burlington, Ontario, Canada and in Secaucus, NJ) and was the best all-purpose device we tested.

The Thermovision 210 is portable, rugged, thermoelectrically cooled, and easy to handle. This device detects infrared radiation between 2 and 5 μm, weighs 1.5 kg, is slightly larger than a 35-mm camera, is made of aluminum casting, and delivers a thermal resolution of 0.1°C at 30°C. The recommended operating range is between −10 and 55°C; we used it at −5°C with good performance. This device has a 8° vertical by 16° horizontal field-of-view and a minimum focal range of 0.4 m, and images are seen directly on a small viewfinder. Images can be clarified through three major controls: a focus control; a brightness control; a contrast control, which can increase or decrease the contrast of the object relative to the background. A video output permits images to be viewed on a television monitor, or images can be frozen on the viewfinder and then sent to a video-camera recorder for a permanent record. The images then can be printed with a video printer. The Thermovision 210 also has the useful feature of reverse polarity so that hot images of animals or sites can be seen as either white images against a dark background or dark images against a white background. Power is supplied through nickel-cadmium 6-volt battery packs (0.85 kg each), each of which lasts ca. 4 h when charged.

We conducted two series of field tests. The first was designed to detect animals or their sign

under a range of conditions. In the Kluane Lake area of the southern Yukon, we tried to locate red squirrels (*Tamiasciurus hudsonicus*) and their active nests, and adult and immature snowshoe hares (*Lepus americanus*) in dense spruce (*Picea glauca*) woods. In southern Ontario north of Toronto, we located free-ranging and nesting meadow jumping mice (*Zapus hudsonius*).

The second series of field tests was designed to obtain a rapid, relative index of density of Arctic ground squirrels (*Spermophilus parryii*) by determining whether active burrows emitted higher thermal profiles than inactive burrows and by correlating thermal profiles with the known presence or absence of squirrels in these burrows. All burrows of Arctic ground squirrels in a 20- by 400-m strip were located and flagged with surveyors' flags. At 0700 h on 14 May 1992, a thermal image of each burrow was obtained to determine whether the burrow entrance was significantly warmer than the adjacent ground. A recent snowfall covered most of the ground to a depth of 5 cm. Each burrow was ranked as hot, indicating a uniform white image against a dark background, or cool, indicating an image that differed little from the background or had no uniform white glow. To assess independently whether each burrow was occupied, a black tile (5 by 11 cm) covered with white talcum powder was placed at each burrow for 8 h and then examined for squirrel tracks (Boonstra et al., 1992). A burrow with three or more tracks was regarded as active, whereas a burrow with less than three tracks indicated that a squirrel had visited the burrow, but was not occupying it as a residence.

RESULTS

Red squirrels make dense nests of dry grass in white spruce trees in the southern Yukon and use these both as sites in which to raise their young and spend their inactive period in winter and summer (pers. obser.). A number of such nests occur in the territory of each red squirrel (pers. obser.). We used the Thermovision 210 in two ways to sample this species. First, we assessed whether the device could be used to determine which nest was currently being used. In the early morning (0500–0600 h), we examined 20 nests known to be active. In two instances, there was a glow detected from the nest entrance, and in both cases a squirrel had recently left the nest (i.e., we saw it leave). Second, we scanned the trees ahead of us with the device to locate squirrels that were not visible to the unaided eye. All known squirrels not in nests and moving about the spruce were easily located up to 15–20 m away. We saw no squirrels that were not previously detected with the device.

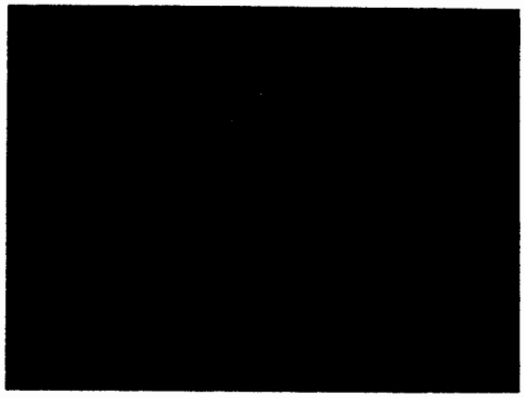

FIG. 1.—Thermal image of a snowshoe hare in the southern Yukon (the image was frozen on the viewfinder of the thermal-imaging camera and then sent to a video-camera recorder). The dark lines across the back and head of the hare are willow branches between the hare and the thermal-imaging camera.

Young snowshoe hares are extremely difficult to find because their fur camouflages them well against the floor of the boreal forest. Pens were constructed in the field in which female hares had litters (O'Donoghue and Krebs, 1992). We examined young in three pens, and all emitted enough infrared radiation that they could be easily detected from 35 to 40 m. We also tested the device on free-ranging adult hares. Hares appeared as glowing silhouettes when 20 m away (Fig. 1), but were less distinct from a distance of 40 m. Direct line-of-sight was necessary as dense undergrowth could block the image. As long as part of the body could be detected by the scanner, however, we saw a glow on the screen.

Four meadow jumping mice had been radiocollared, and we knew their general locations. At 0530 h on 12 June 1993 after a night of heavy rain, we located all four mice readily, either in or outside the nest. The rain maximized the thermal differential between mice and grass, so that the mice appeared as intensely-glowing objects. The grass, however, was 30–60 cm high, and the mice could be detected only within 2 m before the cover obscured them.

There was a significant association of "hot" burrows of ground squirrels with high activity on powder boards (Fisher's exact test: $P < 0.002$, $n = 24$ burrows; number of burrows active and "hot" = 12, inactive and "hot" = 3, active and "cold" = 1, and inactive and "cold" = 8). Burrows with only one or two tracks had clearly been visited during the day, but the burrow was not occupied and thus was cool.

Discussion

The far-infrared thermal-imaging devices that we tested hold potential for use in locating animals or their active nests or burrows. These devices will be most useful in situations where burrows or nests have been located previously and where the primary objective is to determine whether that site is currently active. The devices also may be useful to census free-ranging individuals, providing that vegetation or other structures that might shield the animal are minimal. For example, far-infrared thermal sensors are of use in censusing large mammals from aircraft provided the device is mounted outside the body of the aircraft and animals are not beneath obscuring vegetation (Wiggers and Beckerman, 1993).

Far-infrared thermal sensors offer several potential benefits over other forms of visual censusing. Thermal imaging allows investigators to detect and census individuals even when the animal is virtually invisible to humans. In some instances (e.g., Arctic ground squirrels), this can be extended to include an assessment of the activity of a study animal when that animal is not physically present during a census. In our study on Arctic ground squirrels, however, the estimates of use may have been biased, because burrows often have multiple entrances. For example, in one burrow system with three entrances, the hottest burrow had no tracks, whereas both of the others had numerous tracks but little heat. We interpret this to indicate that the "hot" burrow was a natural vent for this burrow system because of the shape of the burrow system and proximity to the nest cavity. Thermal censusing is nondisruptive and does not require capture or marking of the study animal. Surveys can be completed at some distance, providing the opportunity for more remote forms of censusing (e.g., aerial surveys—McCullough et al., 1969; Wiggers and Beckerman, 1993; C. P. Reynolds et al., in litt.). With more sophisticated versions of the Agema Thermovision series (e.g., Thermovision 450), it is possible to obtain surface temperature of animals directly and, thus, possibly to discriminate among species based on surface temperature. Among large mammals where this has been tried (McCullough et al., 1969), both pelage characteristics and surface temperatures were similar for a variety of species, and, thus, the method was not able to provide good separation among the species. Finally, with experience, it may be possible to determine age, sex, and species on ungulates under optimum conditions. Wiggers and Beckerman (1993) report that, with an aerially-mounted forward-looking thermal scanner, an experienced operator was able to correctly identify sex and age of white-tailed deer (*Odocoileus virginianus*) 100% of the time in August, and biologists using this device were correct >75% of the time. Species identification was highest (93%) when the flight altitudes were between 271 and 370 m.

There are, however, a number of limitations of thermal-imaging devices. First, far-infrared thermal sensors can be used optimally only at certain times of the day or under certain weather conditions. Because

detection of either the animal or heat emanating from an active nest or burrow site relies on a thermal differential to ambient temperature, the best time to maximize this differential is during the early morning when the heat from the previous day has largely dissipated and the sun has not yet heated the ground or vegetation. Thereafter, it becomes increasingly difficult to distinguish between hot spots caused by solar heat and those caused by animals. A thermal differential also can be maintained by working on overcast days, after rains, or in winter when snow cover is present. McCullough et al. (1969) reached similar conclusions for use of an infrared device for aerial censusing.

Second, it may be difficult to detect some animals or their active nests (e.g., nests of red squirrels) because their fur or nests have high insulative properties that minimize heat loss and, thus, the thermal differential between them and their environment. For instance, Stirling (1988) reported seeing an infrared photograph of a polar bear. The animal was not detectable in the photograph, although a bright spot in front of the bear made by its breath was visible.

Third, a number of objects can absorb and radiate infrared radiation, even when ambient temperatures are low. These random hot spots readily mask active sites and severely limit the utility of thermal sensors as a tool to detect new nest sites or activity centers. McCullough (1979) reported that in aerial census of a herd of white-tailed deer at the George Reserve, Michigan, the infrared linescanner overestimated the actual population by 20%; the additional hot spots were produced by something else, such as recent beds of deer. C. P. Reynolds et al. (in litt.) reported that counts of red deer were overestimated by 6–12% on one area, but were similar on another.

Fourth, infrared radiation does not penetrate vegetation well, and, thus, a clear line-of-sight between the imager and the animal is necessary. Tree cover (both deciduous and evergreen) and herbaceous cover can prevent or limit animal detection (McCullough et al., 1969, pers. obser.). Finally, far-infrared thermal imaging devices are expensive. Unless they are shared among numerous researchers for a variety of applications, it may be difficult to justify their cost.

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