

FACTORS AFFECTING ANIMAL DETECTION AND IDENTIFICATION
BY REMOTE SENSING: WITH SPECIAL REFERENCE
TO THERMAL INFRARED SENSORS

by

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ABSTRACT: Factors affecting animal detection and identification by remote sensing are compiled and described. Habitat preference and animal behavior are shown to be the variables that most influence detection and identification. An analysis of the basis of application of thermal infrared sensors to animal detection covering the principles of infrared radiation and animal physiology follows. Reviews of case studies in thermal infrared detection of various animal species are presented. The results are highly variable, and it is clear, due to the many physical variables involved, that the technique needs to be evaluated on a site-specific basis.

The intent of this paper is to identify and describe factors affecting the detection of animals using remote sensing techniques, and to analyze the relationship between the use of thermal infrared sensors for animal studies and these detectability factors. The first section will cover five main areas of variables that influence animal detectability including morphology, distribution, behavior, environment, and mission-planning considerations. The second section will involve an evaluation of the application of thermal infrared sensing to animal detection, with a presentation of this application's conceptual basis and a review and analysis of specific case studies. In closing, the

third section will present the author's views on the advances and obstacles to the development of the technique, as well as current research needs.

DETECTABILITY AND IDENTIFICATION FACTORS

When considering remote sensing applications with a variety of objectives, most researchers feel that spatial resolution is the most important parameter. Although this may be true for certain applications, when one is attempting to image animal groups while intending to enumerate them, detection and identification take on greater importance than resolution alone. Rosenberg (1971) defines these terms as follows:¹

Detectability is the ability of a system to detect the presence or absence of a signal.

Resolution is the ability of a system to distinguish between signals that are close to each other spatially, temporally, or spectrally.

Recognizability is the ability of a system to recognize or identify a signal.

If one accepts these definitions, it appears obvious that although resolution is important, failure of a system to detect or "recognize" an animal on a systematic basis would introduce a much greater error into an animal survey.

Using the above definitions as the basis for argument, factors affecting detection and identification will receive greater coverage than system resolution in the following discussion.

Animal Morphology

Important considerations regarding animal morphology include size and color. Size of the target animal influences both detection and differentiation of species, while color can be useful for both detection and identification of the target species.² Color of the animal conditions the ability of the system to differentiate between the animal and its background.

Distribution Patterns

The individual orientation of an animal influences its detection in the following ways: If a photographic system is used, the animal's position with respect to the incident angle of the sun's radiation can cause it to be highlighted or obscured. The formation of shadows can either aid the identification of animals or obscure a portion of the group, e.g., offspring in their parent's shadow. When using a line scanner, the detectability of an animal is enhanced if its long axis is perpendicular to the sweep direction of the scanner.³

Group orientation and shape also influence detection and identification. Watson and Scott (1956) indicated that the results of their aerial census of caribou in Alaska were negatively influenced by the uneven distribution of caribou in the study area.⁴ Graham and Bell (1969) felt that groups of animals in lines are more easily identified than those in circles, and that uniform distributions of groups was preferred.⁵ Species association can be another aid to detection and identification of animals, as species interactions are easily determined from the ground beforehand.⁶

Animal Behavior

When attempting a survey of an animal species with a remote sensing system, it is essential to be thoroughly familiar with the subject's life history characteristics and behavior. In this way, the optimal season and time of day can be selected for a given objective, whether it be total enumeration, annual production, or habitat relationships. The following will be a discussion of these characteristics, illustrated with examples from studies of elk (Cervus canadensis) research.

Habitat selection. This animal characteristic is the most important consideration in a remote sensing survey of animals. The type of habitat a particular species chooses directly conditions its detectability, which, with sensors currently employed, is a direct function of vegetation type, height, and density.⁷ Seasonal or daily variation in "preference" can also aid or hinder a survey.

Life history characteristics. This aspect of animal behavior, which consists of seasonal and daily variations, is the best indicator of the optimal season and time of day to attempt an animal survey. Components of these variations are breeding and migratory activities, and feeding and bedding activities, respectively.

Taking a sample of current elk research, one can present an example that will show the influence of animal behavior on detection and identification. Current elk research has shown "significant differences in use of habitat types by month, sex, and age."⁸ Breeding behavior causes cows to move from more open habitat into the denser timber; likewise, weather conditions may cause all to seek thermal cover. Both of these are seasonal phenomena that determine when to conduct a survey.

There can be different uses of specific habitats by age, where yearlings are shown to have predominant use of clearcuts over adults. Research also indicates that there are differences in activities and use of specific habitats during the 24 hour period. For example, elk have been shown to feed at early morning and early evening periods in clearcuts.⁹ Thus, one might attempt a survey when the animals are feeding, since they may be hidden by vegetation at other times of the day.

Environmental Factors

The environment plays a major role in influencing the detection of animal species. LeResche and Rausch's (1974) results suggest:¹⁰

Proportions of moose seen may be affected nearly 50 percent by terrain and habitat differences, even in relatively similar areas.

Other environmental factors include: weather conditions such as turbulence, cloud cover, and precipitation; the background "quality," i.e., uniform snow cover, vegetative cover, or physiography. Illumination has a restricting influence on detection as alluded to earlier, with the effects of shadowing, highlighting, or sun angle on contrast.

Mission-planning Considerations

There are a number of considerations involved in mission-planning, the operational aspects of a remote sensing survey. One of these is the time available in the air to conduct a survey. Research indicates that this factor has a major influence on the accuracy of aerial counts, although it is less of a problem with a remote sensing system that produces an image.¹¹ Disturbance by the aircraft can be a two-sided

factor. In some situations where animals are tightly bunched in a group, it may be beneficial to cause them to spread out. However, this "spreading out" can cause some animals to be obscured or missed. The aircraft speed, along with animal density has been determined to influence the rate at which animals can be distinguished. This factor also specifies the interval between aerial photographic frames and the amount of overlap between successive scans of a line scanner.¹² One of the most common methods of censusing animals from the air involves flying a series of successive lines or transects. Gasaway (1978) has identified two operational problems with the transect method: the transect width is difficult to set, and the number of unseen animals is not known since the quantity varies with habitat.¹³ Two additional operational problems that are sources of bias are variations in altitude and navigation. Variations in altitude, caused by pilot error or extreme topographic relief, lead to a non-uniform distance from sensor to subject, which in turn influences the ability of the interpreter to detect and identify a given object. Navigational variables as identified by Wartzok and Ray (1975) include "height, bank, heading, and drift," which cause changes in the transect width, viewing angle, total sample area (which can become larger or smaller as a function of altitude), and transect overlap.¹⁴

The type of sensor employed in an animal survey is another consideration in mission-planning. The two sensors commonly used in animal studies today are the aerial camera and the thermal infrared scanner (there is some work in radar, but it has rather limited applications at this point). The design and resolution of the sensors

are important in determining the aircraft altitude and speed that will maximize detection and identification of the animal species being studied. The limitations of the system used are important in survey design; for example, aerial cameras are largely limited to the visible and near-infrared wavelengths of the electromagnetic spectrum, while thermal sensors are sensitive to the middle and far infrared wavelengths. Further examples of the operational limitations of these sensors include the inability to penetrate green foliage, clouds or fog, as well as problems associated with day and night sensing.

EVALUATION OF THERMAL INFRARED SENSORS RELATIVE TO DETECTION CRITERIA

The Application of Thermal Infrared Sensing to Animal Detection

Thermal infrared energy falls between the wavelengths of approximately 3 μm and 1000 μm . in the electromagnetic spectrum. It can be described as the product of, for any given object, the fourth power of its absolute temperature ($^{\circ}\text{K}$), its emissivity, and the Stefan-Boltzman constant.

The absolute temperature of an object is the result of the interaction of many variables, both internal and external. Included among the internal variables are: the object's heat capacity and thermal conductivity, its surface to volume ratio, its moisture content, and, specifically with living organisms, its metabolism. The external variables include topography, elevation, and atmospheric conditions such as percent cloud cover, precipitation, wind speed, relative humidity, and air temperature.

The emissivity of an object can be defined as:¹⁵

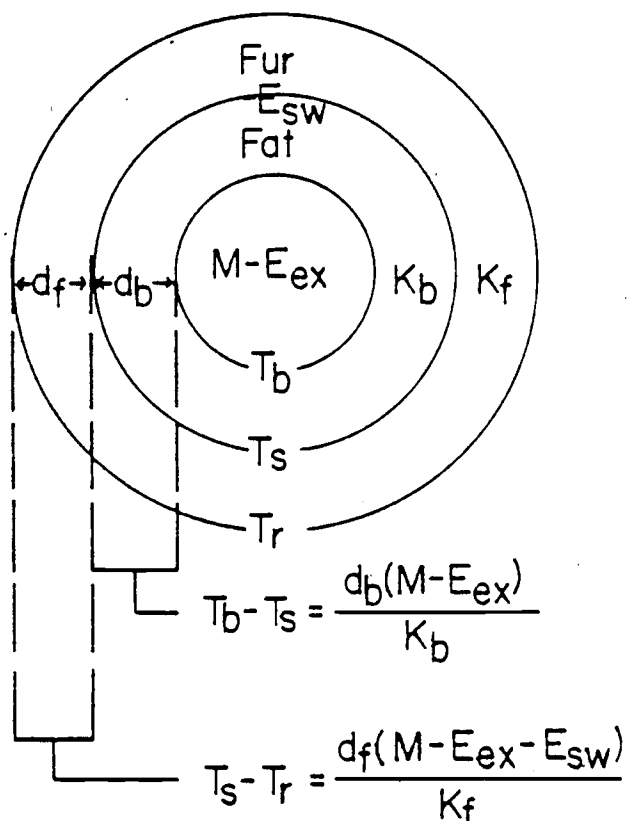
A ratio relating the amount of energy given off by an object to the amount given off by a "blackbody" at the same temperature, and normally expressed as a real positive number between 0 and 1.

The basis for applying thermal infrared sensing to animal detection is to distinguish between the animal being sensed and the physical background through the detection of temperature differences. These differences are in terms of apparent radiant temperature, i.e., the product of the interaction between the animal's emissivity and absolute temperature.

The emissivity of an animal is important in terms of detection, since it directly influences the quantity and quality of radiant heat generated. The closer to the theoretical blackbody value of 1.00, the greater its radiant heat loss and thus its detectability by a thermal sensor. Hammel (1956) established that the emissivity of mammals is approximately 0.98-1.00. He derived these values from radiometric analyses of ten species of arctic fauna.¹⁶ Thus, it can be safely assumed that, theoretically, mammals tend to absorb and emit energy at all wavelengths equally. The importance of this factor is that potentially all infrared energy absorbed by an animal is then emitted and can be detected by a thermal infrared sensor. The radiant energy that this sensor detects, however, is a function of both emissivity and absolute temperature. The sensor actually detects the apparent radiant temperature or heat loss of the animal.

Moen (1968) identifies the four sources of heat loss for animals as conduction, convection, evaporation, and radiation.¹⁷ The significance

of conduction can easily be seen if one thinks of the animal as a collection of concentric circles (Gates, 1969). The energy reaching the surface fur or feather layers of an animal is a function of the thickness and conductance of the fat layers surrounding the body cavity, which is the source of metabolic energy.¹⁸ A schematic of this model is presented in Figure 2-1. Heat transfer is a function of conductance just below the fur layer where it is conducted through the fur along individual fibers, and through air and water vapor trapped in the fur. An influence on heat transfer at this point is natural and forced convection of the air pervading the fur layer, i.e., wind speed.¹⁹ In other words, as wind speed increases, heat loss by convection increases. Evaporation is another avenue of heat loss for animals, with moisture being lost through respiration and perspiration. Essentially, the radiant temperature or heat loss of an animal is the subtraction of conduction, convection, and evaporation from the initial amount of energy generated by the animal's metabolism. The detection of the radiant heat loss is the object of a thermal infrared survey. Research by Kelly (1954), Moen (1968), and Marble (1967) has shown that this quantity increases with decreasing air temperatures as long as the wind speed is minimal; but it is truly dictated by the collective weather conditions, including solar radiation, relative humidity, precipitation, cloud cover, air temperature, and wind speed.²⁰ Based on extensive radiometric measurements and since animal radiant temperatures are relatively stable and generally above background temperatures, Marble (1967) has concluded that the best combination of weather conditions to attempt thermal infrared sensing of animals are: a snow background, overcast sky, low relative humidity, and no wind.²¹



Schematic diagram of concentric cylinder model of animal for heat transfer considerations. The body cavity at temperature T_b is where the metabolic energy M is generated, surrounded by fat of conductivity K_b , thickness d_b terminating at the skin at temperature T_s , and which may be surrounded by fur or feathers of conductivity K_f , thickness d_f terminating at an external surface at temperature T_r . Respiratory loss of moisture is E_{ex} from the body cavity and sweating at a rate E_{sw} occurs from the skin.

Figure 2-1 -- Concentric Cylinder Model

Source: D.M. Gates, "Infrared Measurement of Plant and Animal Surface Temperature and Their Interpretation," in P.L. Johnson, ed., Remote Sensing in Ecology (Athens: University of Georgia Press, 1969), pp. 95-107; p. 97.

The peak intensity of infrared radiation emitted by animals and humans is approximately 10.5 u, assuming an absolute temperature of 300°K.²² This enables the use of thermal infrared sensors to detect animals, as there is a "window" in the atmosphere from 8-14 u, indicated in Figure 2-2. The term "window" is used to describe a range of wavelengths within which, in this case, infrared energy, can be transmitted with little influence from the attenuating components of the atmosphere, such as water vapor, carbon dioxide, or dust particles. The capabilities of thermal infrared are such that at these wavelengths (8-14 u), imagery can be generated during day or night hours, improving the chances of detecting both diurnal and nocturnal species.

General Design Description of a Commonly Used Thermal Infrared Sensor

The most common type of sensor used in this application is generally referred to as a "line scanner," which employs a mirror system, rotating on a shaft and focusing the energy received onto a detector. Two common detectors are the InSb detector (3-5 u) and the MCT detector (8-14 u). The detector produces an electrical signal which is then amplified and displayed on a CRT. Usually, as this signal is in the form of a voltage, it may also activate a light source (LED) to produce a photographic product or be recorded on magnetic tape for later computer processing and enhancement. An example of a typical thermal infrared scanner is shown in Figure 2-3.

An example of the imaging technique of a line scanner is illustrated in Figure 2-4. Basically, as the aircraft flies over an area, the rotating sensor records phenomena in strips, which cover the area from side to side and are perpendicular to the flight path of the aircraft. The width of the strips is a function of the aperture of the

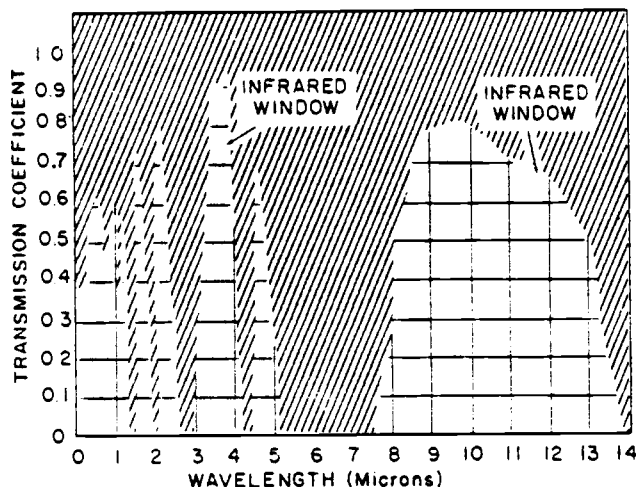


Figure 2-2 -- Atmospheric "Window" for Infrared Energy
Source: D.E. Thackerey, "Research in Infrared Sensing,"
 in R.K. Holtz, ed., The Surveillant Science: Remote Sensing
Of The Environment (Boston:Houghton Mifflin Co.,1973).

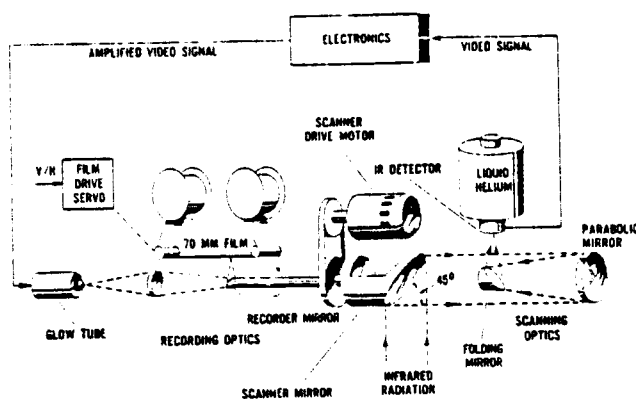


Figure 2-3 -- "A Typical Thermal Infrared Scanner"
Source: J.I. Taylor and R.W. Stingelin, "Infrared Imaging
 for Water Resource Studies," in R.K. Holtz, ed., The
Surveillant Science: Remote Sensing of the Environment
 (Boston:Houghton Mifflin Co.,1973).

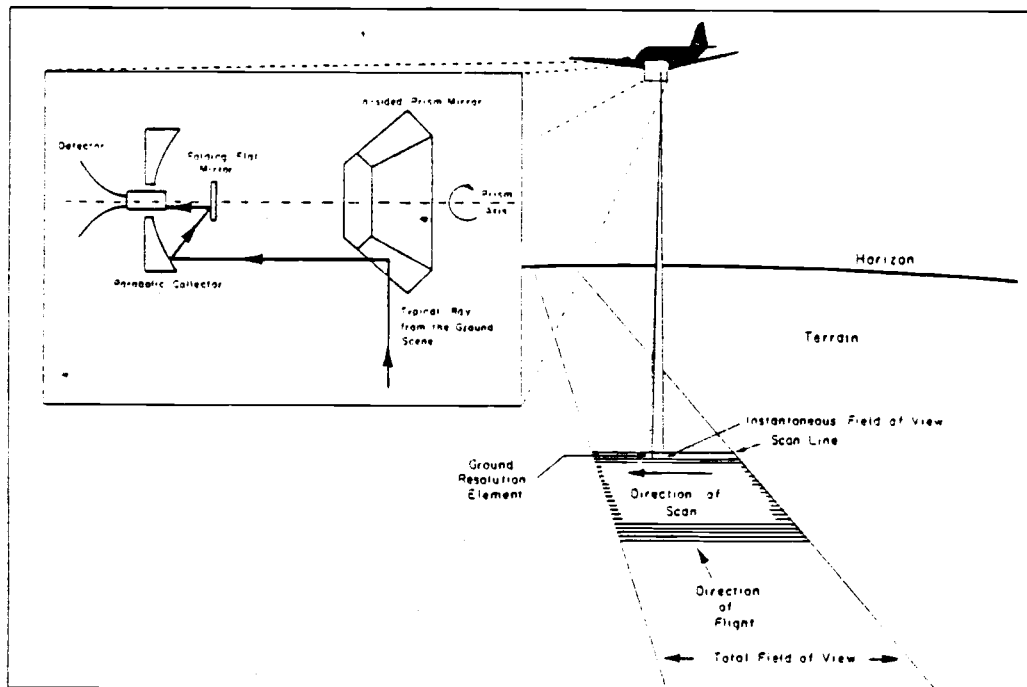


Figure 2-4 -"The Line Scan Technique and Principle"

Source: J.E. Estes and L.W. Senger, eds., Remote Sensing; Techniques for Environmental Analysis (Santa Barbara, Ca.: Hamilton Publ. Co., 1974).

sensor and the altitude of the aircraft, while the length of the strips are a function of the angular sweep of the sensor and once again, the altitude of the aircraft. The ground surface area that is imaged at any one instant is known as the instantaneous field of view (IFV). A typical IFV for thermal scanners is equivalent to three milliradians (a milliradian is one one-thousandth of a radian, which is a form of angle measurement equivalent to 57.3 degrees), or approximately three feet across for every thousand feet in altitude. As for temperature sensitivity, this parameter ranges from 2.0°C to 0.1°C depending upon the model and manufacturer.

It would be valuable at this point to analyze the relationship between resolution and sensitivity of a thermal infrared sensor. Parker (1972) and others have shown that there is an inverse relationship between resolution and temperature sensitivity.²³ The IFV can be considered a cell on the ground over which the emittance of all objects in the cell are averaged, and thus detected by the sensor. If the cell size is decreased, in order to increase spatial resolution, those objects with larger surface areas will contribute proportionally greater amounts of energy to the average emittance. This could result in rocks, tree falls, or vegetation appearing warmer on a thermal image than a given animal, even though their apparent radiant temperatures are lower. Another aspect of decreasing the IFV, is the production of a surface temperature threshold, below which an object of a given temperature cannot be detected, regardless of the temperature differential. It is for these reasons that an IFV of 2-3 milliradians is presently the most effective choice, and the altitude range of the aircraft is severely restricted.

Review and Analysis of Published Applications and Case Studies

This review will consist of published experiments using thermal infrared sensors, arranged chronologically from earliest to most recent.

Garvin, et. al., 1964.²⁴ This application was planned and carried out by military personnel from the Rome Air Development Center, Rome, New York. The actual survey took place on February 3-5 with a series of four different flights at altitudes ranging from 200 to 2,000 feet. The study area was Isle Royale, Michigan and the subject was the moose (Alces alces). The only imagery obtained was during the winter period at approximately noon on February 5, 1964. The habitat type included dense stands of spruce and balsam, scattered stands of birch, aspen, and willow, with a dense understory. All but one of the flights yielded poor imagery. The climatic conditions at the time of the flight were clear with high scattered clouds, light winds, and an air temperature of approximately 1°C.

The results of the study reflect the difficulty in attempting to detect animals under a dense overstory. Other problems were created by tree falls and rocks appearing similar on the imagery to a moose signature. The authors concluded that moose could be detected from altitudes ranging up to 1000 feet if simultaneous photography were obtained, or below 500 feet without photography. They felt that night flights would permit easier detection of moose, due to rapid cooling of the background.

Croon, 1967; Croon, et. al., 1968.²⁵ These reports present the methodology and results of an infrared study by personnel of the Infrared Physics Lab, University of Michigan. The study was conducted

on the E. S. George Reserve, a two-square mile natural area in Michigan consisting primarily of mixed hardwood and grassland habitat. One overflight was attempted on January 4th at 12:30 p.m., with a high overcast sky, an air temperature of -4°C , and a 6-8 inch snow cover. The subject of the study was the white-tailed deer (Odocoileus virginianus).

The results consisted of 93 positive deer identifications and 5 probable, out of a drive census estimate of 101 animals. Radiometric measurements on the ground indicated a 7°C temperature differential between the deer and the colder snow background. Problems encountered included difficulty in detecting deer under a coniferous canopy, and distinguishing between animals of similar size.

On the face of it, this study was highly successful, in that almost 97% accuracy was achieved in the survey, and as a result it ranked as the earliest successful application of this technique for quite some time. Conflicting results have recently been published offering a different estimate of the total population on the Reserve at that time. These results will be discussed following the next review, which involves a continuation of the Croon, et. al. (1968) study.

McCullough, et. al., 1969.²⁶ This study is a continuation of that reviewed above, with investigations of different wavelength ranges. The study area was the George Reserve, and the white-tailed deer was again the object of study. Two separate overflights were conducted, one in late November and one in mid-January, with clear and cold conditions, little wind, and 3-4 inches of snow on the ground.²⁷

The effects of filtering the thermal sensor at 3.5-14 μ and 3.5-5.5 μ were tested on the overflights. Although 12 deer were staked at known locations, none of the deer were detected, but two horses were detected adjacent to the Reserve. The failure to detect deer can be attributed to the wavelengths selected for by using the filters. In the range of wavelengths used there is a great amount of background noise introduced primarily by incident solar radiation, which can degrade the imagery or reduce the temperature differentials detected by the thermal sensor. Another negative influence on the results may have derived from locating the test deer underneath a vegetative canopy, which would prevent the transmission of radiant energy.

The results of the previous study (Croon, et. al., 1968) were also reviewed by McCullough (1969). Of note is a recent publication by McCullough which modifies the results of the previous study. Apparently the drive census estimates at the time of the overflight were incorrect; rather than 101 deer being present, the new estimate is 82 deer. This estimate is derived from a "population reconstruction" technique, which is based on the collection and age analysis of all deer jaws. Assuming a maximum life span for the deer in the Reserve, an estimate of past population totals is derived from the age analysis of the jaws.²⁸ If the latest estimate is correct, counts from the infrared imagery yielded excesses from 11-16 deer in the interpretation. McCullough concluded, after a somewhat obscure mathematical explanation, that "apparently hot spots on the imagery were produced by objects other than deer."²⁹

Brooks, 1970.³⁰ A study conducted by personnel of the U.S. Bureau of Sport Fisheries and Wildlife on the polar bear (Thalarctos maritimus) of the Chukchi Sea ice pack in northwest Alaska was flown at midday on April 5, 1970. The sky was clear, with a north wind of 5 knots, 1.5 inches of snow, and an air temperature of approximately -20°C. The altitude of the aircraft was 500 feet, with two detectors being used, filtered to 8-14 u and 1.5-5 u.

The results indicated that the method needed further testing, although it may be superior to any other currently employed technique to detect polar bear. The actual bear was not detected, but imagery did show its trail. This can be a useful surrogate measure because bear almost always move on the ice when aircraft fly overhead. The bear trails were detected with the 8-14 u detector, while the 1.5-5.0 u detector yielded poor results that may have been due to the aircraft's exhaust. The overall conclusion was that "it is probable that most or all bears in the area being scanned would be detected under conditions that existed during these tests."³¹

Ables, et. al., 1970.³² Personnel of the Remote Sensing Center, Texas A&M University conducted a series of tests on the applicability of thermal detection of animals. The test sites were in southwest Texas (Sonora) in a grassland habitat interspersed with groves of live oak and cedar. The overflights took place on January 29, 1970 from 3:00 to 6:00 a.m., with air temperatures ranging from 4.5-5.5°C, and winds gusting to 25 mph. Animals present in the area included goats, sheep, cattle, horses, deer, javelina, and coyote.

The results were negative, with no animals detectable on the imagery.

The authors concluded:³³

the sudden decrease in air temperature and related winds cooled the animals to the extent that their surface hair temperature approached that of the background terrain thus causing the the temperatures to be less than the detection capability of the sensor.

Seemingly, an increase in wind speed, not air temperature, lowered the animal's apparent radiant temperature, since this would increase heat loss by convection.

Parker, 1972.³⁴ This study consisted of two phases: (1) a preliminary test conducted at Fort Collins; and (2) a more extensive test at Middle Park, Colorado. Parker conducted the first test near the Colorado State Campus in "typical" deer habitat consisting of big sage, shrubs, grasses, and forbs, with no tree overstory. The subjects included mule deer (Odocoileus hemionus) and pronghorn antelope (Antilocapra americana). Three overflights were accomplished at altitudes of 300, 500, and 1000 feet, on August 20, 1971 between 4:00 and 4:30 a.m. Environmental conditions included a 13°C air temperature, mostly cloudy sky, approximately 100% relative humidity, and little to no wind.

The results indicated that animals were detected at altitudes of 300 and 500 feet, but were undetectable at 1000 feet.³⁵ Trial interpretations, performed by persons unfamiliar with the imagery, yielded good results, i.e., 64-65 animals were identified where 66 animals were present. Attempts to separate species based on tonal differences were less successful. Parker attributes the failure of the scanner in detecting animals at 1000 feet as due to poor system resolution (2.5 milliradians).

Overall, he felt that thermal infrared detection of animals is a viable technique, and that greater thermal contrasts may occur in the summer rather than in the winter. This conclusion is contrary to the results of all other studies, except that of Graves, et. al. (1972) which will be reviewed below.³⁶

Driscoll and Gill, 1972.³⁷ These authors tested the capabilities of a thermal scanner to estimate densities of live and dead deer in Middle Park, Colorado. The habitat consisted of Douglas-fir, big sage, juniper, and aspen, and the subjects were deer and antelope. The overflights occurred on January 25-27, 1972 between the hours of 7:00 and 8:00 am. Weather conditions consisted of approximately 90% cloud cover, -5.0 to -6.0°C air temperature, and winds gusting from 10 to 20 miles per hour.

The results indicated limited success due to the failure of the simultaneous aerial photography, that was to serve as a control for the identification and location of the animals. The only positive identifications were those deer seen from the aircraft and noted on the imagery. It is significant that this was one of the first studies to report imaging elk, even though it was only a chance encounter.

Graves, et. al., 1972.³⁸ Tests were performed by researchers from Pennsylvania State University and H.R.B.-Singer, Inc. in Centre County, Pennsylvania. The habitat consisted of a mixed hardwood-conifer overstory interspersed with open shrubland and pasture. The first test involved one overflight in August, 1963, in an attempt to detect cattle with an InSb detector sensitive to the 3-5 μ range. No climate conditions were given. The second test occurred on November 24 and 25,

1969, during the afternoon, evening, and early morning. Deer were the object of the survey, and altitudes of the aircraft ranged from 100 to 500 feet. Climatic conditions included an air temperature between -6.5 to -3.8°C , an easterly wind at nine knots, no cloud cover, and a heavy ground frost. Both the InSb detector and an MCT detector (3-14 μ) were used.

The results for the first test found cattle readily detectable at 1000 feet, and night imagery far better than daytime imagery. The lower quality of daytime imagery illustrates the effects of increased background noise generated by solar radiation. The second test showed better results from the MCT detector, but it was felt that "deer did not image nearly as well as during our summer flights."³⁹ These findings were thought to be a function of the thickness of the deer's fur, because a winter coat is thought to retard radiant heat loss from the animal while a summer coat is thought to aid in heat loss for cooling purposes.

The overall conclusions of Graves, et. al. (1969) generally disagree with those of the other tests reported, except for an implication by Parker (1972). Moen (1968) showed that as air temperatures decrease, the temperature differential between a deer and snow background increases.⁴⁰ This evidence tends to contradict the conclusions of the above authors regarding the optimum time of year to detect deer.

Goldberg, 1977.⁴¹ This study took place near Hyrum, Utah, in a habitat consisting of an overstory of juniper mixed with river birch, bigtooth maple and western red cedar, and an understory of big sage. Animal species included elk and mule deer. Four overflights were made

at altitudes of 1000 and 1500 feet on February 6, 1975, starting at 8:00 a.m. Animal numbers and locations were estimated on the ground using a variation of the strip census to act as a control for the imagery. An 8.5-11.0 u detector was used in the sensor. Weather conditions at the time of overflight included 84% humidity, a five mph wind, an air temperature of approximately 0.8°C , and a 100% cloud cover.

No deer were detected on the resultant imagery at either altitude. Elk were detected at both altitudes and the author identified on the imagery, approximately 91% of those elk present on the ground. Radiometric data showed the elk to have a higher mean temperature differential than that of deer (9.61°C vs. 5.9°C).⁴² This difference could have had a major influence on the results. Other problems identified included excessive background noise and turbulence which increased distortion of the imagery.

Wride and Baker, 1977.⁴³ A study was performed at Elk Island Park, Alberta, Canada, in an attempt to detect the large number of ungulates that inhabit the park. The overflights took place in the winter of 1976, at morning and midday periods with "overcast conditions." An 8-14 u detector was used at an altitude of approximately 1800 feet.

The authors interpreted the imagery and explained that they "did not diverge more than 9.0% and were as low as 2.0%," but they did not include tables that showed quantitative data in the article.⁴⁴ Visual aerial estimates totaled 67% of the estimates derived from thermal imagery. Based on visual bias, the authors concluded that the thermal survey provided a more accurate estimate. Overall, this was a very positive application, however, it would be more useful and effective if quantitative data regarding counts and weather were included.

Overall trends. In closing, it seems that the success rate of this technique has increased with time, perhaps because of advancements in design and construction of thermal infrared sensors. And altitudes below 1000 feet during the overflights were shown to provide better results. One final common factor is the major influence of the vegetational overstory on the results, indicating a need for a lack of green foliage in the canopy.

CONCLUSION

Upon examining the results of the case studies reviewed in the previous section, it is difficult to derive anything more than some very gross trends and restrictions. This situation results from the complexity of the interrelationships of the many environmental variables that can influence the detection of apparent radiant temperatures of animals. As a result, the rather poor results reported should not be used to question the utility of the technique, but should serve to illustrate the site-specific character of an application of this type. That is, the appropriateness of thermal censusing, habitat use studies, or whatever, should be evaluated in a case by case, site by site framework.

The overwhelming influence of environmental variables on the results of this technique underscores a great need for radiometric data on a variety of animal species under a wide range of environmental conditions. These initial physiological data will determine whether thermal infrared detection is feasible under a given set of conditions, long before one gets in the air.

Another area of research that needs more attention is the design parameters of a thermal sensor. Identification of the parameters that most affect animal detection, and strategies for incorporating these parameters or characteristics into the sensor in an optimal manner will have a large impact on the future applicability of this technique. Research into the usefulness of the forward-looking infrared sensor (FLIR) is also needed, as it is reported that this sensor has better resolution and lower distortion than the line scanner.

Finally, what seems to the author to be the greatest need, and obstacle, to further development of the thermal infrared technique, is the general lack of knowledge of the conceptual basis of this application amongst administrators and decision-makers. If the persons who control the funding for research such as this do not, or choose not, to understand the principles underlying the technique, then the direction of this type of research is decided long before it becomes research.

FOOTNOTES

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