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Development and Improvement of Bear Management Techniques and Procedures in Southcentral Alaska

Sterling D. Miller

Federal Aid in Wildlife Restoration
Research Final Report
1 July 1992–30 June 1996

Grants W-24-1, W-24-2
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Study 4.24

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Final Research Report

STATE: Alaska **STUDY:** 4.24

STUDY TITLE: Development and Improvement of Bear Management Techniques and Procedures in Southcentral Alaska

COOPERATORS: Mike McDonald (Alaska Dep. Fish and Game), Brian S. Haroldson and Ernie P. Wiggers (Univ. of Missouri, Columbia)

GRANTS: W-24-1, W-24-2, W-24-3, W-24-4

PERIOD: 1 July 1992 to 30 June 1996

SUMMARY

An infrared detection system was tested to determine if thermal imagery could improve detection rates of brown bears and black bears under field conditions. We found that ability to detect bears with this equipment was lower than for traditional visual spotting techniques from fixed-wing aircraft. A report on our tests as well as a more optomistic appraisal of the tests are presented in appendices to this report. A Wildlife Monograph describing 18 applications of capture-mark-resight techniques to estimate brown and black bear density in different regions of Alaska was completed and accepted during this project. The abstract for this monograph is presented as an appendix to this report. Other jobs originally scheduled for this project have been reported under a separate project.

Key Words: Infrared, thermal imaging, brown bear, black bear, Alaska, census techniques.

CONTENTS

INTRODUCTION

Responsible management of exploited bear populations requires continuous effort on the part of managers to improve their understanding of the significance and utility of the information scources available to them and continued efforts to develop improved indices to the status of bear populations. The general objective of this project was to improve the ability to manage bear popualtions through studies designed to better understand currently available information and to test methods to improve information available to manage bears.

OBJECTIVES

The specific objectives for this project were as follows:

1. Improve understanding of the utility of information colelcted from harvest monitoring programs,

2. Investigate new procedures to monitor status of exploited bear populations using both direct and indirect means, and

3. Develop and refine procedures to estimate appropriate harvest levels for bear populations.

RESULTS

Much of the work originally intended to be accomplished under this project was addressed under a companion project (Study 4.26) that was adopted during the term of Study 4.24 and had overlapping objectives. Progress on the jobs originally described for the current project are listed below.

Job. 1. Mark-resight density estimation technique applications and refinement.

During this reporting period a mark-resight (CMR) density estimate was completed during spring 1995 in the same Su-hydro study area where the original application was conducted a year earlier. These results were reported under a different project (Miller 1996). In addition we assisted in mark-resight estimates in Denai Park conducted by Jeff Keay of the US National Biological Service. A publication describing 18 applications of CMR procedures to estimate bear density in Alaska was completed (Miller et al. 1996). This publication includes a list of software and procedures useful in successful applications of this density estimation technique.

Job 2. Bear survey technique evaluation.

Progress on development of new survey techniques included a preliminary evaluation of number of bears/hour seen during density estimation applications (Miller 1996) and tests of thermal imaging (infred) techniques to enhance detectability of bears (Appendix B).

Job 3. Productivity and survival assessment.

Progress on this job included compilation of additional data on brown bears in GMU 13 (Miller 1993) and publication of a report that compared black bear productivity and cub survival parameters in GMU 13 and on the Kenai Peninsula (Miller 1994).

Job 4. Harvest data interpretation.

An effort was made to use harvest data to predict declines in bear density in a GMU 13 brown bear population that was thought to be heavily exploited (Miller 1993). Predicted

declines in density during the period 1985-1995 that were based on reported heavy harvests were not supported by a density estimate conducted in 1995 (Miller 1996). These results illustrate the continuing problems in using harvest data to predict trends in bear abundance. These results are reported under Study 4.26.

Job 5. Evaluate responses of bear populations to harvest.

There was little progress on this job during the current study. Progress made was reported by Miller (1996) under Study 4.26..

Job 6. Prepare reports and publications.

A major effort was successfully completed to prepare a Wildlife Monograph describing 18 applicaitons of CMR bear density estimation techniques in Alaska (Miller et al. 1996). I also prepared a publication on black bear productivity (Miller 1994) and a report on the economic value of bear hunting and viewing (Miller et al. 1997).

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Appendix A. Abstract of Wildlife Monograph scheduled for publication in October 1996.

BROWN AND BLACK BEAR DENSITY ESTIMATION IN ALASKA USING RADIO TELEMETRY AND REPLICATED MARK-RESIGHT TECHNIQUES

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Appendix A Continued

Abstract: Accurate density and population estimates are needed to manage bear populations but are difficult to obtain. Most such estimates reported for bears are largely subjective and lack estimates of precision. Fifteen brown bear (*Ursus arctos*) and 3 black bear (*U. americanus*) density estimates were obtained in Alaska during 1985 through 1992 using 2-9 replicates of capture-mark-resight (CMR) techniques in 17 different areas. Our studies used radiotelemetry to document movements of marked animals into and from search areas. This procedure essentially eliminated the need to correct density estimates for edge or periphery effects caused by absence of geographic closure. To estimate population size, we used a maximum-likelihood estimator modified to accommodate temporary movements of marked animals into and from our search areas. Our approach permitted direct calculations of density from our population estimates. Our procedures provided density estimates that were repeatable, were comparable among areas, included estimates of precision, and were more objective than methods historically used to estimate bear abundance. Our density estimation procedures have widespread applicability for other wildlife studies using radio telemetry.

Our estimates were obtained within a wide spectrum of habitats and provided a range of Alaskan densities from 10.1 to 551 brown bears (all ages)/1,000 km^2 and from 89 to 289 black bears (all ages)/1,000 km^2. Our highest brown bear density is probably near the maximum for this species but areas with lower densities (3.9/1,000 km^2) have been reported in Alaska. Areas with black bear densities higher than in our study areas probably occur in Alaska. Brown bear densities were 6-80 times greater in coastal areas where abundant runs of multiple species of salmon (*Oncorhynchus* spp.) were available to bears than in interior areas. Our CMR technique provided useful data for bear population management, impact assessments, and has potential for application to other species and areas.

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Appendix B. A test of the capability of thermal imaging (infrared) detection systems to enhance sightability of black and brown bears.

Prepared by: Sterling D. Miller and Mike McDonald (Alaska Dept. of Fish and Game)

SUMMARY

An infrared detection system was tested to determine if thermal imagery could improve detection rates of brown bears and black bears under field conditions. This test was conducted in late May 1995 under weather, temperature, and vegetation conditions that approached ideal for positive results. Although the infrared equipment was able to obtain images of bears, we concluded that detection rates using this equipment were considerably below detection rates obtained using traditional visual techniques from fixed-wing aircraft. This was because of the narrow field of view of the equipment, low resolution of images, and lack of heat differentials between bears and background. In our tests, leaf emergence physically blocked thermal images to an even greater extent than visual images. Best results in terms of thermal contrast between bears and background were obtained in the very early morning, prior to 0900 hours. Although there were some problems with equipment that complicated interpretation of our results, we conclude that the technology we tested is not promising as a means to increase detectability of bears under the Alaskan conditions we encountered. A more optimistic appraisal of these tests, by the operator of the infrared equipment, is presented in Appendix C.

INTRODUCTION

Available technology to estimate abundance of bear populations is inadequate to permit reliable detection of trends in bear numbers. Bears are frequently secretive and difficult to see from aircraft, occur in low densities making visual sightings infrequent, are subject to capture bias in capture efforts, have large home ranges, and hibernate during winter, preventing counts of tracks in snow. Consequently, many of the methods that have been used to establish trends in bear numbers are subjective and lack estimates of precision. Capture-mark-resight (CMR) techniques have been used to obtain density estimates with estimates of precision for bears in relatively small study areas throughout Alaska (Miller et al.1996). However, these techniques do not provide population estimates in areas large enough to encompass all of a population that is of interest from the standpoint of harvest management or population assessment (Miller 1990a).

Observability of radiomarked brown bears known to be in an area from aircraft using visual searches ranged from 11% to 65% (mean = 35%) in 15 CMR studies conducted in Alaska (Miller et al. 1996). Lowest detection rates occurred in forested or bushy habitats. Techniques to assess bear abundance and bear population trends would be helped by techniques that would significantly improvedetection rates.

Thermal infrared-sensing is a potential method to improve detectability of animals. Such systems detect heat rather than the reflected light in the visible portion of the spectrum. These systems are limited by foliage which prevents detection of heat signatures and by the need for a thermal contrast between the animal and the background. Objects such as rocks which retain heat may present a thermal image which can be confused with that for mammals.

Thermal imaging using the infrared portion of the spectrum is one such technique that has been used to enhance detectability of a number of wildlife species (Wiggers and Beckerman 1993, Boonstra et al. 1994). In southeastern Alaska, Schoen and Beier (1990) reported that their tests indicated infrared technology could be useful in monitoring brown bear abundance along salmon streams during night or early morning when thermal contrasts are greatest.

Thermal infrared-sensing techniques have been under investigation since the 1960s. In a review of remote-sensing techniques available to biologists, Anderson et al. (1980::295) concluded "Although thermal scanning has not been proven as a cost-effective operational technique for censusing wildlife at this time, it does offer possible applications in the future." The most recent version of the Wildlife Techniques Manual (Brookhout 1994) has no mention of thermal infrared-imaging in the index, indicating this approach remains experimental for practical purposes. In recent years, however, more sensitive equipment has been declassified and has become available for nonmilitary applications. This new equipment has renewed interest in this technology as a tool for detecting homothermic animals.

This study was conducted with the cooperation of Bill Martin, Federal Aid Coordinator, US Fish and Wildlife Service, who paid for transportation for Brian Haroldson to come to Alaska to assist in the test. Brian Haroldson of the University of Missouri, School of Natural Resources operated the thermal-imaging equipment. Haroldson's work in Alaska was facilitated by Prof. Ernie Wiggers (Univ. of Missouri) and Jay McAnich (Minn. DNR). The Alaska State Troopers, Division of Fish and Wildlife Protection, allowed us to use their helicopter and infrared equipment to test this equipment. First Sergeant Bill Boitnoot facilitated our use of this equipment and trooper pilot Bob Larsen piloted the helicopter. Chuck McMahan piloted the fixed wing. Bob Yates of Clearwater Mountain Resorts allowed us to use his facilities and landing strip. Earl Becker provided suggestions on sampling designs for search patterns for the tests. Karl Schneider obtained the funds used to conduct these tests.

STUDY AREA

The area between the Susitna River and the Denali Higheway where we conducted our tests was thoroughly described in earlier reports (Miller 1990, 1993), in the Su-hydro study area. All bears were located 5-25 miles south of the Denali Highway in the area between the Susitna River and Devil Mountain.

Vegetation surrounding radiomarked bears ranged from open tundra and shrublands with shrub leaves not yet emerged to low elevations near the Susitna River with rapidly emerging leaves on deciduous trees (primarily birch, *Betula papyrifera*), shrubs (primarily alder, *Alnus crispa*) and moderate to dense stands of spruce (*Picea glauca, P. mariana*). The most frequently located bears (521 and 524) were in the most open habitats close to operations base at Clearwater Mountain Resort (formerly Susitna Lodge) about 5-7 miles south of the Denali highway on Butte Creek. In this area, leaves were still dormant during our tests.

METHODS

We used a FLIR Model 2000F infrared-imaging system mounted on a Bell Jet Ranger helicopter, piloted by Alaska State Trooper Bob Larsen. The Global Positioning System (GPS) in the helicopter was a Trimble 3000. Equipment in the helicopter included a super VHS professional quality video tape recorder. Coordinate information from the GPS could be inserted on tape and the pilot and FLIR operator could both record audio statements on the tape describing their activities and what they were "seeing" on the infrared screen. Voice transmissions from a fixed-wing aircraft used to direct the helicopter could also be recorded on the tape. Brian Haroldson, a graduate student at the Univ. of Missouri, operated the FLIR controls. Brian has experience operating FLIR systems in Minnesota, where he worked with Jay McAninch of Minnesota DNR; in Missouri he works with Ernie Wiggers of the University of Missouri on infrared detection of deer, turkeys, and other species.

Our test was the first opportunity for the FLIR operator and the helicopter pilot to work together; some inefficiencies were inevitable, even though both the operator and pilot were very capable. . These inefficiencies increased time required to obtain thermal images.

A fixed-wing aircraft was used to locate radiomarked brown bears. A GPS location for the radio marked bears was radioed to the helicopter which overflew these coordinates in an attempt to obtain a thermal image of the bear. The fixed-wing circled the location of the marked bear at approximately 1,000 feet AGL (above ground level) and corrected the heading of the helicopter flying at lower elevation to assure overflight of the bear if necessary. In almost all cases, the bear was under visual observation by observers in the fixed-wing (Sterling Miller and pilot Chuck McMahan) when overflown by the helicopter at varying altitudes, typically at 300-600 feet AGL on the first passes.

Our initial design for this test called for testing different search patterns (circular, transect) around the location of the radio marked bear to determine which worked best. However, these tests were not conducted because of difficulties in obtaining initial thermal images from the bears even when the helicopter was directed to fly directly over the target by the fixed wing aircraft. In addition, the bear was usually running when approached by the helicopter which would have resulted in the target being outside of a circular search pattern by the time the search was concluded.

Tests were conducted May 25 through May 27, 1995. On these days tests were progressively earlier in the morning (0830-1115, 0630-0915, and 0545-0745) in an effort to improve thermal contrasts between animals and background. On the last day, tests began as soon as there was enough daylight to fly and background temperatures were near freezing (Appendix A). On May 25 and May 26 tests were also conducted in the afternoon when background temperatures were higher (Appendix A).

One radiomarked black bear was in the study area. All detection efforts on black bears, however, were conducted on black bears not radiomarked. These bears were found by the fixed-wing aircraft using general visual searches primarily along Watana Creek, known to be good black bear habitat.

RESULTS AND DISCUSSION

The FLIR equipment was used in 22 tests to detect bears located by fixed-wing aircraft in an effort to obtain a visual image of brown bears 17 times and black bears 5 times. In 20 of these tests, a thermal image was obtained by the FLIR equipment. In 1 case the bear was in a den and was not seen by either observers in the fixed-wing aircraft or by the infrared equipment. Atanother timethe observers in the fixed-wing aircraft saw the bear, but did not obtain a thermal image. Time and funds were available to conduct additional tests, but the trials were terminated because of poor results.

The intended experimental design was not implemented because of unexpected difficulties in obtaining initial thermal images of bears. This difficulty, by itself, provided the answer to our ultimate question which was whether this technology would enhance efforts to find and identify bears under Alaskan conditions. Because of the problems in finding the bears initially, however, it is difficult to quantify this conclusion. We made an effort to do this, after the fact, by quantifying the number of passes it took for the helicopter to find bears and the amount of time to obtain the first thermal image. These data were obtained from reviewing videotapes of the efforts to obtain thermal images of the bears (Table 1). It was occasionally difficult to determine how many passes were made during this review because of inadequate audio clues on the tape; the values on number of passes presented in Table 1 are conservative.

It took an average of 2.5 passes over a bear before a thermal image was obtained or the effort was abandoned (range 1-5) (Table 1). The average time spent obtaining a thermal image was 6.7 minutes (range 1-18 minutes) (Table 1). There were some difficulties in coordinating searches between the FLIR operator and the helicopter pilot. Performance would doubtless improve with additional training.

These data are inadequate as objective measures of the equipment's ability to detect bears because transects were not standardized and bear activity was inconsistent. Regardless, these data are reported because they generally illustrate the difficulties of obtaining thermal images of bears. These data were obtained under conditions when the bear was under clear observation from a fixed-wing aircraft circling at a higher elevation than the helicopter. The team in this fixed-wing aircraft radiotracked to the bear and typically obtained a sighting on the first or second pass within a period of 10-30 seconds. This made the contrast between spotting these bears from the fixed-wing aircraft and obtaining a thermal image from the helicopter especially notable to the biologist and pilot in the fixed-wing aircraft.

The appraisal from the biologist working the IR equipment in the helicopter (B. Haroldson) is presented in Appendix C. This appraisal faults technical problems with the equipment for some of the difficulty in obtaining thermal images of bears. This report notes, however,the equipment was adequate to obtain good thermal images of moose butconcurrently poor images for bears. We agree with the report in Appendix C that obstruction from overstory vegetation reduced our ability to detect bears. From a field application standpoint, however, overstory and weather conditions in Unit 13 are unlikely to be found appreciably better than they were during our tests.

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Table 1. Number of passes and time required to obtain a thermal image of radiomarked bears in tests conducted in Alaska during spring 1995.

Species ID Association	Seen by FLIR? Activity	No. of Passes	No. of minutes	Habitat	Leaf Emer-gence	Air Temp. (°F)	Date Time
Brown 524 Alone	Yes Standing	5-6	24	Shrub	0%	40°	25 May 0915
Brown 521 None	Yes Running	3	18	Alpine	0%	40°	25-May 1021
Brown 314 Alone	No	N/A	N/A	In-den, Rock & Snow	0%	N/A	25-May 1311
Brown 486 w/ 3@ 1	Yes Running	1	0.3	Shrub 10%	0%	46	25-May 1340
Brown 519 Alone	Yes Running	2	7.5	Shrub 30%	0%	-	25-May 1354
Brown 522 Alone	No	2	5	Mixed Forest	Partial	-	25-May 1417
Unmarked Black Alone	Yes Laying	1	1.3	Mixed Forest 50%	50%	-	25-May 1430
Brown 283 Alone	Yes Running	2	4.1	Low Shrub= 50%	0%	44	25-May 1453
Brown 491 Alone	Yes Running	4	12	Tundra	0%	46	25-May 1630
Unmarked Black Alone	Yes	~2	3	Shrub= 50%	Partial		25-May 1703
Brown 524#2 Alone	Yes	2	2.3	Alder= 50% Spruce -20%	0%	32	26-May 0714
Brown 521#2 Alone	Yes	~4 (130	130	Alder= 50%	0%	-	26-May 0728

Table 1 Continued

Species ID Association	Seen by FLIR Activity	No. of Passes	No. of minutes	Habitat	Leaf Emer-gence	Air Temp. (°F)	Date Time
Black Unmarked W/ 3 @ 0	Yes	3	8	Mixed Forest	75%	-	26-May 0830
Black Unmarked W/ 3 @ 0	Yes	2	4	Alder	50%		26-May 0837
Brown 437 W/ Male Unmarked	Yes	1	1	Snow and Rock on Top Tsusen a Butte	0%		26-May 0850
Brown 524 #3 Alone	Yes Running	2	5	Alder	0%	34	26-May 1502
Brown 335 W/ 1 @ 2	Yes Running	1	1	Shrub	0%		26-May 1525
Brown 521 #3 Alone	Yes Standing	6	15	On rock Slide	0%		26-May 1534
Brown 521 # 4 Alone	Yes	~5	8	Alpine Alder= 5%	25%	35°	27-May 0550
Brown 335 W/ 2 @1	Yes	1	1	Alpine	-	-	27-May 0617
Brown 524# 4 Alone	Yes Walking	1	1	Mode-rate Spruce & Tundra	0%	36°	27-May 0645

Appendix C.

USE OF THERMAL INFRARED SENSING TO DETECT BROWN BEARS IN INTERIOR ALASKA

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BACKGROUND

Wildlife professionals have been experimenting with thermal infrared sensing for over 25 years. While initial attempts had limited success (Croon et al. 1968, Graves et al. 1972, Parker and Driscoll 1972), recent improvements in infrared sensing technology have rekindled the interest to evaluate its utility for wildlife surveys (Wiggers and Beckerman 1993, Graves et al. 1995).

In order for infrared sensing to be a viable technique for surveying wildlife, several conditions must be met: 1) The target animal must emit energy in a band which is detectable by the sensor (commercially available sensors are filtered to detect thermal emissions in the 8-12 m range); 2) A temperature differential must exist between the target animal and its background, and this differential must be detectable by the sensor; 3) A portion of the target animal must be in direct line-of-sight of the sensor in order to be detected, since thermal emissions in the 8-12 m range are obstructed by vegetation.

All objects at a temperature above absolute zero emit infrared energy. The intensity and spectral distribution of this energy varies with the surface temperature of the emitting object (Parker 1972). Croon et al. (1968) reported that maximum energy from animals is emitted between 9-10 m.

Typically, thermal infrared images are recorded in shades of grey, with warm objects in the scene appearing in light tones and cool objects appearing in dark tones. Sufficient thermal contrast must exist in the scene in order for the target object to be separated from its surroundings. This contrast is affected by time of day, habitat, weather conditions (i.e., solar radiation, ambient temperature, wind, humidity, precipitation), and emissivity of target and background objects.

Using a commercially available thermal infrared system, we evaluated the feasibility of using this technology to detect free-ranging, radiomarked brown bears (*Ursus arctos*) in central Alaska. Specifically, we wished to determine detectability of bears at various fixed distances (vertical and oblique) from the animals using both line transect and quadrat sampling techniques. Results would be compared to detection rates derived from the visual observation approach currently utilized. Readers are referred to the accompanying report by Miller for a review of conventional sampling techniques for brown bears.

This research was a cooperative project between the University of Missouri's School of Natural Resources and Alaska Department of Fish and Game. The lead investigator from Alaska was Sterling Miller, with additional collaboration provided by Jay McAninch, Minnesota Department of Natural Resources.

METHODS

On 23 May 1995, captive bears from the Alaska Zoo in Anchorage were used to assess thermal emissions and temperature differential between the bears and their environment. Surface temperatures of two brown bears, one black bear (*Ursus americanus*), and the open lawns adjoining each enclosure were measured at 0800 hours using an Omega OS85-EM hand-held infrared thermometer (Omega Engineering, Inc., One Omega Drive, Box 4047, Stamford, CT 06907). Since the bears were not immobilized and could move freely throughout their enclosures, measurements were taken opportunistically after enticing the animals to approach the periphery of their enclosure. We used a Forward Looking Infrared (FLIR) 2000F system (FLIR Systems Inc., 16505 S.W. 72nd Ave., Portland, OR 97224) mounted on a Bell Jet Ranger Helicopter for our evaluation of free-ranging bears. The system consisted of a sensor, hand-held system controller, display monitors for the image operator and pilot, and a video cassette recorder. The image operator controlled the direction and reception quality of the sensor by using the system controller and viewing the monitor. Video images were displayed in real-time on the 2 monitors and recorded on standard vertical helical scan (VHS) tape. In addition, communication between individuals in the aircraft was recorded on the VHS tape. The FLIR system operates within a spectral band from 8 to 12 m, has a minimum resolvable temperature of 0.25°C and a resolution equivalent of 350 by 343 lines. The optic modes of the sensor include a wide field of view of 28 x 15° (1.9X magnification) and a narrow field of view of 7 x 3.25° (7.5X magnification). The helicopter was equipped with a Trimble 3000 global positioning system (GPS) (Trimble Navigation Ltd., P.O. Box 3642, Sunnyvale, CA 94088) and software program allowing date, time, and location information to be inserted onto the video tape. The infrared system and aircraft were owned by the Alaska State Troopers.

Tests were conducted on radiomarked brown bears near Cantwell, Alaska during 25-27 May, 1995. A Piper supercub airplane (PA-18) with radio-tracking equipment located each bear both electronically and visually, then provided high-altitude surveillance to guide the helicopter along a series of transect lines over each animal. Black bears found incidental to the radiomarked brown bears were included in the evaluation. The helicopter began its search at 500 ft above ground level and adjusted altitude, accordingly, until clear recognition of the bear's image was obtained. Image characteristics (completely white, partially white, entirely black), habitat type (alpine, shrub, mixed forest) and phenology, background thermal conditions, and ambient weather conditions (air temperature, cloud cover) were documented for each animal observed. In addition, surface temperatures from representative landscape features were measured at base camp prior to and after each flight using the hand-held infrared thermometer described above.

RESULTS

Ground temperatures outside the bear enclosures at the zoo ranged from 45-47°F, while animal temperatures varied between 52-54°F and 53-55°F for black and brown bears, respectively. All measurements on the bears were obtained from the head and upper thorax of each animal. The 5-10°F temperature differential observed between the animals and their environment was considered sufficient to allow detection using the aforementioned infrared system and to proceed with the evaluation.

Flights to test equipment on free-ranging bears were conducted during the morning and afternoon hours of 25-27 May, 1995. Thermal images were recorded for 8 brown bears (with multiple observations obtained for 3 animals) and 5 black bears (Table 1).

We experienced immediate and continuous problems with the infrared equipment, including dark bands of interference across the monitors, washout of the screen (thermal blooming), diminished horizontal resolution, and impeded control of the gain setting. Although the cause of these equipment problems could not be isolated or corrected in the field, the resultant effect was undeniably a reduction in image quality and ultimately animal detection. Consequently, equipment malfunction precluded continuing with initial objectives. We, therefore, redirected our efforts to obtaining video footage of the radiomarked animals in a variety of habitats and at various times of the day. This information would enhance our understanding of the capabilities and limitations of thermal infrared sensing as a population monitoring tool. The remainder of this paper will focus on these findings.

Detectability of brown bears was highest during the early morning hours when the temperature differential between the animals and background was greatest (Table 1). Visual analysis of this video footage indicated that bears emitted the most thermal radiation, followed by trees, shrubs, and ground vegetation, respectively. Surface temperatures measured at base camp corroborate this pattern (Table 2). The thermal images of all brown bears (n=4) observed by 0900 hours were completely white in appearance and easily discernable from the background (Table 1).

By mid-morning, solar radiation was heating objects in the environment at dissimilar rates, reducing thermal contrast between the animals and background, and minimizing detectability (Table 1). Similar thermal patterns and results were reported by others (Marble 1967, McCullough et al. 1969, Graves et al. 1972, Parker 1972, Garner et al. 1995). By mid-morning, background thermal conditions were transposed from early morning conditions, with ground vegetation warmer than the shrubs and trees (Table 2). The infrared images of 6 of 7 brown bears were a mosaic of dark and light tones (Table 1). While each animal's head and back remained the warmest objects in the scene, the majority of the body surface appeared dark and cooler than the background vegetation. The combination of inconsistent thermal loading to the environment and low thermal contrast between the animal and background inhibited detectability of brown bears by mid-morning.

Multiple observations (n=4) were recorded for 2 adult male brown bears with extremes in coat color (Table 1). Except for time of day effects, we found no apparent difference in detectability due to age or coat color of the animal. In addition, no differences were noted in detectability between adult females and cubs observed in family groups (n=3) (Table 1).

Detectability of bears, however, was affected by habitat. Since thermal emissions cannot penetrate vegetation, detectability was highest in open alpine areas and lowest in dense shrub and conifer forest habitats. Even though leaf emergence was minimal, high stem density in shrub habitats appeared to hamper detection of the animals in those areas. As a result, multiple passes from different directions and altitudes were frequently required to locate bears in spruce stands and alder thickets.

DISCUSSION

Croon (1967) and Marble (1967) recorded apparent temperatures of a variety of animal species (i.e., deer, antelope, bison, fox, squirrel) and found little difference among them. However, in this study, the image characteristics of brown bears were drastically different from those of black bears and moose (*Alces alces*). In general, thermal images from brown bears were completely white only during the early morning hours. In contrast, images of black bears and moose were completely white throughout the day. In addition, 2 independent observations were recorded during afternoon flights with brown bears and moose in the same video frame (bear 491 on 25 May; bear 335, with cub, on 26 May). In both instances, the moose were readily detected while the bear's image blended in with the background. If the bears had not been running, they would have gone undetected. Results from this study suggest a dramatic difference in apparent temperature between brown bears, black bears, and moose. Although the reason(s) for this inconsistency is not clearly understood, variable thermal loading and/or thermal emissions are suspected. Additional research is needed to document temporal changes in thermal emissions between species of animals.

Notwithstanding temporal effects, detectability of brown bears was impeded by obstruction from overstory vegetation. Since thermal emissions cannot penetrate vegetation, at least a portion of the animal must be in direct line-of-sight of the sensor to be detected. Intensive searching via line transect methods would obviously be impractical for field applications on brown bears. However, an orbital search pattern may enhance detection efficiency by providing multiple views from a variety of angles. Regardless of search technique employed, infrared sensing will not be applicable in habitats with dense overhead canopy (Croon et al. 1968, Prinzivalli 1992, Wiggers and Beckerman 1993, Boonstra et al. 1994). Our observation of reduced detectability in dense shrub habitats suggests a potential limitation of infrared sensing. However, the confounding impacts of equipment problems mandates further investigation to determine limitations in various habitat types.

Until the current study, there was no test of the ability of thermal imaging to detect bears. However, although sample sizes were small, we have shown that infrared sensing can be used to detect bears under appropriate sampling conditions. The optimal time to conduct surveys is apparently during early morning or evening hours when maximum thermal contrast exists between the animals and background. Carefully designed studies are still needed to further evaluate infrared sensing as a population monitoring technique.

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Table 1. Physical parameters, thermal image quality, and observation times of brown and black bears observed during infrared trials near Cantwell, AK, 25-27 May, 1995.

Species	ID #	Sex	Age	Coat color	--- 25 May ---		--- 26 May ---		27 May
					0930-1030 h	1330-1700 h	0715-0900 h	1500-1600 h	0600-0730 h
Brown	524	M	15	Dark Brown	1[a]		1	1	1
Brown	521	M	8	Blond	2[a]		1	2	1
Brown	283	F	27	Light brown		2			
Brown	486[b]	F	8	Dark Brown		2			
Brown	491	F	4	Blond		2			
Brown	519	M	4	Blond		2			
Brown	437[c]	F	12	Blond			1		
Brown	335[d]	F	17	Light brown				2	1
Black	---	unk.	unk.	Black		1			
Black	---	unk.	unk.	Black		1			
Black	---	unk.	unk.	Black			1		
Black	---	unk.	unk.	Black			1		
Black	---	unk.	unk.	Black			1		

[a]Qualitative classification of thermal infrared image of bears: 1=body completely white, good contrast with background; 2=mottled color pattern, poor contrast with background.
[b]Accompanied by 3 cubs.
[c]Accompanied by 1 adult male.
[d]Accompanied by 1 cub

Table 2. Mean surface temperature[a] (°F) of representative landscape features near Cantwell, AK, 25-27 May, 1995.

	25 May	----------- 26 May -----------			
	1400 h	0615 h	0930 h	1415 h	1630 h
Snow bank	32.0	30.0	31.0	30.0	30.0
Lake surface	48.0	42.0	42.0	44.0	45.0
Wet sand at shoreline	----	32.7	46.0	49.7	51.3
Dry gravel at shoreline	----	34.7	51.3	58.3	61.3
Gravel air strip	56.0	32.0	55.3	53.3	55.7
Substrate (moss, lichen, etc.)	----	32.0	72.7	54.3	58.0
Low shrubs (willow)	57.0	36.3	47.0	46.0	51.3
Spruce tree	----	----	----	43.3	47.0

[a]Temperatures were obtained using an Omega OS85-EM hand-held infrared thermometer, with emissivity fixed at 0.95.

Alaska's Game Management Units