Sightability Model For California Bighorn Sheep In Canyonlands Using FLIR Mounted On An Airplane.

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Abstract: The purpose of this study was to determine if a forward-looking infrared radiometer (FLIR) mounted in a fixed-wing airplane could detect and verify California bighorn sheep (*Ovis canadensis californiana*). The study area included the highly dissected rhyolite canyons of southwestern Idaho. All age and sex classes could be detected with the FLIR. Flying at 2,000 ft above ground level (AGL) the FLIR could distinguish bighorn sheep from other ungulates (i.e., pronghorn antelope, mule deer, livestock) on most occasions. Flying directly over the animal group and/or using the daylight video camera with full zoom provided confirmation. The survey was conducted after sunrise allowing for verification using a natural color video camera housed within the FLIR gimbal. Image clarity and the ability to circle the animal without disturbance allowed determination of male age classes for use in setting harvest of available rams. Bighorn sheep could be detected in all habitats used within the study area. Data were collected over three years with probability of detection of 89%. A set search pattern allowed consistent detection rates between sensor operators, airplane type, or between years. This study identified variables that influence sighting probability using FLIR. The use of a FLIR mounted on an airplane flying at 2,000 ft AGL has advantages over visual surveys using human observers in airplanes or helicopters: reduced stress to the animals, reduced violations of assumptions of sightability models, and reduced hazard to observers.

Key Words: sightability, population estimates, aerial surveys; Idaho; USA; infrared surveys; forward-looking infrared; FLIR, California bighorn sheep; (*Ovis canadensis californiana*)

A major problem in studying mammals in the field is finding them (Boonstra et al. 1994). Because ground-based observation of mountain sheep (*Ovis canadensis*) is often limited by access and topography, aerial census is often the only practical way to estimate mountain sheep numbers (Remington and Welsh 1989). This technique has limitations because biases may occur as a result of observers (Simmons and Hansen 1980), technical problems (Caughley 1974), or more commonly, sightability (Remington and Welsh 1989, Bodie et al. 1995). Visibility is the most important factor affecting population estimates (Pollock and Kendall 1987, Samuel et al. 1992, Bodie et al. 1995). This parameter is influenced by weather and lighting conditions, season, heterogeneity of terrain, vegetative cover, observer fatigue, search speed altitude, and distribution pattern of bighorn sheep (Simmons and Hansen 1980, Remington and Welsh 1989, Bodie et al. 1995).

Idaho Department of Fish and Game (IDFG) uses helicopters to survey for California bighorn sheep (*Ovis canadensis californiana)* (Neal et al 1993, Bodie et al. 1995). These surveys are conducted within the canyon at or below 30 m above

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ground level (AGL) (Simmons and Hansen 1980, Remington and Welsh 1989). Helicopters are highly stressful to bighorn sheep and other ungulates (Bodie et al. 1995, Stockwell et al. 1991, Bleich et al. 1990). Bighorn sheep respond to helicopter disturbance in a variety of forms (Bleich et al. 1990, Bleich et al. 1994), including grouping up and running which cause them to alter both their distribution and movements. This disturbance is prolonged since mountain sheep reportedly moved 2.5 times further the day following the survey than on the day before the survey. Stockwell et al. (1991) found that helicopter overflights reduced the foraging efficiency of mountain sheep. Potential consequences such as altering habitat use, increasing susceptibility to predation, or increasing nutritional stress, are unknown (Bleich et al 1994).

The repeated disturbance from the helicopter surveys has resulted in questioning the results therefore, the utility of these surveys. A 1998 helicopter survey for California bighorn sheep in the South Fork Owyhee River, Idaho highlight the reliability problems with this survey technique (IDFG 1998, unpublished data). Over 40 animals were not found during the helicopter surveys that were subsequently located two weeks later during ground surveys. In addition, bighorn sheep were observed to change behavior including grouping and running when the helicopter is six or more km away. Movements during helicopter surveys violate several assumptions required for population estimation: individuals maybe counted more than once so the probability of "recapturing" an animal is not constant; and surveys are not independent. Violation of these assumptions affects accuracy and precision of the population estimates (Bleich et al 1990).

Helicopter surveys have other limitations because biases may occur as a result of technical problems or more commonly the observer's ability to detect the subject animals (Caughley 1974, Caughley et al. 1976). Visibility, the most important factor affecting population estimates (Pollock and Kendall 1987, Samuel et al. 1992), is influenced by weather and lighting conditions, season, heterogeneity of terrain, vegetative cover, observer fatigue, search speed, altitude, and distribution pattern of animals (Samuel et al. 1987). In addition, these surveys pose high-risks for the biologists collecting the data. The helicopter must fly low to search for animals in rough terrain where wind turbulence is unpredictable. Alternatives to helicopter surveys that provide reliable information are needed.

Tests conducted in 1997 under the first phase of this study indicated that a forward-looking infrared (FLIR) mounted on an airplane could detect bighorn sheep (Bernatas, 1997, unpublished data). The use of a color video camera housed within the FLIR gimbal provided the ability to determine age class of rams. These test flights were conducted in May when the bighorn sheep were more likely to be in smaller groups within lambing areas. Maximum likelihood of disturbance was anticipated during this period however, the animals did not respond to the airplane flying at 2,000 ft AGL. Late winter was selected for future surveys for three reasons: animals would more likely be located in the upland facilitating sighting potential; cool temperatures allow a longer period to perform the survey before the ground temperature reached the temperature of the animals; and, potential for good weather for aerial surveys. Flight parameters (e.g., scan pattern, airspeed and altitude) were tested and reconfigured to optimize their effect on detection rates. A list of variables was developed to provide input into sightability model development such as environmental variables (i.e., cover type, sun/shade, and position in canyon) and animal behavior (i.e., running, standing, bedding, walking) and group size. This goal of the second phase was to develop a sightability model to determine population estimate.

STUDY AREA

The study area was located in Owyhee County in southwestern Idaho. It included the East and South Forks of the Owyhee River and Dickshooter Creek. Elevations ranged from 1,380 to 1,660 m. The terrain includes gentle rolling uplands and steep rhyolite canyons that range from 30 to 300 m deep. Canyon width ranges from approximately 300 to 1,500 m. These canyons are highly dissected with areas of cliffs, talus slopes and mid-elevational benches with shallow soils. Soils in the uplands are relatively deep soils and the vegetation is sagebrush-steppe dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) that averages 1.0 m tall. Thin, stony soils are dominated by low sagebrush (*A. arbuscula*) in the uplands. The western portion of the study area includes scattered Western juniper (*Juniperus occidientalis*). Mountain mahogany (*Cercocarpus ledifoius*) and hackberry (*Celtis retuculata*) are found rarely in the riparian or lower benches in the canyon. Rabbitbrush (*Chrysothamus* spp) is found in disturbed areas and on north facing slopes. Common grasses include: bluebunch wheatgrass (*Pseudoroegneari spicata*), Sandberg's bluegrass (*Poa sandbergii),* and bottlebrush squirreltail (*Sitanion hystrix*).

Along with bighorn sheep, mule deer and pronghorn antelope inhabit the study area. Cattle and horses were infrequently found during the study period.

METHODS

Paired observations were obtained using 30 radio-collared bighorn sheep available from a previous Bureau of Land Management (BLM) study. Canyon habitat was divided into segments to form survey plots. Survey orbits of 1,500 m in diameter and spaced 450 m apart, were plotted on a 7.5-minute topographic map of the survey area. Each orbit was assigned a unique number to facilitate communication between the two aircraft. The center of the orbit was noted on the 1:24,000 and 1:100,000 maps. Latitude and longitude coordinates of the center point of the orbit were programmed into the aircraft GPS navigational system to locate and maintain the correct flight path.

Two airplanes and crews were required for data collection. A crew including a pilot and a biologist using telemetry, hereafter telemetry crew, located collared bighorn and identified them within the predefined plots. The bighorn group was identified as the sample. A second airplane and crew included a pilot, sensor operator and biologist, hereafter FLIR crew. The biologist with the FLIR crew coordinated the two aircrews and recorded data. Only those plots where bighorn sheep located by the telemetry crew were selected to avoid expenditure of resources by sampling in canyon reaches with no bighorn sheep. The telemetry crew located bighorn sheep groups and radioed the plot number, location information, group size and habitat to the biologist with the FLIR crew. The sensor operator was not provided any information on the group. The operator scanned the selected plot in a predefined search pattern. The IR sensor operator could not see out the windows because the windows were blacked out to reduce screen glare.

The search pattern included two revolutions around the selected orbit. The orbit was flown with a 1.1 km radius providing a 0.8 km search radius to avoid having to search directly under the airplane. The sensor operator searched the orbit using a radial search pattern and located animals by their level of emitted heat versus the background using the IR sensor. Each orbit was flown with two revolutions. All surveys were flown at 2,000 ft. AGL. If the subject group was not located, the crew offset with another orbit located upstream of the selected orbit provided overlap. An additional overlap was provided downstream of the selected orbit. These offset points of the selected orbit providing 50 % overlap. If the group was not located after completing this search pattern it was considered a miss. The number of revolutions and overlap of adjacent orbits was established for an operational survey. As such, selecting the center orbit and the adjacent upstream and downstream orbits provides a measure of efficacy of an operational survey when known groups were available. Once detected, positive species identification was confirmed using specific body features using the color camera.

The sample was defined as the collared animal and their respective group. The group was counted as one sample even if more than one collar was located within the group. Although there was concern about the ability to recognize and define a single sample group or the sample group(s) from other unmarked groups, this did not prove problematic because the animals did not move in response these two airplanes used for these surveys. Weekly telemetry flights have been conducted over this East Fork Owyhee herd to support a BLM research project reduced any response to the lower flying telemetry airplane.

The fixed wing airplane type changed between years however, this did not affect data collection since flight speeds, navigation equipment, crew size, and FLIR remained the same. The gimbal, which houses the FLIR and color TV camera, was mounted to provide a 360-degree view. The gimbal was mounted in the fuselage of the Cessna 303 in 1998 and 1999 and under the left wing of the Cessna 337 in 2000. Both aircraft had a LORAN and a Northstar global positioning system (GPS). The FLIR was a commercially available Westinghouse WesCam DS16 FLIR (WesCam, Burlington, Ontario, Canada) which operates in the 8-12 micron spectral band. At 2,000 ft AGL looking straight down, the footprint or field of view (FOV) is 110 m in the wide or 10^{o} FOV and 30 m in the narrow or 3^{o} FOV. (All altitudes are provided in English units since all aircraft use this system.) The FLIR can detect differences in temperature of 0.25^{o} C. The latitude, longitude, date, and time were overlaid on the screen as well as the simultaneous recording of the voices of the sensor operator, pilot, and observer to provide reference for subsequent review upon return. The operator sat in the rear seat and manually aimed and focused the sensor or TV camera. The operator scans using the FLIR in wide FOV and switched to narrow FOV for object identification. The natural color TV was used for species identification and to determine ram age class. Either the color TV picture or IR image was recorded with screen overlay for future reference and analysis.

Flight speeds ranged between 70-100 knots. Surveys commenced approximately 30 to 60 minutes prior to sunrise and continued until temperature of the background was hotter than the animals.

The survey period was typically three hours. Night surveys were not considered because of the goal of determining ram age class requires using the natural color camera to verify horn curl size. Latitude and longitude coordinates of the center point of the orbit were programmed into the aircraft GPS navigational system to locate and maintain the correct flight path. Upon completion of the surveys, the sensor operator and observer/biologist reviewed each tape and recorded the number of animals and groups detected.

A hit or miss, along with the variables associated with the group, were recorded. If a group was missed the two airplane crews worked together to identify the attributes of the missed group and attempt to locate them with the sensor. The two aircraft did not fly in the same orbit during the IR search for safety and to avoid disturbance to the search pattern. They did work together to locate the group after the IR search pattern resulted in a missed group. They also worked together to verify that any groups found were the same as the sample. This clarification was important because group size or location occasionally changed between the time the telemetry airplane flew over the group to when the IR airplane flew over the group.

Data Analysis

Logistic regression has been used to build sightability models (Samuel et al 1987, Ackenson 1988, Unsworth et al 1990, Bodie et al 1995) because predictor variables are not normally distributed and some variables are discrete or categorized (Johnson 1998). Chi-squared test was used to test for differences between estimators among survey flights. SYSTAT 9.0 (SPSS Inc. 1998) was used for the analysis.

RESULTS

A total of 92 samples were collected in March between 1998 and 2000. The sightability or percent seen was 85.2 %, 89.4 %, and 88.9%, for 1998, 1999, and 2000, respectively, with no significant difference between years for sightability ($p = 0.861$). Chi-square value for all covariates (i.e., group size, cover, slope position, activity type, and sky) was 22.456 (11 df) ($p = 0.021$) indicating these variables were significant predictors of sightability. The univariate chi-squared comparisons of variables were not significant except for cover type (Table 1). Backward logistic regression revealed that cover type and sky remained in the model.

DISCUSSION

FLIR capabilities

Results show that the IR sensor and natural color camera mounted on an airplane perform well to locate and verify bighorn sheep with a detection rate of nearly 90%. The current technology is far improved over initial uses of IR sensors, which showed promise but had limited success (Croon et al. 1968, McCullough et al. 1969, Graves et al. 1972, Parker and Driscoll 1972, Wride and Baker 1977). Those problems included inability to differentiate species, inability to distinguish animals from background objects, bias in sampling techniques, and canopy cover limited the widespread use of this technology. Early surveys relied on computer analysis of survey tapes to identify target species. This procedure involved measuring the emitted temperature, via the IR sensor, of an animal and the temperature of the environmental background prior to a survey.

Advances include increases in thermal detection resolution, improvements in optics, real-time data acquisition, and

Table 1. Univariate comparisons of independent variables tested during the IR surveys in the East Fork of the Owyhee River during 1998, 1999, and 2000.

Variable		n	% seen	Chi^2
Year				0.861
	1998	27	85.2	
	1999	47	89.4	
	2000	18	88.9	
Group Size				0.359
	1-6	35	82.9	
	7-13	35	88.6	
	14+	22	95.5	
Sky				0.151
	Bright	67	85.1	
	Dull	25	96.0	
Slope Position				0.10
	Upland	63	93.6	
	Upper slope	22	77.3	
	Mid-slope	4	75.0	
	Lower slope	3	66.7	
Cover Type				0.0
	Rock	21	61.9	
	Sagebrush	60	96.7	
	Grass	8	87.5	
	Juniper	3	100.0	
Activity Type				0.911
	Bed	19	89.6	
	Stand	60	88.3	
	Walk	13	84.6	

miniaturization of equipment (Garner et al. 1995). The current IR technology allows the sensor operator to identify animals in flight using morphology or specific body features during surveys. Finer resolution through an increase in the number of pixels represents the most important advancement in thermal-IR technology for wildlife survey applications. Increase thermal sensitivity combined with increase in pixels provides the ability to determine the animal through morphology. A natural color camera housed in the gimbal can facilitate species verification. The sensor operator can switch between the FLIR and the color camera to detect and verify the animal. Infrared sensors have been used to detect small mammals (Boonstra et al. 1994), waterfowl (Best et al. 1982, Sidle et al. 1993), turkeys (*Meleagris gallopavo*) (Garner et al. 1995), birds and their nests (Boonstra et al. 1995, Benshemesh and Emison 1996), marine mammals (Barber et al. 1991, Cuyler et al. 1992, Ryg et al 1988), fox (*Vulpes* sp. and *Alopex lagpus*) (Klir and Heath 1992), bats (Sabol and

Hudson 1995), moose (*Alces alces*) (Adams 1995, Garner et al. 1995), white-tailed deer (*Odocoileus virginianus*) (Wiggers and Beckerman 1993, Garner et al. 1995, Naugle et al. 1996, Haroldson 1999), wild horses and burros (Bernatas 1999), and other animals (Havens and Sharp 1998).

Wiggers and Beckerman (1993) used FLIR to survey captive white-tailed deer of known sex and age classes, and Garner et al. (1995) surveyed free ranging white-tailed deer and found that age and sex discrimination was possible. Both studies found that canopy cover reduced the probability of detection. Best times were when the thermal contrast between the target animals and the environmental background was the highest, generally during the early morning hours, on overcast days, or in the cooler seasons of the year. Adams (1995) found that overall sightability of moose was 88%, in comparison to salt lick surveys and that FLIR surveys were more cost effective relative to traditional aerial surveys and had greater survey area. Naugle et al. (1996) compared aerial IR surveys with spotlight surveys of white-tailed deer and found IR surveys a more reliable density estimator. A wild horse and burro survey conducted in July near Yuma, AZ, found that these animals could be detected while bedded under salt cedar (*Tamarix pentandra*) (Bernatas 1999) suggesting that ambient temperature may not be the best indicator of thermal contrast. Temperatures during flights were in the high 80^{o}s F to low 90^{o}s F.

A major goal for the improvement of aerial survey estimates is to determine the number of animals missed during surveys (Samuel et al. 1987). The degree of visibility bias depends on many factors, including animal behavior and dispersion, observers, weather, vegetation cover, and equipment (Ackerman 1988). Visibility also may confound the estimation of age and sex ratios when males, females, or young have different visibility factors. Unsworth et al. (1990) found that to assure the most accurate and precise estimates when using the elk sightability technique, surveys should be conducted when group sizes are at a maximum and elk are using the most open habitats. In addition, double counting can be reduced by surveying elk when mobility is restricted by snow and using unit boundaries that restrict elk movements. Double counting can be avoided further during helicopter surveys by flying adjacent units consecutively and paying particular attention to the size and composition of groups near unit boundaries.

Our study finds that aerial IR provides a higher detection rate than the current helicopter survey being used to develop the population estimate in this area. Using the increased detection capabilities of an IR sensor over human vision and flight altitudes above 1,000 ft eliminates the problems associated with helicopter. The animals don't run or otherwise change behaviors therefore the probability of double counting or under counting can be sharply reduced. This study identified variables that influence sighting probability using an infrared sensor. These data indicate that all members of the population have a greater than zero probability of being detected using this survey technique. This study finds that IR provides for higher detection rate than the helicopter survey (i.e., 89 % vs 50 %). All age and sex classes may be detected, and it is possible to detect these animals in all habitats used. Although there does appear to be in increase in the detection rates with increased group size, it is not statistically significant ($p = 0.359$). Even small group sizes have a high detection rate (82 %).

The two greatest influences in detection rate are season of survey and search pattern as evidenced by the increase from 25 % to nearly 90 % when these parameters were tested in 1997 in Little Jacks Creek. A radial search pattern appears optimal for the highly dissected canyons allowing all possible look angles. Circling each orbit twice and having a 50 % overlap has increased the sightability from about 20 % in 1997 to 89 % in 1999. Airspeed of 80-90 knots appears optimal to allow the IR sensor operator to search the area. In 1998, the orbit radius was 1.6 km, however plotting the observed and missed groups indicated that the actual search radius was 0.8 km. Therefore, those sample groups classified within the orbit (i.e., being located within 1.6 km from the orbit center point), but were determined to be located greater than 0.8 km from the orbit center were missed. Orbit centers were plotted 0.8 km apart in 1999 to provide a better representation of the actual coverage of each orbit.

Trained observers are imperative to reliability traditional aerial surveys (Unsworth et al. 1990, Haroldson 1999). This is also true of aerial IR survey. Wiggers and Beckerman (1993) found that sensor operator bias was high resulting in a wide range (e.g., 25-80%) in detection rates. However, there was no cross training between the IR firm conducting the surveys and the wildlife biologist requesting the survey. Standard and tested search protocols were not established for subject species and habitat. Our initial tests found that the trained military sensor operator with over 2,000 hrs had a 25% detection rate for bighorn sheep in this study area. However, cross training where the biologist learned to operate the system and the sensor operator learned more about wildlife proved fruitful. Subsequently, survey search and scan protocols were established and detection rates increased. Using standard protocols there was little difference between sensor operators as evidenced by the between years ($p = 0.861$) comparisons. Wiggers and Beckerman (1993) also found that a biologist could review the IR tapes with reasonable accuracy after an eight-hour training period. This has limited application if the sensor operator collecting the data incurs survey bias or is ill trained to operate the system. (Basic training time for a sensor military operator is over 200 hours.)

Also influencing detection rate was the difference in surfacing temperature. Bighorn sheep on rock or talus slopes are more difficult to detect, although the detection rate is still fairly high (61 %). The study goal included determining when to stop the surveys because of increased temperature gain. As such, flights were conducted into periods that were not optimal for locating animals. Most “misses” occurred later in the survey period where background temperature occluded group detection. This is particularly true for groups located on rocky or gravelly terrain. Operationally, the sensor operator would suspend the survey prior to degraded detection.

Cost comparison

The helicopter survey for bighorn sheep in this area requires search both sides of the canyon and all mid-elevational benches within the canyon. A hypothetical, 10 miles long canyon reach with a lower, mid and upper elevational bench and the uplands were used to compare costs. The helicopter flight would require 4 passes on each side or 80 miles for a minimum time flight time at 40 knots of 2 hours. The cost is estimated at $1,200 for the flight time. Salaries for two biologists, plus fuel truck transport and other helicopter support requirements and ferry time costs are additional costs. This same segment would require 20 orbits for a minimum flight time of 2 hrs with the cost estimated at $1,100. Additional biologists as observers are not required. Ferry time is typically less for a fixed wing and the hourly rate is much less.

Direct costs for a fixed wing airplane and FLIR are less as indicated above. Perhaps as important are the risk and stress issues. The detection rate is much higher, the risk to the observers and stress to the animals are sharply reduced. The IR survey costs could be reduced by modifications of the flight patterns based on knowledge of detection rates. A very high proportion of the collared animals were located in the uplands (63 %) or upper third of the canyon (24 %). The bighorn sheep in the sagebrush uplands were typically located during the first revolution of the orbit since there is very little to confound the detection. If the scanner passed over the group it was detected. As such, transects would be effective in the uplands reducing the survey time by for this segment of the habitat by 50 %. In addition, those groups located in the upper third of the canyon can be located using two revolutions of the orbits without using overlap a high proportion of the time. The survey time would be reduced by reducing the overlap of the orbits, hence reducing the number of orbits to be flown in a given canyon reach. The survey time and cost would be reduced through the use of transects in the uplands and modifying the sampling approach in the canyon.

Benefits of surveying for California bighorn sheep with IR sensors over traditional aerial surveys include: 1) IR sensors can detect animals at greater distances than human eyesight, especially animals that are not moving; 2) the aircraft can fly at higher altitude 1,500 – 2,000 ft vs. 30 ft, allowing for increased ground coverage in less time and decreased disturbance to study animals; 3) reduced costs; 4) increased detection rates; and 5) increased human safety.

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