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Aerial Thermal Infrared Census of Canada Geese in South Dakota

There was a 10.98 percent error difference between the estimates from aerial thermography flown at 455 m and the actual number of geese determined from counts made on aerial photographs

(Abstract on next page)

INTRODUCTION

CANADA GEESE (*Branta canadensis*) concentrate on the mainstem reservoirs of the Missouri River in central South Dakota during fall migration. A significant portion of these Canada geese are relatively large birds and are hunted and shot by large numbers of hunters who consider the birds as trophies. Commercial or controlled goose hunting operations are becoming more common and increasingly efficient at providing geese for hunters to shoot. The goose harvest and the potential for a larger harvest is increasing. This is cause for concern by goose managers in both state and federal wildlife management agencies, in regard to (1) extent of present harvest in relation to that which the goose population can withstand; (2) the proper distribution of harvest among areas, states, and people; and (3) the population size in relation to potential population size or population goal based on available nesting habitat.

Goose population distribution, trend, and status is determined by visual estimates made by trained observers in small aircraft during day-light flights. The trend of population distribution is toward fewer and larger concentrations of geese. This is due primarily to increased availability of food in controlled goose hunting areas. Accurate estimates of numbers of birds in these concentrations, and thus the entire population, are becoming more difficult, or impossible, to make. Photographic spot checks have indicated that visual estimates may be 50 to 75 percent lower than the actual numbers of birds in a concentration. The degree of error probably varies among observers, thereby resulting in inconsistent estimates.

An additional problem in the census of geese is that varying numbers of geese feed in surrounding agricultural areas during the day, and are not present on the water or in the immediate area when counts are made. A technique for estimating goose numbers, which relies on remotely sensed imagery collected at night when all geese are resting on the reservoirs, would provide for more accurate censusing. The results could provide a more reliable basis for regulation of harvest to meet population and harvest goals.

The development of airborne thermal infrared sensors has provided a potential method for censusing warm-blooded animals whose behavior would allow them to be more accurately censused during periods of darkness. Thermal infrared imagery has been used, with varying degrees of success, for the census of white-tailed deer (Croon *et al.*, 1968; McCullough *et al.*, 1969; Graves *et al.*, 1972); elk, moose, and deer (Wride and Baker, 1977); harp seals (Lavigne and Ronald, 1975); and polar bears (Brooks, 1970). Wyatt *et al.* (1980) recently evaluated statistically the use of remotely sensed thermal data for deer census. The effectiveness depends on the thermal characteristics of the animal and its habitat and the characteristics of the scanner.

These investigators evaluated census techniques based on imagery generated from aerial thermal scanner data. The production of imagery with the cathode ray tube (CRT) system may be

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 48, No. 12, December 1982, pp. 1869-1877.
0099-1112/82/4812-1869$02.25/0

limiting the information content of the imagery as a result of data smoothing during image generation. The thermal information interpretable by direct computer digitization of the analog thermal signal should surpass the visual representations generated on CRT produced images and may make counts of individual geese possible.

Goldsbrough (1977) concluded that there was a considerable improvement in thermal detail when contour plots were generated from digitized thermal scanner data. He reported an improvement in signal-to-noise ratio when an exponential smoothing technique was used.

The objective of this project was to evaluate the use of predawn aerial thermal infrared data for censusing Canada geese. In order to achieve this objective it was necessary to (1) determine which of two wavelength detectors (4.5 to 5.5 μm; 8.7 to 11.5 μm) would provide maximum apparent temperature contrast; (2) establish the ambient temperature range at which the procedures would be most effective; and (3) evaluate optimal altitude-resolution parameters for data collection. Both the visual interpretation of aerial thermal infrared imagery and the computerized digitization of the original analog signal were evaluated.

ABSTRACT: *Accurate goose census data are necessary to formulate harvest regulations and provide both maximum recreational opportunity and a more equitable distribution of harvest. Current methods for censusing Canada goose concentration on the mainstem reservoirs in South Dakota have sizable errors. Significant errors occur because a large proportion of the geese may be feeding away from the reservoir during counts and return only in the evening. The objective of this project is to determine the feasibility of an operational inventory utilizing predawn aerial thermal infrared data for censusing Canada geese. The apparent temperature of Canada geese was measured at varying environmental temperatures. The results of this data were used in conjunction with test flights to determine ambient temperature constraints for successful aerial thermal infrared data collection. Geese could be distinguished from the background of water or ice on aerial thermal infrared imagery collected with a trimetal detector (8.7 to 11.5 μm) at altitudes less than 455 m above ground level (AGL). There was a 10.98 percent error between estimates of goose numbers from thermal imagery and the number of geese determined from counts made on aerial photographs. The Signal Analysis and Dissemination Equipment (SADE) at RSI was modified for analog-to-digital conversion at several cross-track sampling rates from 190 to 10,500 samples per scan line. Digitization rates of 350, 1350, and 2670 samples per scan line were evaluated for delineating low densities of geese in widely dispersed flocks and for delineating density differences within high density flocks.*

RADIANT HEAT LOSS FROM CANADA GEESE

The major factors contributing to heat loss from a goose are conduction, convection, radiation, and evaporation. The temperature profile near the skin is determined solely by conduction (Birkebak *et al.*, 1966). A major proportion of the sensible (non-evaporative) heat loss from the back of a Canada goose resting on water can be attributed to a combination of convection and radiation. The radiated component, which can be measured with remote sensors, should be the most significant because the environment acts as a heat sink. Kelly *et al.* (1954) discussed the importance of heat loss by radiation in the energy balance of animals. Latent (evaporative) heat loss is insignificant at low temperatures (Salt and Zeuthen, 1960). Heat loss from the bill was probably negligible because resting or sleeping geese generally place their bill under their wing during cold weather.

The energy emitted from the surface of a goose depends not only on the temperature of the feathers, but also the emissivity of the surface as expressed by the Stephan-Boltzman Law (Campbell, 1977):

$$R = \epsilon\sigma T^4$$

where

R = energy emitted by non-blackbody, $W\ m^{-2}$;
ϵ = emissivity of the surface;
σ = Stephan-Boltzman constant, 5.67×10^{-8} $W\ m^{-2}\ K^4$; and
T = absolute temperature in °K.

The infrared emissivity and the apparent temperature of the Canada goose determine if sufficient thermal contrast exists between the goose and the background so that it can be distinguished on thermal imagery. Best and Fowler (1981) found that the mean emissivity of Canada geese was 0.962 ± 0.017 and was not significantly different from other species of geese. Canada geese have an insulating integument to minimize heat loss and reduce the temperature differential with the environment. However, Best and Fowler (1981) found that Canada geese have a relatively high radiant temperature relative to ambient air temperature, which should provide sufficient thermal contrast to distinguish geese from the background on thermal data. The rate of radiant heat loss from geese depends on the potential or temperature difference between the goose and the environment. The potential increases rapidly as ambient temperatures decrease.

In addition to ambient temperature, other climatic factors will effect the radiant heat loss for Canada geese. Moen (1974) and Moen and Jacobsen (1974) found that there was an increase in the radiant temperature on the surface of the integuments of white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), snowshoe hare (*Lepus americanus*), cottontail rabbit (*Sylirlagus floridanus*), and red fox (*Vulpus fulva*) when wind velocities increased. They reported that changes at lower wind velocities had a relatively greater effect than changes at higher wind velocities. Parker and Harlan (1972) and Moen and Jacobsen (1974) found that direct-beam solar radiation would result in a higher radiant temperature, which may increase apparent temperature contrasts during daylight data collection missions. Marble (1967) identified cloudy days as best for detecting big game animals from a snow background with a thermal scanner.

Procedures

Collection of Aerial Thermal Infrared Data

Aerial thermal infrared data of goose concentrations on the Missouri River reservoir in the Pierre, South Dakota area were collected five times between 16 November 1979 and 31 January 1980 with a single channel Daedalus* thermal scanner with a scan rate of 80 scans/sec. A brief description of the Daedalus thermal scanner and detectors used in this project was reported by Best and Fowler (1980). Thermal infrared data were collected both during daylight and predawn periods. Aerial photography was exposed concurrently with the thermal imagery during all daylight missions. Daylight missions were flown to develop interpretation procedures and to establish the goose density relationship. The photovoltaic (InSb) detector (4.5 to 5.5 μm) was used during the first daylight data collection mission only. The trimetal (Hg:Cd:Te) detector (8.7–11.5 μm) was used on all data collection missions. A 10° C temperature inversion was present at 305 m (1000 ft) AGL during the 16 November 1979 night data collection mission.

The aerial thermal infrared data were processed into a photographic format which was scaled to base maps and aerial photographs. The thermal data was 'level sliced' into equal temperature increments during the processing. The 'level slicing' process divides the voltage signal from the scanner into six equal voltage increments, which produce discrete gray tones on the photographic imagery. Each of the gray levels represent an equal apparent temperature increment. Any one or more consecutive levels can be further divided into six more levels to increase apparent temperature resolution.

Estimates of the Numbers of Geese

Goose counts were made on enlargements of aerial photography using the technique developed by Chatten (1952). Ten random counts were made within each region of relatively uniform goose density. The areas of each density region were measured with a Numonics electronic digital planimeter, and goose totals were calculated directly from these figures. Chatten (1952) found that the results from this technique were accurate to within 15 percent or less.

Areal measurements of goose concentrations on enlargements of aerial thermography and average goose densities determined from the aerial photography were used to estimate total goose numbers from the thermography for purposes of comparison. An average density of geese weighted for areal density differences was calculated from counts made on aerial photographs.

Digitization of Thermal Infrared Data

The original analog aerial thermal infrared data were converted to digital image arrays for computer processing. Thermal data of both high densities of geese on ice and open water background and low densities of widely dispersed geese were selected to evaluate the digitization process.

The Signal Analysis and Dissemination Equipment (SADE) system analog-to-digital conversion hardware and software were modified to accommodate a wider sampling range through time scaled playback and engineering changes. The system was redesigned to produce crosstrack sampling rates of 190, 350, 1350, 2670, and 10,500 samples per scan line. The five digitization rates are determined by the playback speed of the analog tape deck. The analog tape deck has three speeds for reproducing the recorded scanner signal: 30 inches per second (ips), 15 ips, and 3¾ ips. Using two compatible tape decks, one to repro-

* Inclusion in this report of registered trade names or trade marks does not constitute an endorsement by the authors or the Remote Sensing Institute.

duce the original signal at 3¾ ips and re-record at 30 ips, provides five playback rates for digitization.

An Ohio Scientific Microprocessor System was interfaced to command/control the conversion process. Data sample-and-store software were implemented to build a digital image array during the conversion process. High spatial resolution digitization of experimental study areas yielded matrices of image data which were directly accessed, searched, isolated, enhanced, and displayed with existing software designed to utilize the disk file.

The aerial thermal infrared data were digitized at three rates—350, 1350, and 2670 samples per scan line—in this project. The lowest sampling rate generates pixels that represent ground intervals approximately two times the instantaneous-field-of-view (IFOV) of the original scanner data. The 1350 and 2670 digitization rates generate pixels that represent ground intervals approximately equal to ½ and ¼ the IFOV of the original scanner data, respectively.

A small subarea in the digital array that coincides with the center of a single aerial photograph was selected for display. The spatial arrangement of geese at the instant recorded by the photography only corresponds to slightly more than one scan line. Additional scan lines recorded between photographic frames will image spatial relationships as they change. Thus, the selection of a digital image subarea from the thermal data which is in close proximity to a photo frame center assures that the spatial relationships within the photo are as close as possible to those actually recorded by the scanner. The digital data were color encoded into eight equal intervals and displayed on color CRT. Software was utilized to improve the observation of temperature resolution by contrast stretching digital values.

Results and Discussion

Data Collection Requirements

The apparent temperature difference between Canada geese and the ambient temperature is not constant and increases with decreasing ambient temperatures (Figure 1). This relationship must be considered in flight planning to determine if the apparent temperature of the geese will be significantly different from the background temperature at a specific ambient temperature. It is an approximately linear relationship and can be calculated from the following statistical model:

$$T_{APD} = -0.322\,T_{AMB} + 6.510$$

where

T_{APD} = apparent temperature difference between goose and ambient (°C), and
T_{AMB} = ambient temperature (°C)

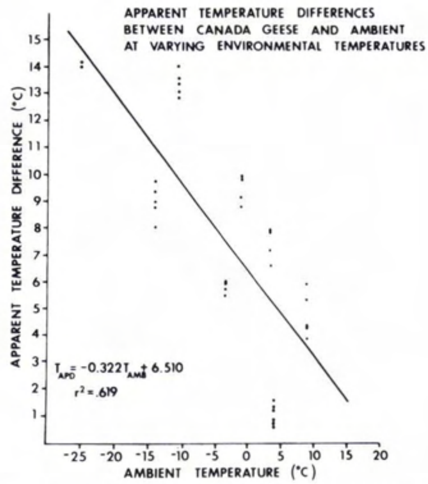


Fig. 1. Apparent goose temperature, ambient temperature differences determined with PRT radiometer.

The background from which the geese must be differentiated is open water during fall and early winter and water and ice during late winter. Both water and ice have a very uniform radiance and provide an ideal background. The emissivity of water is very close to that of a perfect blackbody so that the apparent background temperature is very close to the sensible temperature and can be measured with an immersed thermometer.

Background temperature used in conjunction with apparent goose temperature data can be used to determine optimal conditions for aerial thermal data collection (Figure 2). The "cross-hatched" region of Figure 2 indicates ambient temperature—water temperature constraints where the thermal contrast between geese and water background would be sufficient to detect geese

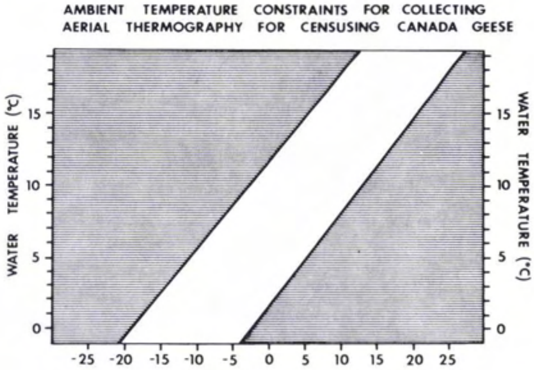


Fig. 2. Ambient temperature/background temperature constraints for collecting aerial thermography for detecting geese. The cross-hatched region represents ambient/water temperatures where sufficient contrast would be present to distinguish geese.

on thermal data. These data are based on the assumption that a minimum apparent temperature difference of 5° C is necessary to distinguish geese from an open water background.

INTERPRETATION OF AERIAL THERMAL INFRARED IMAGERY

The tone (lightness or darkness) on the thermal imagery is relative to the apparent temperatures of scene features. The lighter the tone the higher the relative apparent temperature. The temperature range on the imagery is determined by the operator during data collection. The optimal range would encompass only the total range of temperatures of landscapes. The thermal data can be processed into analog or digital image formats. The analog format is a continuous tone image representing a continuous temperature range. The contrast of the image can be controlled during image generation by a variable gain control.

The effectiveness of aerial thermal infrared data as a census tool is a function of both apparent temperature resolution and spatial resolution. Croon *et al.* (1968) reported that single animals smaller than a fox probably cannot be detected with present thermal scanning equipment. The objective of this project is not to enumerate individual geese, but to determine the areal extent of goose concentrations and estimate total numbers as the product of area and goose density as determined from aerial photographs.

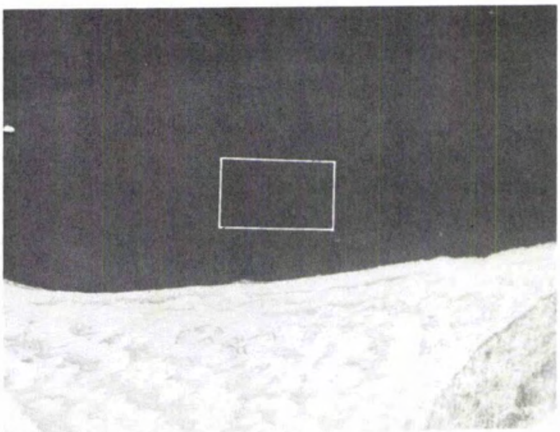
The minimum temperature that can be resolved by the Daedalus thermal scanner used in this project is 0.5° C and the spatial resolution is 2.5 milliradian. Consequently, the signal recorded by the scanner is an average of the apparent temperature of all objects within a resolution cell. The results of this study indicate that the apparent temperature of a goose must be at least 3° different from the background in order to produce a response which is different than the background alone.

Spatial resolution of the thermal scanner is a function of the altitude. The size of the resolution cell increases proportionally with the altitutde. Geese could not be resolved on thermal infrared imagery (thermography) collected at altitudes above 758 m (2500 ft) AGL. Goose concentrations could be delineated on altitudes of 455 m (1500 ft) and 305 m (1000 ft) AGL. Data collected at 305 m (1000 ft) AGL had the smallest spatial resolution (0.76 m at the nadir) and were best suited for delineating geese, especially when they occurred in low densities.

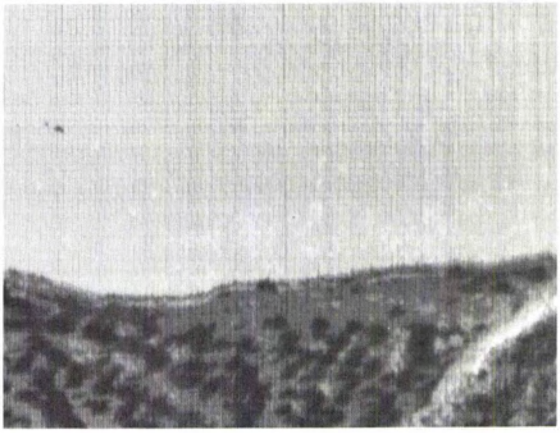
Geese could not be distinguished from the background at any altitude on thermography collected with the photovoltaic detector (4.5 to 5.5 μm). The signal-to-noise ratio was very low, resulting in data with very low temperature contrasts. This may be attributed to the very strong thermal absorption band, due to water vapor, that begins at about 5 μm. There is also some absorbance by carbon monoxide. The effects of ozone absorption would be minimal on the trimetal detector (8.7 to 11.5 mm) because of the low concentrations of ozone at the altitude flown.

Graves *et al.* (1972) successfully located white-tailed deer with the 3 to 5 μm detector under certain conditions. Croon *et al.* (1968) and McCullough *et al.* (1969) recommended the use of a detector sensitive to the 8 to 14 μm spectral region because peak radiation from animals occurs in this range, and it coincides with an "atmospheric window."

Very low densities of geese resting on open water could be distinguished on thermal imagery collected with the trimetal detector from 1000 ft AGL (Figure 3). The temperature of the water background was slightly above 0° C and the apparent temperature of the geese was approximately



(a)

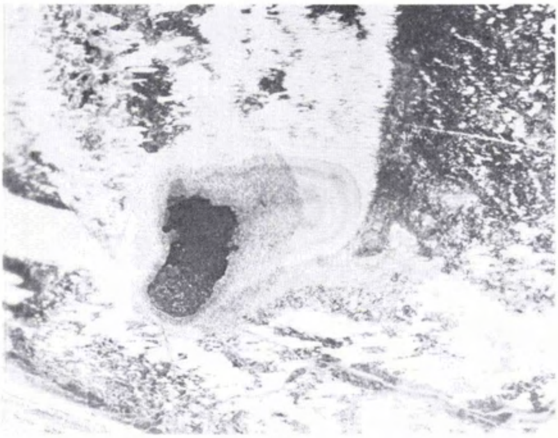


(b)

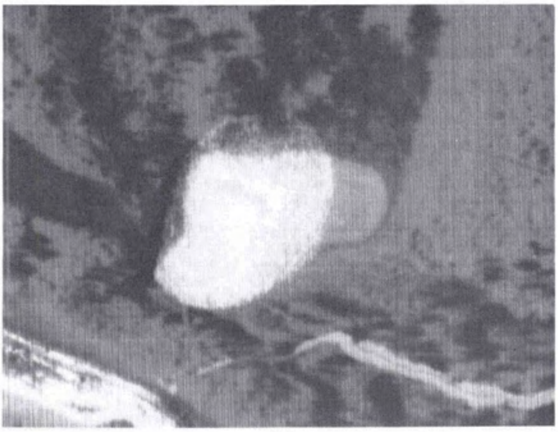
FIG. 3. Aerial photograph and thermal imagery (collected at 1000 ft AGL with trimetal detector) illustrating the detection of low densities of geese with open water background. (a) Aerial photograph, (b) Full range level-sliced thermal infrared imagery.

3.25° C. The small groups of geese appear as light "dots" on the thermal imagery. Larger groups have similar tones and appear in larger irregular shaped areas. Most groups of geese of two or more in close proximity could be distinguished from the water background. These small groups of geese could be individually counted on the imagery, which will provide a very accurate estimate in low density areas. Geese resting on the shore could not be easily distinguished from the background which had a less uniform radiance.

High densities of geese were easily distinguished from water and ice background on aerial thermography collected at altitudes of 455 m (1500 ft) or less (Figure 4). The thermal anomaly representing the geese has the lightest tones and warmest apparent temperature on the imagery. Differences in image texture within the area of geese are a result of differences in goose density. Densities of geese less than 2000 per hectare could not be consistently interpreted on the imagery with snow and ice background. In six goose concentration areas on two different days, only one had a singificantly large area of low density geese. There was an 8.9 percent error between the areas of geese over 2000/hectare on the thermography and the area of geese over 2000/hectare measured on the aerial photography.



(a)



(b)

FIG. 4. Aerial photography and thermal imagery (collected at 1000 ft AGL with trimetal detector) illustrating the detection of high densities of geese with a predominantly ice and snow background. (a) Aerial photograph, (b) High gain analog thermal infrared imagery.

The average density of geese in six goose concentrations on two different days, as determined from aerial photography, was 4301 geese per hectare. This figure was used to calculate estimates of total geese from area measurement on thermography. There was a 10.98 percent error difference between the estimates from thermography and the actual number of geese determined from counts of the aerial photography. Improvements in this estimate may be possible if apparent goose density differences were delineated on the thermography and the empirical goose density calculations were refined.

The thermal imagery can be generated with tones representing six equal discrete apparent temperature increments between blackbody temperatures. One or more of these apparent temperature increments can be "level sliced" into another six equal levels with a subsequent increase in temperature resolution. The selection of apparent temperature levels representing geese can be very difficult if the location of some geese which could be used as a training set is not known.

DIGITAL ANALYSIS OF THERMAL INFRARED DATA

The original thermal infrared radiance data are recorded as an analog signal. The radiance value at any point in the analog data is determined by the proportion of each target and the magnitude of the apparent temperature of each target within the IFOV. It may be possible to detect the presence of a target smaller than the IFOV if the apparent temperature difference between the target and background feature is large enough. It is not possible to detect the precise location; only that the target is within that IFOV.

The cross-track resolution of the recorded scanner analog data is a function of the scanner and detector viewing geometry and the altitude of data collection. The smallest IFOV is at the nadir and the largest is at the maximum look angle. The IFOV is 0.76 m (2.5 ft) at the nadir and 1.46 m (4.8 ft) at the maximum look angle when data are collected at an altitude of 305 m (1000 ft) with the 2.5 milliradian detector and Daedalus thermal scanner system used in this project.

The effective ground spacing of cross-track IFOVs in the digital data is determined by the sampling rate and the altitude of the data collection. The along-track coverage and resolution is a function of aircraft speed, altitude, and scanner characteristics and is not changed by digitization. The effective along-track resolution of the system used is approximately 0.76 m (2.5 ft) when data are collected at an altitude of 305 m (1000 ft) AGL.

Subtle tonal differences related to small apparent temperature differences are difficult to detect on continuous tone analog aerial thermography. Visual interpretations of geese on thermography can be very subjective if the apparent temperature of geese is close to that of the open water or snow and ice background. Interpretations are further complicated when geese are present in low numbers in widely dispersed flocks (Figure 3).

Digitization assigns a discrete value, relative to the thermal radiance, to each picture element (pixel). Pixels can be color encoded in up to 16 equal apparent temperature increments and displayed on the SADE monitor. Three-dimensional plots of pixel values were generated for the small subarea, outlined by the rectangle in Figure 3, in order to evaluate digitization rates (Figure 5). The height of the peak is relative to the digital value. Pixels in which geese are present have the highest digital values. Only pixels with a value greater than 224 are included in the display. The exact digital value threshold selected to isolate geese is dependent on environmental conditions and scanner setup.

The lowest sampling rate generates pixels that represent ground intervals approximately twice the size of the IFOV of the original scanner data. The probability of detecting a single goose or small groups of geese decreases when the sampling interval is greater than the IFOV. These data are suitable for previewing and determining the location of geese. The two higher digitization rates generate pixels that represent ground intervals smaller than the IFOV of the original scanner data. The cross-track array dimension increases proportionally with the digitization rate which can result in cross-track aspect distortion of data displays. The aspect was corrected during generation of the three-dimensional illustrations. An increase in the digitization rate increases the probability of detecting a goose by increasing the probability of sampling a peak in the original analog data. Furthermore, there is a potential for more pixels per goose at higher digitization rates. It was possible to identify pixels that may be small groups or individual geese at the higher digitization rates but it was not possible to distinguish individual geese that were in close proximity.

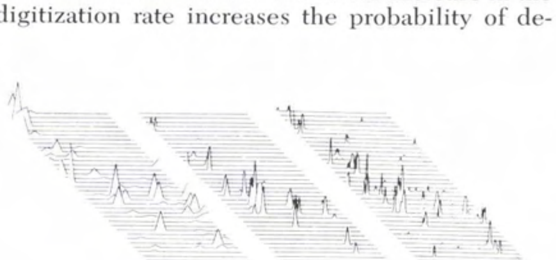


FIG. 5. Three-dimensional plots of pixel valves generated for the subarea outlined by the rectangle in Figure 3. Plot scales have been adjusted to offset the increasing number of samples per scan line.

When geese occur in large dense flocks, it is not difficult to interpret the location or aerial extent of the flocks on thermography (Figure 4). However, subjectivity in delineating areas of different densities of geese within the flock may result in errors when estimating total numbers. Digitization and thresholding can be used to isolate thermal anomalies related to differences in goose density. The thermal patterns of the high density goose flocks were similar at the three digitization rates tested in this project. The colors within the flock on digital monitor display reflect differences in apparent temperature that may be a result of goose density differences. The SADE system has a built-in planimeter which may be used to measure the area of any one or more color levels. The mid-range digitization rate (1350 samples per scan line) would probably provide the best results. At this digitization rate, the ground interval represented by a pixel is smaller than the IFOV of the original data and the data matrix is smaller and more manageable then at higher digitization rates.

Contrast stretch options available on the SADE system can be employed to enhance apparent temperature differences in the digital displays. Contrast options can also be used to refine the thresholding of the digital matrix. There is a potential for improving the spatial resolution of aerial thermal infrared data if a proportion estimation algorithm can be developed to calculate digital pixel values based on the overlapping IFOVs of the original analog data and the digitization rate. It is possible to develop software to improve the signal-to-noise ratio using the oversampling of the higher digitization rates to average out certain noise components.

SUMMARY AND CONCLUSIONS

Canada geese can be distinguished from a water or ice background on aerial thermal infrared imagery. The techniques developed in this project might be used in an operational predawn census of Canada geese during fall migration when geese are concentrated on open water refuges. Estimates of geese in high concentrations can be calculated from measurements of the area of geese made on thermal images and empirical goose densities derived from aerial photographs. Level slicing of the thermal data prior to generating an image increases the temperature resolution of the image, which will improve the apparent temperature contrast on level sliced images. High gain analog or full range level sliced images are the easiest to produce and should be used except when contrast is very low.

The spatial resolution of the thermal scanner that was used in this project limited the altitude for data collection to 1500 ft AGL or less. The best results were obtained when data were collected at 1000 ft AGL. The photovoltaic detector did not provide sufficient apparent temperature contrasts to distinguish geese from the background under the environmental conditions experienced during the test flight. Data collected with the trimetal detector produced imagery best suited to the objectives of this project.

The visual interpretation of Canada geese on aerial thermal infrared imagery can be very subjective due to the small size of the geese and lack of apparent temperature contrast under certain environmental conditions. The delineation of the thermal infrared signature of geese on open water or snow and ice background requires intense sampling rates compatible with the target size at the altitudes involved, signal frequency fidelity, and recording media playback rates. The computerized digital analysis of the aerial thermal infrared analog signal can generate sampling rates that represent ground increments smaller than the IFOV of the scanner system. It may be possible to improve the spatial resolution of aerial thermal infrared data if a proportion estimation algorithm can be developed to calculate digital pixel values based on the overlapping IFOVs of the original analog signal and the digitization rate. Thresholding and contrast stretch options can be used to enhance apparent temperature differences and reduce interpretation subjectivity.

There is information present in the analog signal that is not interpretable on thermography which may be developed with proper processing techniques into an improved source of thermal infrared information. These techniques could replace current census methods and provide more reliable census data. Accurate census data are necessary to formulate harvest regulations which provide both maximum recreational opportunity and more equitable distribution of harvest.

Acknowledgments

The authors would like to extend their sincere appreciation to Mr. Gerald Jasmer and Mr. Roger Brees for the many hours spent helping on the project. We are particularly grateful to Mr. Jean Mehegan for allowing us to make apparent temperature measurements of his hand reared Canada geese. We are indebted to Mr. John Link, Mr. Paul Bultsma, Mr. Gerald Jasmer, Mr. Robert Houck, and the Lake Sharpe Goose Ranch for donating the goose skins used for emissivity measurements. Funding for this project is provided by the South Dakota Department of Game, Fish and Parks and the NASA Technology Transfer Division under grant #NGL-42-003-007.

References

Best, R. G., and R. Fowler, 1980. Thermal infrared census of Canada geese in South Dakota, pages 21–53 in *Remote sensing applications to resource problems in South Dakota.* Semi-Annual Rpt. SDSU-RSI-80-02. 110 pp.

———, 1981. Infrared emissivity and radiant surface temperatures of Canada and snow geese. *J. Wildl. Manage.* 45(4):1026-1029.

Birkebak, R. C., E. A. LeFebure, and D. G. Raveling, 1966. *Estimated heat loss from Canada geese for varying environmental temperatures.* Minnesota Museum Nat. Hist. Tech. Rept. 11, 25 p.

Brooks, J. W., 1970. Infrared scanning of polar bear, *Bears and their management,* IUCN Pub. No. 23, Calgary, Canada.

Campbell, G. S., 1977. *An introduction to environmental biophysics.* Springer-Verlag. New York, New York. 157 p.

Chatten, J. E., 1952. Appraisal of California waterfowl concentrations by aerial photography. *Trans. N. American Wild. Conf.,* Wildlife Management Inst., Washington, D.C., pp. 421-426.

Goldsbrough, P. F., 1977. Digital processing of analog thermal infrared scanner data. *Photogrammetric Engineering and Remote Sensing* 43(2):145-153.

Croon, G. W., D. R. McCullough, C. E. Olson, and J. M. Queal, 1968. Infrared scanning techniques for big game censusing. *J. Wildl. Manage.* 32:751-759.

Graves, H. G., E. D. Bellis, and W. M. Knuth, 1972. Censusing white-tailed deer by airborne thermal infrared imagery. *J. Wildl. Manage.* 36:875-884.

Kelly, G. F., T. E. Bond, and H. Hertman, 1954. The role of thermal radiation in animal ecology. *Ecology* 35:562-569.

Lavigne, D. M., and K. Ronald, 1975. *Improved remote sensing techniques for evaluating seal populations.* ICES C.M. 1975. 1N:12.

Marble, H. P., 1967. *Radiation from big game and background: a control study for infrared scanner census.* M.S. Thesis. Univ. Montana, Missoula. 86 pp.

McCullough, G. W., C. E. Olson, and L. M. Queal, 1969. Progress in large animal census by thermal mapping. Pages 138-147 in P. L. Johnson, ed., *Remote Sensing in Ecology.* Univ. Georgia Press. Athens.

Moen, A. N., 1974. Radiant temperatures of hair surfaces. *J. Range Manage.* 27:401-403.

Moen, A. N., and F. L. Jacobsen, 1974. Changes in radiant temperature of animal surfaces with wind radiation. *J. Wildl. Manage.* 38:366-368.

Parker, H. D., Jr., and J. C. Harlan, 1972. *Solar radiation affects radiant temperature of a deer surface.* U.S.

For. Serv. Res. Note Rm-213, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 4 p.

Salt, G. W., and E. Zeuthen, 1960. The respiratory system. Pages 363-409 in A. J. Marshall, ed., *Biology and comparative physiology of birds*. Vol. 1 Academic Press, New York. 518 p.

Wride, M. C., and K. Baker, 1977. Thermal imagery for census of ungulates. *Proc. II Int. Symp. of Remote Sensing of Environ.*, Univ. Michigan Ext. Service. 11:1091-1099.

Wyatt, C. L., M. Trivedi, D. R. Anderson, 1980. Statistical evaluation of remotely sensed thermal data for deer census. *J. Wildl. Manage.* 44:397-402.

(Received 23 November 1981; accepted 28 April 1982; revised 18 May 1982)

Rocky Mountain Region
AMERICAN SOCIETY OF PHOTOGRAMMETRY
and
Colorado Section
AMERICAN CONGRESS ON SURVEYING AND MAPPING

17 TH ANNUAL SYMPOSIUM AND WORKSHOPS

REGENCY INN — DENVER, COLORADO — JANUARY 10 - 14, 1983

WORKSHOP REGISTRATION

(Preregistration mandatory to guarantee Workshop space and fees)

A — ACSM / PLSC Plane Coordinates / Projection Workshop

- ☐ "Plane Coordinates" - $75 — January 10
- ☐ "Projections / State Plane Coordinates / UTM & Problems" - $150 — January 11 - 12
- ☐ "All of the above" - $160 — January 10 - 12

B —

- ☐ "BLM / ASP Aerial Photography and Photo Interpretation" - $75 — January 11 - 12

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