TECHNICAL AND TECHNOLOGICAL ALTERNATIVES FOR AERIAL MOOSE (*Alces alces*) SURVEY

by

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ABSTRACT

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Moose (*Alces alces*) aerial surveys provide the information needed for effective management only when they are accurate and precise. I aimed to identify gaps in and improve understanding of aerial moose surveys in North America by comparing survey techniques and exploring an application of thermal camera technology. Current aerial moose survey methods are compared in a jurisdictional review, including approaches to correcting visibility bias and a discussion of implementation of new technological advancements. Stratified random block (SRB) surveys are the most common, alongside distance sampling (DS) and other survey types. Thermal imagery, Geographic Information Systems (GIS), and Global Positioning Systems (GPS) have been implemented into survey designs to improve the accuracy of estimates or logistics of the survey.

Using a virtual population of moose derived from Newfoundland aerial moose survey observations, a simulation of SRB and two DS surveys is used to compare accuracy, precision, and effort of each survey type. DS survey transects are spaced 1000- and 5559-m apart, and both survey types are sampled at high (~3 moose/km^2) and medium (~1 moose/km^2) densities. Accuracy is used as the bias in the simulation and statistically significant differences in precision and effort occur for each survey type.

The final chapter focuses on the use of thermal and colour cameras for locating moose and explores a 22-km^2 study site located at La Verendrye Provincial Park, Ontario. Collared moose travelling from Grand Portage Indian Reservation in Minnesota are visible in colour and thermal orthophotos. Moose thermal hotspots are computed from the thermal imagery, in a automated model. Hotspots were then examined manually. Two thermal hotspots over open water are misidentified as moose and 19 of 20 moose in the imagery were correctly identified by the automated search.

Management implications of the study are that DS is a viable alternative to SRB surveys and that thermal aerial imagery is limited to animal counts without correction. Under the simulated conditions, DS performs comparably to SRB surveys and is possibly less expensive, or at least less variable in cost. Manual identification of moose by viewing colour imagery is still required to complement a thermal-imagery system, and sexing moose is not achievable from orthophotos alone.

Keywords: moose, *Alces alces*, aerial survey, thermal imagery, remote sensing, distance sampling, stratified random block survey

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Moose (*Alces alces*) are a commercially important species in many jurisdictions across North America (Timmerman 2003). Hunters and nature enthusiasts travel the world to see moose, and moose hunting is also enjoyed by local and indigenous people. Effective population management is necessary to sustain a moose population and the hunting and viewing opportunities it affords. Population estimates are also important for other endeavours, such as to inform mitigation of the effects of mining and forestry developments. Regular aerial surveys, for both population abundance as well as age and sex ratios, provide the information needed for effective management as long as they are accurate and precise (Timmermann 1993).

As technology and understanding of survey techniques improve over time, methods for moose management, and monitoring in particular, should also be examined and evaluated. Every jurisdiction will have differing objectives and constraints for aerial moose surveys, sometimes leading to the development of new or altered techniques. Advances in technology, such as from thermal cameras, may also lead to the exploration of new techniques. This thesis looked at the ways aerial moose surveys are improving in jurisdictions across North America, as well as at specific cases of surveys and the application of thermal camera technology.

1.1 PURPOSE

The purpose of this thesis was to identify gaps in and improve understanding of aerial moose surveys in North America by comparing survey types and exploring thermal technology.

1.2 OBJECTIVES

i. To evaluate the current moose aerial survey techniques in jurisdictions across North America.
ii. To evaluate the accuracy, precision, and efficiency of distance sampling (DS) versus current methods of stratified random block (SRB) surveys of simulated moose on a virtual landscape.
iii. To develop and explore a proof of concept of the application of thermal and colour orthoimagery for locating moose.

2.0 LITERATURE REVIEW: A JURISDICTIONAL REVIEW OF AERIAL MOOSE SURVEYS IN NORTH AMERICA

2.1 INTRODUCTION

Aerial surveys are the most common and practical method for estimating the abundance and distribution of moose (*Alces alces*) in North America. Moose have been surveyed from the air since the first recorded fixed-wing transect survey on Isle Royale in 1945 (Timmermann 1993). Aerial surveys of moose can be used to measure population sizes, determine population trends over time, estimate annual recruitment, and build confidence in public opinion of moose management. The population parameters obtained, usually from successive aerial surveys, include density, sex and age ratios, recruitment (usually into the midwinter population, *i.e.*, of eight-month old moose), mortality, and the rate of change in a population (Bontaites *et al.* 2000). Sex and age identification from aerial surveys of moose is outlined in detail by Timmermann (1993). The shortcomings of aerial surveys include their high cost, difficulty in access to appropriate aircraft and other equipment, difficulty in finding experienced aircraft crew and observers, a high error rate that arises from visibility bias, and limitations in scheduling created by winter weather conditions. Some of these shortcomings are perpetuated by lack of updated training and implementation of new techniques such as the "horseshoe posture" exhibited by bull moose (Crichton 2002). The technique may be used to identify moose but is not known by all observers even though it is a published and verified technique.

Survey types vary from jurisdiction to jurisdiction. Differences may arise from different funding models for moose management and from choosing the survey type that best fits the ecosystems, the management approach, and the financial outlook of a jurisdiction with respect to its goals for its moose population. It is important to note that, whereas moose have a range of social and economic values across North America, and their populations are declining or recovering in some jurisdictions, they have only once, in Nova Scotia, been listed as an at-risk species (Timmermann and Rodgers 2005). As there is a general lack of funding across jurisdictions, focus should be given to vulnerable, or likely to become vulnerable populations of moose. The purpose of this jurisdictional review is to present insights and developments related to aerial moose surveys in North America.

2.2 METHODS

Jurisdictions reviewed here include Canadian provinces and territories, as well as the United States, where some monitoring and management of the population occurs. Federal, First Nation, other indigenous, and protected-area jurisdictions were not included in this review to minimize overlap with the management implemented by state, provincial and territorial jurisdictions. Data were collected from: (1) peer-reviewed literature produced by the responsible agency in each jurisdiction; (2) management plans and survey reports by these agencies; and (3) online sources maintained by these agencies.

Review of peer-reviewed literature began with *Alces*, a journal devoted to the biology and management of moose, which has a North American focus. Articles that most recently described moose aerial survey techniques for each jurisdiction were prioritized. Further review of the peer-reviewed literature continued from citations in *Alces* articles or in management plans and survey reports. Reports on surveys of moose populations and moose management plans were obtained directly from provincial and territorial as well as state websites, where available. When not published in a report form, information from some jurisdictions came from updates on the agency website responsible for moose management in that jurisdiction.

Survey types, such as the stratified random block (SRB) survey and the GeoSpatial Population Estimator (GSPE), have manuals that have been made available to assist biologists and technicians with survey design. Manuals such as these are referenced to describe the methods of survey in this review.

2.3 SURVEY TYPES

Various types of moose aerial survey have been developed to improve accuracy of estimates of population parameters. Cost, efficiency, and ease of logistics are additional reasons that different survey types have been developed. The first surveys on moose were done along flight transects, but this approach has largely been discontinued in favour of a SRB survey, which improved accuracy (Timmermann 1993). Regardless of survey type, Timmermann's (1993) general recommendations for moose survey include: fresh (2-5 days after) snowfall, clear or overcast weather, wind speeds less than 16 km/h, survey times under 2-3 hours to prevent observer fatigue, use of only experienced observers, use of multiple observers to increase accuracy, and counts in early winter before moose retreat to heavy cover. Other recommendations include taking habitat selection and time of year, and peak time of moose activity into consideration when performing aerial moose surveys (Peterson and Page 1993). The following subsections describe the major survey types used in North American jurisdictions.

Stratified Random Block (SRB) Survey

The SRB survey is used by most jurisdictions in North America (Table 2.3.1; Timmerman 2003). Written into a user manual by Gasaway *et al.* (1986), the SRB survey design introduces a stratification step to reduce variance by grouping SUs expected to have similar moose densities, which then improves the overall precision of a moose density or abundance estimate. The study area is broken down into sampling units (SUs) that are then split into two or more (usually three) strata based on the expected density of moose. Strata can be identified from previous knowledge of the management area, or, preferably, with a pre-survey stratification flight. Weather can affect moose distribution and make strata identification even more difficult or skew results. Very few jurisdictions have the funding to do regular pre-survey flights. In a random block survey design, the variance of a population estimate can be decreased by increasing the number of SUs thus using more information. With stratification, the variance of estimates for each stratum is calculated separately and repeatedly, allowing for more precise population estimates and direction on when to cease sampling based on desired precision. A stratum with high moose density will have higher absolute values of variance in counts across SUs and additional sampling effort is directed to high-density strata than to low- and medium-density strata, using formulae described by Gasaway *et al.* (1986).

The general steps are to: (1) define a population and select the appropriate survey area; (2) divide the area into SUs; (3) stratify the area based on expected moose densities, preferably with a preliminary flight; (4) randomly select SUs in which to count moose, and, if using a more intensive search to determine a "sightability correction factor" (SCF, term for an approach to visibility bias), recount a subset of SUs with at least double the search intensity; and (5) calculate a moose population estimate with confidence limits, along with other population parameters.

Advances in Geographic Positioning Systems (GPS) and other Geographic Information Systems (GIS) tools have led to improvements to the original Gasaway *et al.* (1986) approach. For example, most jurisdictions employing SRB surveys for moose use onboard computers equipped with software to show SU boundaries and allow input of GPS coordinates for the aircraft route and any observed moose.

GeoSpatial Population Estimator (GSPE)

A relatively new technique adapted from Gasaway SRB surveys is the GSPE, which has been implemented with success in Alaska and the Canadian territories. The widely used Gasaway *et al.* (1986) SRB survey type is unsuitable for an expected distribution of moose that is non-random (Ver Hoef 2002). With the increase in availability and capability of GPS and GIS technologies, and with growth in the field of spatial statistics, the GSPE allows for: (1) estimates of moose populations in smaller zones nested within a survey area; (2) increased precision; and (3) more flexibility in designing the survey (Kellie and DeLong 2006).

The GSPE is used to calculate estimates of moose in unsampled SUs by using a fitted empirical semivariance function created from the distance between observed SUs, as well as the difference in observed moose density between each SU pair (Kellie and DeLong 2006). Semivariance for each SU pair is calculated as:

$$Semivariance_i = \frac{(d_i - d_j)^2}{2} \qquad \text{Eq. 1}$$

where d_i and d_j are the moose densities of the *i*th and *j*th SU respectively. The empirical semivariance is created by grouping the calculated semivariances into bins of set distances and retrieving the average semivariance for each distance bin. The resulting average semivariances for each distance bin are then modeled using a restricted maximum likelihood estimator. The final step uses the finite population block kriging method to predict moose densities in a high and a low stratum. Populations for each SU can then be estimated and a total estimate made across all SUs.

One of the major advantages of the GSPE survey type is the similar field methods to the SRB survey. Adoption of a GSPE requires less retraining of field staff and can offer a smooth transition from a SRB design (Boertje *et al.* 2009). An advantage over SRB surveys is that random sampling is not part of the GSPE, allowing for more systematic approaches to survey design. Assumptions of the GSPE are less stringent and can work around weather and other survey interruptions, simply by reducing the number of SUs counted or substituting SUs in areas that are more easily surveyed.

Distance Sampling (DS)

Previously known as modified transect surveys in the 1980s and 1990s, the original estimators from DS underperformed their counterparts from SRB surveys in terms of accuracy and precision (Timmermann 1993). Problems included difficulties in fitting a required, distance-based detection function as there was a lack of accuracy in the distance measurements from an aircraft (Wald and Nielson 2014). Recently, DS has been redeployed with adaptations enabled by GPS and GIS, and it allows for moose aerial surveys with more successful parameter estimation than precursors (Peters *et al.* 2014).

In general, DS uses sample points or, with moose and many other animals, line transects to survey populations, obtaining parameter estimates that reflect a functional response to distances of observed individuals to the observer or the point on the ground immediately below an aircraft. Assumptions of DS surveys are that: (1) objects directly on the transect or point where the observer is located have 100% detectability; (2) objects are stationary; and (3) distance measurements are exact (Thomas *et al.* 2010). The first assumption is not met for moose aerial surveys because of a blind spot under the aircraft and frequent heavy cover concealing moose, but DS-based estimates of moose density can be corrected with SCFs or by using multiple observers, just as for SRB surveys (Wald and Nielson 2014). The second and third assumptions are effectively met by designing a survey such that animals move slower than the observer (aircraft), and by using precise GPS technology.

While the distance between transects in DS is uniform, the starting coordinates of the first transect should be selected randomly so that the entire survey area has an equal opportunity of being surveyed (Thomas *et al.* 2010). Results from DS can be analyzed with the program Distance or packages in the R statistical software (Peters *et al.* 2014, Miller 2016). The development of a detection function is a significant component of the DS analysis and is done by assigning key functions and adjustment terms as the possible detection functions. Model distributions could be half-normal, uniform, or hazard-rate with sinusoidal or polynomial adjustment terms (Peters *et al.* 2014). The most probable detection functions are determined using model quality analysis with Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC). Once a detection function has been chosen, population estimates and other survey information can be exported from R or the Distance program.

<u>“Potvin” Double-Count (“Potvin”)</u>

The “Potvin” survey technique was developed to alleviate visibility bias in aerial white-tailed deer (*Odocoileus virginianus*) surveys in Quebec. New Brunswick was the first jurisdiction to apply the “Potvin” survey to moose (Cumberland 2012). The methods associated with the “Potvin” survey are described in Rivest *et al.* (1995). While flying line transects, two or four independent observers identify animals and classify them based on variables that would affect visibility. The variables include group size, activity level of animal, and degree of cover. Target animals are then stratified based on these visibility variables. “Potvin” surveys can only account for perception bias, the observers’ ability to see a target, and not availability bias, whether a target is in fact there (Rivest *et al.* 1995). Independence between observers is maintained by using a modified intercom system that connects the navigator, who records observations, with each of the two observers or observer-pairs (Potvin and Breton 2005). Observers cannot hear each other and should not make any attempt to communicate observations.

SUs should be >200 km^2 with transects 1 km apart to reduce chance of counting an animal twice (Cumberland 2012). In New Brunswick and Maine, GIS land classification and other habitat information are used to determine the SU based on its similarity to the overall study site (Kantar and Cumberland 2013). An advantage of the "Potvin" survey is that a portion of the visibility bias is accounted for during the survey, reflecting the survey conditions exactly (Rivest *et al.* 1995).

Other Techniques

Other aerial moose survey techniques that have been used in North American jurisdictions include total counts (TC), incidental, two-phase sample (TPS), and Airborne Imaging Multispectral Sensor-Thermal (AIMS-T). TC surveys are attempts at counting all moose in a select area. Visibility bias makes accounting for all moose improbable in practice, so many jurisdictions treat TC surveys as a minimum population estimate with no correction (DeCesare *et al.* 2016). TC surveys are usually done in jurisdictions with smaller moose populations that have well defined winter ranges. TPS (or double sampling) surveys are specific to Quebec and are an adaptation to surveying large areas with low moose density that loses efficiency over smaller survey areas. In a TPS survey, a fixed-wing aircraft is flown in transects searching for track networks. A second flight using a helicopter will investigate any track networks discovered, seeking to identify moose. The technique takes advantage of the efficiency of the fixed-wing aircraft and the manoeuvrability of the helicopter. An AIMS-T is a thermal imagery-based survey for moose that uses orthophotos of thermal and colour imagery. Discussion on AIMS-T and other thermal imagery continues in Section 2.6 New Technologies .

Table 2.3.1. Aerial survey types for North American moose management jurisdictions. Where jurisdictions employ two or more survey types, the main survey type is listed.

Survey Type	**Jurisdictions**
Stratified Random Block	Michigan, Minnesota, New Hampshire, British Columbia, Manitoba, Newfoundland, Nova Scotia, Ontario, Saskatchewan
GeoSpatial Population Estimator	Alaska, Northwest Territories, Yukon
Distance Sampling	New York, Washington, Alberta
"Potvin" Double Count	Maine, New Brunswick
Total Counts	Colorado, Montana, North Dakota, Utah, Wyoming
Other	Idaho (Incidental), Vermont (AIMS-T), Quebec (Two-phase sample)
No regular surveys	Connecticut, Massachusetts, Nevada, Oregon, Wisconsin

2.4 VISIBILITY BIAS

Aerial survey estimates have negative bias when observers miss animals (Rivest *et al.* 1995). Visibility (also referred to as detection or sightability) bias is the error that results from missed targets in a survey, in this case moose (Oehlers *et al.* 2012). The bias can come from observer fatigue, poor weather conditions, aircraft, or other factors that may make an animal difficult to see, such as heavy vegetation cover (Pollock and Kendall 1987). Many of these factors frequently go untested in aerial moose surveys (Gosse *et al.* 2002).

To correct visibility bias, many jurisdictions use a Sightability Correction Factor (SCF) to account for missed moose. Two main methods for determining a SCF are intensively resurveying a subsample of the SU, and using a mark-recapture technique with collared animals or independent observers. Many jurisdictions use one of these methods, or use a model or set SCF based on previous information (Table 2.4.1). Harris *et al.* (2015) found that sightability models borrowed from other states failed when applied to Washington moose estimates. Survey-specific SCFs should not be used on other surveys, because a correction factor created under one set of conditions may not reflect the correction needed for a survey with different conditions (Rivest *et al.* 1995). Funding sightability surveys or research into site-specific sightability models can be expensive, resulting in situations like in Utah, where a SCF of 80% that is based on a decades-old study continues to be used, even though it may not be accurate (Wolfe *et al.* 2010).

Visibility bias can be broken down into perception and availability biases. Perception bias is the error from missing an animal that is detectable, while availability bias describes the case when the target is unable to be seen at all. DS and "Potvin" survey techniques allow for correction of perception bias, but not availability bias (Potvin and Breton 2005). Additional SCFs can be used with those methods, such as from the common mark-resight distance sampling (MRDS). Attempts to minimize visibility bias include: using helicopters instead of fixed-wing aircraft, adopting strict survey protocols, applying a variety of statistical techniques, and correction with factors derived from known population sizes (Potvin and Breton 2005). Tests for visibility bias are: surveys of enclosures with known numbers of moose, a more accurate subset study, such as tracking marked animals as a sample of the known population, and use of tools like thermal cameras to assist detection.

Table 2.4.1. Approaches to correcting for visibility bias (undetected moose) in aerial surveys of moose by jurisdiction in North America.

Sightability Correction Technique	**Jurisdictions**
Intensive subsample survey	New Hampshire, Montana
Mark-resight estimate	Maine, Washington, New Brunswick
Visual obstruction estimate	Michigan, Minnesota, British Columbia
Model or fixed sightability correction factor (SCF) based on previous study	Idaho, Montana, Utah, Wyoming, Newfoundland
Built into survey design	Alaska, New York, Alberta, Northwest Territories, Yukon, Quebec
Deliberately uncorrected	Ontario

2.5 JURISDICTIONS

The North

The northernmost subspecies of moose, *A. a. gigas* or the Alaskan moose is found in Alaska and western Yukon. Vast remote areas and cold climates characterize the northern jurisdictions of North America. Alaska, Yukon and the Northwest Territories have all switched from SRB to GSPE surveys for moose over the last few decades.

The Alaska Department of Fish and Game has been at the forefront in the development of new approaches to moose aerial survey, and produced the technical manuals for both SRB and GSPE moose surveys (Gasaway *et al.* 1986, Kellie and DeLong 2006). Today in Alaska, moose surveys are conducted in Game Management Units (GMUs) every 3-5 years using the GSPE (Wald and Nielson 2014). The GSPE is usually more precise, robust to non-random sampling, and an improvement particularly in small survey areas when compared to the SRB (Ver Hoef 2008). In areas with heavy snow conditions or linear landscape features, DS may still be preferred in Alaska (Wald and Nielson 2014). Surveys are usually done in early- or late-winter, because of difficult weather and lighting conditions at other times of the year. As suggested by the GSPE manual, SUs are 2′ latitude by 5′ longitude for each of the northern jurisdictions (Kellie and DeLong 2006, Larter 2009)

Environment Yukon has adapted the GSPE technique to using Traditional Ecological Knowledge (TEK), stratification flights, and habitat quality to determine high and low strata (Clarke *et al.* 2014). Aerial moose surveys in the Yukon have changed their approach from modified transect surveys to SRB surveys to the GSPE currently used. One of the noticeable changes in moose surveys in Yukon is from the irregular SUs used in the SRB surveys to rectangular SUs in GSPE surveys (Clarke *et al.* 2014). While not necessary for GSPE, a SCF of 1.09 was applied, requiring SU selection to be randomized. Surveys are conducted in each Moose Management Unit (MMU) no more than once every five years since trends in northern moose populations change slowly (Environment Yukon 2016).

Moose in the Northwest Territories are co-managed by the Northwest Territories Department of Environment and Natural Resources (NWTENR) and First Nations groups (Larter 2009). After a 2003 workshop on moose management, the NWTENR established the GSPE method as the survey of choice in consultation with Aboriginal communities (Cluff 2005). In practice, continued consultation and workshops with Aboriginal representatives lead to TEK-based determination of high and low strata in an area to be surveyed. Where information is lacking, land cover information from satellite imagery can be used for further stratification (Larter 2009). Some regions will also be stratified for moose survey using incidental moose observations during bison (*Bison bison athabascae*) surveys (Cluff 2005). Standard GSPE methods from the *GeoSpatial Survey Operations Manual* (Kellie and DeLong 2006) are used for the rest of the survey (Davison and Callaghan 2011). SUs are chosen non-randomly and analysis of the survey data is done by the Alaska Department of Fish and Game (Cluff 2005).

Western United States

Moose are found in lower densities in the western states compared to Alaska, and management attention is more often focused on more abundant elk (*Cervus canadensis*), white-tailed deer, mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*) populations (Nadeau *et al.* 2017). Subspecies of moose in the western U.S. include *A. a. shirasi* (the Shiras moose) and *A. a. andersoni*. Moose aerial surveys in the western states are among the most underfunded and irregular of all jurisdictions, because of the challenges of working with widespread and low-density populations of moose and a focus on management of other ungulates.

The Colorado Division of Wildlife models moose population dynamics without regular aerial survey because of the difficulties and costs associated with flights over low-density populations of moose; the models are based on infrequent total counts of the entire moose winter range (Wagner 2006). The Idaho Department of Fish and Game uses no standardized method to examine moose populations across the state. Surveys are not conducted in every region since the logistics of surveying steep and heavily vegetated terrain are difficult (Toweill and Vecellio 2004). Incidental counts of moose are done while conducting elk surveys (Nadeau *et al.* 2017). Montana Fish, Wildlife and Parks biologists use minimum-count surveys for their low-density moose population. Annual surveys are limited to the denser subsets of moose populations in the northwest part of the state, and surveys occur only infrequently where moose are found in lower densities (DeCesare *et al.* 2014). Oregon and Nevada have seen recent moose range expansion, but only opportunistic or incidental surveys have been used to date to estimate moose abundance (Nadeau *et al.* 2017). The Utah Division of Wildlife

Resources combines moose and elk total count surveys, which are carried out approximately every three years on individual units based on expert opinion of biologists on what constitutes the ranges for these ungulates (Wolfe *et al.* 2010). The Washington Department of Fish and Wildlife recently started using Mark-Recapture Distance Sampling (MRDS) on an annual basis for the core moose winter range in an effort to standardize surveys and improve accuracy and precision (Harris *et al.* 2015b). Surveys in Washington result in indices of abundance rather than attempts at estimating density (Harris *et al.* 2015a). The Wyoming Game and Fish Department uses total count winter surveys conducted annually for some regions, as well as summer surveys in one management unit where moose can be found in open habitats (Brimeyer and Thomas 2004). Separate surveys to determine age and sex ratios may also be done in Wyoming (Monteith *et al.* 2015).

Midwest United States

Moose in the U.S. Midwest are declining and constitute small populations in Michigan, North Dakota, and Minnesota. Wisconsin has no moose population. The Michigan Department of Natural Resources conducts biannual SRB surveys in January (Largent *et al.* 2015). Moose have been extirpated in the south and only Michigan's Upper Peninsula range is surveyed (Dodge *et al.* 2004). SUs are approximately 3.2 km by 19.3 km and split into two strata, based on the results of past surveys and current reconnaissance surveys (Largent *et al.* 2015). Visibility bias is corrected with a visibility model based on visual obstruction and group size (Drummer and Aho 1998) or with a SCF of 75% specific to Isle Royale (Peterson and Page 1993). The North Dakota Game and Fish Department conducts annual winter surveys of moose in three areas aimed at total counts and focusing on a population trend rather than an accurate estimate (Maskey 2011). Moose in Minnesota are managed by partnerships between the Minnesota Department of Natural Resources and a number of First Nations bands (Edwards *et al.* 2004). Annual SRB surveys are conducted in the northeastern portion of the state in 4.3 km by 8.0 km SUs (Delgiudice 2016). SUs are stratified as high, medium, or low using land cover variables in a boosted regression tree prediction model (Fieberg and Lenarz 2012). A fourth stratum based on habitat was recently added to study the effects of fire and logging disturbance on moose population parameters (Delgiudice 2016). A sightability model is used to correct visibility bias based on a visual obstruction estimate represented by the proportion of vegetation covering an area 10 m around the moose (Lenarz 2011). The strength of Minnesota moose aerial surveys is the consistence of the standardized procedure adopted in 2005 that included a switch from fixed-wing aircraft to helicopters, irregular SUs to grid plots, and a double-count method of determining visibility bias to a sightability model (Fieberg and Lenarz 2012).

Northeastern United States

Growing or stable moose populations have existed in the northeastern U.S. states over the last few decades (Wattles and DeStefano 2011). These states can be split into two distinct groups, as moose are longer established in northern New England where they receive management attention, whereas relatively new moose populations, for which few or no aerial surveys have occurred, exist in southern New England (Wattles and DeStefano 2011).

Moose management is well developed in the northern New England states of Maine, New Hampshire, and Vermont. New Hampshire Fish and Game combines white-tailed deer hunter observations into a SRB survey modified to use Forward-Looking Infrared (FLIR) cameras that record the thermal signature of moose (Bontaites *et al.* 2000; Wattles and DeStefano 2011). SU boundaries are determined from municipal boundaries, as municipalities represent the finest resolution in hunter mail-out surveys that are used in part to determine strata. The cost of FLIR precludes thermal surveys over the entire state or even in select areas on a regular basis (Rines 2015). The Maine Department of Inland Fisheries and Wildlife has used various aerial survey types in the past, including a similar FLIR-modified SRB survey (Wattles and DeStefano 2011). Recently, the "Potvin" survey has been implemented in Maine in part to assist with stratification of the moose range, because fewer deer hunters exist in this state to assist with stratification compared to New Hampshire (Kantar and Cumberland 2013). The Vermont Fish and Wildlife Department has not conducted regular aerial moose surveys but has assisted with the development of the Airborne Imaging Multispectral Senor (AIMS-T) to survey moose using thermal imagery (Millette *et al.* 2011). Vermont's approach to thermal imagery involves orthophotos, photos taken facing directly down and easier integrated into GIS layers than photos taken from an oblique angle, as is the case in New Hampshire (Millette *et al.* 2014).

Moose recolonized Southern New England (Massachusetts, New York and Connecticut) as recently as the 1980s (Wattles and DeStefano 2011). The Massachusetts Department of Fish and Wildlife does not fly aerial surveys, and instead runs a New Hampshire-based regression model for white-tailed deer hunter observations that, combined with moose vehicle accident data, provides an idea of moose distribution. The Connecticut Department of Energy and Environmental Protection also does not conduct regular aerial surveys, but has begun drafting moose management plans. The New York Department of Energy and Conservation has begun working with universities to conduct research in part to determine moose abundance. The first aerial surveys in New York focused on moose distribution rather than abundance. Starting in 2015, DS has been tested for use in New York as part of a broader moose research program in this state (Fuller *et al.* 2016).

Western Canada

A long history of inventory of moose occurs in western Canada and, until recently, all four provinces (British Columbia, Alberta, Saskatchewan and Manitoba) used SRB aerial surveys. Alberta Environment and Parks recently switched focus from SRB surveys to a DS approach that is easier matched to other surveys in its Ecosystem Management Emulating Natural Disturbance (EMEND) project (Alberta Environment and Parks 2016a, 2016b). Peters *et al.* (2014) found that DS was capable of similar precision compared to SRB surveys, while reducing costs over a 10-year study. Wildlife Management Units (WMUs) may be surveyed for moose specifically, or receive a multispecies survey with other ungulates, as in the EMEND approach (Alberta Environment and Parks 2016c). DS for moose in Alberta is typically done in good weather and snow conditions during January and using helicopters for best visibility.

Manitoba Sustainable Development (previously Manitoba Conservation) primarily uses SRB surveys to monitor moose populations, but has adapted other approaches, such as TC, depending on the specific needs of a Game Hunting Area (GHA; Manitoba Sustainable Development, 2015, 2016a). Priority for aerial surveys of any "big game" species in Manitoba is based on indications of a change in a local population, public interest, a situation where a population is highly used, evidence for changes in the environment, and cases of economic development (Manitoba Sustainable Development 2016b). Specific areas of concern and areas where research is focused on moose may be surveyed annually (Crichton *et al.* 2004), but the majority of GHAs in Manitoba are surveyed much less frequently.

The Saskatchewan Ministry of Environment (formerly Saskatchewan Environment and Resource Management) conducts modified SRB surveys over four-year cycles (Arsenault 2000, Saskatchewan Ministry of Environment 2015). Aerial moose surveys in Saskatchewan began in 1954 with transect-based surveys, but the provincial authority started to change to SRB surveys in 1979. Methods follow Lynch and Shumaker (1995), and surveys are conducted in early December with a goal of a 90% confidence interval of 20-25% of the population estimate (Arsenault 2000). Priority for surveys is based on size of the moose population and moose harvest, with only hunted populations requiring a survey.

The British Columbia Ministry of Forests, Lands and Natural Resource Operations use multiple survey types to monitor moose. SRB surveys were shown to be more precise, while transects had a role in identifying moose distribution and population structure (Ministry of Sustainable Resource Management 2002). SRB surveys are the primary survey type (Quayle *et al.* 2001), but less intensive surveys done on specific populations of moose allow for determination of age and sex classes, variables that can be estimated economically and then be used in conjunction with population modelling (Ministry of Forests 2015). There is concern for improvement of the survey approach in response to climate change that creates more frequent situations of lack of snow (Gorley 2016). One response is a two-stratum survey where stratification is based on site characteristics, similar to the GSPE, and SUs are amalgamated in such a way that at least 4 km^2 of high-density moose areas are in the combined blocks in order to improve the odds of observing at least one moose per survey area (Heard *et al.* 2008). Minnesota's DNR Garmin extension for ESRI's ArcView and a Garmin GPS unit allow observers in British Columbia's surveys to accurately place an observed moose within a stratum or survey boundary.

<u>Central Canada</u>

The Ontario Ministry of Natural Resources and Forestry (MNRF) monitors moose using the SRB approach with a goal to survey WMUs every three to five years. The first SRB surveys in Ontario began in 1958 (Timmermann 1993). Two or three strata are outlined for each WMU depending on its area, the overall expected density of moose, and how accurately strata boundaries can be discerned (McLaren 2006). Stratification is based on spatial data, such as from a land classification, and other variables like the presence of white-tailed deer. If such data are lacking, a pre-census stratification flight with transects spaced 10 km apart can be flown. The high-density stratum should have the most blocks flown and each stratum should start with a survey goal to count at least five blocks, adding SUs until a 90% confidence interval falls within ±20% of the population estimate. The MNRF admits that moose aerial inventory alone does not necessarily provide an accurate population estimate, but the estimator is precise and reliable in determining trends, which are arguably more important in moose management overall (McLaren 2006). Precise surveys require very clear survey prerequisites in variables such as time since last snowfall, temperature, sky conditions, and wind speed. The Standards and Guidelines for Moose Population and Inventory in Ontario (McLaren 2006) details the specific conditions required for a survey, as well as all other aspects of Ontario moose aerial survey.

The Ministère des Forêts, de la Faune et des Parcs monitors moose in Québec using multiple survey types (Courtois 1997). Surveys are done in January or February in five- to seven-year intervals. For smaller survey units, the SRB survey is deployed, while for larger areas a TPS survey is deployed. For the TPS, sample units are 60 km^2 and start with transect survey from fixed-wing aircraft used to locate track networks (Crête *et al.* 1986). In the second phase, helicopters survey the track networks intensively to search for moose. This survey type has been shown to produce a consistent visibility bias of ~70% of the population estimate (Rivest and Crepeau 1990).

Atlantic Canada

Moose in Newfoundland and Labrador are managed by the province's Department of Environment and Conservation with assistance from the Department of Natural Resources (Newfoundland Department of Environment and Conservation 2015). Management of moose in Newfoundland differs slightly from the situation in other jurisdictions to account for a recognized overpopulation (McLaren *et al.* 2004). A modified SRB approach is used with 2- to 4-km^2 SUs and an average SCF of ~2.0

(McLaren and Mercer 2005), up to as high as 2.6 for heavily forested SUs (Gosse *et al.* 2002).

A coalition between the Nova Scotia Department of Natural Resources (NSDNR), Parks Canada, and the Unama'ki Institute of Natural Resources First Nations manage moose (*A. a. andersoni*) reintroduced from Alberta to Cape Breton Island (Bridgland *et al.* 2007), while the currently endangered native moose (*A. a. americana*) on the Nova Scotia mainland are specifically the responsibility of the NSDNR (Beazley *et al.* 2008). Recent surveys of mainland moose in Nova Scotia have been unsuccessful because of low densities, unpredictable maritime weather, low levels of snow, and lack of available helicopters (Pulsifer and Nette 1995, Beazley *et al.* 2006). Since 1998, and continuing as a joint effort, Parks Canada and NSDNR use SRB surveys for the Cape Breton population with a goal of 90% confidence intervals within ±20% of the population estimate (Bridgland *et al.* 2007). These surveys are conducted every two years, each time with a full stratification pre-survey flight and SUs of 2″ latitude by 1″ longitude. A separate survey for sex and age classification is carried out in spring.

The New Brunswick Department of Natural Resources (now Energy and Resource Development) has been adapting the "Potvin" double-count method, originally used for Quebec white-tailed deer surveys, for simultaneous moose population estimates (Cumberland 2012). SUs of Wildlife Management Zones (WMZs) are large and comprise six 43-km^2 tiles that are based on GIS map tiles. The ~258 km^2 SU that best represented the entire WMZ's topographical characteristics and habitat is then surveyed using 40-km transects spaced 1 km apart. Previous approaches to monitoring moose include the SRB survey based on Ontario methods (Boer 1988).

2.6 NEW TECHNOLOGIES AND CHOICE OF AIRCRAFT

Bontaites *et al.* (2000) tested the use of FLIR cameras in a SRB survey of moose in New Hampshire. The FLIR showed thermal heat signatures of moose and other animals in real time while the survey is conducted. Previous attempts with FLIR cameras in the 1960s and 1970s could not distinguish moose from other species as there were technological limits at the time. The goal in New Hampshire was to improve visibility with the FLIR camera. Tested on enclosed white-tailed deer populations, FLIR cameras showed great promise in identifying animals in open areas, but the approach failed in conifer stands (Potvin and Breton 2005). An advantage of imagery is that it can be digitally recorded to be analyzed or re-analyzed post-survey.

Millette *et al.* (2011) had success with the AIMS-T, the system that takes both thermal and colour imagery facing directly down. The advantage of the orthophotos is an almost seamless integration with GIS and other remotely sensed data. In addition, thermal imagery technology has been improving such that a “turning point” has been reached where heat signatures of large-bodied animals take on a shape that allows animals to be identified (Millette *et al.* 2011). Overcast skies provide the best opportunity for a study comparing environmental variables and moose would require expensive collars or would settle for coarse spatial information, but the fine-scale location data from thermal moose imagery allows a more efficient and accurate approach to estimating resource selection functions for moose (Millette *et al.* 2014).

The most significant downside to thermal imagery is that it is not able to sex moose. Determining the structure of the population is equally important for managing moose populations as at least 50 bulls:100 cows is needed for a stable population and ratios at parity to realize production potential (Aitken and Child 1992)

Most, if not all jurisdictions are now using GIS software throughout aerial moose surveys. Lynch and Shumaker (1995) used GIS software to build and export SU boundaries. At one time, the resulting maps were still printed, but now computers onboard the aircraft are used to record moose locations in real time (Poole *et al.* 1999). GPS and GIS technology has improved surveys by simplifying pre-survey mapping and preparation, improving navigation, recording flight path to calculate accurate coverage, and inputting survey data. Minnesota has developed an ESRI ArcMap Add-In that provides a moving map for aerial surveys, which can be used by any jurisdiction and for aerial surveys of animals other than moose (Wright *et al.* 2015).

The type of aircraft that is used to survey can have drastic effects on results. Helicopters are superior at counting moose and determining sex and age class (Gosse *et al.* 2002). Using fixed-wing aircraft can lower costs, possibly being able to survey more area and reduce variability. Helicopters allow for the possibility of reduced speed and greater manoeuvrability. As Quebec has shown with TPS surveys, there are advantages to being able to choose the right aircraft for the job. Alaska, Yukon and the Northwest Territories all frequently use fixed-wing aircraft to survey the vast ranges of moose in these jurisdictions. In the densely forested Isle Royale National Park, fixed-wing surveys were considered comparable to helicopter counts done elsewhere with similar intensity (Peterson and Page 1993)

2.7 ISSUES WITH MOOSE AERIAL SURVEYS

Issues in the accuracy and precision can occur when methods of aerial moose survey are not followed. For example, distance sampling surveys assume absolute accuracy at zero distance. In reality this is extremely unlikely and a correction is applied to account for the missed moose (Peters *et al.* 2014). Violating other assumptions, such as consistency in observer skill or awareness could also prove to limit the accuracy of aerial moose surveys. An inaccurate estimate of moose abundance or population distribution could tempt wildlife managers to allocate too many hunting tags and damage the population or not enough, bringing in complaints from hunters.

Moose aerial surveys in Ontario focus on high levels of precision to determine trends rather than focus on accuracy of stratified random block surveys. To do this, as many variables must be held constant as possible. This includes timing of surveys and observer accuracy which can be affected greatly by weather. Inconsistency could lead to poor precision which then decreases the effectiveness of a trend to depict what moose populations are doing.

It is common, if not universal, to include a CI or some estimate of precision with moose estimates from sampling techniques. A CI of 20% will allow for the detection of drastic changes in the population (Ward *et al.* 2000). Beyond this limit, an extreme decline in population could go unnoticed. Using a CI threshold allows for consistency in population management.

In determining harvest quotas, moose population estimates need to be used carefully. Dynamic, or changing, harvest quotas can exaggerate the probability of population collapse due to lag effects and environmental stochasticity (Fryxell 2010). Quotas should be managed incrementally and aim towards a stable level of effort from hunters. Jurisdictions such as Ontario focus solely on trends and may not survey a management area for multiple years. This enforces trend-like thinking and management decisions, as quick and drastic changes in population estimates could instigate unnecessarily reactive management decisions.

2.8 CONCLUSION

There are many ways to count moose from the air and new methods are possible with advances in technology and knowledge of sampling theory. Older methods may become practical again, such as the case for DS. Transect methods have been around since aerial moose surveys began, but even when a detection function based on distance was used in the 1970s, results did not compare favourably to those from SRB surveys (Thompson 1979). Inaccuracies in distance measuring have been virtually eliminated by GPS and GIS advancements over the past 30 years. Alberta and other jurisdictions are revisiting DS as a cost-effective option that can be as accurate and precise as SRB surveys today (Peters *et al.* 2014). The GSPE is another new survey method that was developed on the backbone of GIS, GPS, and spatial statistics. SRB surveys have themselves seen improvements in efficiency and logistics thanks to GIS integration. As the “gold standard” for decades, SRB surveys will need to keep improving or another survey may become the new norm. Its wide applicability to survey in the relative uniform boreal forest habitats and the availability of a user-friendly manual put together by Gasaway *et al.* (1986) are an explanation for the dominance of the SRB survey for estimating the parameters associated with a moose population. New opportunities may change that logic.

In addition to GPS and GIS, thermal camera technology is improving to the point where it could be used for all moose surveys. Cost of this technology has become minimal in comparison to the overall cost of aerial moose surveys (Millette *et al.* 2011). The technology is close to ready as a user-friendly interface for the moose observer, and could become widely adopted as soon as it is packaged with the best survey design and type. Millette *et al.* (2014) have already shown how easy it interfaces with GIS data. New applications of camera technology may be driven by a demand for using Unmanned Aerial Vehicles (UAVs) that can be safer than sending observers into the air (Chrétien *et al.* 2016). The changes in technology and survey design can present new opportunities for improvements to wildlife management generally.

3.0 A MODEL TO COMPARE ACCURACY AND EFFICIENCY OF DISTANCE SAMPLING AND STRATIFIED RANDOM BLOCK SURVEYS FOR MOOSE

3.1 INTRODUCTION

Stratified random block (SRB) surveys are the primary survey method for estimating moose population size in North America, but distance sampling (DS) is arguably as precise and accurate, and also more efficient in certain circumstances (Peters *et al.* 2014). The technique for moose SRB surveys has been outlined and described in detail by Gasaway *et al.* (1986). Slight modifications have been made to reflect changing technology and to suit the needs of a specific area or study (Lynch and Shumaker 1995). SRB surveys consume a lot of effort in terms of aircraft flight time, especially where moose population density is low (Peters *et al.* 2014). This inefficiency leads to increased costs that can limit frequency or spatial extent of surveys.

While a problem common to any survey is visibility bias, intensively resurveying is one of the main ways in moose surveys to develop a correction factor (often called sightability correction factor, SCF), notwithstanding that over heavy coniferous cover, even the most intensive aerial searches can miss moose (Peters *et al.* 2014). While not accounting for availability bias, DS inherently has a correction for observer bias based on the distance from observer to the target object. SRB has no inherent correction and must create corrections from extra flights or other data sources (Oehlers *et al.* 2012). Time or budgetary constraints limit the ability for extra flights to be done. As one example of a response to this issue, Ontario focuses on precision with their SRB surveys and does not correct estimates, rendering the value of moose surveys to trends as opposed to absolute values (McLaren 2006). Alberta similarly leaves surveys uncorrected for visibility bias if moose densities are below a threshold of 0.39 moose/km^2 (Peters *et al.* 2014).

DS in its current form is relatively new, as SRB has been the standard for many years. Multiple jurisdictions are considering the effectiveness of DS over SRB. In an Alberta study comparing DS and SRB surveys, both survey techniques achieved similar estimates with comparable precision when conducted in the same year (Peters *et al.* 2014). A similar effort, in terms of flying time, required a twofold expenditure for SRB without including the additional costs of stratification flights. Part of the explanation is that precision in DS is based on subject (*i.e.*, moose) encounter rates, and is not as reliant on the proportion of a population surveyed. As DS has been shown to outperform SRB surveys in medium- to high-density moose populations elsewhere (Peters *et al.* 2014), DS may be a preferred survey type in Newfoundland, where moose population density is much higher than in many other jurisdictions (McLaren *et al.* 2004). Where effective, adoption of DS surveys could lead to more frequent aerial moose inventories, and thus, better moose management. Accuracy and effort are fundamental in determining how effective a moose aerial survey will be.

The comparison of DS and SRB surveys done by Peters *et al.* (2014) was limited to one year of overlap. In addition, moose aerial surveys are not considered effective or accurate for a single survey; trends from estimates made over multiple years should be used for moose management. With that logic in mind, a real-world survey comparison lacks the consistency in variables needed to compare DS to SRB. Simulated models, on the other hand, allow for direct control of variables, such as probability of detection and number of target animals. To assess DS and SRB aerial moose surveys as an extension of the empirical work done elsewhere, I used a simulation of aerial moose surveys on a virtual population to compare accuracy, precision (expressed as the size of the confidence interval, CI, on the estimate) and effort associated with simulated aerial moose surveys derived from Newfoundland moose inventory data.

3.2 METHODS

The general methods for SRB surveys and DS were described in Chapter 2. Specific methods as they have been adapted for the modeling exercise in this chapter are described below.

Study Area

Newfoundland is 112 000 km^2 in area, of which two-thirds is forested (McLaren *et al.* 2004). Tree species are mainly balsam fir (*Abies balsamea*), white spruce (*Picea* glauca) and black spruce (*Picea mariana*), mixed with pioneer species that include *Belula* spp. and *Populus tremuloides*, as well as tolerant hardwoods such as *Acer* spp. and *Sorbus* spp. (McLaren and Mercer 2005). Moose distribution data were simulated using the stratified SUs from Moose Management Area (MMA) 15, also known as Twin Lakes, from an aerial survey conducted in 2014. MMA 15 is 3500 km^2 and almost 75% forested, with other areas in shrubland, lakes or municipal areas. Sampling units (SUs) where total moose counts were attempted ranged from 2 km^2 to 4 km^2 with the basic shape being 2-km by 2-km square (Figure 3.2.1). To create a dataset of moose densities for each stratum, other MMAs were used for strata density determination.

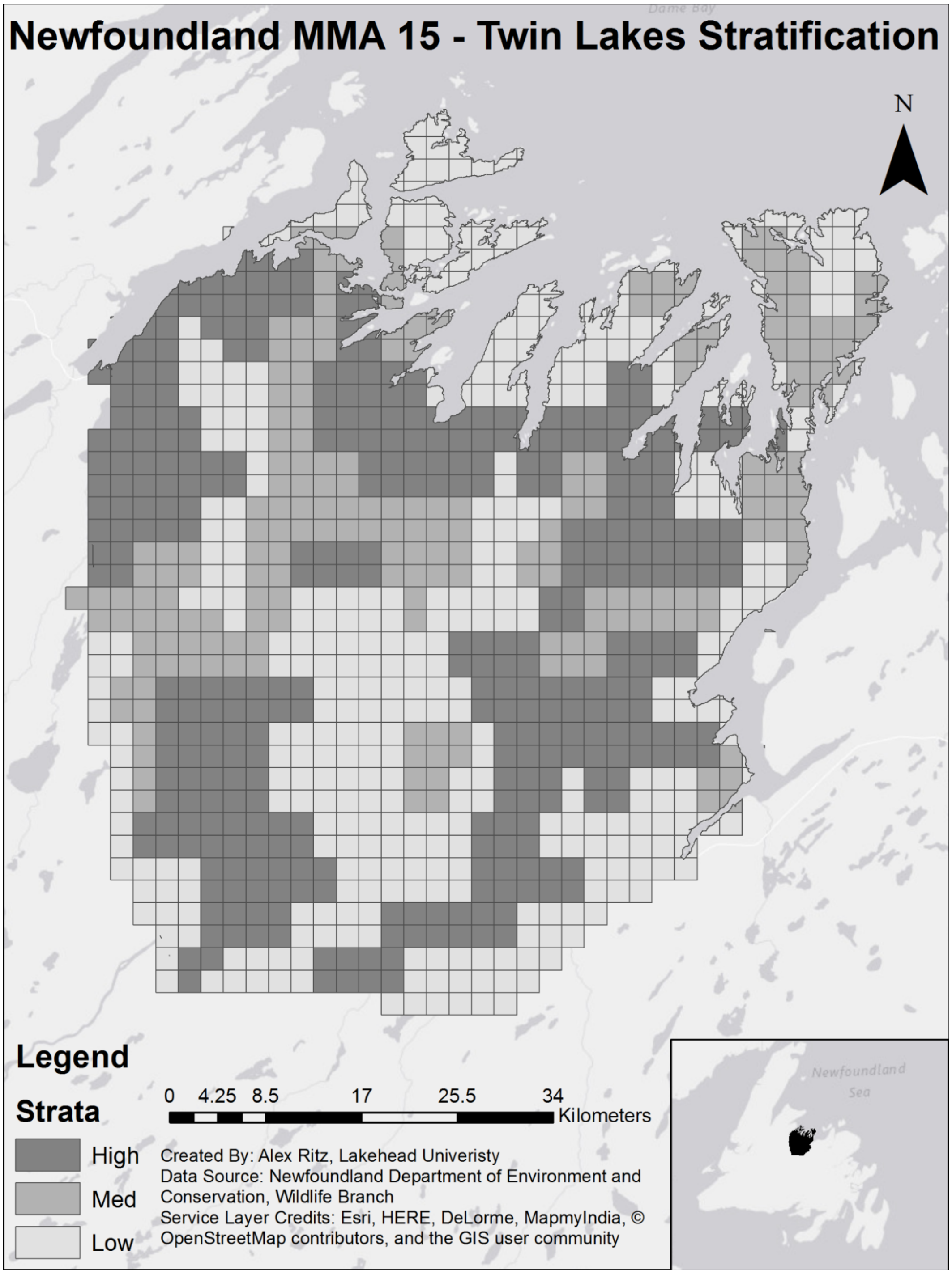

Figure 3.2.1. Map of stratification for Moose Management Area 15, Twin Lakes, in Newfoundland, where moose observations were used as a case model for simulating a set of aerial surveys.

Virtual Population

Moose observations from aerial surveys for MMAs that occurred between 2011 and 2016, as well as forest cover and SU stratification for MMA 15 in 2014, were provided by the Newfoundland Wildlife Division of the Department of Environment and Conservation, Newfoundland and Labrador. Moose observations from high-, medium-, and low-strata were used to create ten thousand randomized frequencies of moose density for each stratum (Figure 3.2.2). The resulting random lists were then each divided by a density adjustment variable (DAV=0.853), calculated from Bergerud and Manuel's (1969) sightability calculations, and then multiplied by desired treatment density to create high (~3 moose/km^2) and low (~1 moose/km^2) “moose” (object) densities. Each SU was then assigned a random density from its respective stratum and imported to ArcGIS (ESRI 2012).

Moose aggregation within SUs has been found to random (Bergerud and Manuel 1969), justifying a choice of random points to represent moose within each SU. Therefore, the extension Hawth’s Tools (Beyer 2004) was used to access the generate random points function within each SU. The add XY coordinates function in ArcGIS assigned each point coordinates that were used in the simulated DS and SRB surveys. Forest cover over each SU was used as an index of visibility.

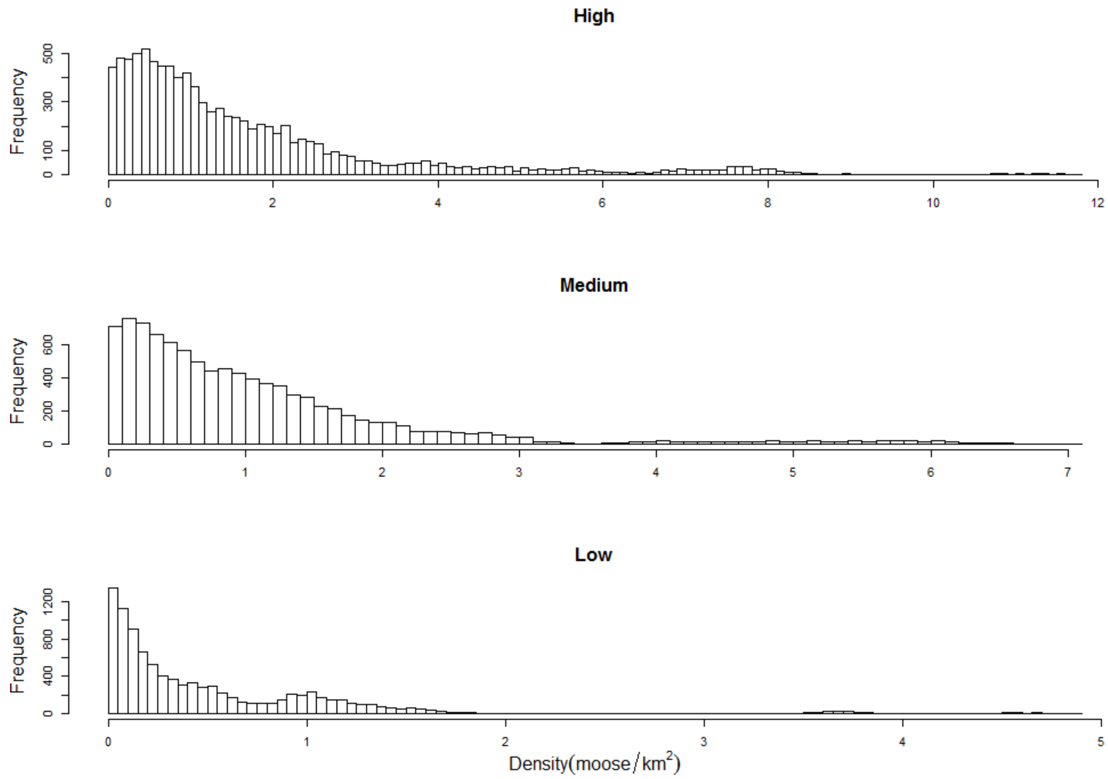

Figure 3.2.2. Histograms of random moose densities for high, medium, and low strata created using density curves derived from Newfoundland moose observations in each stratum.

The probability of detecting moose was based on the function developed by Bergerud and Manuel (1969) for Newfoundland moose:

$$\log(\mathit{percent\ cover}) = -1.56 + 1.91(SCF), \qquad \text{Eq. 2}$$

and the probability of detection can be defined as:

$$\mathit{Probability\ of\ detection} = \frac{1}{SCF}, \text{ or} \qquad \text{Eq. 3}$$

$$\mathit{Probability\ of\ detection} = \frac{1.91}{\log(\mathit{Percent\ cover}) + 1.56} \qquad \text{Eq. 4}$$

The distance detection function, g(x), models the probability of detecting moose as a function of distance:

$$\mathrm{g(x)} = e^{\frac{-x^2}{2\sigma^2}}, \qquad \text{Eq. 5}$$

where x is the perpendicular distance of moose groups to the flight transect and $\sigma = 255$ was derived from a Peters *et al.* (2014) distance detection function at little to no canopy cover. The distance detection curve was then refined by multiplying the probability of detection from Eq. 4:

$$\hat{\mathrm{g}}(\mathrm{x}) = \mathrm{g(x)} \times \mathit{Probability\ of\ detection}, \text{ and} \qquad \text{Eq. 6}$$

$$\hat{g}(x) = e^{\frac{-x^2}{2(225)^2}} \times \left(\frac{1.91}{\log(\text{Percent cover})+1.56}\right). \qquad \text{Eq. 7}$$

The resulting equation was inserted into the DS and SRB simulations. Since SRB assumes 100% accuracy of surveyed area, ĝ(x) was set as equal to the average of the first 200 m of the curve for the entire SU of the SRB simulations, while the simulation for DS used the detection function as is, with observed distances of “moose” objects (Figure 3.2.3). A SCF based on Bergerud and Manuel (1969) was used to create the detection probability in the model, and could have been used for either SRB or DS simulations, but correction was not important in this study as it would have an equal effect on both DS and SRB simulations.

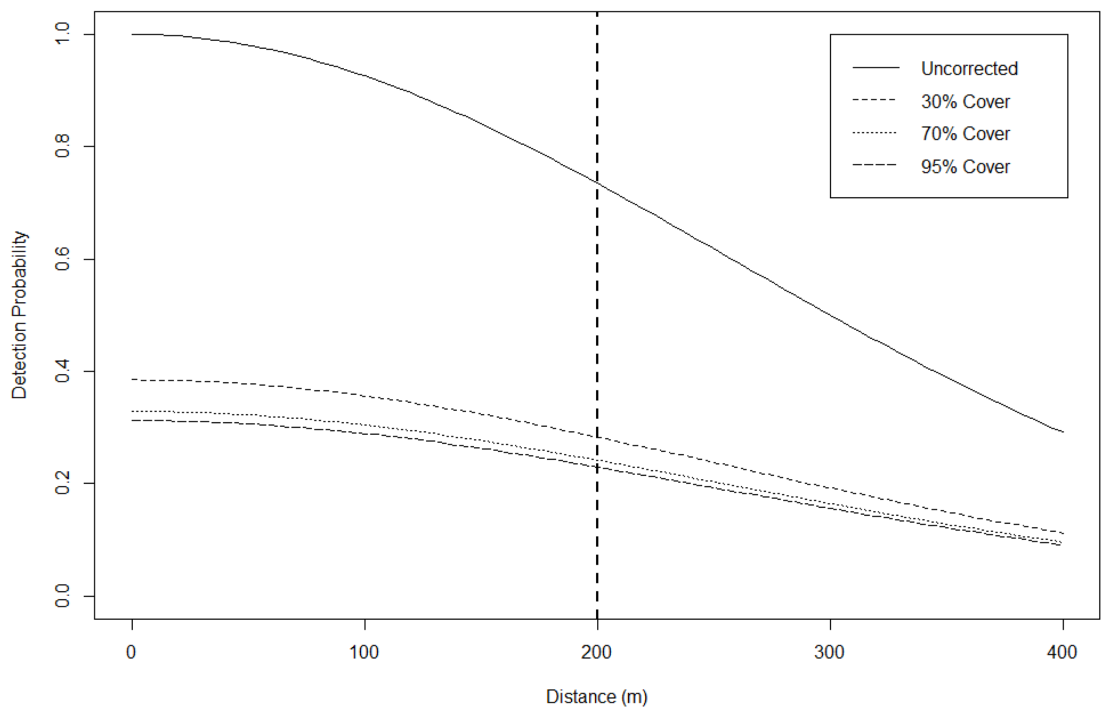

Figure 3.2.3. Detection probability curves used for input moose detections in the simulation. Uncorrected curve was derived from Peters *et al.* (2014) with no cover correction (Eq. 5; σ = 255). Each "moose" object is associated with a percent cover calculated from the SCF determined for Newfoundland by Bergerud and Manuel (1969). The simulation considers a "moose" observed or not based on the detection probability of the percent cover of that "moose" for DS. In SRB surveys all "moose" are assumed to be seen, so the average values determined from the curve up to 200 m was used instead.

Distance Sampling

A virtual survey using DS methods was approximated using Java code written and run in *Eclipse* (Eclipse 2014). The detection probability function from line transects was determined by analyzing the perpendicular distance of observed targets to the flown transect. The detection probability function was modelled for goodness of fit as a function with polynomial or cosine adjustments.

A 5559 m transect spacing was used for one of the simulated surveys using DS, because it approximated the surveys by Peters *et al.* (2014). An additional survey based on DS with transects spaced at 1000 m was tested to show the effect of a change in the effort to precision ratio. The basic DS methodology was mimicked and "moose" were detected based on the probability in Eq. 7. The distances to observed "moose" were recorded in a matrix and input into the Distance package in R (R Development Core Team 2013, Miller 2016). The population size estimate, standard error (SE), 90% confidence interval (CI) as a fraction of the population estimate, and effort associated with the simulated surveys were output for analysis.

Stratified Random Block-Surveys

Two simulation programs written in Java and run in *Eclipse* were used to set up and analyze SRB surveys. The first program read the virtual "moose" population tables of observed and true "moose" numbers, then calculated the number of "moose" observed in each SU based on the probability of detection described in the Section Virtual Population above. The second program took the resulting detection matrix and ran a full SRB survey. To begin, lists of each SU for each strata were shuffled randomly, then the first five SUs from each stratum were “surveyed.” Subsequent SUs were chosen based on the optimum allocation of effort formula described by Gasaway *et al.* (1986), and continued to be added until a 90% CI $< 20\%$ of the population estimate had been reached. Final output was the population estimate, its standard error (SE), the 90% CI expressed as a percent of the population estimate, simulated effort, the “true” number of moose, and the number of SUs “surveyed” after all flights were complete. Effort did not include simulated flights from a base, fuel depot, or from SU to SU, only the “flying” distances within all SUs.

Statistical Analysis

Two-way Analysis of variance (ANOVA) was used to compare accuracy, precision and effort across three survey types and two virtual moose densities for a total of six treatments. The ANOVA is used to compare the means of population estimates because it allows for the comparison of both moose density level and survey type. Treatments were repeated on ten unique virtual moose populations to compare the effects of “moose” density and survey types on the accuracy, precision, and effort of the simulated surveys. Accuracy was the ratio of the estimate of “moose” abundance divided by true virtual moose abundance. Precision was expressed as the CI divided by the simulated population estimate, and effort was the simulated number of kilometers flown within SUs for SRB, or over transects for DS. Survey type was one of DS with transects spaced at 1000 m, DS with transects spaced at 5559 m, and the SRB survey. Density was either high (~3 moose/km^2) or medium (~1 moose/km^2) density.

Non-normality of results prompted the use of an Aligned Rank Transformation using the *ARTools* package in R (Kay and Wobbrock 2016). The transformation allows nonparametric analysis for both main and interaction effects by preprocessing data into aligned ranks (Wobbrock *et al.* 2011).

3.3 RESULTS

Under the conditions of the simulation, “moose” were only observed approximately 35% of the time, because of the detection probability that was used to simulate “missed moose” from tree cover. No significant differences in mean “moose” abundance occurred in the comparison of accuracy of each survey type and of accuracy with different virtual moose density (Table 3.3.1). The variance in accuracy of SRB surveys across the replicates, however, was greater, especially in lower simulated moose density (Figure 3.3.1). Precision varied significantly across survey types, with differences in the variation across the two simulated moose densities, *i.e.*, with a significant interaction term with moose density (Table 3.3.1). DS with transects spaced at 5559 m had the poorest precision, followed by SRB surveys (Figure 3.3.2). The DS with transects spaced at 1000 m performed significantly better at the higher simulated moose density. The right tail of the SRB precision is censored at 20% to mimic the approach that SRB surveys take in surveying additional SUs until a 90% CI < 20% of the estimate is reached. The simulated effort varied across survey types, while differences in simulated moose density had some effect on effort (Table 3.3.1). DS with transects spaced at 1000 m required, by far, the greatest amount of effort (Figure 3.3.3). DS with transects spaced at 5559 m and SRB surveys required similar effort, although the variation in simulated effort across replicates was much greater for SRB surveys.

Table 3.3.1. The results of two-way ANOVAs comparing the effects of moose density and survey techniques on the accuracy, precision, and effort in a case study simulation of Newfoundland moose surveys. Aligned Rank Transformation was performed prior to the ANOVA to correct for the normality assumption.

Dependant Variable	Source of Variation	df	*F*	*P*	η^2
Accuracy	Survey	2, 54	0.39	0.68	246.9
	Density	1, 54	7.8	< 0.01	2041.7
	Survey × Density	2, 54	1.1	0.33	651.7
Precision	Survey	2, 54	183.2	< 0.001	15523.6
	Density	1, 54	11.8	< 0.01	3168.3
	Survey × Density	2, 54	8.1	< 0.001	3801.6
Effort	Survey	2, 54	57.1	< 0.001	12160.0
	Density	1, 54	6.3	< 0.05	1837.1
	Survey × Density	2, 54	1.96	0.15	1186.3

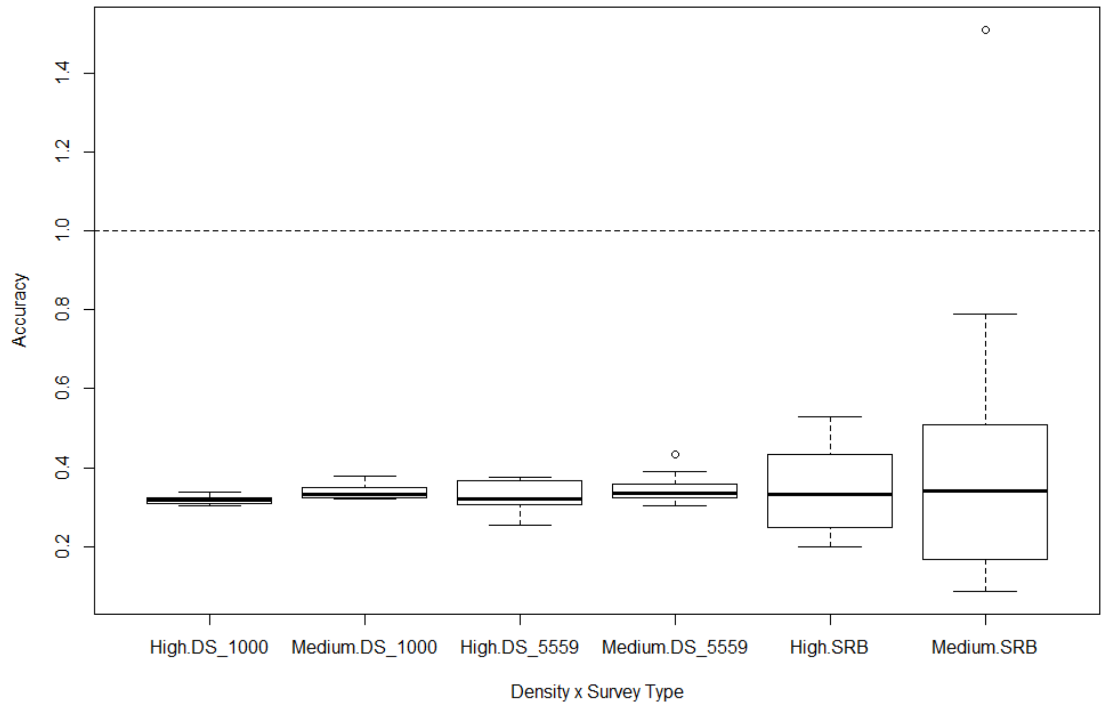

Figure 3.3.1. Boxplots showing accuracy in estimating virtual moose according to survey type and moose density, with 100% accuracy identified by dashed horizontal line. Survey types from left to right are distance sampling with transects spaced at 1000 m, distance sampling with transects spaced at 5559 m, and stratified random block surveys. High-density moose were modelled at ~3 moose/km^2 and medium-density at ~1 moose/km^2. Mean accuracy should differ very little as it is the constant introduced to compare effort and precision, but interestingly SRB surveys show much greater variation in accuracy than both DS survey types.

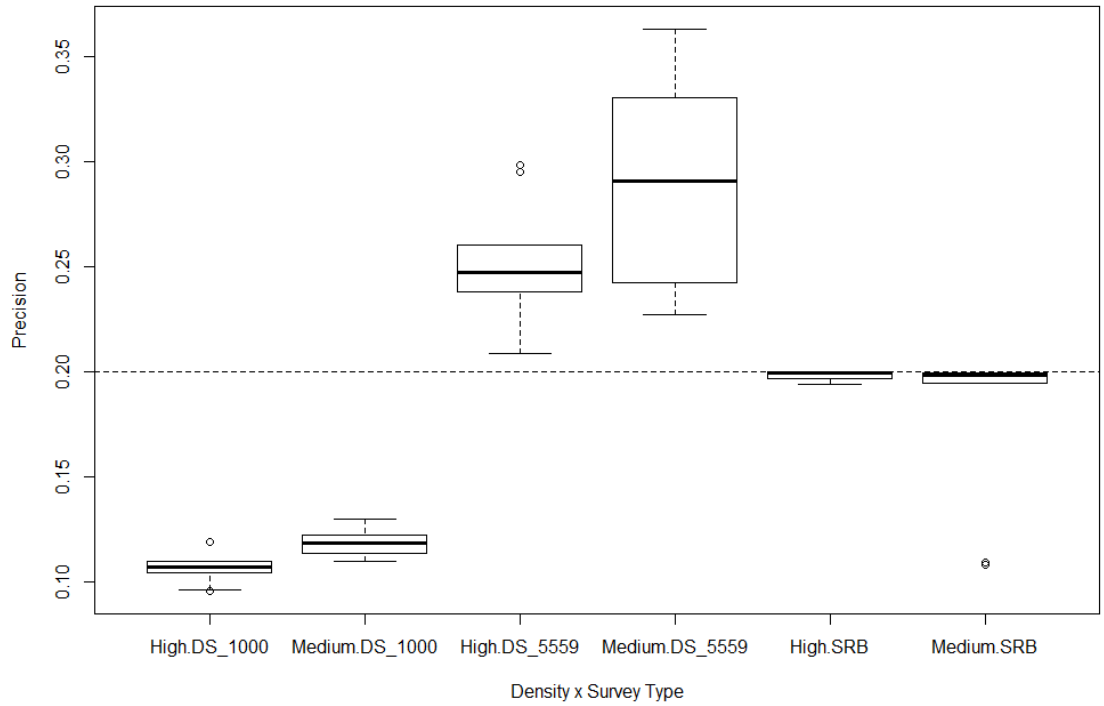

Figure 3.3.2. Boxplots showing precision expressed as the confidence interval (CI) as a proportion of the simulated population estimate for virtual moose by survey type and moose density. A 90% CI equivalent to 20% of the estimate, the target used by many jurisdictions using SRB surveys, is identified by dashed horizontal line. Survey types and moose densities are as in Fig. 3.3.1. DS has more variation in precision than SRB but, as shown with the high-effort 1000-m transect DS, DS can have as good or better precision depending on the level of effort.

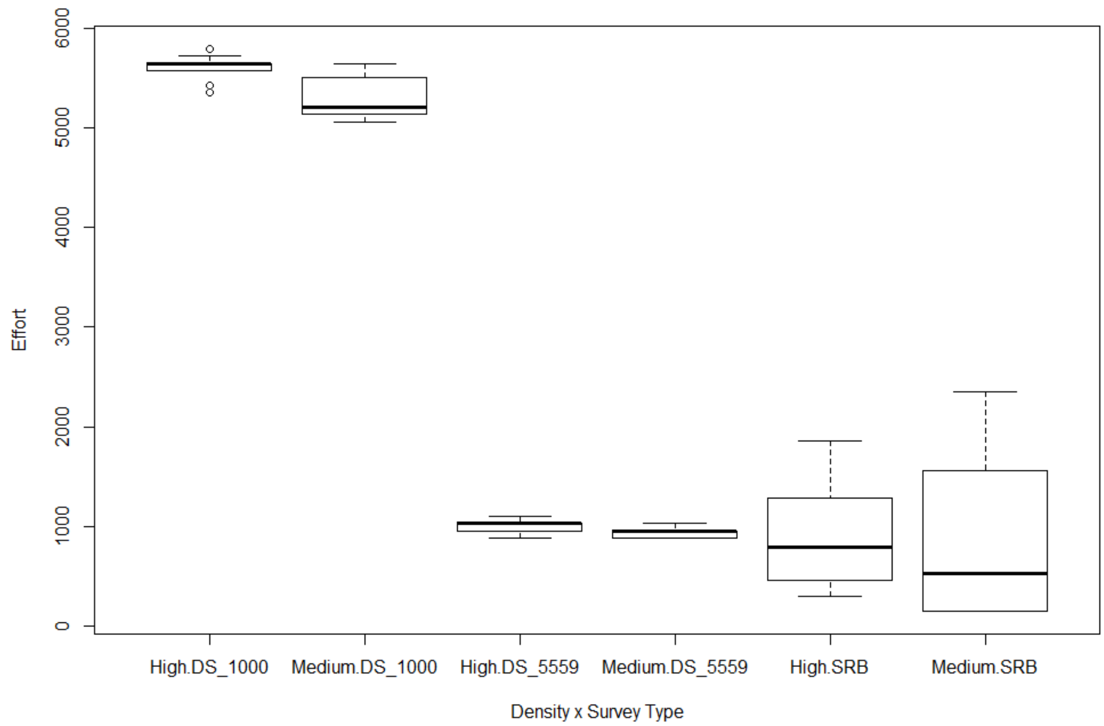

Figure 3.3.3. Boxplots showing effort, in approximate kilometers of survey flown for virtual moose, by survey type and moose densities, defined as in Fig. 3.3.1. Effort is extremely high in the 1000-m DS but significantly comparable between DS with 5559-m transects and SRB survey types (see Table 3.3.1). The variation of effort is much greater in SRB surveys, however. This could provide moose managers with more predictability in budgeting aerial surveys.

3.4 DISCUSSION

The results from the simulation support the claim by Peters *et al.* (2014) that DS can be as accurate as SRB surveys in estimating moose population size. Moose density and spacing of transects in DS surveys do not appear to affect accuracy in the simulated population estimates. It is possible to survey less area with DS and still achieve the same accuracy, so long as density of what is surveyed remains constant.

Precision in DS, however, is affected more by variation in encounter rates of moose, unlike the differences in precision created with variation in the proportion of area counted using SRB surveys for moose (Peters *et al.* 2014). The highest proportional 90% CIs in the simulation were still lower than some estimates reported for SRB surveys of moose (Lenarz 2011). Precision closer to the standard 90% CI of less than ±20% can be economically achieved using DS, by flying transects spaced closer together than the 5559 m spacing used in the simulation, but not so close that economy is compromised by excessive effort. In the simulation, the 90% CI for DS with transects spaced at 5559 m was more precise than what was reported by Peters *et al.* (2014) in the Alberta moose surveys. The effect may be from the simulation using higher moose densities based on the Newfoundland situation. Encounter rates, as a function of moose density, do affect precision in DS, as the higher CIs for the medium moose density simulation show.

Unlike the empirical study done by Peters *et al.* (2014), DS with 5559 m transects and SRB surveys took similar "effort" in the simulation. The difference may be a bias created against DS in the simulation by not including route and fuelling logistics into the “effort” calculation. In reality, SRB probably requires more travelling time between most SUs than DS, as well as possibility more days spent flying to add additional SUs to meet the requirement that the 90% CI fall within ±20%. SRB surveys may also require stratification flights that were not included in the simulated effort calculation. Thus, including the possible bias, DS is easily able to match SRB in survey effort with transects spaced 5559 m apart.

In a real-world SRB survey, budget constraints would stop surveys when they reach a 90% CI close to ±20%, whereas the simulation always continued to run until a 90% CI within ±20% of the “moose” population estimate was reached, regardless of “effort” and simulated costs. This constraint could be loosened in a revised simulation. There were also many times when a simulated SRB survey was “flown” with only the minimum number of SUs and achieved a 90% CI within ±20% of the population estimate. These “lucky” surveys may skew the SRB surveys to have lower effort than would be expected in the real world. An advantage to DS is that there is a very predictable range of effort that is needed for a comparable accuracy and precision to SRB surveys.

The simulations provide insight into the most basic examples of both DS and SRB. Future research could expand on testing the various improvements to each survey type. Other methods of visibility bias correction could be added to future revisions of the model to examine the accuracy of simulated surveys with correction, or to test the effectiveness of the correction techniques themselves. These tests could even include mark-recapture used in DS in Washington moose surveys (Harris *et al.* 2015b). DS could also be more effectively simulated and tested by allowing a model to run through additional detection functions, which is the real-world approach to population estimation from DS. Different truncation settings could also be applied, including a left-tail truncation on the distance function to exclude inaccurate counts under the aircraft (Wald and Nielson 2014). SRB survey simulation could be improved by adding a logical series of additional SUs that can be collectively done in a day to more closely follow SRB logistical practices. Alternatively, the 90% CI constraint could be relaxed and a budget constraint can be added to reflect moose surveys for real-world situations, where budgets guide moose aerial surveys as much or more than standard protocols.

DS is usually done on linear features to keep survey homogenous (Wald and Nielson 2014), but the simulation used “east-west” transects for simplicity and to reflect the fact that the virtual moose were not generated with consideration of any landscape variation. A revised simulation would reflect real-world DS that follows linear features of the landscape. In the same vein, future simulations could examine further the effects of varying moose density on survey type. Rather than test two densities set at “high” and “medium” moose, a range of densities could be compared. The virtual population could also be improved by using more data, or by using data from different real-world jurisdictions. Detection of the virtual moose population could also be made more realistic by combining a detection function with habitat variables other than just forest cover. The difference in outcomes comparing various CI targets could be compared in the simulated SRB surveys, such as allowing up to ±30% of the estimate or restricting 90% CI to ±10% of the population estimate, to see how much effort might be affected.

<u>Management Implications</u>

The advantages of DS in medium- to high-density moose populations (Peters *et al.* 2014) would appeal to those responsible for moose aerial inventory management in jurisdictions like Newfoundland. Managers in other locations similar in moose density, forest cover, and survey area to Newfoundland would also see DS as a superior survey type. The larger 90% CI on estimates using DS may dissuade users from this approach, but larger survey error can be mitigated by using a closer spacing between flight transects with only a slightly increased cost in effort, especially given that straight-line flying is easier and safer than the searches required by SRB. Other techniques could be used to increase precision, such as stratifying transects and flying over linear features rather than east-west transects (Thomas *et al.* 2010).

DS also has the advantage of having a clear effort estimate, which can be calculated before surveying. This advantage is important for biologists, who can take accurate estimates of effort to policy makers and stakeholders to more easily build survey plans into a budget. In contrast, in planning SRB surveys, biologists can set budgets that then may not reach the target 90% CI in a given year, affecting the precision and trends associated with moose population size estimates, or face consequences of exceeding pre-set budgets. Such political consequences could include failure to approve future-year surveys of moose, equally affecting the ability to determine trends and manage a moose population.

4.0 EXPLORING THERMAL REMOTE SENSING FOR USE IN AERIAL MOOSE SURVEYS

4.1 INTRODUCTION

Advances in technology have allowed for enhanced use of aerial imagery in wildlife surveys. Aerial surveys of moose (*Alces alces*) are almost exclusive to visual searches with onboard observers, but some success has been reported with including colour and thermal imagery in the survey design (Millette *et al.* 2011). Development of thermal aerial imagery for identifying wildlife began in the 1960s with a study on the capability of its use in observing penned white-tailed deer (*Odocoileus virginanius*; Croon *et al.* 1968). Early techniques were limited by high costs of thermal sensors. In recent decades, use of Forward Looking Infrared (FLIR) cameras has been applied to real-time observations of moose and other animals (Adams *et al.* 1997). More recent applications are more in line with remote sensing, such that imagery is taken as an orthophoto (bird's-eye view) and analysed post-survey (Millette *et al.* 2011). Remote sensing in wildlife tracking may continue to progress to incorporate fine-scale habitat information and GIS data easily integrated into aerial surveys (Millette *et al.* 2014).

Having a camera collect survey data allows for verification of results as an advantage if there is dispute over the identification of an animal. It also allows for a GIS database to store all ecologically relevant information from an image for future processing. Image analysis could include forest cover type, elevation, microclimate, and proximity to human activity, in addition to characteristics of the individual animal, and any other variables that might increase survey accuracy and information content (Millette *et al.* 2011). Use of cameras in aerial surveys also allows for the progression to non-visual spectrum imagery, such as from a thermal imager, as another way to lower observer bias. In open fields and deciduous stands, close to 100% accuracy with thermal camera technology was achieved by Millette *et al.* (2011).

An automated method of finding moose that is more comprehensive than using conspicuous hotspots is the next step in using thermal technology in moose aerial surveys. Previous thermal studies of moose have relied on the time consuming task of post-survey manual visual interpretation (Millette *et al.* 2011). Automation of this task has been studied on white-tailed deer in enclosed areas, but with much higher resolution from UAVs (Chrétien *et al.* 2016). Those surveys are limited to the short range and flight time of the UAV. Automation may still be possible at lower resolutions obtained from fixed-wing aircraft at higher altitudes. This chapter aims to explore and develop a proof of concept for automated moose population counts using relative heat signatures in thermal imagery collected from a fixed-wing aircraft outfitted with a dual-camera system to find local maximum heat signatures indicative of possible moose thermal hotspots. Colour imagery and collared moose are used to identify moose and evaluate the effectiveness of the thermal hotspot model. The practical advantage of this approach is that it leads to cost-effective moose abundance estimates or minimum moose counts. It also allows research on fine-scale habitat parameters to take place, including a means to improve survey accuracy. As a proof of concept of the automated system used to identify thermal hotspots as moose, no attempt was made to evaluate the accuracy of the approach.

4.2 METHODS

Study Site

The area flown covered 22 km^2 just north of the Canada-USA border. Most of the area surveyed fell within the Pigeon River Clay Plain of La Verendrye Provincial Park, Ontario (Figure 4.2.1). Vegetative communities encountered were a mix of boreal and Great Lakes-St. Lawrence species including: paper birch (*Betula paperifera*), balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), tamarack (*Larix larcina*), eastern white cedar (*Thuja occidentalis*), and jack pine (*Pinus banksiana*). Also found in reduced frequency were red (*P. resinosa*) and white pine (*P. strobus*), maples (*Acer* spp.), and black ash (*Fraxinus nigra*; pers. comm. Evan McCaul, Ontario Parks; Crins *et al.* 2009). Collared moose in the area are part of a research project in the Grand Portage Indian Reservation of Northeastern Minnesota.

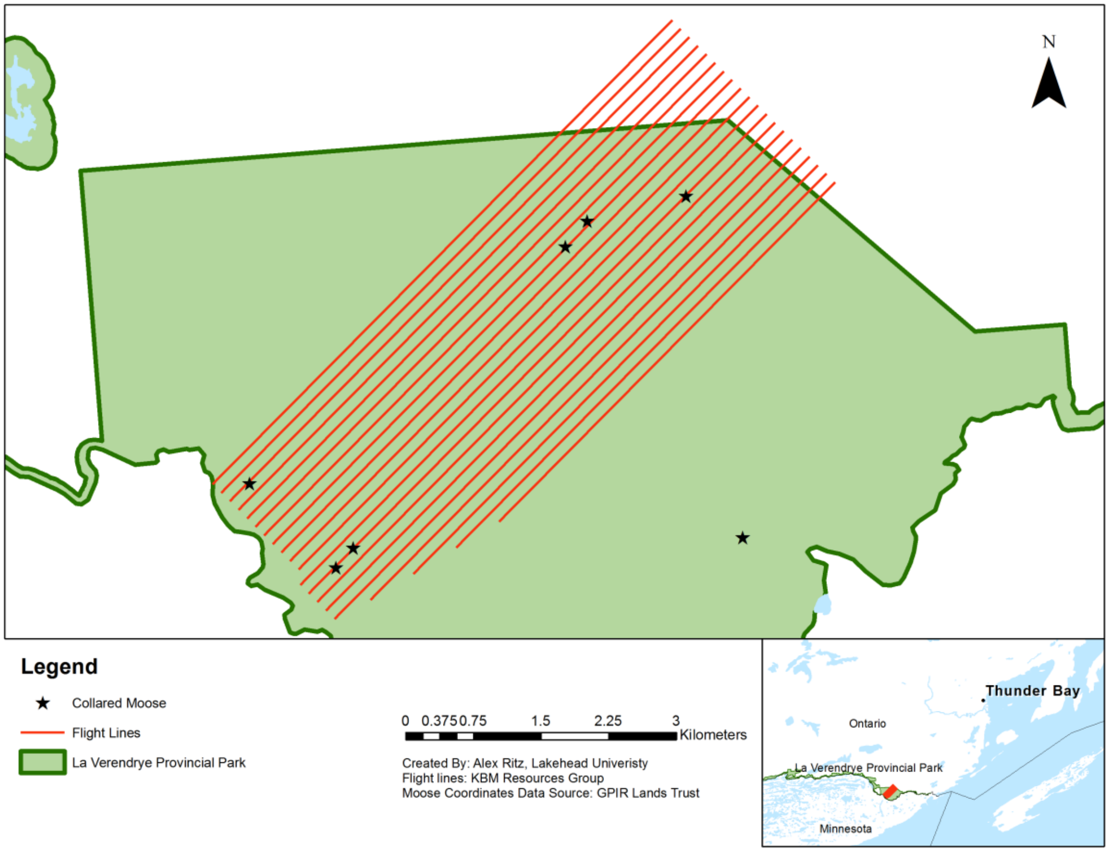

Figure 4.2.1. Map of flight lines over the study site located primarily in La Verendrye Provincial Park, Ontario. Six collared moose were located within the survey area, with a seventh just over 2 km away.

Data Collection

Location data from 141 moose GPS-collared since 2010 were collected by the Grand Portage Indian Reservation Trust Lands biologists for a program to evaluate habitat use, mortality, and maternal and calf health. Coordinates were used to determine flight plans leading up to a flight, and to evaluate detection of moose through imagery analysis. Thermal and colour imagery was obtained using a Piper Seneca II fixed-wing aircraft on January 21, 2016 and deployed by KBM Resources Group of Thunder Bay, Ontario. The two cameras mounted on the aircraft were the FLIR SC655 thermal camera and Trimble TAC65+ 60MP calibrated frame mapping camera with Forward Motion Compensation and 50 mm lens for colour imagery. The navigation and positioning system comprised a Novatel GNSS receiver (Propac V, and an FSAS IMU). The flight trajectory was computed using Novatel's Waypoint Explorer Software. The survey area was flown at an altitude over 400 m above ground level. The resulting resolution for the thermal imagery was 30 cm/pixel and for the colour resolution was 7.5 cm/pixel.

Image Analysis

Initial inspection of the thermal and colour imagery revealed thermal hotspots of moose with thermal values 0.3 Celsius degrees or higher than ground thermal values as well as slightly increasing thermal values overall from the beginning of the flight to the end. Relative thermal imagery was created using the Focal Statistics function in ArcGIS to determine the average temperature in a radius 3 m around each pixel. The thermal raster was then divided by the focal raster to get the relative temperature of each pixel. Pixels with values equal to a difference of 0.3 Celsius degrees and higher, except those with no-data values, were classified as thermal hotspots. Hotspots were converted into polygons to calculate the combined area of pixels they represent. Polygons with areas between 0.5 and 4.0 m^2, to include any shape of approximate moose size, were identified as possible moose. The relative thermal raster image was then used to calculate an average thermal value within each hotspot polygon using the Zonal Statistics tool. The result was a set of points added to the image identifying thermal moose hotspots.

Using a buffer with a 1400-m radius based on mean daily moose activity radii (Lowe, Patterson, and Schaefer 2012; approximately Phillips, Berg, and Siniff 1973), moose collar locations were compared with moose identified in the imagery. Possible double counts from overlapping imagery were checked with the individual, non-mosaicked images, on which the moose thermal hotspots were identified. Thermal hotspots were then counted and compared to the number of thermal hotspots found in the mosaicked image.

After analysing imagery with the aforementioned model, constraints were relaxed to locate all thermal hotspots with values greater than 0.3 Celsius degrees in the imagery. Hotspots were converted to point shapefiles to manually analyse the colour imagery around each point for moose detection.

An attempt at object-based image analysis using eCognition Developer 9 was made to find moose by creating objects from groups of pixels. The ultimate use of the thermal hotspot system did not need detail at this level of distinction and the processing time needed for object based image analysis precluded the use of eCognition software over the image manipulation and analysis tools available in ArcMap.

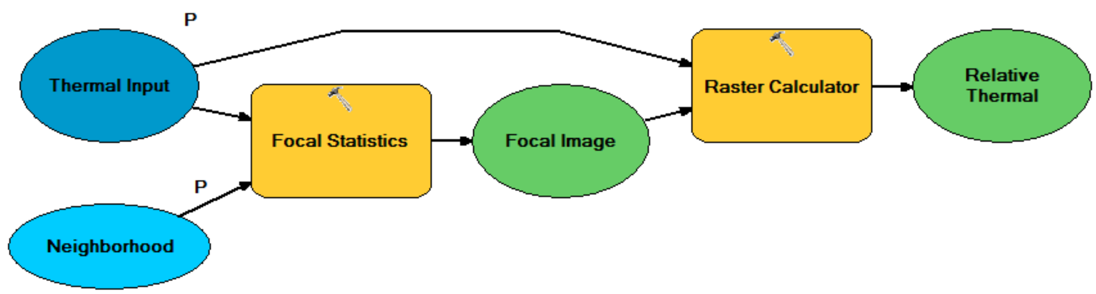

Figure 4.2.2. The first portion of the model. A relative thermal raster image is created by using focal statistics to generate the mean thermal values within the neighbourhood of each cell. Each original thermal cell is then divided by the focal image cell to return the relative thermal values. Input data are represented as a dark blue circle and the light blue circle represents an input variable. Yellow blocks represent tools or functions and the output files are symbolized as green circles.

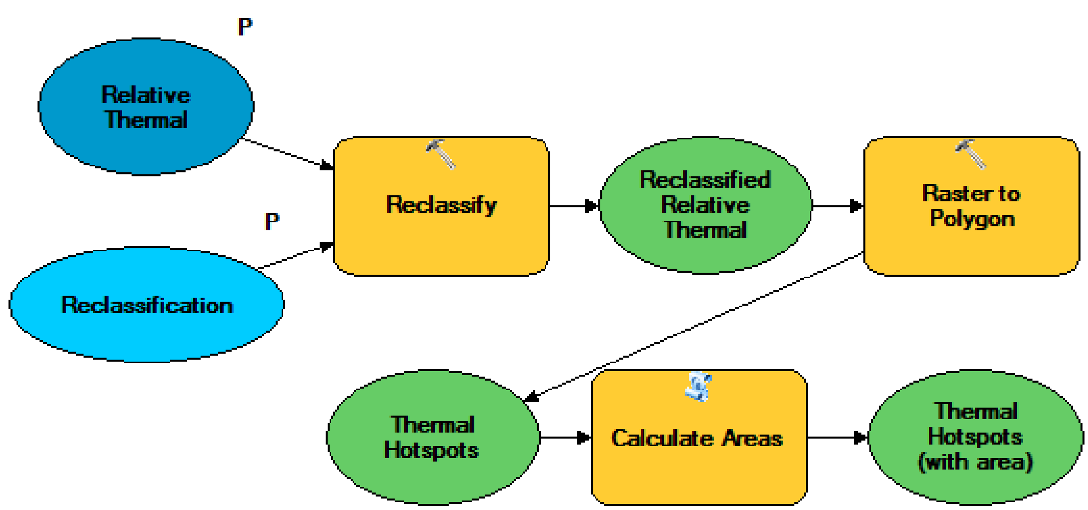

Figure 4.2.3. The second portion of the model uses the relative thermal raster created in Figure 4.2.2 to output thermal hotspot polygons with measured areas. Diagram symbology is as in Figure 4.2.2.

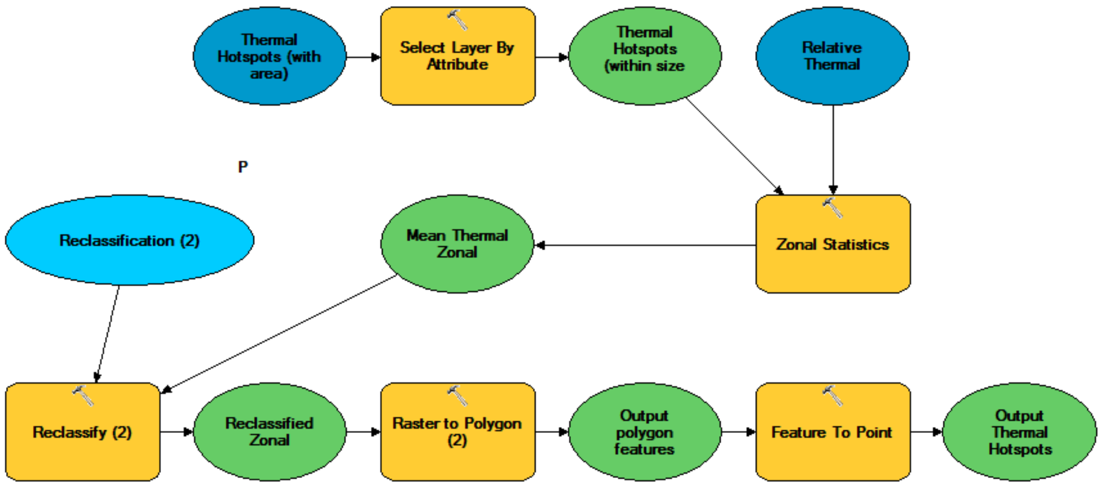

Figure 4.2.4. The final part of the model takes the relative thermal raster and the thermal hotspot polygons to create zones where thermal hotspot polygons within the size constraint of 0.5 m^2 to 4.0 m^2 are located. The mean relative thermal value is calculated within each zone. Zones with hotspots greater than 0.5 Celsius degrees are identified as moose and exported as point shapefiles for analysis and examination. Diagram symbology is as in Figure 4.2.2.

4.3 RESULTS

Six moose collar coordinates were last updated on the same morning of the survey flight and with one observation from the preceding day falling within the survey area. A seventh collared moose was just over 2 km from the survey area. All collared moose locations were observed in both the thermal and colour imagery within the mean daily activity radius of 1.4 km; five of the six were observed within 200 m of the last collared location (Table 4.3.1).

Twenty-one thermal hotspots were identified as possible moose in the survey area. Two patches of open water or ice were misidentified as moose (*e.g.* Figure 4.3.3) and the remaining 19 were correctly identified (*e.g.* Figure 4.3.2). After relaxing the constraints of the model, 7596 thermal hotspots were identified and manually analysed for moose. Manual detection took under two hours and one moose was found that had been missed by the automated search (Figure 4.3.4). No evidence of double-counting either moose or thermal hotspots was found when examining individual aerial images.

Table 4.3.1. Information on collared moose found within survey. Of the seven collared moose close by, six were flown over. Five were within 200 m of a moose observation and the sixth was 425 m away. Most moose collar data is within five hours of the survey with only two earlier. One of those was from the day before.

FID	Time difference between collar location estimate and survey flight (hours:minutes)	Distance from closest moose in imagery (m)
1	22:44	150
3	2:30	105
4	6:45	35
6	2:30	30
7	4:38	425
11*	4:38	-
22	2:30	75

* Moose outside of survey area

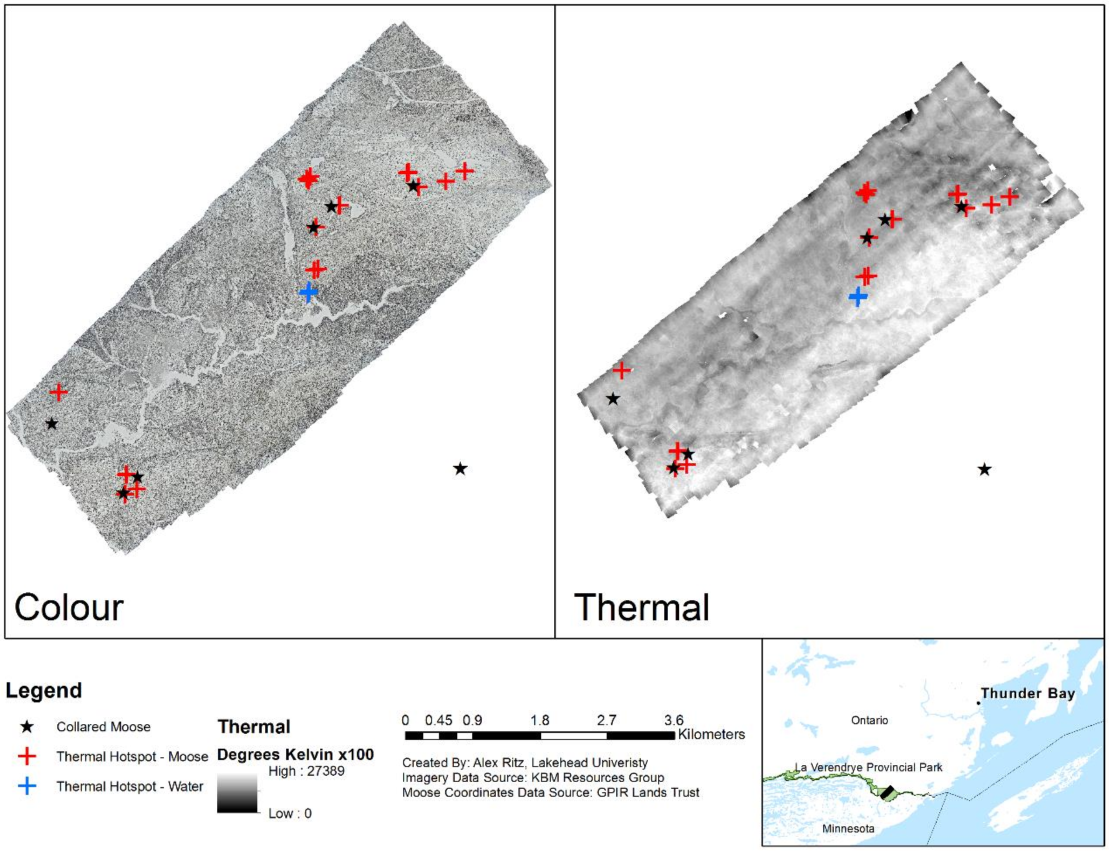

Figure 4.3.1. Thermal hotspots found using an ArcGIS automated model. Nineteen moose were correctly identified while two thermal hotspots over water were misidentified as moose. For each collared moose location, a moose was found in the imagery that was within an acceptable distance to be considered a match (see Table 4.3.1).

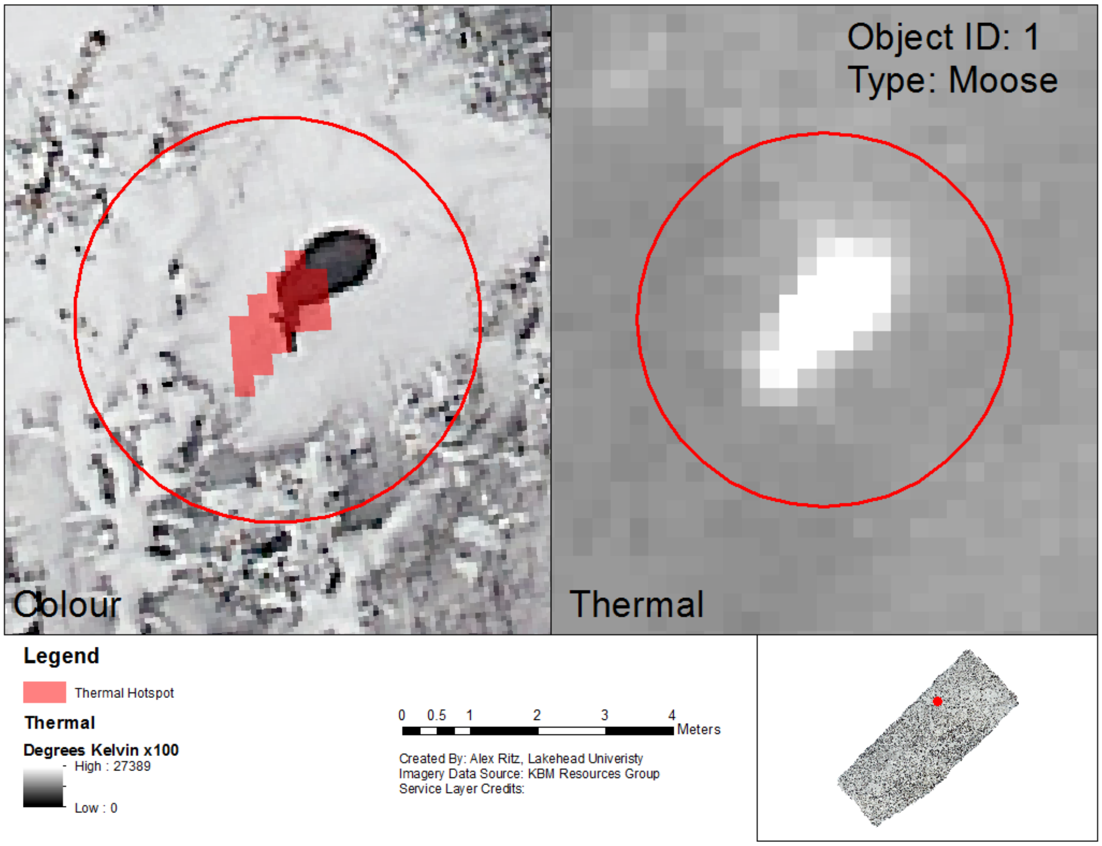

Figure 4.3.2. Example of colour (7.5 cm/pixel) and thermal (30 cm/pixel) imagery of moose thermal hotspot. Images taken on January 21, 2016 over La Verendrye Provincial Park, Ontario. Specific location within the imagery is depicted in the lower-right map. The thermal hotspot generated by automated model overlays moose in thermal and colour imagery.

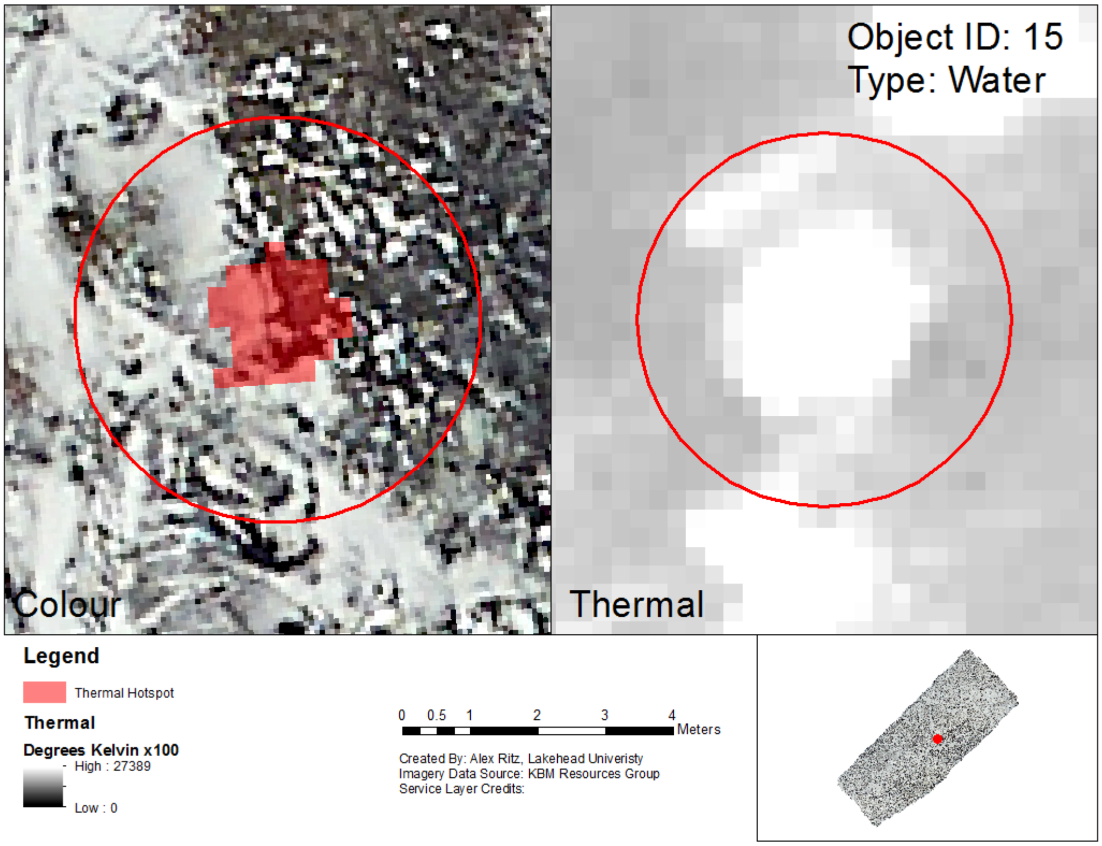

Figure 4.3.3. Example of a thermal hotspot of water incorrectly identified as moose. It is clear in the thermal imagery that the high thermal values are following a linear feature, and the colour imagery is clearly not a moose. Comparison with Figure 4.3.2 shows the clarity of moose in the colour imagery.

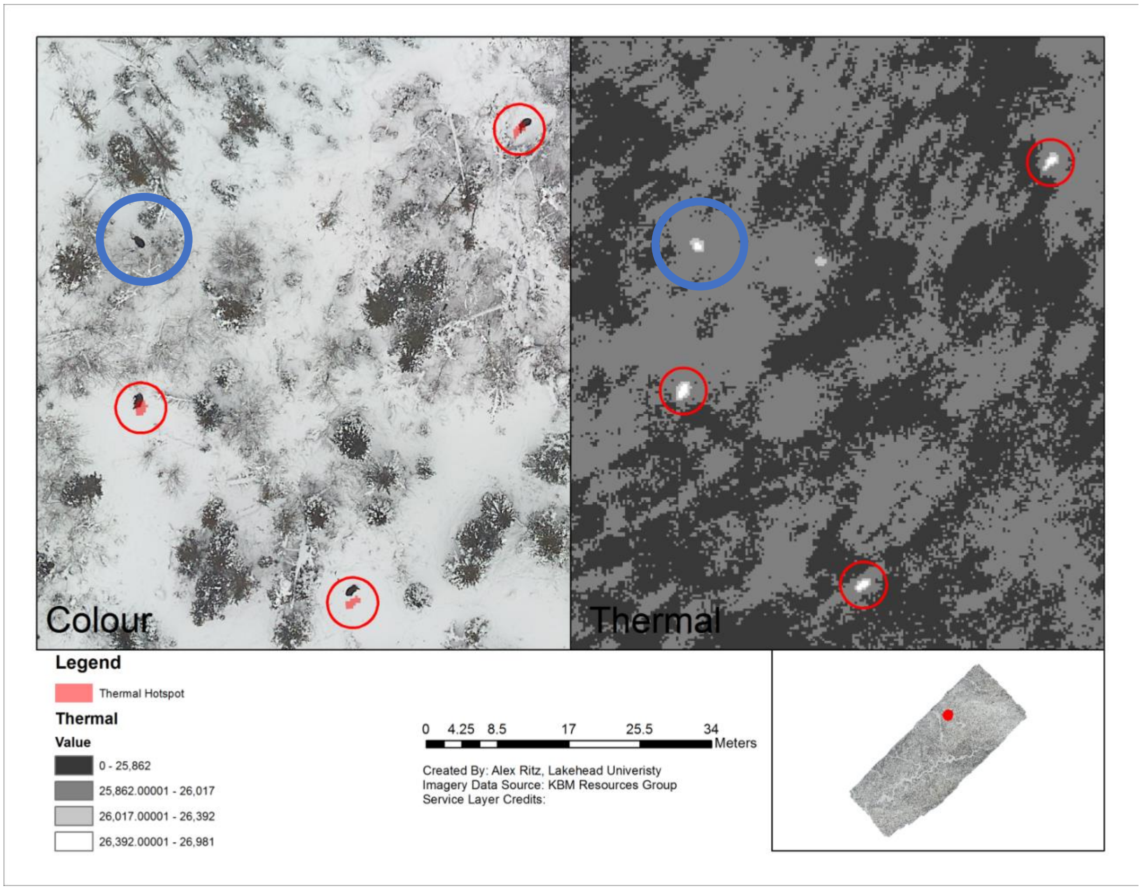

Figure 4.3.4. Three out of four moose found in relative thermal and colour imagery following the constraints of the model. A fourth moose, inside the blue circle, was not found in the thermal hotspot model. Since the model uses relative temperature, a moose that is less warm than others will have a thermal signature less distinctive than other moose and possibly missed by the constraints of the thermal algorithm. No other moose were missed.

4.4 DISCUSSION

The thermal hotspot model uses relative heat to determine whether a high pixel value is different enough from surrounding pixels (the ground) to be a moose. The model was able to correctly identify 19 moose out of 21 potential moose from hotspots. The false positives in this study appear to have been open water covering the same extent as the defined moose area (see Appendix for all thermal hotspots). Manual analysis of the colour imagery was able to immediately differentiate these hotspots as non-moose by shape and location relative to other water features. The moose that was not identified by the model using the thermal imagery alone was slightly cooler in comparison to the other moose. I did find that moose external temperatures varied little from the ground and nearby objects. Temperature signatures in the pixels with moose were all less than 1 Celsius degree warmer than the ground, making it difficult to identify and compare thermal hotspots, and the difficulty can increase as non-moose objects warm during the day. A warm ground would make the moose thermal signature less pronounced and hotspots from fallen trees or their uncovered trunks under other circumstances could have created additional false positives.

A common second issue is determining how many moose are missed, or the visibility bias in the results of a moose survey. A denser forest cover (>60% coniferous tree cover) has a relatively lower detection rate of moose in helicopter surveys (Quayle *et al.* 2001) and in thermal imagery (Millette *et al.* 2011) that was found in this study, if the collared moose are an indication of its lower visibility bias. Many jurisdictions use a "sightability correction factor" to get a more accurate estimate of the population (Section 2.4 Visibility Bias). Quayle *et al.* (2001) suggested using a measure of tree canopy cover in a radius around the moose to help develop a factor to correct for moose missed by observers. The orthophoto technique used in this study could be adapted to retool this approach to visibility bias by measuring the total vegetation cover in the imagery and calculating the fraction of moose that were seen covered by each vegetation cover class. Moose were observed in this study under relatively low tree cover. Snow cover was also fairly good in this study, but if more complete it would have also covered open water and fallen trees and made moose appear clearer in both thermal and colour imagery. Generally, for any approach to moose surveys, weather and other flight constraints do not make it possible to maintain ideal conditions.

The attempt of this study was to create and test a method of using only thermal imagery to find moose. Unfortunately, water hotspots interfered with the ability to survey moose with thermal imagery alone at a 30 cm/pixel thermal resolution. Because the model was adapted and hotspots were also visually reviewed with colour imagery, constraints of temperature and extent could be relaxed to allow for a wider range of thermal hotspots and reduce the chance of a missed moose. Using ArcGIS to identify thermal hotspots with a less constrained version of the model, I was able to identify and examine thermal hotspots manually in less than two hours. I also attempted to use object-based image analysis software to analyse imagery, but the thermal and colour imagery failed to align. It is possible that multi-band analysis using aligned images could have automated the detection of moose similar to the thermal imagery research on white-tailed deer done by Chrétien *et al.* (2016), although thermal imagery alone in this study did not have enough resolution to warrant an object-based program such as eCognition. The model used in this study approximates the same functionality with thermal imagery at a fraction of the processing time.

Movement of moose should be acknowledged in aerial surveys. Overlap of imagery in this study could have increased the number of moose observed if a moose moved far enough between flights of a transect. Overlap was less than 10% on average, but the combined imagery did include some moose that were seen in more than once in multiple images. Reviewing the individual images, I found no instances of double-counting from the imagery; however, I recommend spacing flight transects at a distance of a few hundred meters to reduce the chance of a moving moose being seen in two areas when the image mosaic is created. If an application were explored that requires a comprehensive survey of an area, some transects could be taken out of the analysis when counting moose, in order to reduce or eliminate the chance of double counts. Testing of the collection of imagery at different times of the day and through multiple lighting scenarios would have improved the test of this approach to moose population estimates. Flights should plan to represent all possible weather conditions suitable to thermal imagery acquisition.

As it stands, the thermal cameras available and affordable for wildlife survey do not produce an image resolution useful to discerning moose sizes and shapes. Image resolution posed a problem with thermal imagery in these trials. There is a trade-off in having higher versus lower altitude of flight; at a lower elevation imagery is much easier to interpret and contains more detail at the cost of a smaller field of view and less overall data collected (Millette *et al.* 2011). Introducing techniques to improve the resolution could vastly increase the effectiveness of identifying moose with a solo thermal camera technique. Chrétien *et al.* (2016) was able to use unmanned aerial vehicles (UAVs) in a white-tailed survey to achieve a 5.4 cm thermal resolution from a flight altitude of 60 m, creating an almost sixfold improvement over the 30-cm thermal resolution used in this study. At the resolution of imagery taken by cameras mounted on an UAV, thermal hotspots may be able to take on the shape of moose rather than a circular heat signature. One image analysis approach used was similar to my methods in creating a thermal mask of the imagery; in this approach, Chrétien *et al.* (2016) found that object-based analysis was superior to other approaches but requires a large amount of time for setting up optimal detection parameters and processing imagery. The area needed to estimate moose populations is large, therefore UAVs are not yet capable of completing effective moose surveys. Battery life, especially in cold weather, lasts less than an hour for many UAVs. Selected, smaller survey areas for moose could use a system with UAVs. Other issues with imagery for animal detection in general were the lack of animal movement to aid observations and limited camera angles. Automation also requires high resolution imagery to be effective.

Aerial thermal camera systems has been successful with other species such as Pacific walrus (*Odobenus rosmarus divergens*; Burn *et al.* 2006). In the Pacific walrus survey, different resolutions of thermal imagery were evaluated and lower resolutions of thermal imagery were just as effective as the higher resolutions due to fewer false positives. Using imagery rather than visual observations is advantageous, because a record and data can be kept and analyzed further, and observer bias is removed. Flight time can be increased without reduction in visibility bias thus reducing costs of surveys. Another interesting realization of the study by Burn *et al.* (2006) was that time since emergence from the water affected the thermal signature of the Pacific walrus. Similar climatic and environmental factors could be explored for moose and should be taken into consideration when planning surveys.

Management Implications

Use of thermal cameras in aerial moose surveys may be most appropriate for areas with only one ungulate species present and with relatively open vegetation cover. A simple, cost-effective thermal moose survey is not currently ready for use in moose management. Moose aerial surveys are frequently used to produce sex ratios and age class ratios, which are possible for observers to carry out by carefully choosing the time of year for the survey and electing for experienced observers. On the other hand, determining sex from thermal imagery alone is not possible with current technology. As thermal camera technology improves, and moose thermal signatures become increasingly clearer, new techniques may come about. Antlers could be seen in thermal imagery of white-tailed deer (Wiggers and Beckerman 1993) so it may be possible to sex moose if flying while antlers are still present in the early winter. The best approach with current technology to count moose appears to be to include colour imagery to double-check thermal hotspots, a process that would add less than an hour for survey areas similar to the 22 km^2 site used in testing this approach.

5.0 CONCLUSION

Moose aerial surveys in North America are in flux between traditional approaches and innovation. Managers of moose aerial surveys, by necessity, rarely change methods, because their aims are to sustain constant precision of population parameter estimates and to follow trends in a population consistently. Introducing a different survey type may interrupt this consistency. I have shown, as have others, that DS can be just as effective as SRB surveys in the right conditions. Currently, SRB surveys are the most common survey type in North America, but DS is gaining awareness in some jurisdictions. In New York, for example, moose aerial surveys are newly implemented and present an opportunity to try different approaches, such as DS. Thermal imagery is also being used in a few jurisdictions, but its use has yet to be standardized. Thermal cameras can locate moose easily in low-cover areas, but still require the assistance of colour cameras in imagery analysis, including to sex moose. Moose aerial survey should be, and frequently is being, improved as technology advances.

6.0 REFERENCES

Adams, K. P., P. J. Pekins, K. A. Gustafson, and K. Bontaites. 1997. Evaluation of infrared technology for aerial moose surveys in New Hampshire. Alces 33:129–140.

Aitken, D. A., and K. N. Child. 1992. Relationship between in utero productivity of moose and population sex ratios: An exploratory analysis. Alces 28:175–187.

Alberta Environment and Parks. 2016a. WMU 531 moose aerial survey (2016). Edmonton, Alberta.

Alberta Environment and Parks. 2016b. Wildlife management unit 500 moose aerial survey (2016). Edmonton, Alberta.

Alberta Environment and Parks. 2016c. Wildlife management unit 526 2016 aerial ungulate survey. Edmonton, Alberta.

Arsenault, A. A. 2000. Status and management of moose (*Alces alces*) in Saskatchewan. Saskatoon, Saskatchewan.

Beazley, K., M. Ball, L. Isaacman, S. Mcburney, and P. Wilson. 2006. Complexity and information gaps in recovery planning for moose (*Alces alces americana*) in Nova Scotia, Canada. Alces 42:89–109.

Beazley, K., H. Kwan, and T. Nette. 2008. An examination of the absence of established moose (*Alces alces*) populations in Southeastern Cape Breton Island, Nova Scotia, Canada. Alces 44:81–100.

Bergerud, A. T., and F. Manuel. 1969. Aerial census of moose in central Newfoundland. The Journal of Wildlife Management 33:910.

Beyer, H. L. 2004. Hawth's analysis tools for ArcGIS. http://www.spatialecology.com/htools.

Boer, A. H. 1988. Mortality rates of moose in New Brunswick: a life table analysis. Journal of Wildlife Management 52:21–25.

Boertje, R. D., M. A. Keech, D. D. Young, K. A. Kellie, and T. C. Seaton. 2009. Managing for elevated yield of moose in Interior Alaska. Journal of Wildlife Management 73:314–327.

Bontaites, K. M., K. A. Gustafson, and R. Makin. 2000. Gasaway-type moose survey in New Hampshire using infrared thermal imagery: preliminary results. Alces 36:69–75.

Bridgland, J., T. Nette, C. Dennis, and D. Quann. 2007. Moose on Cape Breton Island, Nova Scotia: 20th century demographics and emerging issues in the 21st century. Alces 43:111–121.

Brimeyer, D. G., and T. P. Thomas. 2004. History of moose management in wyoming and recent trends in Jackson Hole. Alces 40:133–143.

Burn, D. M., M. a Webber, and M. S. Udevitz. 2006. Application of airborne thermal imagery to surveys of Pacific walrus. Wildlife Society Bulletin 34:51–58.

Chrétien, L.-P., J. Théau, and P. Ménard. 2016. Visible and thermal infrared remote sensing for the detection of white-tailed deer using an unmanned aerial system. Wildlife Society Bulletin 40:181–191.

Clarke, M., L. Jessup, S. Westover, and S. Czetwertynski. 2014. Teslin Burn early-winter moose survey 2013. Whitehorse, Yukon, Canada.

Cluff, H. D. 2005. Survey of moose abundance in the boreal forest around Yellowknife. Yellowknife, NT Canada.

Courtois, R. 1997. Management System and Current Status of Moose in Québec. Alces 33:19.

Crête, M., L. P. Rivest, H. Jolicoeur, J. M. Brassard, and F. Messier. 1986. Predicting and correcting helicopter counts of moose with observations made from fixed-wing aircraft in southern Quebec. The Journal of applied ecology 23:751–761.

Crichton, V. 2002. The horseshoe posture in moose - a reaction to perceived threats. Alces 38:109–111.

Crichton, V., T. Barker, and D. W. Schindler. 2004. Response of a wintering moose population to access management and no hunting - A Manitoba experiment. Alces 40:87–94.

Crins, W. J., P. A. Gray, P. W. C. Uhlig, and M. C. Wester. 2009. The ecosystems of Ontario, part 1: ecozones and ecoregions. Peterborough, Ontario.

Croon, G. W., D. R. Mccullough, C. E. Olson, and L. M. Queal. 1968. Infrared scanning techniques for big game censusing. Journal of Wildlife Management 32:751–759.

Cumberland, R. E. 2012. Potvin double-count aerial surveys in New Brunswick: are results reliable for moose? Alces 48:67–77.

Davison, T., and K. Callaghan. 2011. Moose (*Alces alces*) population size and density in the Inuvik Region of the Northwest Territories , Canada. Rangifer 33:123–128.

DeCesare, N. J., J. R. Newby, V. J. Boccadori, T. Chilton-Radandt, T. Thier, D. Waltee, K. Podruzny, and J. A. Gude. 2016. Calibrating minimum counts and catch-per-unit-effort as indices of moose population trend. Wildlife Society Bulletin 40:537–547.

DeCesare, N. J., T. D. Smucker, R. A. Garrott, and J. A. Gude. 2014. Moose status and management in Montana. Alces 50:35–51.

Delgiudice, G. D. 2016. 2016 aerial moose survey. St. Paul, Minnesota.

Dodge, W. B. J., S. R. Winterstein, D. E. Beyer, and H. I. Campa. 2004. Survival, reproduction, and movements of moose in the Western Upper Peninsula of Michigan. Alces 40:71–85.

Drummer, T. D., and R. W. Aho. 1998. A sightability model for moose in Upper Michigan. Alces 34:15–19.

Eclipse. 2014. Eclipse Downloads. https://www.eclipse.org/downloads/.

Edwards, A. J., M. Schrage, and M. Lenarz. 2004. Northeastern minnesota moose management - a case study in cooperation. Alces 40:23–32.

Environment Yukon. 2016. Science-based guidelines for management of moose in Yukon. Page Yukon Fish and Wildlife Branch Report MR-16-02. Whitehorse, Yukon, Canada.

ESRI. 2012. ArcGIS Desktop 10.1.

Fieberg, J. R., and M. S. Lenarz. 2012. Comparing stratification schemes for aerial moose surveys. Alces 48:79–87.

Fryxell, J. M. 2010. Resource management cycles and the sustainability of harvested wildlife populations. Science 328:903–333.

Fuller, A., K. Schuler, J. Friar, and J. Hurst. 2016. Monitoring moose - New York moose. http://ny-moose.weebly.com/monitoring-moose.html.

Gasaway, W. C., S. D. DuBois, D. J. Reed, and S. J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Bilogical papers of the University of Alaska:1–108.

Gorley, R. 2016. A strategy to help restore moose populations in British Columbia.

Gosse, J., B. McLaren, and E. Eberhardt. 2002. Comparison of fixed-wing and helicopter searches for moose in a mid-winter habitat-based study. Alces 38:47–53.

Harris, R. B., M. Atamian, H. Ferguson, and I. Keren. 2015a. Estimating moose abundance and trends in Northeastern Washington State : index counts , sightability models , and reducing uncertainty. Alces 51:57–69.

Harris, R. B., S. Hansen, J. Oyster, K. Mansfield, E. Rowan, J. Goerz, and M. Mitchell. 2015b. Moose abundance, distribution, and demographic characteristics in eastern Washington: Progress report – Year 1. Olympia, WA.

Ver Hoef, J. M. 2008. Spatial methods for plot-based sampling of wildlife populations. Environ Ecol Stat 15:3–13.

Ver Hoef, J. 2002. Sampling and geostatistics for spatial data. Ecoscience 9:152–161.

Kantar, L. E., and R. E. Cumberland. 2013. Using a double-count aerial survey to estimate moose abundance in Maine. Alces 49:29–37.

Kay, M., and O. J. Wobbrock. 2016. ARTool: aligned rank transform for nonparametric factorial ANOVAs.

Kellie, K. A., and R. A. DeLong. 2006. Geospatial survey operations manual. Fairbanks, Alaska, USA.

Largent, E., H. W. Scullon, and D. E. Beyer. 2015. 2015 Western Upper Peninsula moose survey. Page Wilflife report no. 3616. Lansing, Michigan.

Larter, N. C. 2009. A Program to Monitor the Moose Populations in the Dehcho Region, Northwest Terrritories, Canada. Alces 45:89–99.

Lenarz, M. S. 2011. 2011 Aerial Moose Survey. St. Paul, Minnesota, United States.

Lowe, S. J., B. R. Patterson, and J. a. Schaefer. 2010. Lack of behavioral responses of moose (*Alces alces*) to high ambient temperatures near the southern periphery of their range. Canadian Journal of Zoology 88:1032–1041.

Lynch, G. M., and G. E. Shumaker. 1995. GPS and GIS assisted moose surveys. Alces 31:145–151.

Manitoba Sustainable Development. 2015. Survey results from 2014-15. Winnipeg, Manitoba.

Manitoba Sustainable Development. 2016a. Big game aerial survey results – 2016. Winnipeg, Manitoba.

Manitoba Sustainable Development. 2016b. Big game aerial surveys. http://www.gov.mb.ca/sd/wildlife/hunting/biggame/survey/index.html.

Maskey, J. J. 2011. Giant liver fluke in North Dakota moose. Alces 47:1–7.

McLaren, B. E., and W. E. Mercer. 2005. How management unit license quotas relate to population size, density, and hunter access in Newfoundland. Alces 41:75–84.

McLaren, B. E., B. A. Roberts, N. Djan-Chekar, and K. P. Lewis. 2004. Effects of overabundant moose on the Newfoundland landscape. Alces 40:45–59.

McLaren, M. 2006. Standards and guidelines for moose population inventory in Ontario. Page Southern Science and Information Technical Report Number SSI #121. Peterborough, Ontario.

Miller, D. L. 2016. Distance: distance sampling detection function and abundance estimation.

Millette, T. L., E. Marcano, and D. Laflower. 2014. Winter distribution of moose at landscape scale in Northeastern Vermont: a GIS analysis. Alces 50:17–26.

Millette, T. L., D. Slaymaker, E. Marcano, C. Alexander, and L. Richardson. 2011. AIMS-thermal - a thermal and high resolution color camera system integrated with gis for aerial moose and deer census in northeastern vermont. Alces 47:27–37.

Ministry of Forests, L. and N. R. O. 2015. Provincial framework for moose management in British Columbia. Victoria, B.C.

Ministry of Sustainable Resource Management. 2002. Aerial-based inventory methods for selected ungulates: bison, mountain goat, mountain sheep, moose, elk, deer and caribou. Victoria, B.C.

Monteith, K. L., R. W. Klaver, K. R. Hersey, A. A. Holland, T. P. Thomas, M. J. Kauffman, · A Andrew Holland, T. P. Thomas, and M. J. Kauffman. 2015. Effects of climate and plant phenology on recruitment of moose at the southern extent of their range. Oecologia 178:1137–1148.

Nadeau, S. M., N. J. DeCesare, D. G. Brimeyer, E. J. Bergman, R. B. Harris, K. R. Hersey, K. K. Huebner, P. E. Matthews, and T. P. Thomas. 2017. Status and trends of moose populations and humting opportunity in the western United States. Alces.

Newfoundland Department of Environment and Conservation. 2015. 2015 - 2020 Newfoundland and Labrador moose management plan. St. John's, NL.

Oehlers, S. A., R. T. Bowyer, F. Huettmann, D. K. Person, and W. B. Kessler. 2012. Visibility of moose in a temperate rainforest. Alces 48:89–104.

Peters, W., M. Hebblewhite, K. G. Smith, S. M. Webb, N. Webb, M. Russell, C. Stambaugh, and R. B. Anderson. 2014. Contrasting aerial moose population estimation methods and evaluating sightability in west-central Alberta, Canada. Wildlife Society Bulletin 38:639–649.

Peterson, R. O., and R. E. Page. 1993. Detection of moose in midwinter from fixed-wing aircraft over dense forest cover. Wildlife Society Bulletin 21:80–86.

Phillips, R. L., W. E. Berg, and D. B. Siniff. 1973. Moose movement patterns and range use in Nortwestern Minnesota. Journal of Wildlife Management 37:266–278.

Pollock, K. H., and W. L. Kendall. 1987. Visibility bias in aerial surveys: a review of estimation procedures. The Journal of Wildlife Management 51:502–510.

Poole, K. G., G. Mowat, and D. Pritchard. 1999. Using GPS and GIS for navigation and mark-recapture for sightability correction in moose inventories. Alces 35:1–10.

Potvin, F., and L. Breton. 2005. Testing 2 aerial survey techniques on deer in fenced enclosures—visual double-counts and thermal infrared sensing. Wildlife Society Bulletin 33:317–325.

Pulsifer, M. D., and T. L. Nette. 1995. History, status and present distribution of moose in Nova Scotia. Alces 31:209–220.

Quayle, J. F., A. G. MacHutchon, and D. N. Jury. 2001. Modeling moose sightability in South-Central British Columbia.

R Development Core Team. 2013. R Software.

Rines, K. M. 2015. New Hampshire moose assessment. Concord, New Hampshire.

Rivest, L.-P., and H. Crepeau. 1990. A two-phase sampling plan for the estimation of the size of a moose population. Biometrics 46:163–176.

Rivest, L. P., F. Potvin, H. Crepeau, and G. Daigle. 1995. Statistical-methods for aerial surveys using the double-count technique to correct visibility bias. Biometrics 51:461–470.

Saskatchewan Ministry of Environment. 2015. Saskatchewan wildlife management report 2013-2014. Saskatoon, Saskatchewan.

Thomas, L., S. T. Buckland, E. a Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. Bishop, T. a Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. The Journal of applied ecology 47:5–14.

Thompson, I. D. 1979. A method of correcting population and sex and age estimates from aerial transect surveys for moose. Alces 15:148–168.

Timmerman, H. R. 2003. The status and management of moose in North America-circa 2000-01. Alces 39:131–151.

Timmermann, H. 1993. Use of aerial surveys for estimating and monitoring moose populations-a review. Alces 29:35–46.

Timmermann, H. R., and A. R. Rodgers. 2005. Moose: competing and complementary values. Alces 41:85–120.

Toweill, D., and G. Vecellio. 2004. Shiras moose in Idaho: status and management. Alces 40:33–43.

Wagner, C. 2006. Moose data analysis unit plan M-4 Southwest Colorado. Monte Vista, Colorado.

Wald, E. J., and R. M. Nielson. 2014. Estimating moose abundance in linear subarctic habitats in low snow conditions with distance sampling and a kernel estimator. Alces 50:133–158.

Ward, R., W. Gasaway, and M. Dehn. 2000. Precision of moose density estimates derived from stratification survey data. Alces 36:197–203.

Wattles, D. W., and S. DeStefano. 2011. Status and management of moose in the Northeastern United States. Alces 47:53–68.

Wiggers, E. P., and S. F. Beckerman. 1993. Use of thermal infrared sensing to survey white-tailed deer populations. Wildlife Society Bulletin 21:263–268.

Wobbrock, J. O., L. Findlater, D. Gergle, and J. J. Higgins. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. Pages 143–146Proc. CHI ’11. Vancouver, BC, Canada.

Wolfe, M. L., K. R. Hersey, and D. C. Stoner. 2010. A history of moose management in Utah.

Alces 46:37–52.

Wright, R. G., B. S. Haroldson, and C. Pouliot. 2015. DNRSurvey - moving map software for aerial surveys. http://www.dnr.state.mn.us/mis/gis/DNRSurvey/DNRSurvey.html.

7.0 APPENDIX

7.1 THERMAL & COLOUR IMAGERY

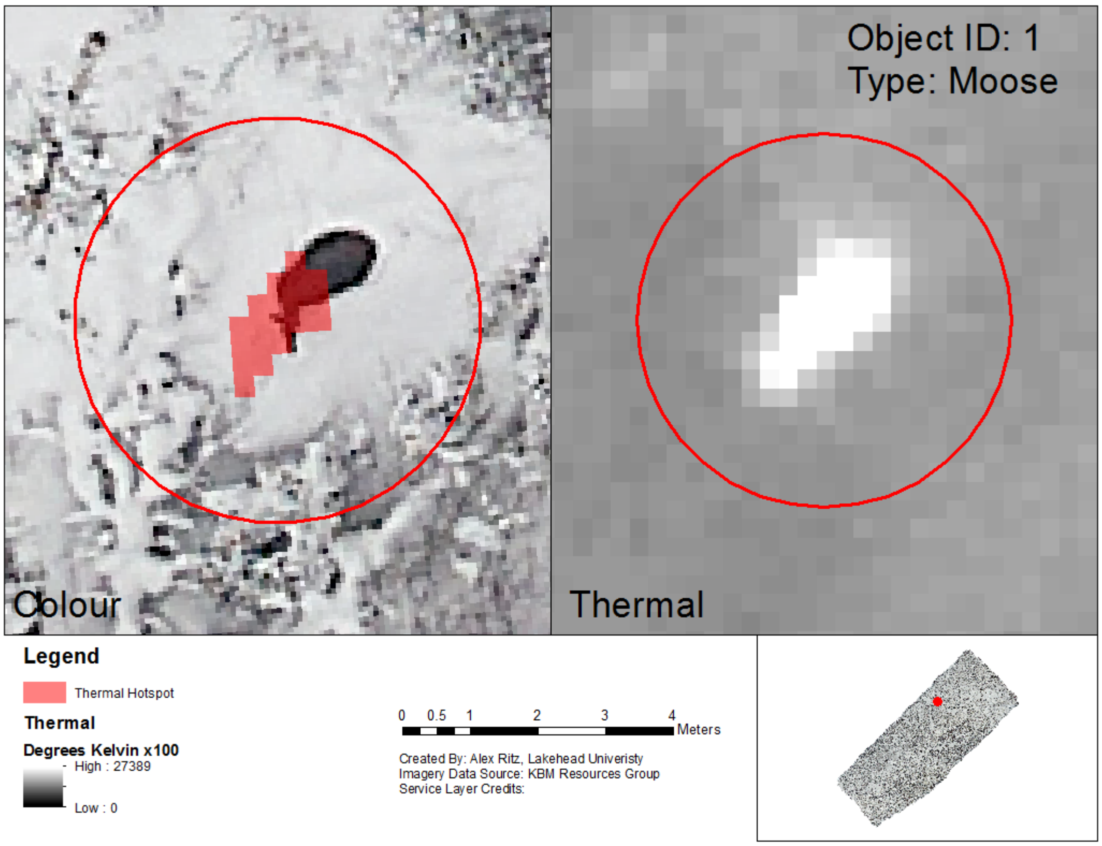

Figure 7.1a. Colour and thermal imagery of moose thermal hotspot. Images taken on January 21, 2016 over La Verendrye Provincial Park, Ontario. Specific location within the imagery is depicted in the lower-right map.

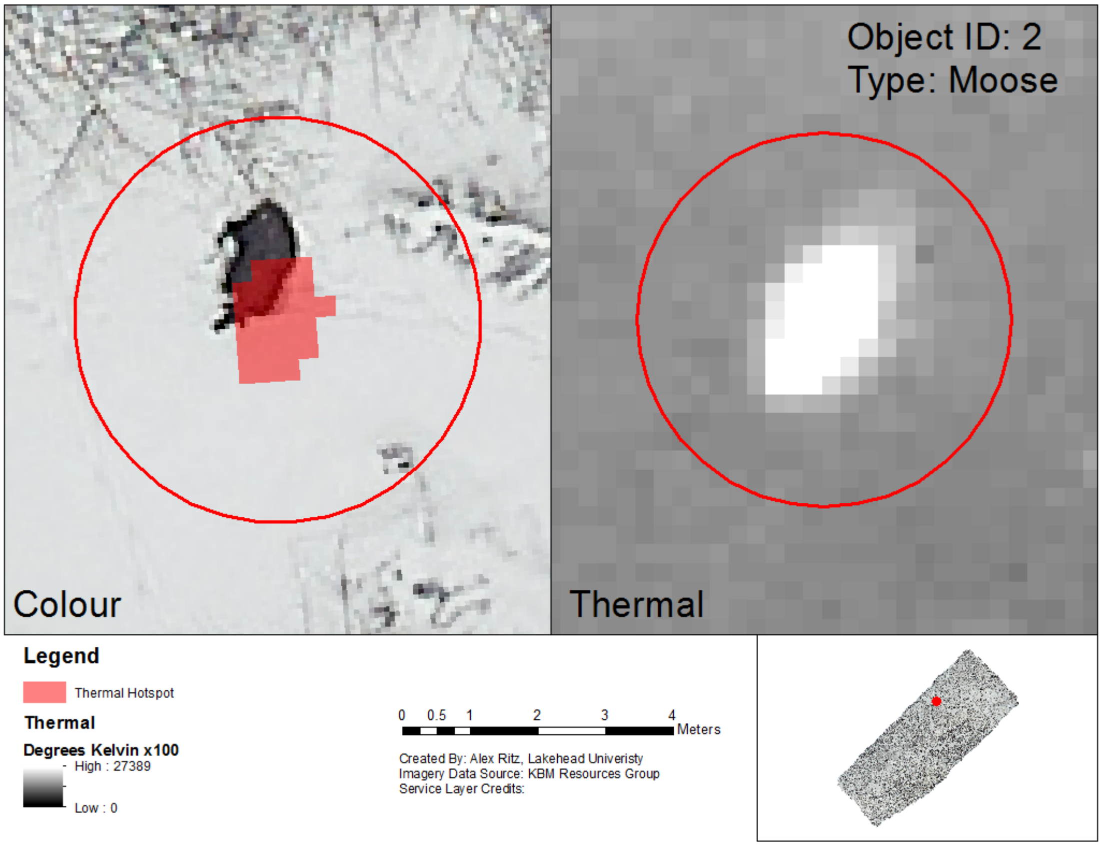

Figure 7.1b. As described in Figure 7.1a.

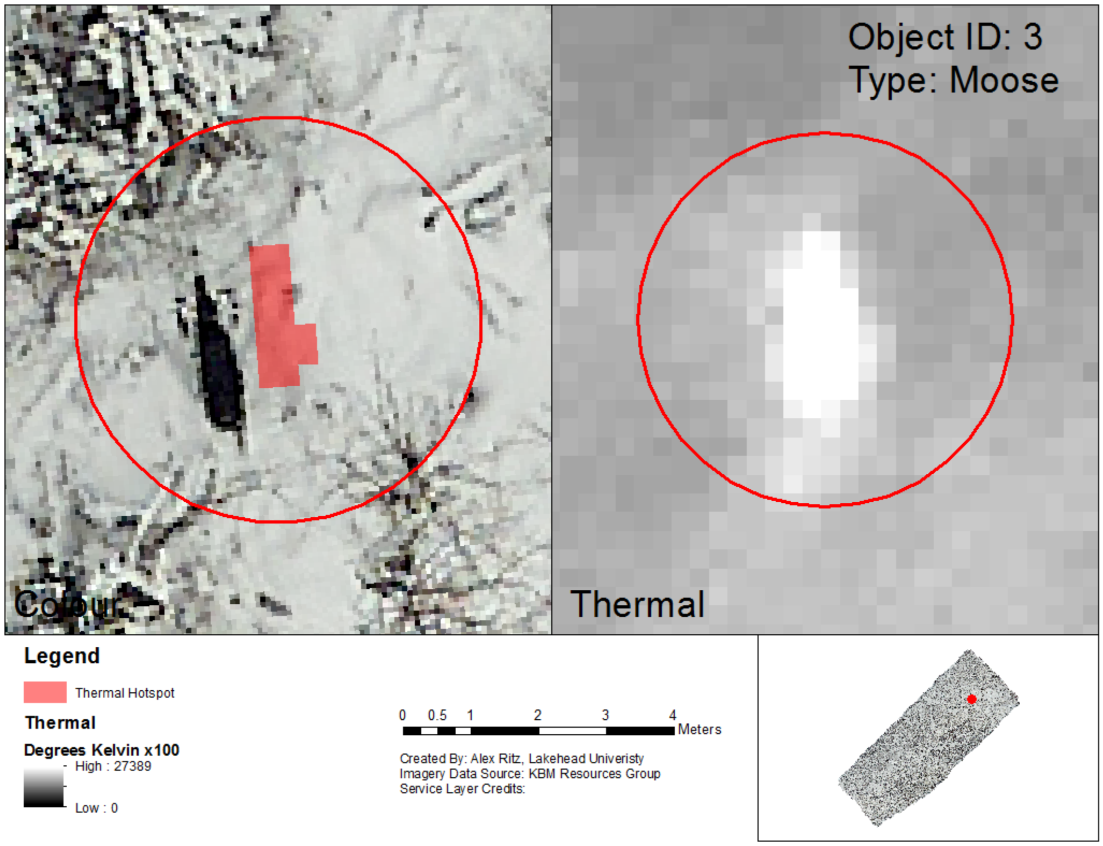

Figure 7.1c. As described in Figure 7.1a.

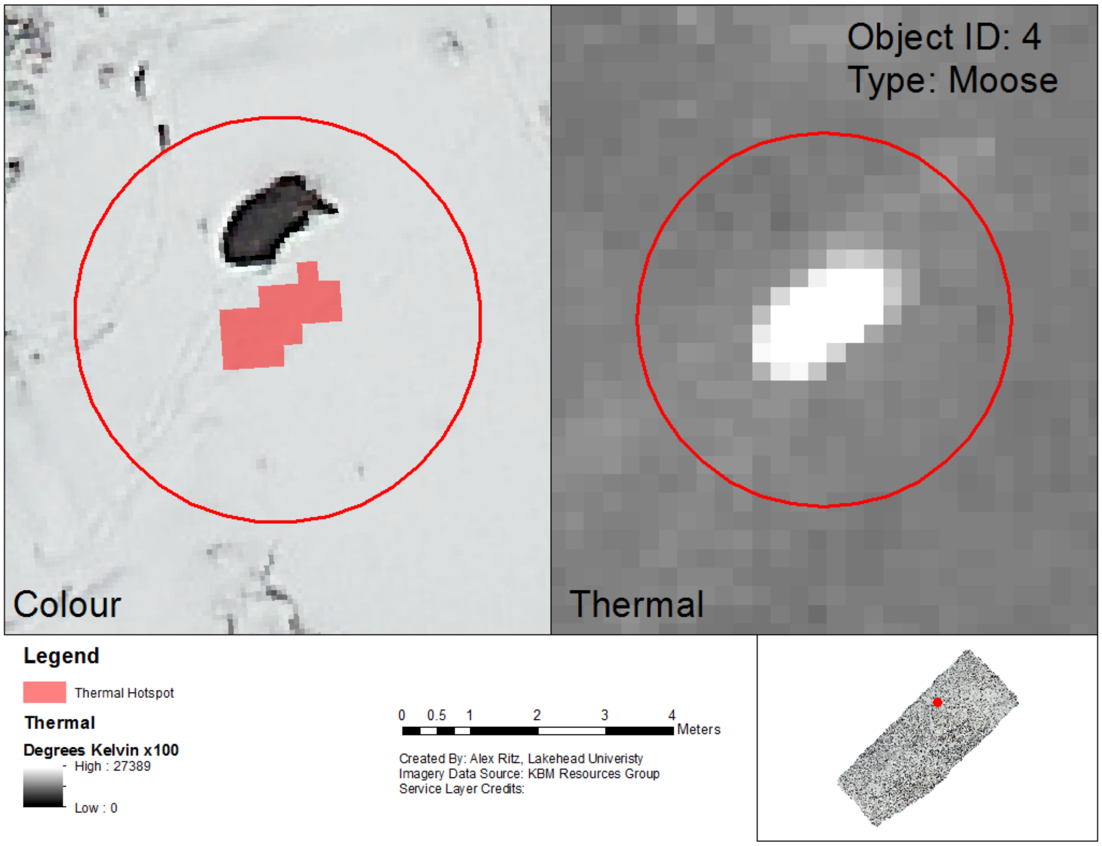

Figure 7.1d. As described in Figure 7.1a.

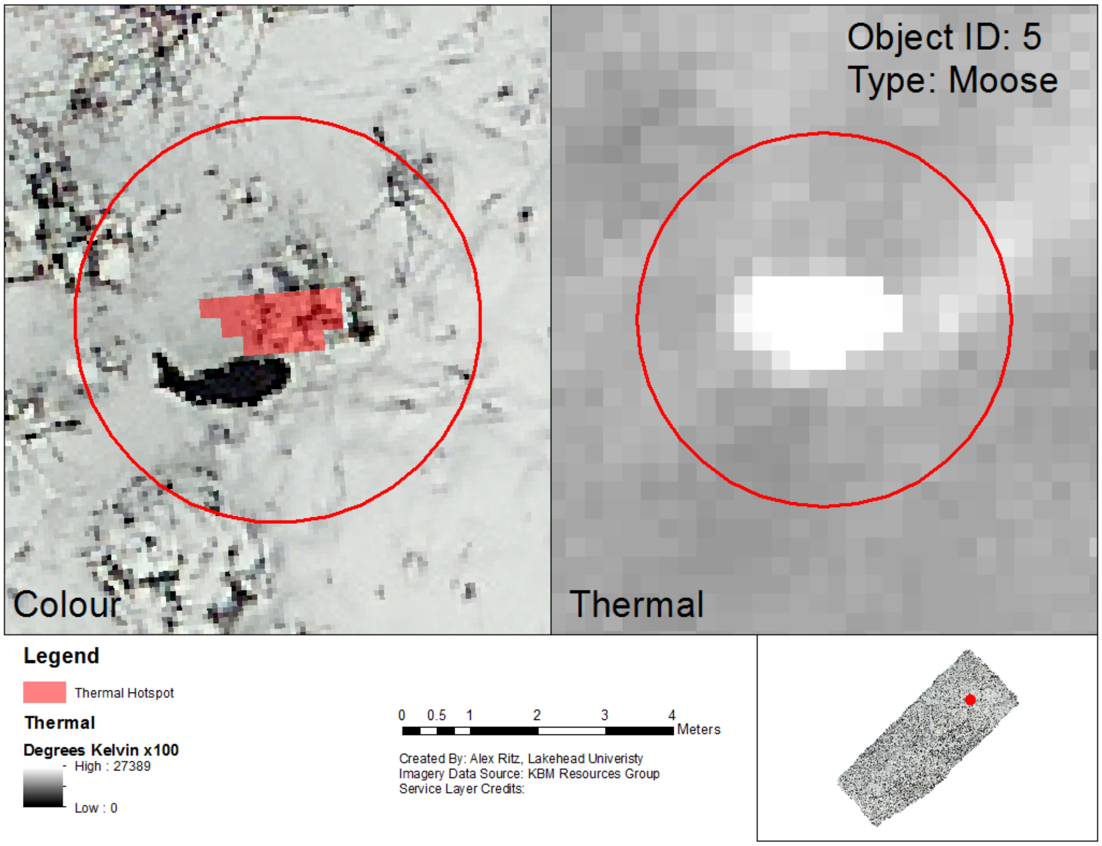

Figure 7.1e. As described in Figure 7.1a.

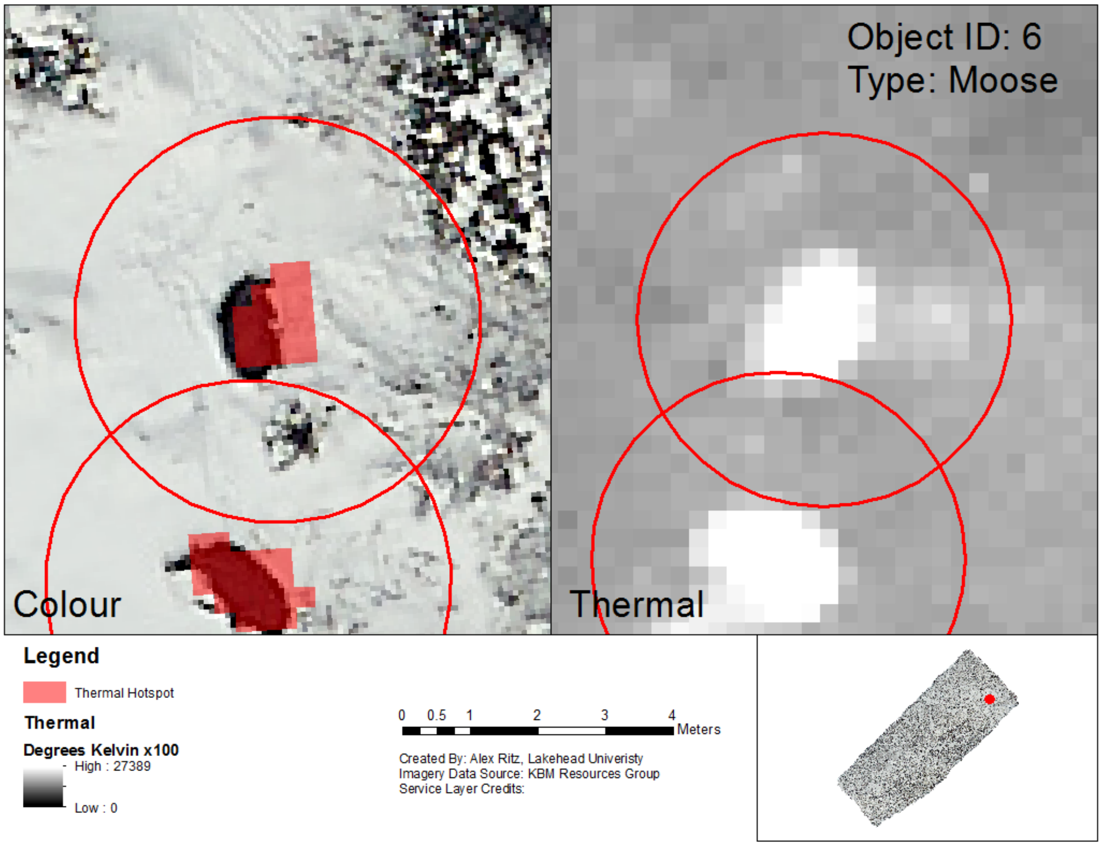

Figure 7.1f. As described in Figure 7.1a.

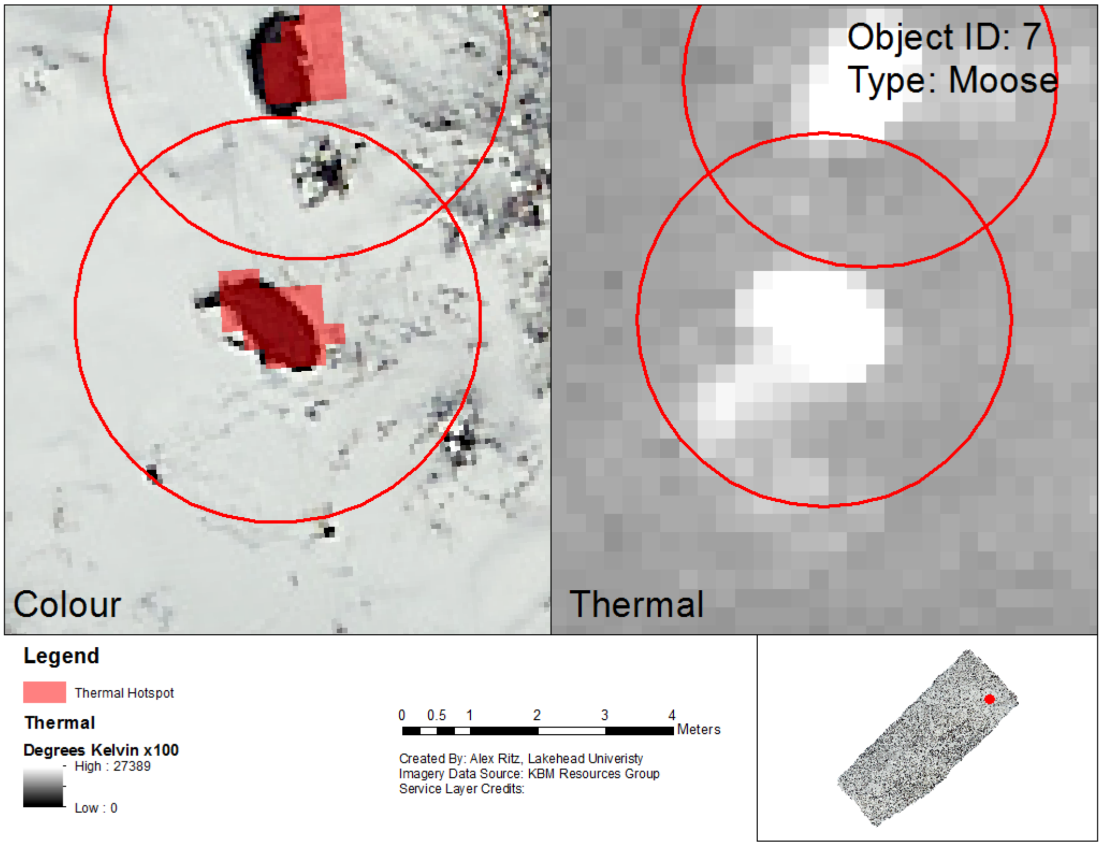

Figure 7.1g. As described in Figure 7.1a.

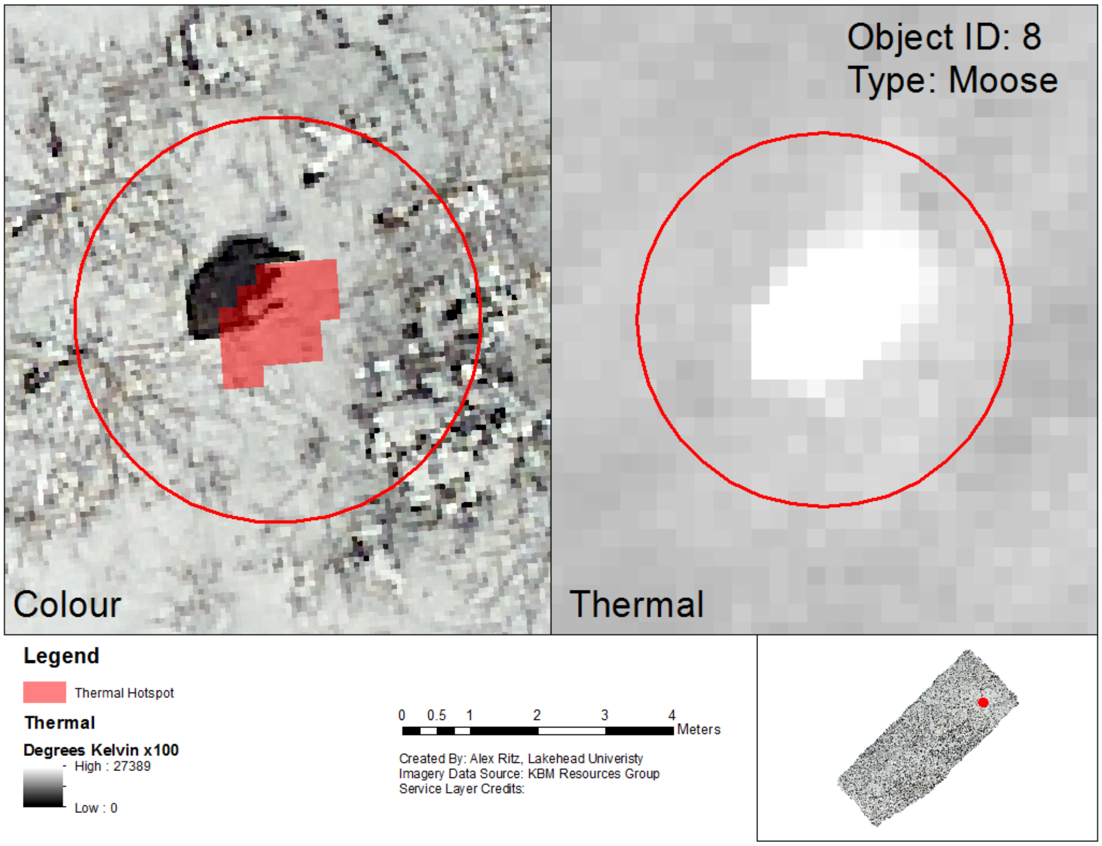

Figure 7.1h. As described in Figure 7.1a.

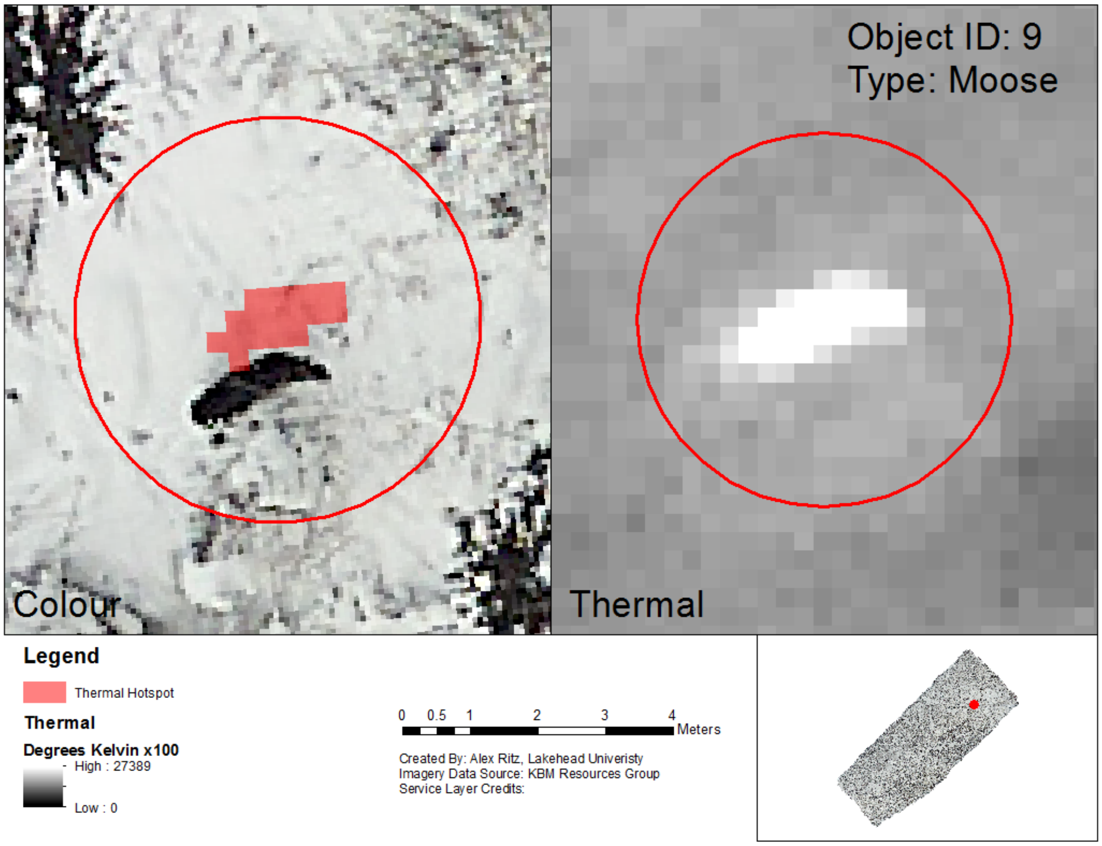

Figure 7.1i. As described in Figure 7.1a.

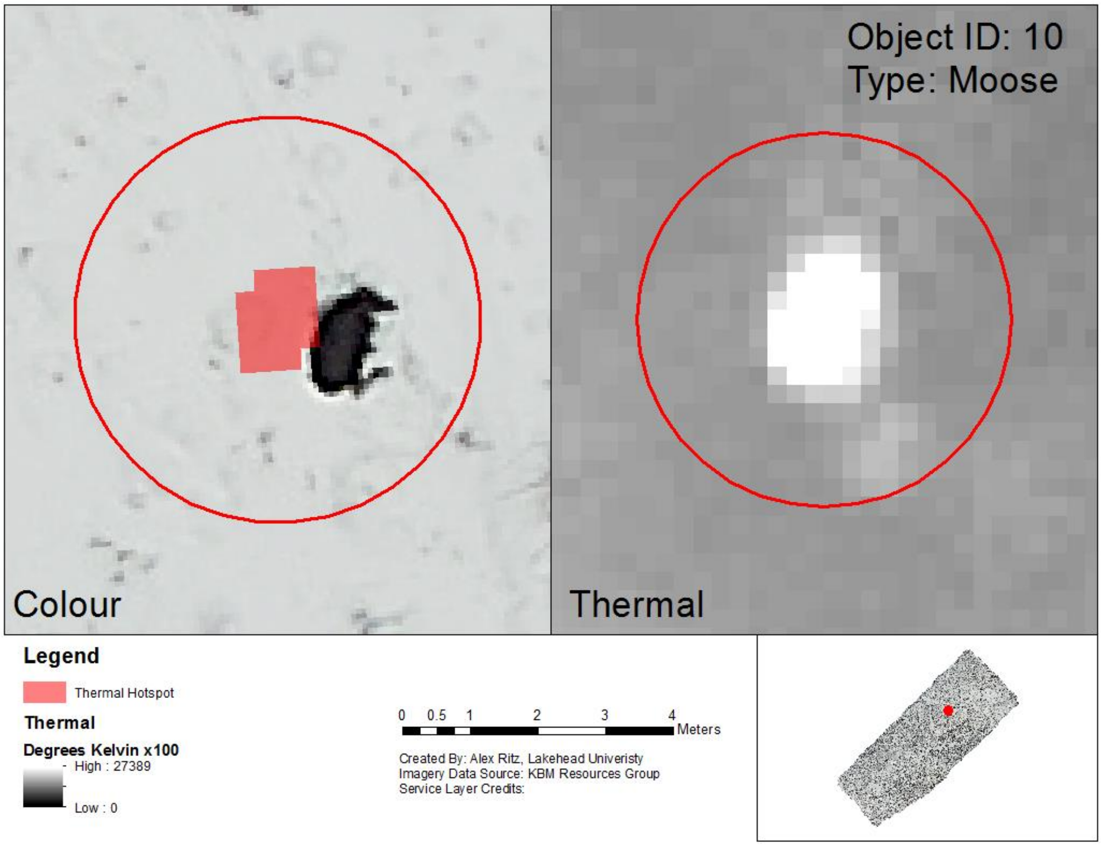

Figure 7.1j. As described in Figure 7.1a.

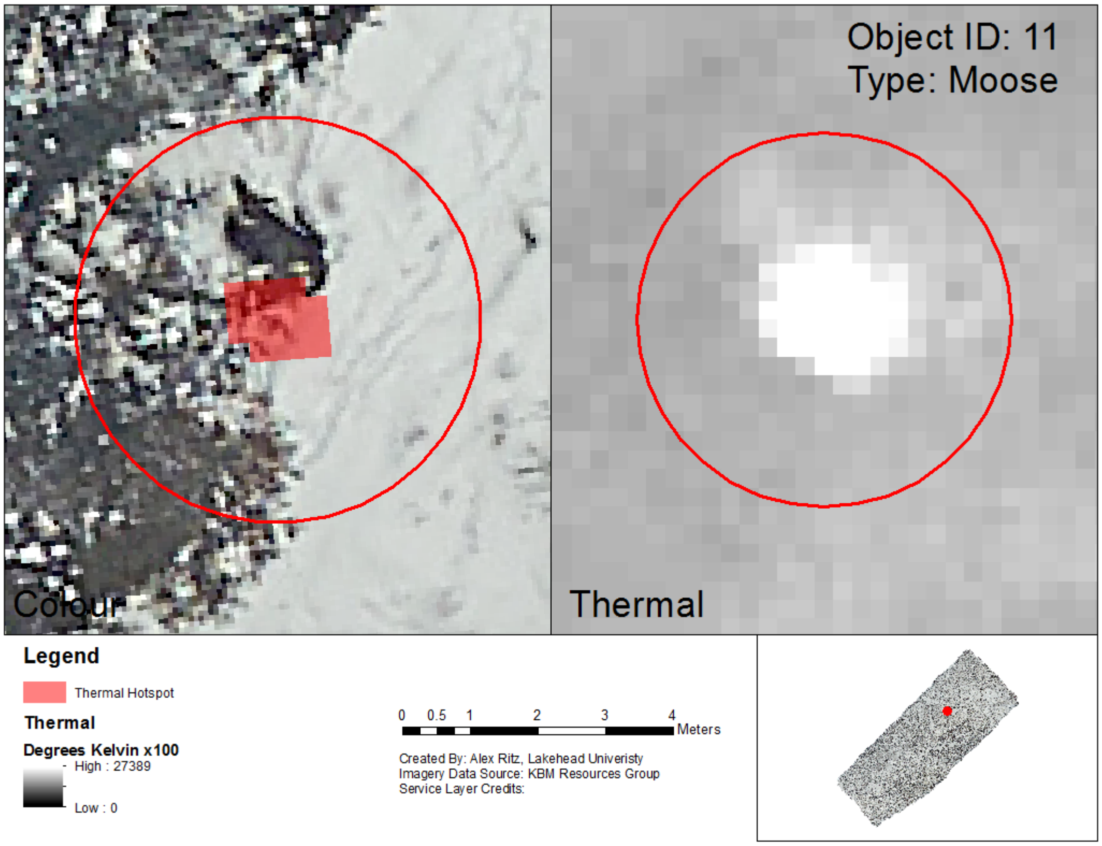

Figure 7.1k. As described in Figure 7.1a.

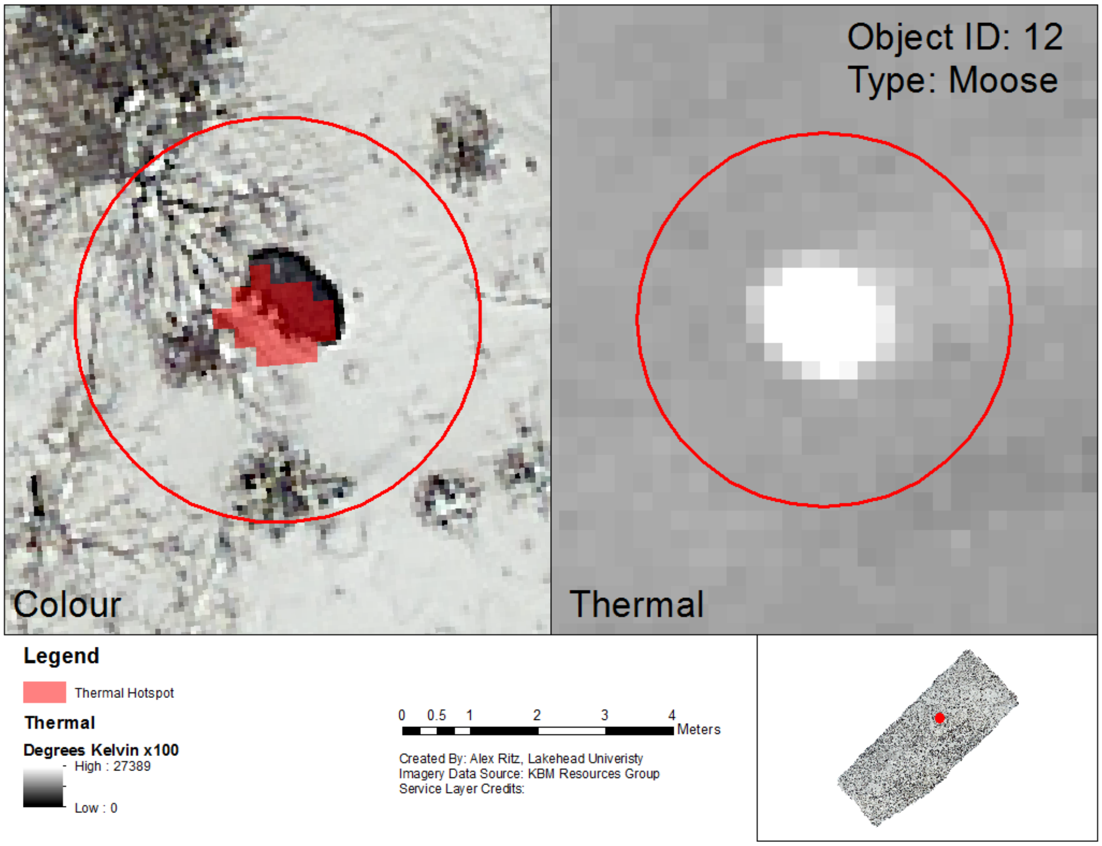

Figure 7.1l. As described in Figure 7.1a.

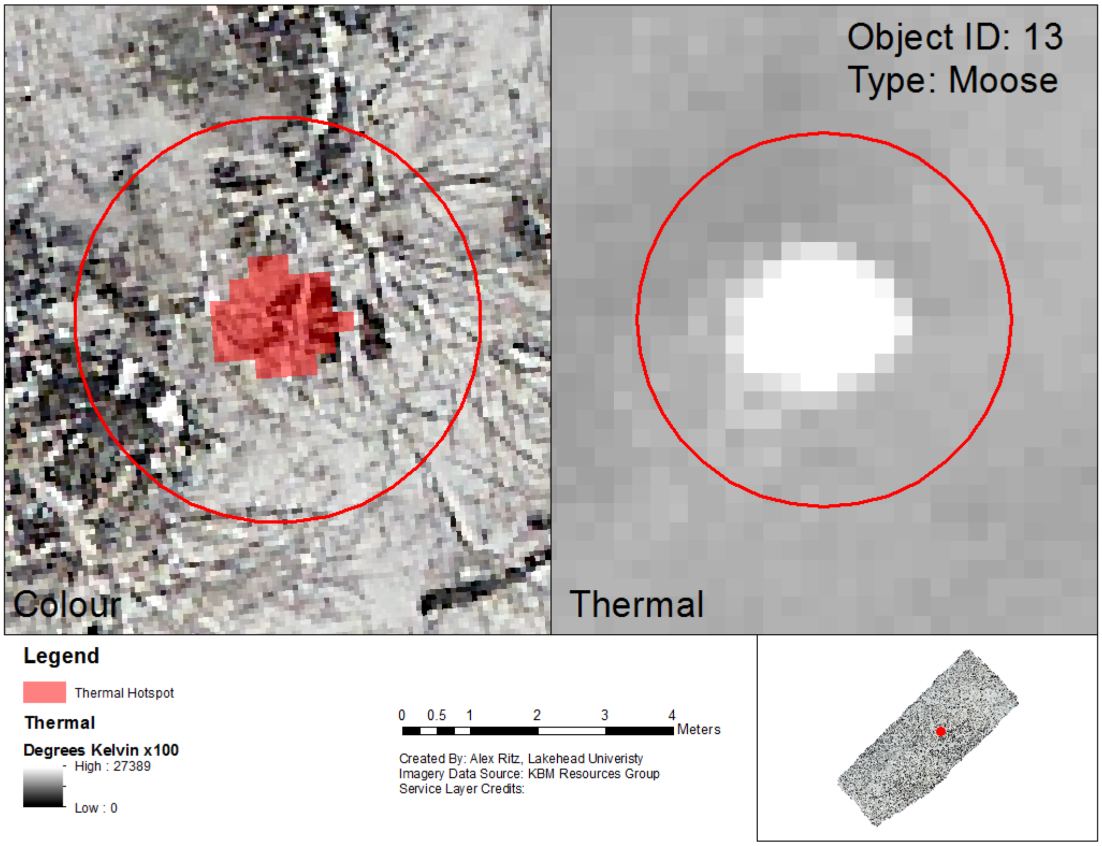

Figure 7.1m. As described in Figure 7.1a.

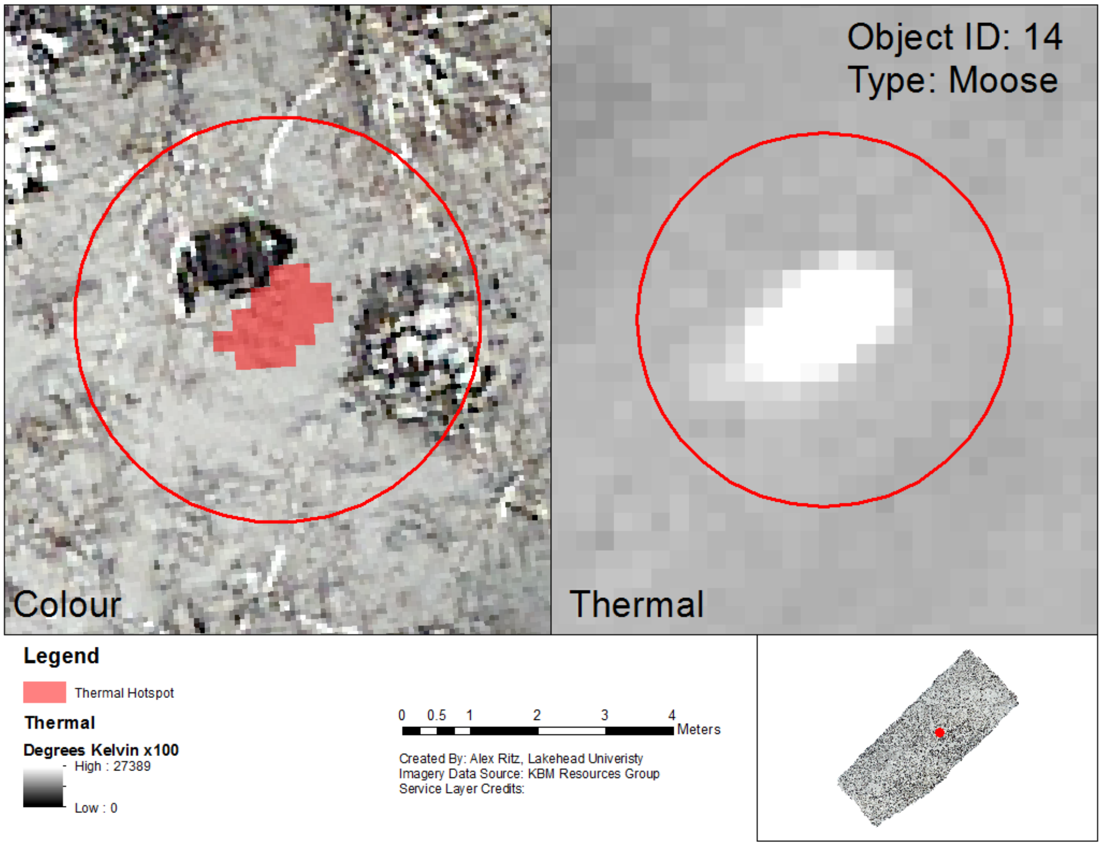

Figure 7.1n. As described in Figure 7.1a.

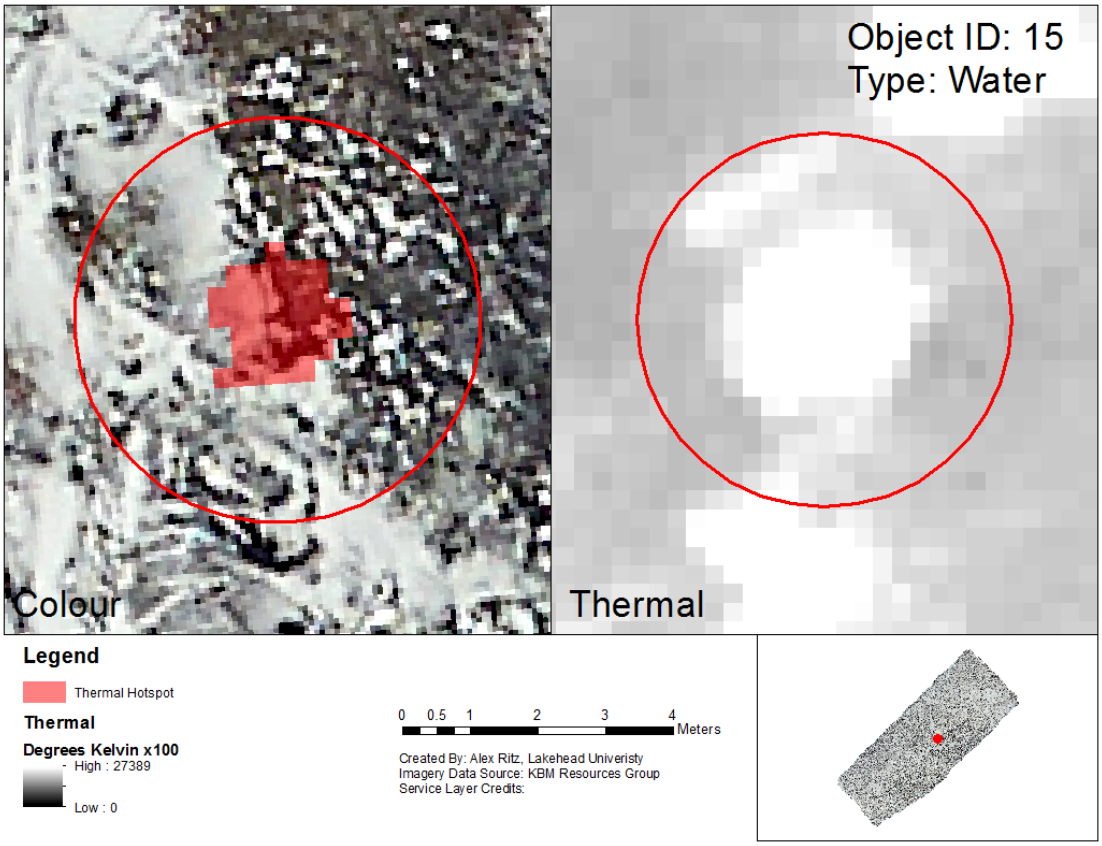

Figure 7.1o. As described in Figure 7.1a.

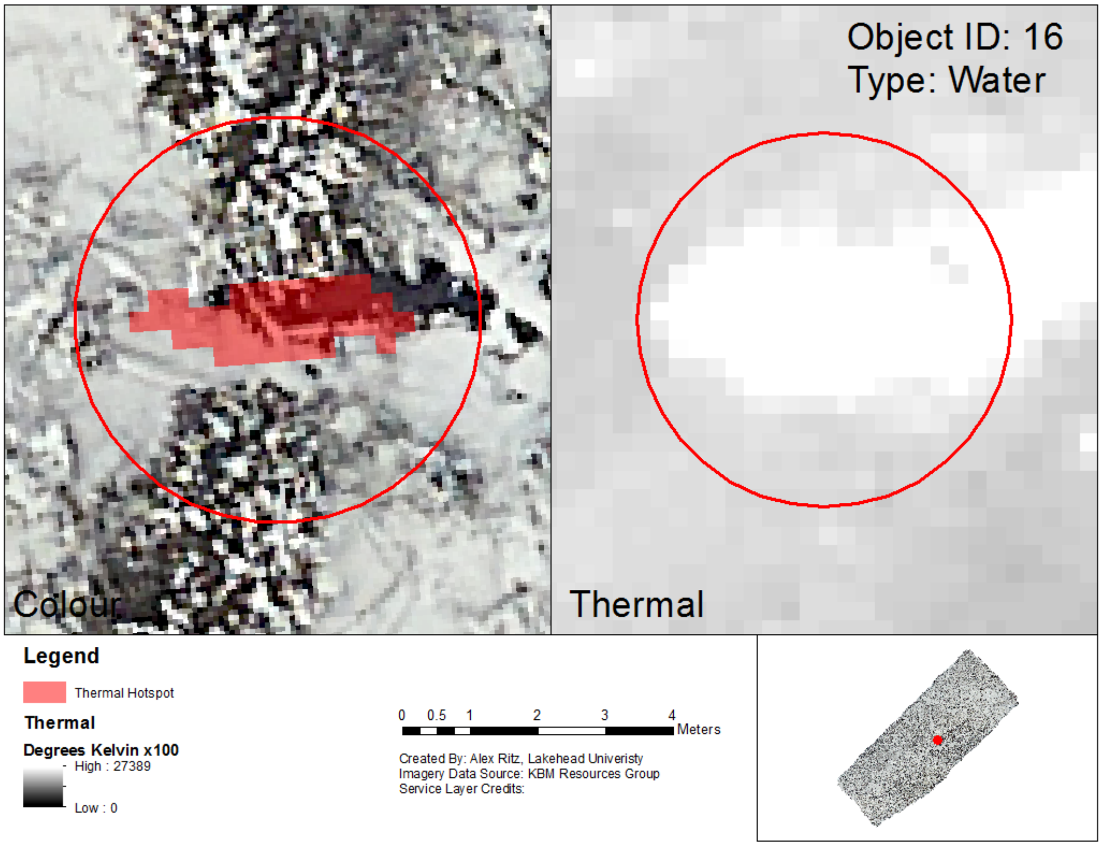

Figure 7.1p. As described in Figure 7.1a.

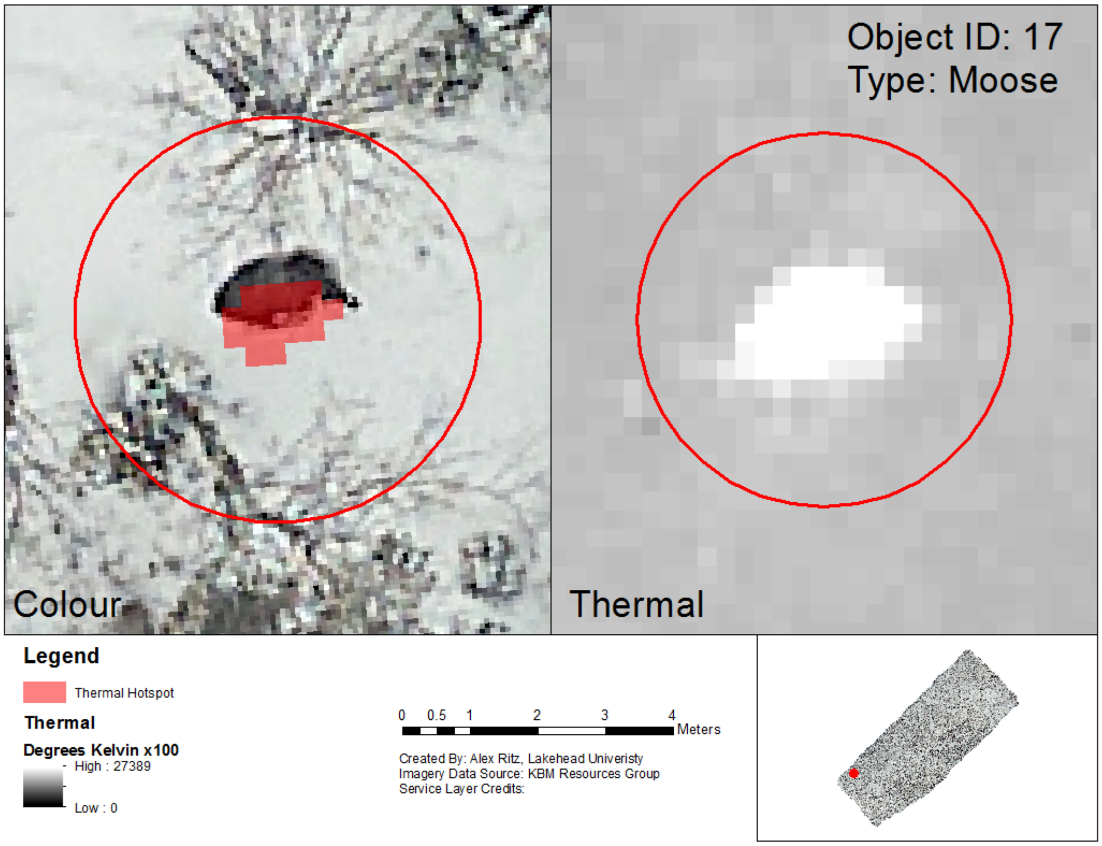

Figure 7.1q. As described in Figure 7.1a.

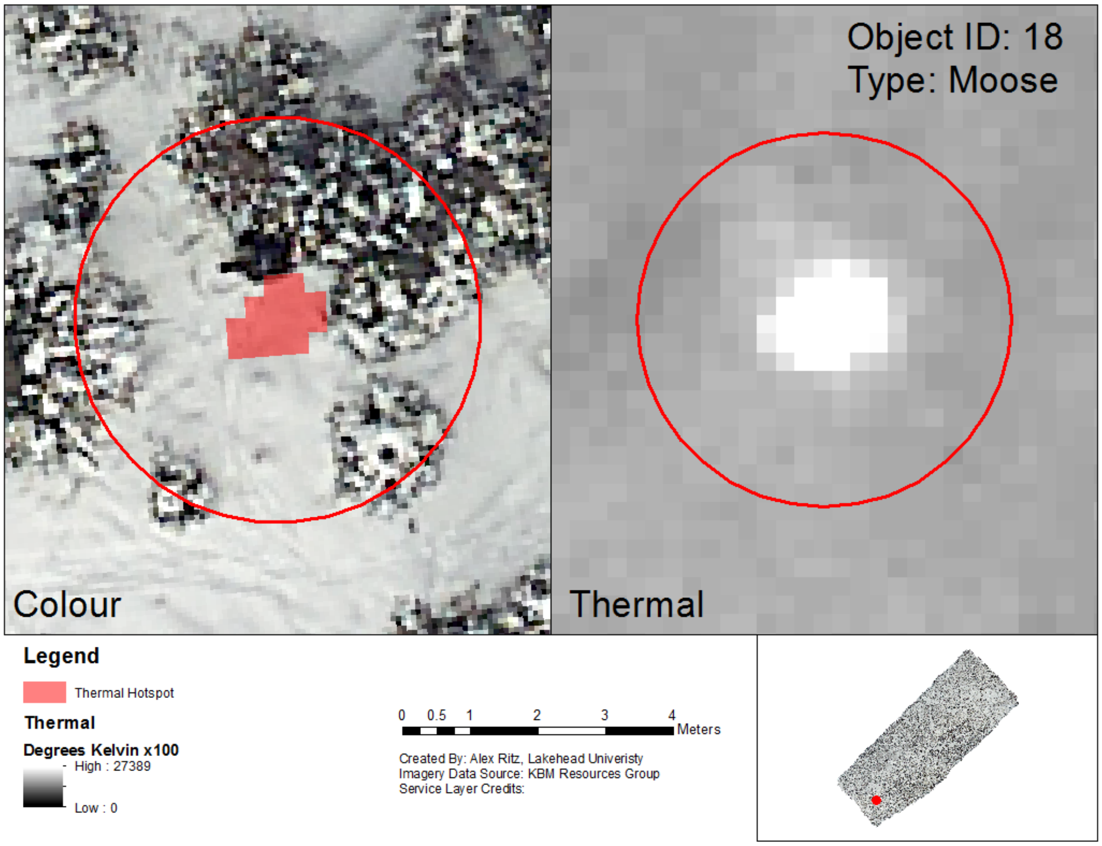

Figure 7.1r. As described in Figure 7.1a.

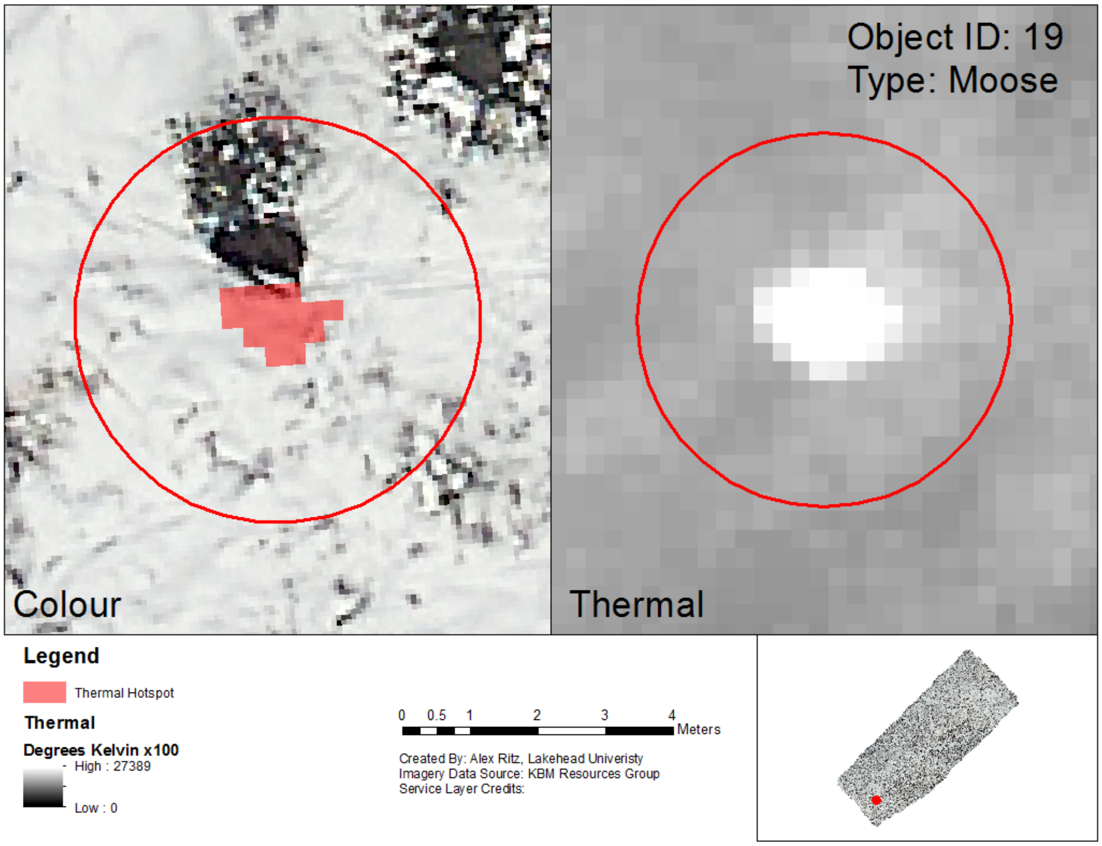

Figure 7.1s. As described in Figure 7.1a.

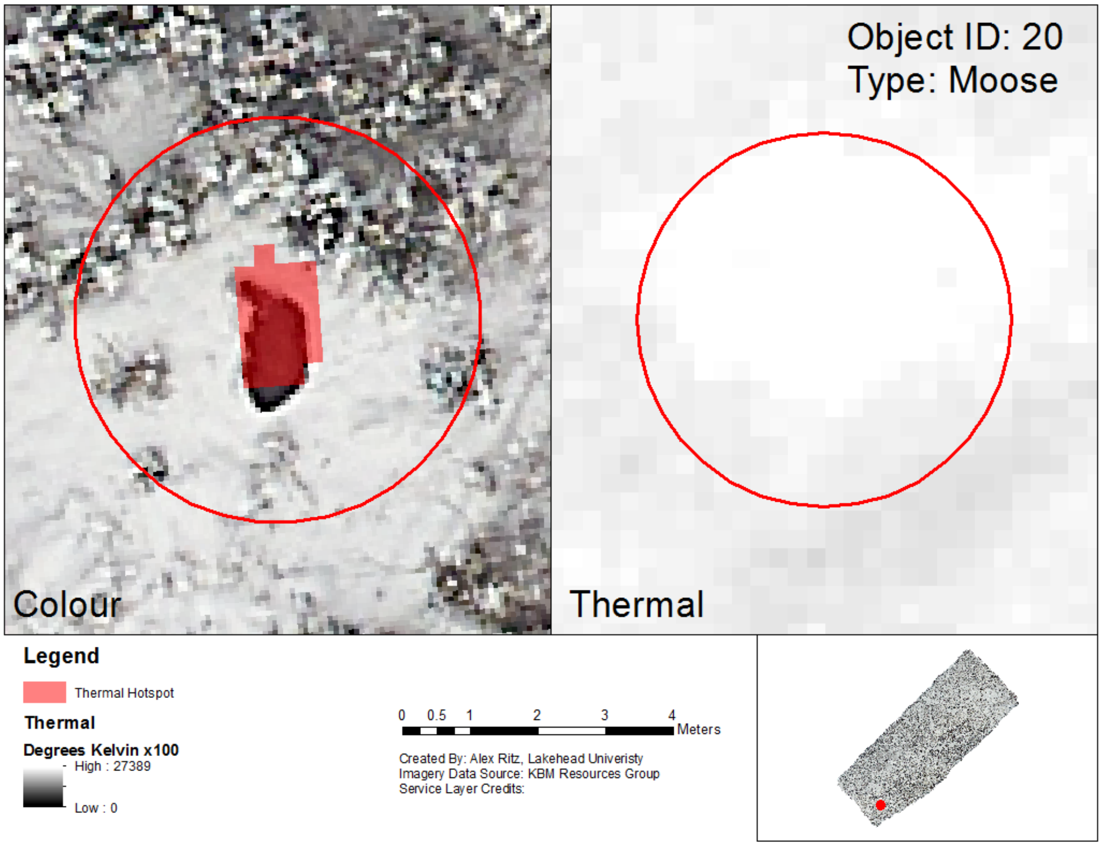

Figure 7.1t. As described in Figure 7.1a.

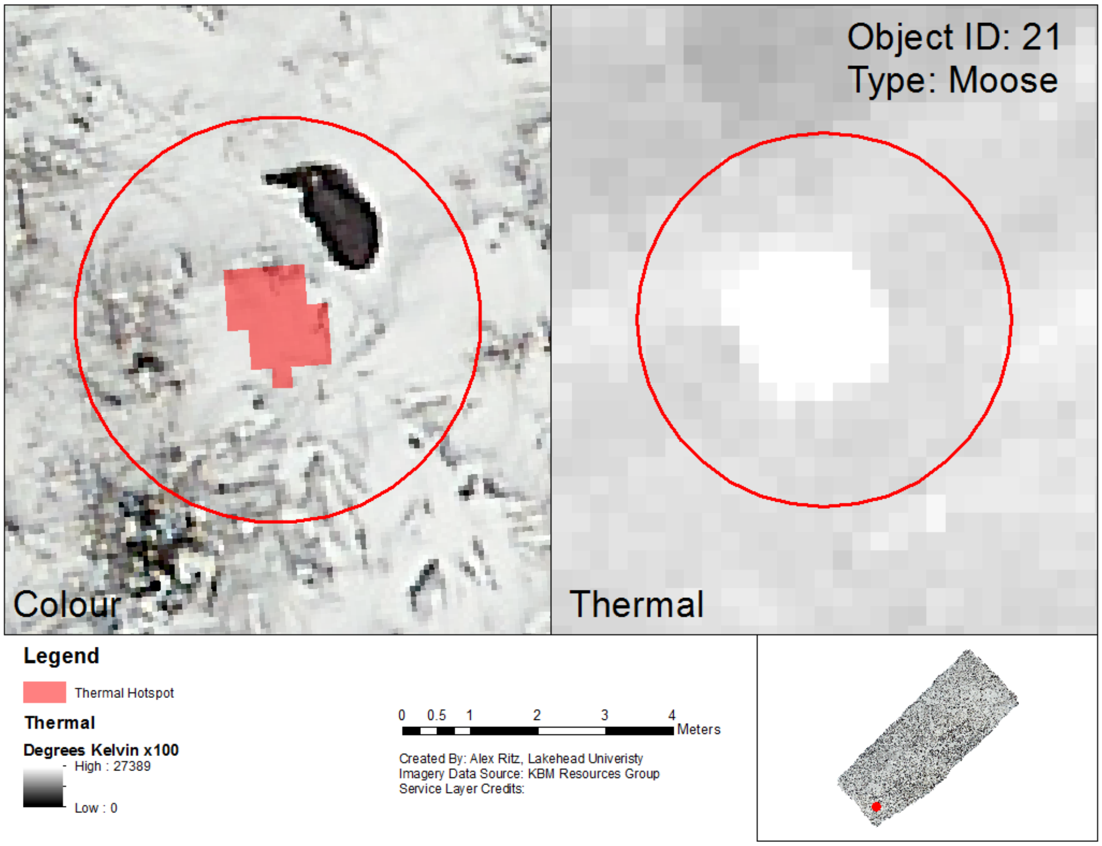

Figure 7.1u. As described in Figure 7.1a.