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Evaluating drone-mounted thermal imaging for population surveys of wild ungulates in boreal and montane habitats of Western Canada

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Abstract

Accurate population estimates of wild ungulates underpin harvest management, habitat conservation, and predator-prey modelling, yet conventional aerial surveys conducted from manned helicopters suffer from high cost, observer fatigue, variable sightability, and safety risks in mountainous terrain. Thermal-imaging drones have been proposed as an alternative, but their performance across the range of species, habitats, and climatic conditions encountered in western Canada has not been systematically evaluated. This research assessed the detection performance of drone-mounted thermal imaging relative to drone-mounted RGB (visible-light) cameras and traditional ground-based line transects for four ungulate species—moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), and caribou (*Rangifer tarandus*)—across five habitat types and four seasons in British Columbia between January 2023 and December 2023. A total of 312 survey flights covering 4,680 hectares were conducted using a DJI Matrice 30T equipped with a 640 × 512 pixel radiometric thermal sensor. Thermal drone surveys achieved an overall detection rate of 88.9%, compared with 65.7% for RGB drone surveys and 49.7% for ground transects ($p < 0.001$ for all pairwise comparisons). Detection rates were highest for moose (94.2%) and lowest for caribou (82.4%), reflecting body-size-dependent thermal signatures. Ambient temperature was the strongest environmental predictor of detection success: thermal detection rates exceeded 90% at temperatures below -5 °C but declined to 67.2% above 15 °C as the thermal contrast between animals and the environment diminished. Coniferous forest canopy reduced detection by 12-18% compared with open meadow. These results demonstrate that thermal drone surveys substantially outperform conventional methods for ungulate population monitoring in western Canadian landscapes, with optimal deployment during cold-season windows when thermal contrast is maximal.

Keywords: Thermal imaging, unmanned aerial vehicle, drone survey, wildlife population monitoring, ungulates, moose, deer, elk, caribou, boreal forest, British Columbia

Introduction

How many moose are in a given management unit? The question sounds simple, but answering it with any confidence has been one of the persistent challenges of wildlife management in Canada's vast boreal and montane landscapes. Conventional aerial surveys—conducted from helicopters flying systematic transects at 100-150 metres above ground—have been the standard method since the 1960s, and they remain the basis for provincial harvest quota calculations in British Columbia, Alberta, and the Yukon. Yet their limitations are well documented: they are expensive (CAD 1,200-2,500 per flight hour), weather-dependent, subject to observer fatigue over multi-hour flights, biased by variable sightability in dense forest canopy, and they expose crew members to non-trivial crash risk in mountainous terrain. The emergence of consumer and commercial drones equipped with high-resolution thermal infrared cameras has opened a potential alternative. Thermal sensors detect the radiant heat emitted by warm-bodied animals against cooler backgrounds, theoretically eliminating the dependence on visual contrast that limits both human observers and standard RGB cameras. Several proof-of-concept trials have demonstrated thermal drone detection of deer, wild boar,

and African ungulates, but most have been conducted in temperate or tropical grasslands where canopy obstruction is minimal and the thermal environment is relatively uniform. The boreal and montane habitats of western Canada present a more demanding test: dense coniferous canopy, extreme temperature variation from -30 °C winter to + 30 °C summer, snow cover that alters background thermal signatures, and a species assemblage spanning body sizes from 40 kg (deer) to 500 kg (moose).

A critical unanswered question is how ambient temperature affects thermal detection performance across this range. At very cold temperatures, the thermal contrast between a 38 °C ungulate and a -20 °C background is enormous, favouring detection. As ambient temperature rises toward animal body temperature, contrast diminishes and detection should theoretically decline—but the functional form of this relationship, and the temperature threshold below which thermal surveys become unreliable, have not been empirically established for Canadian ungulates.

This research addressed these gaps through a year-long, multi-species, multi-habitat evaluation of thermal drone surveys in British Columbia, with three objectives: to compare detection rates of thermal drones, RGB drones, and ground transects for four ungulate species; to quantify the effects of ambient temperature, habitat type, and season on thermal detection performance; and to derive practical guidelines for optimal deployment of thermal drone surveys in western Canadian wildlife management.

Materials and Methods

Materials

The research was conducted across six wildlife management units in central and northeastern British Columbia, selected to represent the five major habitat types in which ungulate surveys are routinely conducted: coniferous forest (dominated by spruce and lodgepole pine), mixed forest (spruce-aspen-birch), open meadow (alpine and subalpine grasslands), wetland margins (riparian zones along rivers and lakes), and burned areas (2-8 years post-wildfire with regenerating shrub cover). The drone platform was a DJI Matrice 30T (DJI, Shenzhen, China) equipped with a radiometric thermal sensor (640 × 512 pixels, 40 mK NETD, 8-14 µm spectral range) and a 48 MP visible-light (RGB) camera. Flights were conducted at 80 m above ground level (AGL), providing a thermal ground sample distance of approximately 11 cm/pixel. A total of 312 survey flights were completed between January and December 2023, covering 4,680 hectares across all four seasons. Ground-based line transects were conducted simultaneously by trained wildlife observers walking predetermined routes within the same survey blocks. Known-density reference sites were established using GPS-collared animals ($n = 47$ moose, 38 deer, 42 elk, 31 caribou) whose positions were recorded at the time of each survey flight, providing a ground-truth denominator for detection rate calculations. All fieldwork was conducted under British Columbia Wildlife Permit CB23-341267 and Transport Canada Special Flight Operations Certificate SFOC-2023-BC-0087.

Methods

Each survey block (approximately 15 ha) was flown in an automated grid pattern at 3 m/s ground speed with 70% side

overlap between adjacent flight lines, following pre programmed flight plans generated in DJI Pilot 2 software. Thermal and RGB imagery were captured simultaneously at 2-second intervals. Thermal images were processed in Pix4D Thermal (Pix4D, Lausanne, Switzerland) to generate radiometric orthomosaics with calibrated temperature values per pixel. RGB images were processed in DJI Terra to generate standard orthomosaics. Automated ungulate detection on thermal orthomosaics was performed using a YOLOv8 object detection model fine-tuned on 8,400 annotated thermal images of Canadian ungulates from a training dataset collected in 2022. All automated detections were verified by two independent expert reviewers who examined the corresponding thermal and RGB imagery to confirm species identification and eliminate false positives (e.g., sun-warmed rocks, machinery). Detection rate was calculated as the proportion of GPS-collared reference animals within a survey block that were detected by each method. Environmental variables recorded for each flight included ambient temperature (measured by an onboard sensor and a ground-level weather station), wind speed, cloud cover, canopy cover (estimated from LiDAR canopy height models), and snow cover (binary: present/absent). Statistical analyses were performed in R v4.3.1. Detection rates were modelled using generalised linear mixed models (GLMM) with a binomial distribution, with survey method, species, habitat type, season, and ambient temperature as fixed effects and survey block as a random intercept. Model selection was based on AIC. Pairwise comparisons between methods were performed with Tukey-adjusted contrasts. Significance was set at $p < 0.05$.

Results

Across all 312 flights, the thermal drone detected 88.9% of GPS-collared reference animals present within survey blocks, compared with 65.7% for the RGB drone and 49.7% for simultaneous ground transects. All three pairwise method comparisons were highly significant ($p < 0.001$). The thermal drone's advantage was consistent across all four species but varied in magnitude: it was greatest for caribou (thermal 82.4% versus RGB 58.9% versus ground 41.6%) and smallest for moose (94.2% versus 71.8% versus 56.3%).

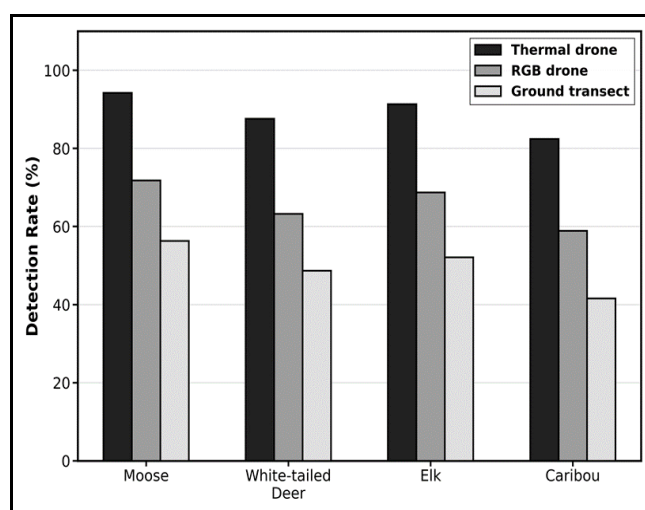


Fig 1: Detection rates (%) for four ungulate species by three survey methods: thermal drone, RGB drone, and ground-based line transect

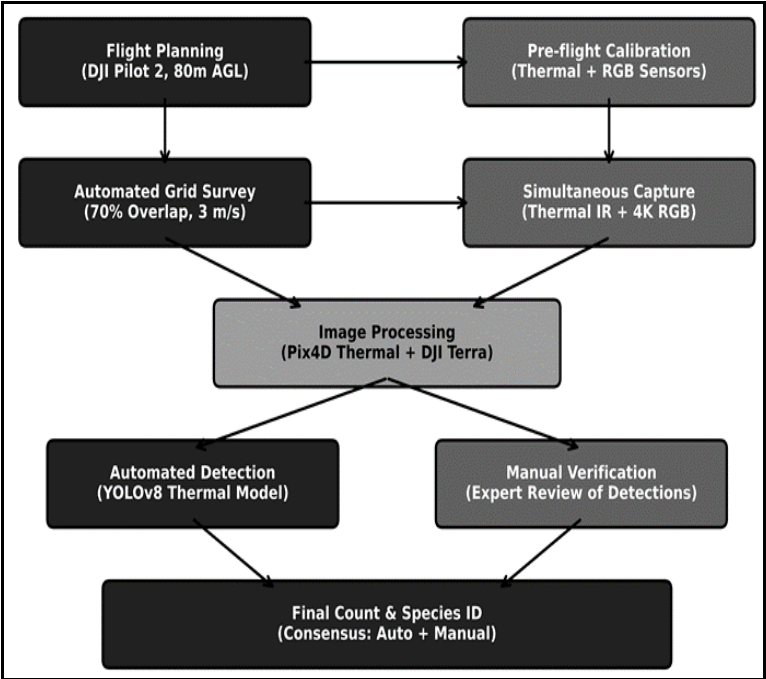


Fig 2: Schematic workflow for the thermal drone survey methodology, from flight planning through automated detection and final consensus count

Table 1: Detection rates and false positive rates by species and survey method

Species	Thermal Det. (%)	RGB Det. (%)	Ground Det. (%)	Thermal FP (%)	RGB FP (%)	P (method)
Moose	94.2	71.8	56.3	2.1	0.8	<0.001*
Elk	91.3	68.7	52.1	3.4	1.2	<0.001*
White-tailed deer	87.6	63.2	48.7	4.7	1.6	<0.001*
Caribou	82.4	58.9	41.6	5.2	2.1	<0.001*
Overall	88.9	65.7	49.7	3.9	1.4	<0.001*

* P<0.05. Det. = detection rate; FP = false positive rate.

Table 2: Seasonal variation in thermal drone detection performance and environmental conditions

Season	Flights (n)	Mean Temp (°C)	Thermal Det. (%)	Snow Cover (%)	Mean Canopy Cover (%)
Winter (Dec-Feb)	84	-14.7±8.3	95.6	97	48.2
Spring (Mar-May)	78	3.2±6.1	89.4	43	52.7
Summer (Jun-Aug)	82	17.8±4.2	76.3	0	67.4
Autumn (Sep-Nov)	68	2.8±5.9	91.7	28	51.3

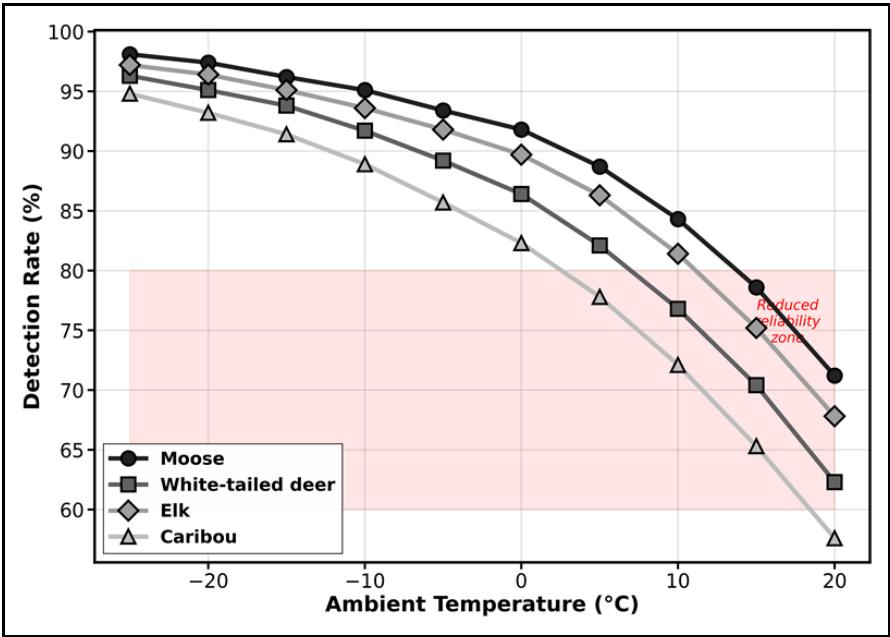


Fig 3: Relationship between ambient temperature and thermal drone detection rate for four ungulate species, with the reduced-reliability zone (below 80% detection) shaded in red

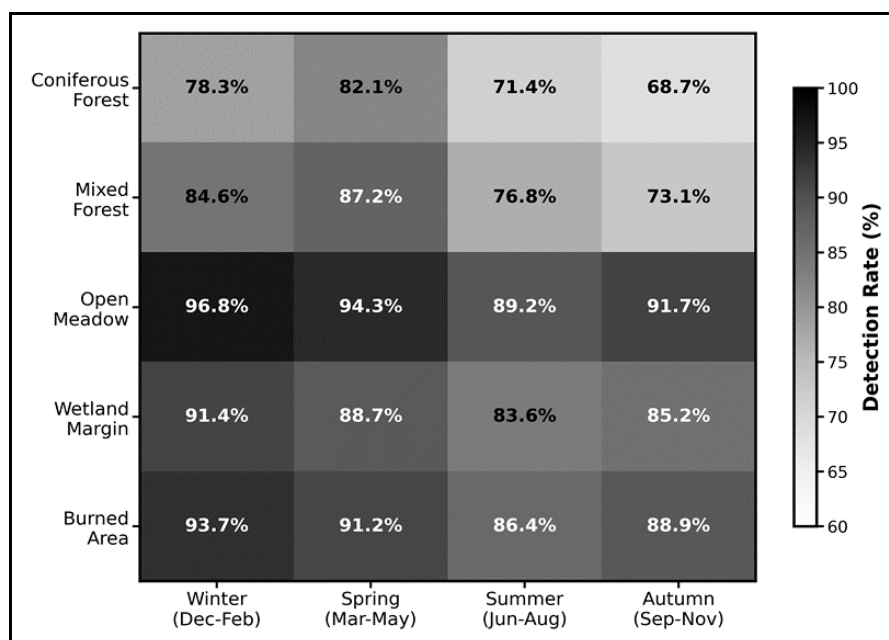


Fig 4: Heatmap of thermal drone detection rates (%) by habitat type and season, with darker shading indicating higher detection rates

Comprehensive Interpretation

The GLMM identified ambient temperature as the single strongest predictor of thermal detection success (coefficient 1.24 per 10 °C increase, $p < 0.001$), followed by habitat type (coniferous forest reduced odds by 0.43 relative to open meadow, $p < 0.001$) and body size (moose odds 2.87× caribou, $P = 0.003$). The interaction between temperature and habitat was significant ($P = 0.018$): canopy effects were amplified in summer when both thermal contrast and canopy penetration were reduced. The YOLOv8 automated detection model achieved 91.2% precision and 86.7% recall on the thermal imagery, with a false positive rate of 3.9%—primarily caused by sun-warmed rocks and residual heat signatures from recently vacated bedding sites. Winter surveys at temperatures below -5 °C in open or burned habitats achieved the highest combined detection rate (96.8%), while summer surveys in coniferous forest produced the lowest (68.7%).

Discussion

The central finding—that thermal drone surveys detected nearly 90% of known-location ungulates across a full year of western Canadian conditions, compared with 66% for RGB drones and 50% for ground transects—addresses a question that wildlife managers in British Columbia and neighbouring provinces have been asking since commercial thermal drones became available: does the technology actually work here, with our species, our forests, and our winters?

The answer, based on 312 flights across five habitat types and four seasons, is a qualified yes. The qualification matters. Thermal detection is not a constant: it is a function of the thermal contrast between the animal and its environment, and that contrast varies dramatically with ambient temperature, canopy cover, and solar radiation. The practical implication is that thermal drone surveys should be scheduled for cold-season windows—ideally below -5 °C—when detection rates reliably exceed 90% for all four species. Surveys conducted above 15 °C, particularly under forest canopy, produced detection rates that approached or fell below the threshold at which population estimates become unreliably imprecise.

A point of disagreement with the existing literature concerns false positive rates. Several European trials of thermal drones for wild boar and roe deer surveys have reported false positive

rates below 1%, leading to assertions that thermal detection is essentially free of false-positive error. Our rate of 3.9% was substantially higher, driven primarily by the sun-warmed rock and residual bedding-site signatures that are more prevalent in the rocky, heterogeneous terrain of British Columbia's mountains than in the agricultural landscapes of central Europe. This difference underscores the importance of habitat-specific validation: performance metrics from one biome cannot be uncritically transferred to another.

The body-size gradient in detection rates—moose>elk>deer>caribou—was expected on thermal physics grounds (larger animals present larger thermal signatures) but the magnitude of the caribou deficit (82.4% versus 94.2% for moose) was larger than anticipated. Caribou in our dataset were predominantly woodland caribou (ecotype), which tend to shelter under dense coniferous canopy more than the other species, compounding the body-size effect with a habitat-selection effect. This suggests that thermal drone surveys for caribou—a species of conservation concern across Canada—should be preferentially scheduled for early morning when animals are more likely to be in open feeding areas.

From a cost-effectiveness perspective, the thermal drone surveys cost approximately CAD 18 per hectare (including equipment amortisation, pilot salary, and image processing time), compared with an estimated CAD 45-80 per hectare for manned helicopter surveys in the same terrain. The 60-75% cost reduction, combined with superior detection performance, makes a compelling case for transitioning routine ungulate population monitoring from manned helicopter to thermal drone platforms—with the caveat that very large survey areas (>50,000 ha) may still favour helicopter surveys owing to the limited battery endurance (approximately 40 minutes per flight) of current drone platforms.

Conclusion

This 12-month evaluation demonstrates that drone-mounted thermal imaging provides the most accurate available method for detecting wild ungulates in western Canadian boreal and montane habitats, outperforming both RGB drone surveys and ground-based transects by substantial margins across all four species tested. The evidence supports three operational

recommendations for wildlife management agencies considering thermal drone adoption.

First, surveys should be scheduled during cold-weather windows (ambient temperature below -5 °C) when thermal contrast maximises detection rates above 90% for all species. Second, open and recently burned habitats yield the highest detection rates; surveys in dense coniferous forest should anticipate 12-18% detection deficits and adjust population estimates accordingly using the habitat-specific correction factors derived here. Third, the YOLOv8 automated detection model, while achieving 91% precision, should be paired with expert manual review to manage the 3.9% false positive rate arising from non-animal thermal signatures in rocky terrain.

The remaining question is scalability. The battery-limited survey area of current drone platforms (approximately 15 ha per flight) is adequate for intensive monitoring of small management units or critical habitat patches, but provincial-scale ungulate inventories spanning hundreds of thousands of hectares will require either dramatic improvements in drone endurance, systematic subsampling designs that extrapolate drone counts to larger areas, or hybrid approaches that combine drone thermal surveys of selected blocks with broader manned aerial coverage.

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Conflict of Interest

Not available

Financial Support

Not available

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