Natural Resources and Renewables
Biodiversity Conservation and Forestry Technical Report Series

Technical Report | Biodiversity Tech Report 2023-001 | January 2023

Comparing Moose aerial survey methods in Nova Scotia: distance sampling, density surface models, and stratified random blocks

Jason Airst and Jared Tomie

Comparing Moose aerial survey methods in Nova Scotia: distance sampling, density surface models, and stratified random blocks

Jason Airst[1]* and Jared Tomie[2]

Nova Scotia Department of Natural Resources and Renewables,
136 Exhibition Street, Kentville, NS

[1]*Jason.Airst@novascotia.ca*
[2]*Jared.Tomie@pc.gc.ca*

ISBN 978-1-77448-441-8

* Author to whom correspondence should be addressed

Abstract

The most accurate way to assess ungulate populations is to use aerial surveys, but this method is cost prohibitive. So, researchers are always looking for ways to reduce costs and maximize efficiency. In 2020, Nova Scotia Department of Natural Resources and Renewables and Parks Canada tested three moose population estimation methods: stratified random block sampling, distance sampling alone, and distance sampling with density surface models in Cape Breton, Nova Scotia to determine which produced the most precise estimates and which was most economical. We found that density surface models produced the most precise estimates and required less time than stratified random block surveys. Also, only density surface models accounted for the spatial autocorrelation that was observed onsite.

Keywords: aerial surveys, population estimates, population density, stratified random block, distance sampling, density surface models

Introduction

Effective species monitoring is fundamental to successful species management. Without knowing how many individuals are in a population or where they are on the landscape, it becomes difficult to predict how management decisions will impact species (Månsson et al., 2011). Ungulates are normally monitored using surveys, hunter records, and indirect measures such as pellet group counts. Aerial surveys produce the most accurate results, but also have the highest cost (Månsson et al., 2011; Boyce, 2012; Found and Patterson, 2020). So, wildlife managers are constantly looking for ways to reduce these costs and improve survey efficiency (Boyce, 2012; Peters, et al. 2014; Found and Patterson, 2020).

The two most common aerial survey methods are stratified random block sampling and traditional distance sampling (Gasaway et al., 1986; Buckland et al., 2001; Peters et al., 2014). When both methods were compared, they produced similar results, with distance sampling taking less time to complete (Peters et al., 2014). However, neither of these methods account for spatial autocorrelation. Not accounting for spatial autocorrelation can lead to misleading results (Miller et al., 2013; Camp et al., 2020). Distance sampling with density surface models (DSM), can account for spatial autocorrelation and may provide a solution to this problem (Miller et al., 2013; Valente et al., 2016; Hinton et al., 2022).

Our goal was to compare stratified random block sampling, distance sampling, and DSM to determine which produced the most precise population estimates for the least amount of survey effort. We compared these methods by carrying out an aerial survey on moose (*Alces alces andersoni*) across the Greater Highlands Ecosystem (GHE) of Cape Breton, Nova Scotia in early March 2020. The GHE was chosen because this area is regularly monitored for moose and previous work has shown that moose are rarely observed outside of this area on Cape Breton Island (Airst and Power, 2021).

Site Description

The GHE encompasses the northwestern third of Cape Breton Island and covers 3,890 km^2. Cape Breton Highland National Park (CBHNP) is 948 km^2 and is in the north of the GHE (Fig. 1). The area is bordered by the Gulf of Saint Lawrence in the west, where the land rises rapidly from the ocean to a height of 500 m. The land then forms a large plateau that slopes eastward and northward toward the Atlantic Ocean. The area has a maritime climate, with average winter and summer temperatures of -5°C and 18°C, respectively. In an average year there is 1,053 mm of rainfall and 337 cm of snowfall (Environment and Climate Change Canada, 2021).

The GHE is primarily composed of 55% boreal forest, 33% Acadian forest, and 10% taiga (Neily et al. 2017). The Acadian forest is dominated by sugar maple, red maple, beech, and yellow birch and is found along the coast and on the southern edge of the GHE. The boreal forest and taiga are dominated by balsam fir and to a lesser extent white and black spruce, respectively. Taiga is found on the eastern side of CBHNP, while boreal forest makes up the rest of the interior (Neily et al., 2017). Breaking it down by forest type, 41% is coniferous, 21% is mixed, 10% is deciduous, and 28% is non-forested (Nova Scotia Lands and Forestry, 2020a).

Methods

Survey procedure

Flight procedure- Surveys were flown in H-125 Airbus helicopters at a speed of 90-110 km/h and at an altitude of 90-150 m. The navigator was seated in the front left seat, the recorder in the back left, the dedicated observer in the back right and the pilot in the front right. All staff were tasked with observing for animals. The major difference between the two survey methods was that observers in the random stratified block survey only recorded observations made within a set distance from the helicopter while no such restriction existed for the distance sampling survey.

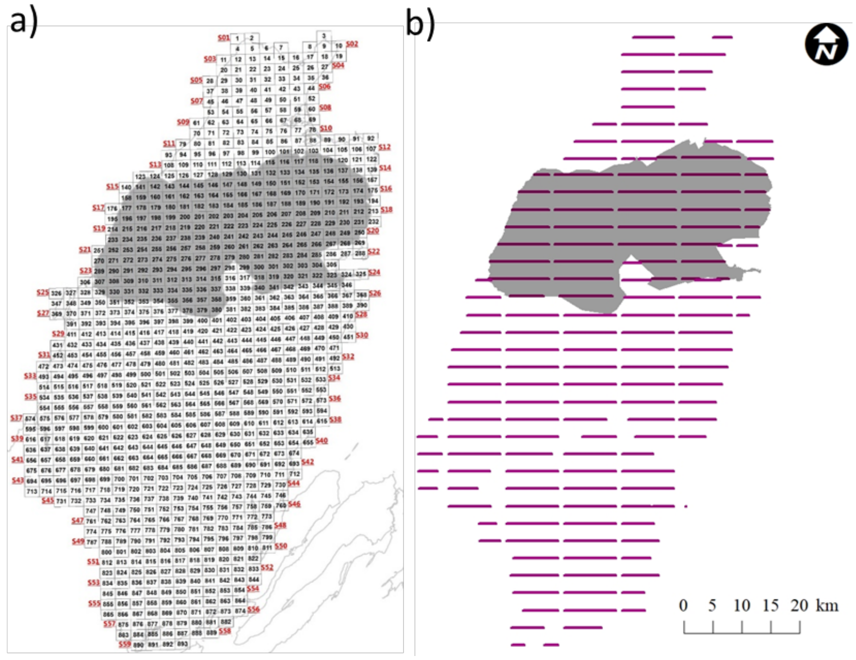

Fig. 1. Map of the Greater Highlands Ecosystem showing the random stratified block survey units (a) and the distance sampling survey lines (b). The grey area in both figures is Cape Breton Highlands National Park. The outer numbers in figure "a" represent the stratification line numbers, with the numbers inside the rectangles being the survey unit numbers.

Stratified Random Block Survey- A stratified random block survey was conducted from March 8-16, 2020. The survey took 90 hours to complete (Gasaway et al., 1986). The GHE was divided into 893 equal-sized survey units (SU; Please note that "survey unit" and "block" are synonymous terms in this paper), with 231 SUs inside CBHNP and 662 outside. Each SU measured 2 minutes of longitude (approx. 2.5 km) by 1 minute of latitude (approx. 1.9 km) and covered approximately 4.7 km^2 (Fig. 1a). A stratified random block survey consists of two phases: stratification, and random block surveys (Lemieux et al., 2020).

Stratification involved flying an east-west transect line through the center of each SU, to determine an estimate of moose presence. Only moose and their recent tracks within 150 m of either side of the helicopter were recorded. Moose estimates for each SU on the transect line were calculated by adding the number of moose seen on the line to 1/4 of the number moose tracks on the line and then rounding the result to the nearest whole number (Gasaway et al., 1986). Habitat sightability was also determined by crews through consensus using a one to five scale; one (1) indicated poor sightability and five (5) denoted ideal sightability. This measure was used to account for the likelihood of missing animals in each SU. A cluster analysis was then used to assign each SU to a low, medium, or high density stratum (Lemieux et al., 2020). Based on the stratification flight results, we initially randomly selected 38 low, 17 medium, and 5 high density SUs to block survey to determine the average moose density within each stratum type. This involved flying six east-west transect lines across the SU with lines equally spaced 300 m apart (Fig. 2). All moose, but not their tracks, within 150 m of the helicopter were recorded. After this first selection, we then used an optimization process to determine the number of additional block surveys required within each stratum to reduce the width of the 90% confidence interval (i.e., percent error range) for moose density estimate to less than 20% as recommended (Gasaway et al., 1986). In 2020, it took 91 flights (57 low, 23 medium, and 11 high,) to achieve a percent error range of 22%, which was deemed acceptable.

Intensive surveys were carried out on 9 high density, 15 medium density, and 14 low density SUs immediately after their block surveys were completed. Intensive surveys involved flying six north-south transect lines over one quarter of the SU with transects lines spaced 150 meters apart. In the intensive survey, only observations within 75 m of the helicopter were recorded (Fig. 2). Moose counts from the standard and intensive surveys were compared to create a sightability correction factor (SCF) for the entire GHE. A greater proportion of high stratum SU (82%) had intensive surveys flown over them compared to medium SU (65%) and the same was true for medium SU compared to low SU (25%). The reason for this was that the higher SU had greater variation in the chances of sighting a moose than the lower SU, so we sampled accordingly. The SCF was calculated by dividing the sum of moose observed in the intensive survey, by the sum of moose seen in the standard survey (in the same area as the intensive survey, Fig. 2), plus a correction for small sample bias as outlined in Gasaway et. al (1986). If the count was higher in the standard survey compared to the intensive survey, the intensive count was raised to match that of the standard. The results of these comparisons were then averaged to create the SCF (Gasaway et al. 1986). Separate SCF were calculated for CBHNP and the entire GHE. For additional detail on survey methods, see Parks 2020a, Parks 2020b.

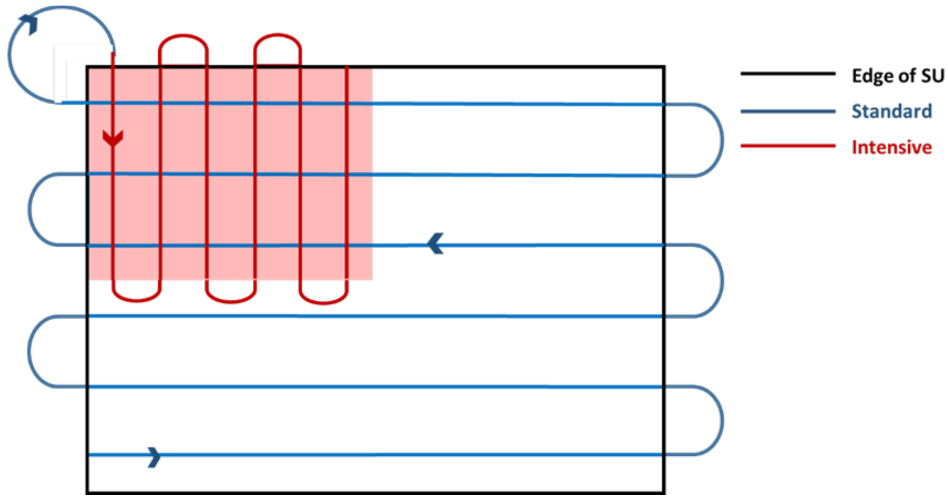

Fig. 2. Schematic of the typical flight lines for a Survey Unit. Blue flight lines indicate the path of the standard survey; red lines and pink shading indicate the flight path and area covered in the Intensive survey. Intensive surveys may have taken place in any corner of the survey unit and were in the corner with the most representative habitat.

Distance sampling- Distance sampling was carried out on March 2nd, 3rd, and 6th, 2020 and took 40 hours to complete. 2 to 9 km lines were placed east/west in series with 1 km breaks between lines. Lines were kept short to allow small areas to be excluded when necessary. Each line series was spaced 3 km apart from the subsequent series on the north/south axis. Based on this sampling design, 255 lines were needed to cover the entire area. This resulted in a linear distance of 1,113 km (Fig. 1b).

While flying lines, the observers scanned the landscape for moose groups, and when spotted, the recorders took a GPS waypoint on the line. The activity of the group (i.e., bedded, standing, or moving) was also recorded. The helicopter then continued the line until perpendicular with the group. Once there, the helicopter flew from the line to where the group was first spotted, and a second waypoint was taken. The helicopter then circled the group to age all individuals and sex adults. If groups were unable to be found off the line, individuals were recorded as unknown. Efforts were made to minimize animals' stress by limiting circling. Once groups were assessed, the helicopter returned to the line, and continued the survey from where it had left off. Because multiple groups may have been observed simultaneously, different groups may have had the same line waypoint, but each group had its own unique group waypoint. Groups were defined as all individuals within 50 m of one another. Groups that were first spotted off the line were excluded. However, if these same groups were spotted when back on the line, then the group was counted. This process continued until all lines were flown and all groups were assessed.

Data analysis

Stratified Random Block Survey- Cluster analysis of stratification lines flown over SUs was completed using R and a k-mean algorithm (R Core Team 2021 version 4.0.4) to assign each SU into a stratum (i.e., high, medium, and low). Moose transect estimates ranged from zero to eight, with one SU having an estimate of 11. Due to the cluster analysis being sensitive to outliers, we excluded the SU with an estimate of 11 from the analysis and later manually assigned it to the high stratum. Ten permutations were computed resulting in 11 SUs being classified as high density, 123 medium density, and 759 low density areas. To determine the moose density within each stratum, we first divided the block survey results for each SU by the area they covered and averaged the results within each stratum. We corrected for missed animals by multiplying density estimates by the SCF. Based on the area each stratum covered, we then calculated the overall moose density and abundance in the GHE. These estimates were calculated based on a 90% confidence interval ($\alpha = 0.1$) and a t-distribution. A 90% confidence interval is standard for stratified random block surveys (Gasaway et al., 1986). Values were separately calculated for the area inside CBHNP and the whole GHE. For additional detail on survey analysis methods, see Smith (2016), Lemieux (2019) and Lemieux et al. (2020).

Distance Sampling- Data were analyzed using the R package “distance” (Miller, 2021, version: 1.0.4). The first step of this analysis was determining the minimum distance each group was observed relative to the nearest survey line. Distance sampling assumes that fewer groups are seen farther from the line because it is easier to miss animals at distance (Buckland et al., 2001). To correct for this, a correction factor was calculated based on the regression line fitted to the detection curve of the survey data. A detection curve is a histogram that shows the number of groups observed at various distances. The correction factor was then applied to the count data based on the observed distance of the group (Buckland et al., 2001). When developing a detection curve, it is common to use a right truncation to remove the farthest groups observed, as these groups tend to be overly influential (Buckland et al., 2001). In our study we used a 10% truncation. We also tested if the inclusion of group activity, crown closure, and group size improved the fit of the detection curve. Including these covariates allowed us to account for factors other than distance that may have affected sightability. Model selection was based on Akaike's Information Criterion (AIC). We then used model averaging to incorporate the effect of all models that had a model weight of at least 1%. To estimate the moose population, we calculated values for the area within CBHNP and the whole GHE. Because the random stratified block survey estimates were based on a 90% confidence interval, we used the same confidence interval for all distance sampling estimates.

Density Surface Model- DSMs are a generalized additive model-based approach that uses detection curves from distance sampling to account for the uncertainty of spotting animals at distance. The model accounts for this uncertainty by creating a sightability correction factor for each observation based on the distance each observation was made at and the detection curve. This correction factor is then treated as an offset in the model (Miller et al., 2013; Valante et al., 2016). We used the R package "dsm" for this analysis (Miller et al., 2021, version: 2.3.1). By using a generalized additive method such as the DSM we were able to include linear and non-linear relationships in our model (Wood, 2017). Model selection was based on AIC.

In the model, distance sampling count data was the response variable. We treated distance to nearest road, distance to nearest surface water feature, and habitat type as linear fixed effects. These variables were chosen to examine how habitat composition affected the moose distribution. The UTM location of groups was also included in the model as a non-linear effect to account for spatial autocorrelation due to the potential uneven distribution of moose across the study area. Habitat classification and crown closure estimates were based on the 2020 Nova Scotia Forest Inventory (Nova Scotia Lands and Forestry, 2020a) This inventory classified habitats based on % tree cover and species composition (Nova Scotia Lands and Forestry, 2020a). Areas with <25% tree cover were classified as non-forest. Areas composed of >75% coniferous trees were classified as conifer forest. Those composed of >75% deciduous trees were classified as deciduous forest and those in the middle were classified as mixed forest

(Nova Scotia Lands and Forestry, 2020a). Location of roads and surface water were based on data from the Nova Scotia geographic database (Nova Scotia, 2021).

We subdivided our survey lines into 1-km long line segments (n = 1,011) and calculated the fixed effects for the centroid of each segment. This increased our sample size and made the centroid values more representative of the line segments. We then compared model distributions using the "DHARMa" package (Hartig, 2022, version 0.4.6), and found that a Tweedie and negative binomial distribution produced a better fitting Q-Q plot than a quasi-Poisson distribution (Fig. 3). Further, the Tweedie distribution also produced a lower AIC value (negative binomial = 1077.74, Tweedie = 990.82). We also found that the negative binomial distribution had a dispersion issue likely due to the data being zero inflated ($P\text{-value}_{nb} = 0.032$; $P\text{-value}_{tw} = 0.792$). To predict the overall moose density and abundance we first created a 1 km^2 predictive grid with coefficient values for the entire study area. We then used the "dsm" package to extrapolate the population density and abundance estimates from the predictive grid and model estimates. Separate estimates were calculated for the area within CBHNP and the whole GHE. Because the random stratified block survey estimates were based on a 90% confidence interval, we used the same confidence interval for all density surface model estimates.

The "dsm" package has two methods for calculating the detection curve estimates. It either averages the detection curve estimates for each survey segment or it calculates a Horvitz-Thompson-like estimator for each section (Miller et al. 2021). A Horvitz-Thompson-like estimator (HT) is calculated by dividing the sum of the detection curve covariate effects by the detection curve estimate (Buckland et al. 2015). Only the HT method allows detection curve covariates to vary within segments. Group size varies between groups observed within segments, so to include group size in the detection curve used for the DSM we need to use the HT method. When we compared AIC values between models, we found that the model that included group size in the detection curve and the HT produced the lowest values (averaging method = 1089.56; HT method = 1067.72; HT method with size covariate = 990.82)

Model comparisons- AIC cannot be used to compare the random stratified block survey results to the other methods. Instead, we used the coefficient of variation (CV) to determine the precision of the estimates produced from the three survey methods. This same approach was taken by Peters (et al. 2014) when they compared distance sampling and random stratified block survey results (Peters et al. 2014). Additionally, we used two sample t-tests and a Bonferroni correction for multiple comparisons, to determine if these methods produced reliable density estimates. Comparing three methods (three comparisons) means that the results of the t-test comparing these methods must produce P-values of < 0.016 for the methods to be considered significantly different.

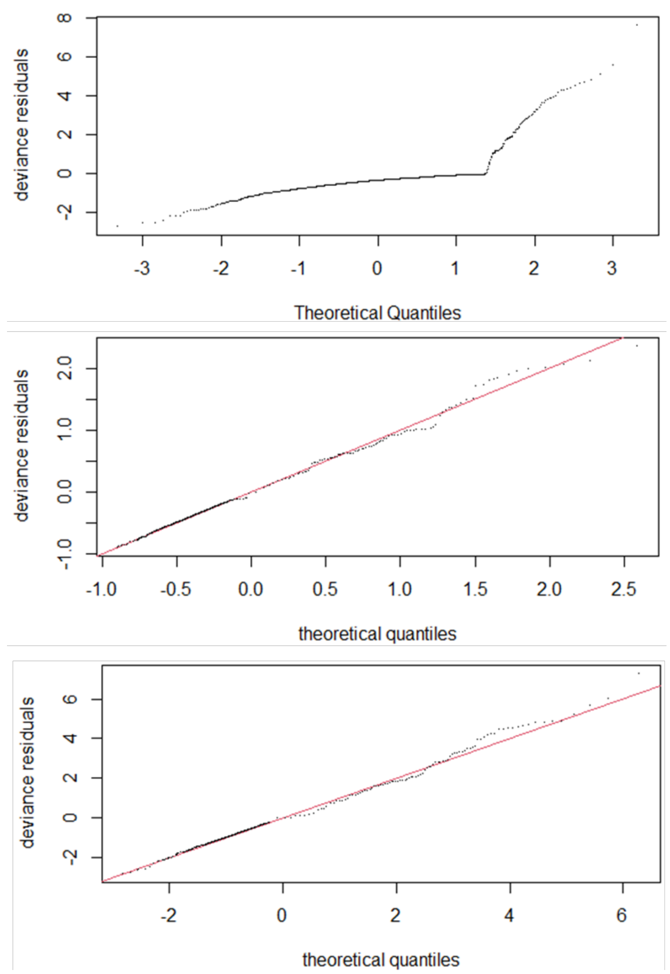

Fig. 3. Q-Q plots showing how well DSM models fit when using a (a) quasi-Poisson, (b) negative binomial, or (c) Tweedie distribution.

Results

Stratified Random Block Survey- After completing the stratification flight we found that there were 11 high SUs, 123 medium SUs, and 759 low SUs (Fig. 4a). Based on the block survey results we would expect a moose density of 0.88 (90% CI: ± 0.21) moose/ km^2 inside CBHNP and 0.60 (± 0.13) moose/ km^2 across the whole GHE. This equated to 838 (± 201) moose inside the CBHNP and 2,322 (± 521) across the whole area. These numbers were corrected by an SCF of 1.18 (± 0.004) for the GHE, and 1.09 (± 0.003) for CBHNP.

Distance Sampling- In total 109 (59 inside park; 63 outside park) groups were observed within 338 m of the helicopter and 301 moose (186 inside the park; 115 outside the park) were assessed. When we compared different detection curve distributions and adjustment terms combinations, we found that the best combination was a uniform distribution with two cosine adjustments, but a half normal distribution with no adjustment terms was <1 AIC point higher and had a lower k value, so we chose the half normal distribution (Table 1).

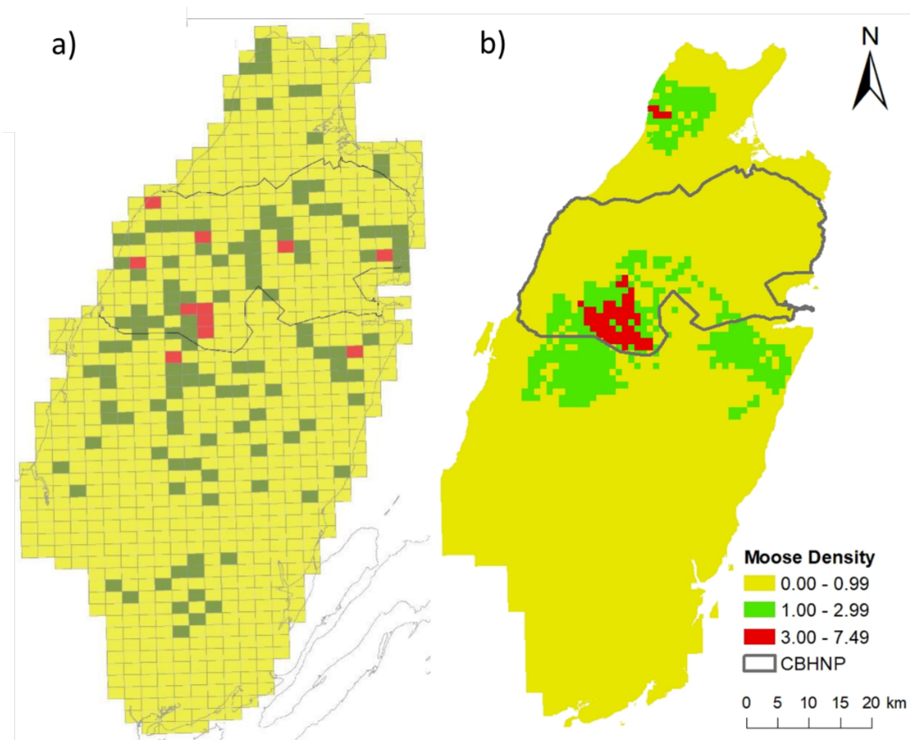

Fig 4. Distribution of moose in the Greater Highlands Ecosystem of Cape Breton during the winter of 2020 calculated using stratified random block sampling (a: pop. est. ± 90% CI; 2,322 ± 521) and density surface models (b: 1827 ± 371). The grey line shows the borders of Cape Breton Highlands National Park (CBHNP).

When we looked at the effect of adding covariates into the half-normal model, we found that group size, group activity, and crown closure all explained some amount of variation in sightability, so all three covariates were included in the averaged model (Table 2; Fig. 5). This produced a model that had a probability of detection of 0.50% (± 0.04%). Increasing group size increased the likelihood of detecting a group (odds ratio [90% CI]; 1.37 [1.09, 1.71]). We also found that bedded groups were easier to detect than standing groups (0.79 [0.64, 0.99]) or moving groups (0.70 [0.55, 0.90]). Crown closure was found to have little effect (1.00 [0.99, 1.00]). Based on this we would expect a moose density of 1.08 (± 0.51) animal/km^2 inside the CBHNP and 0.55 (± 0.16) animals/km^2 across the GHE. This equated to 1,025 (± 485) moose inside the CBHNP and 2,158 (± 617) moose in the whole area. Moose were also found in larger groups inside CBHNP than outside (inside = 2.40 ± 0.40; outside = 1.58 ± 0.19; df = 103, t-score = 3.095, p-value = 0.003).

Table 1. Comparing detection curves (n = 109) generated from aerial moose surveys completed over the Greater Highland Ecosystem of Nova Scotia in 2020 using distance sampling. Measures include Number of parameters (k), AIC, delta AIC (Δ), average detection probability (P_a), 90% error for the detection probability (P_a CI)

Distribution	Adjustment term	k	AIC	Δ	P_a	P_a error
uniform	cosine (1), (2)	3	-277.39	0	0.48	0.07
uniform	cosine (1)	2	-276.61	0.78	0.56	0.05
half normal	none	1	-276.58	0.81	0.54	0.06
half normal	cosine (2)	2	-276.27	1.12	0.47	0.09
hazard rate	none	1	-276.17	1.22	0.50	0.10
half normal	simple polynomial	2	-275.79	1.60	0.51	0.11
hazard rate	cosine (2)	2	-275.05	2.34	0.49	0.12
half normal	Hermite polynomial	2	-274.62	2.77	0.54	0.09
hazard rate	Hermite polynomial	2	-274.62	2.77	0.44	0.15
hazard rate	simple polynomial	2	-274.18	3.21	0.48	0.12
uniform	simple polynomial	2	-267.39	10.00	0.68	0.04
uniform	Hermite polynomial	2	-267.10	10.29	0.69	0.05

Density Surface Model- When we compared half normal detection curves in the DSM using AIC, we found that the best model included group size. (no covariate = 1089.56, group size = 990.82, group activity = 1062.91, crown closure = 1068.80, group size and activity = 995.08), Using this detection curve we found that the best DSM model included group location, distance to nearest road, and whether an area was forested or unforested. While the variable habitat type was used in one of the top models that accounted for 1% model weight, the other top models used the simpler habitat variable forest. So, habitat type was excluded from the averaged model. Distance to the nearest water source was also excluded as it did not appear in any of the top models (Table 3). The averaged model showed that moose were more likely to be observed farther from roads and in forested areas (Table 4). Based on this we would predict a moose density of 0.71 (± 0.18) animal/km^2 inside the CBHNP and 0.47 (± 0.10) animals/km^2 in the GHE. This equated to 671 (± 173) moose in the CBHNP and 1,827 (± 371) moose across the whole area. When we plotted our predicted DSM results, we found that moose clustered on the western side of CBHNP and northwest of the park (Fig. 4b).

Table 2. Comparing half normal distance sampling models (n = 255) generated from aerial moose surveys completed over the Greater Highland Ecosystem of Nova Scotia in 2020 to determine which model explained the most variation.

Model	k	AIC	Δ	Weight
Group Size + Group activity	5	-286.84	0	30%
Group Size + Group Activity + Crown Closure	6	-286.30	0.54	23%
Group Size + Crown Closure	3	-286.04	0.8	20%
Group Size	2	-285.42	1.42	15%
Group Activity + Crown Closure	5	-283.86	2.98	7%
Crown Closure	2	-282.19	4.65	3%
Group activity	4	-279.43	7.41	1%
No covariates	1	-278.58	8.26	0%

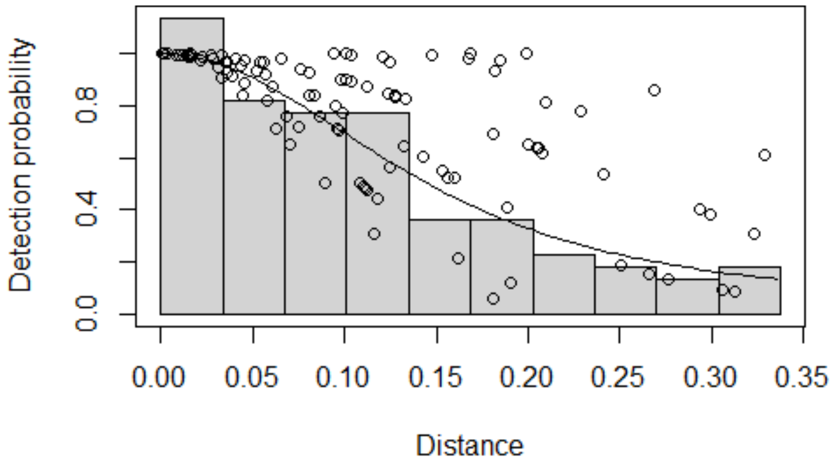

Fig. 5. Moose detection curve for the Greater Highlands Ecosystem of Cape Breton (n = 109). Results are based on animal sightings, group activity, and group sizes. The regression line shown is fitted to a half-normal model distribution.

Model comparison- When we compared stratified random block survey, distance sampling, and DSM using the coefficient of variance, we found that the stratified random block survey had the lowest coefficient of variance (Table 5). However, all three methods gave statistically similar results for both the GHE and CBHNP (Table 6). Finally, the stratified random block survey took 90 hours to complete, while the distance sampling survey took 40 hours to complete.

Table 3. Comparing density surface models (n = 1,011) to determine which variables best predict moose population size in the Greater Highlands Ecosystem of Cape Breton, Nova Scotia. Forest classifies areas as forest or non-forest. Habitat type classifies areas as non-forest, conifer forest, deciduous forest, and mixed forest. Road dist. and water dist. refers to the distance to nearest road and water source, respectively. Location refers to the UTM location of groups.

Variables	Parameters	AIC	Delta	Weight
Location + Near Roads + Forest	4	866.97	0	94%
Location + Forest	3	873.10	6.13	4%
Location + Habitat Type	6	875.82	8.85	1%
Location + Road Dist.	3	878.64	11.67	0%
Location	2	883.46	16.49	0%
Location + Water Dist.	3	884.95	17.98	0%
Near Roads	2	964.19	97.22	0%
Forest	2	987.30	120.33	0%

Null	1	990.82	123.85	0%

Table 4. Incidence rate ratios of the chances of finding moose in Nova Scotia's Greater Highlands Ecosystem based on forest age in an area and its geographic location (n = 1,011). Results were generated using a density surface model with group size being used as a covariate in the half normal detection curve. Horvitz-Thompson-like estimator were used to generate detection curve offsets in the model and the model had a Tweedie distribution. The effective degrees of freedom (EDF) shows the optimal number of spline smoothers needed to accurately account for moose locations.

a) Linear variables			
Variables	Incidence rate ratio	90% CI	
(Intercept)	0.19	(0.14, 0.27)	
Forest vs. non-forest	2.87	(1.76, 4.67)	
Nearest road (km)	1.25	(1.11, 1.40)	
Non-linear Spline smoothers			
Variables	EDF	F	P-value
b) UTM Location (x, y)	18.34	5.288	< 0.001

Table 5. Moose population estimates from the Greater Highlands Ecosystem (GHE) of Cape Breton, NS and Cape Breton Highlands National Park within the GHE based on a random stratified block survey, a distance sampling survey, and a density surface model. Bracketed values represent 90% confidence intervals.

Cape Breton Highland National Park			GHE (including national park)		
Density (moose/ km^2)	Population Estimate	Coefficient of Variance	Density (moose/ km^2)	Population Estimate	Coefficient of Variance
a) Random stratified block: n = 31			*n = 91*		
0.88 (± 0.21)	838 (± 201)	0.14	0.60 (± 0.13)	2,322 (± 521)	0.13
b) Distance Sampling: n = 70			*n = 255*		
1.08 (± 0.51)	1,025 (± 485)	0.28	0.55 (± 0.16)	2,158 (± 617)	0.17
c) Density surface model: n = 278			*n = 1,011*		
0.71 (± 0.18)	671 (± 173)	0.16	0.47 (± 0.10)	1827 (± 371)	0.12

Table 6. Comparing model estimates from moose population surveys completed in 2020 in the Greater Highlands Ecosystem (GHE) of Cape Breton, NS and Cape Breton Highlands National

Park using two sample t-tests and two tailed p-values. t-scores are shown in each box and p-values are bracketed

a) GHE

	Distance sampling (n = 255)	DSM (n = 1,011)
Stratified block (n = 91)	0.450 (0.653)	0.916 (0.360)
Distance (n = 255)	---------------------------	0.553 (0.580)

b) CB Highland National Park

	Distance sampling (n = 70)	DSM (n = 278)
Stratified block (n = 31)	0.450 (0.654)	0.737 (0.462)
Distance (n = 70)	---------------------------	0.888 (0.375)

Discussion

We found that moose density estimates from all three methods were similar, but that DSM estimates were the most precise. Additionally, the random stratified block survey took more than twice as long to fly. One problem with comparing survey methods based on CV and time required for completion is that these measures are likely correlated. As more samples are collected, which takes more time, model results should become more precise. However, one of the goals of this project was to balance survey time and precision. So, a more appropriate question to answer is, do each of the methods tested produce a reasonably precise estimate given the effort used? If we use a criterion of a CV less than 0.20 (suggested by Gasaway et al., 1986), then all methods were successful in precisely estimating the moose population in the GHE, but distance sampling fell short of giving a precise enough estimate for the park (Table 5).

Something else to consider is the utility of these methods in other areas of the province. Gasaway (et al., 1986) suggested that stratified random block surveys should only be used in areas with moose densities above 0.36 moose/ km^2. Even within the GHE there were large areas in the south where the moose density was under 0.1 moose/ km^2 (Moose zone 3 in Nova Scotia Lands and Forestry, 2020b). This becomes an even bigger issue when we survey areas of Cape Breton outside the GHE, where moose densities are lower, but still managed. In these areas stratified random block survey could not be carried out, but distance sampling could. This is why 2020 was the first year moose management zone 4 was assessed by the Nova Scotia Department of Natural Resources and Renewables (Nova Scotia Lands and Forestry, 2020b).

DSM and other distance sampling techniques can also be used to assess even smaller populations (Sollmann et al., 2015; Hinton et al., 2022). DSMs can assess small populations by using survey data from multiple years or different data sources (Hinton et al., 2022). Distance sampling can be used to assess rare species by combining sighting of multiple species together to generate a single detection curve. This curve can then be employed to estimate the population size of each of the species observed (Miller et al., 2013). However, this approach does carry the risk that results may be misleading if detectability varies greatly between the species employed (Sollmann et al., 2015; Found and Patterson, 2020). While these approaches were not tested in Cape Breton, it should be noted that this distance sampling approach is used to assess other moose (*A. a. americana*) populations in Nova Scotia.

An advantage that DSMs have over distance sampling and the random stratified block survey, is its ability to account for spatial autocorrelation in the population estimate. Figure 3b shows that spatial autocorrelation exists between moose observations in the GHE, since moose are highly concentrated in certain areas. Not accounting for spatial autocorrelation in a model can lead to spurious results (Miller et al., 2013; Camp et al., 2020). However, since our estimates in all three survey methods were statistically similar, this does not seem to be a major issue in our study. One other advantage of understanding a species spatial distribution is that this information can help better target management or conservation efforts (Camp et al., 2020).

An issue with all three density estimating methods was that none fully accounted for undetected animals present during the survey. In stratified random block surveys, the SCF assumes that if one sampled an area with a high enough intensity, one should be able to find all the animals present (Quayle et al., 2001). Both distance sampling and density surface models assume that surveyors see every animal at the line (Buckland et al., 2001). If these assumptions are violated, then the population will be underestimated (Quayle et al., 2001; Peters et al., 2014). One solution to this is to use location data from GPS collared animals to determine how often known animals are missed when surveying (Quayle et al., 2001; Peters et al., 2014). It is possible to incorporate this information into each of the survey methods (Peters et al., 2014; Miller et al., 2021). However, because there were no collared animals in our survey area, we were unable to use this method to improve the accuracy of our estimates.

These methods also assume that animals are only sampled once (Gasaway et al., 1986; Buckland et al., 2001). The risk of accidental resampling exists because surveys take multiple days to complete and poor weather can increase the time required to survey the entire sampling area, increasing the risk that animals will move and be counted twice. This could lead to overestimating a population. However, if animal movement is random relative to the choice of surveying locations, then there should be no bias as animals are just as likely to move into a previously surveyed area from an un-surveyed area as they are to move in the opposite direction (Buckland et al., 2001). This is likely the case for distance sampling and by extension DSM, but this is likely not true for stratified random block surveys as the choice of survey locations is based on the SU's stratum. Density surface models can also account for sampling done over separate periods by using random effects (Buckland et al., 2001). Either way, to minimize this problem, we made efforts to survey the sampling area in as few days as possible. We also organized our survey effort so that we thoroughly covered an area before we moved onto another area, making it less likely that moose could travel between surveyed and un-surveyed areas in the time available.

Overall, our results and the work of others suggest that DSMs were the best survey method for assessing moose populations (Valente et al., 2016; Hinton et al., 2022). This was based on the DSM method producing precise estimates and requiring less time to fly than the stratified random block survey.

Acknowledgments

We would first like to acknowledge that this work took place in Unama'ki, the ancestral and unceded territory of the Cape Breton Mi'kmaq. This work was done in partnership with the Nova Scotia Department of Nature Resources and Renewables, Parks Canada, the Unama'ki Institute of Natural Resources, and the Confederacy of Mainland Mi'kmaq. The authors wish to thank James Bridgland, Michée Lemieux, Derek Quann, Rosie Smith, Dan Kehler, and Sarah

Penney for their contributions to data analysis and development of analytical methods for the stratified random block survey. We would also like to thank Jason Power and Clayton D'Orsay for organizing and carrying out this work. Additionally, we would like to thank Tara Crewe, Joseph Hinton, and Maureen Cameron-MacMillan for reviewing this manuscript. Further, we like to thank the many staff and volunteers that participated in this survey.

Supplementary Material

Data files and R code used in this paper are available on GitHub at: https://github.com/jason-airst/Comparing_moose_aerial_survey_methods_in_nova_scotia

References

Airst, J. I., & Power, J. W. (2021). Winter habitat use of moose in Cape Breton, Nova Scotia. Alces 57: 99-111.

Boyce, M. S., Baxter, P. W., & Possingham, H. P. (2012). Managing moose harvests by the seat of your pants. Theoretical Population Biology, 82: 340-347.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press

Buckland, S. T., Rexstad E. A., Marques T. A., & Oedekoven C. S. (2015). Distance Sampling: Methods and Applications. Springer International Publishing

Camp, R. J., Miller D. L., Thomas L., Buckland S. T., & Kendall S. J. (2020). Using density surface models to estimate spatio-temporal changes in population densities and trend. Ecography 43:1–11.

Environment and Climate Change Canada (2021) Grand Etang, Nova Scotia historic weather data. Government of Canada. Accessed March 15, 2020.

Found, R., & Patterson, B. R. (2020). Assessing ungulate populations in temperate North America. Canadian Wildlife Biology and Management, 9: 21-42.

Gasaway, W. C., DuBois, S. D., Reed, D. J., & Harbo, S. J. (1986). Estimating moose population parameters from aerial surveys. Institute of Arctic Biology. University of Alaska. Fairbanks, Alaska.

Hartig, F. (2022). DHARMa: Residual diagnostics for hierarchical (multi-level/mixed) regression models. Version 0.4.6

Hinton, J. W., Wheat, R. E., Schuette, P. Hurst, J., Kramer, D., Stickles J., & Friar, J. (2022) Challenges and opportunities for robust population monitoring of moose along their southern range in eastern North America. Journal of Wildlife Management.

Lemieux, M. (2019). Cape Breton Highlands National Park Moose Population Survey – Review of Analytic Methodology. Internal Report. Cape Breton Highlands National Park, Ingonish Beach, NS.

Lemieux, M., Penney, S., & Tomie, J. (2020). Cape Breton Highlands National Park 2020 Moose Population Survey – Technical Report. Internal Report. Cape Breton Highlands National Park, Ingonish Beach, NS.

Månsson, J., Hauser, C. E., Andren, H., & Possingham, H. P. (2011). Survey method choice for wildlife management: the case of moose *Alces alces* in Sweden. Wildlife Biology. 17: 176-190.

Miller D. L. (2021) Distance: Distance Sampling Detection Function and Abundance Estimation. Version 1.0.4.

Miller, D. L., Burt, M. L., Rexstad, E. A., & Thomas, L. (2013). Spatial models for distance sampling data: recent developments and future directions. Methods in Ecology and Evolution. 4:1001-1010.

Miller D. L., Rexstad, E. A., Burt M. L., Bravington, M. V., Hedley, S. (2021) DSM: Density surface modelling of distance sampling data. Version 2.3.1.

Neily, P. D., Basquill. S., Quigley, E., & Keys K. (2017). Ecological land classification for Nova Scotia. Nova Scotia Department of Natural Resources, Renewable Resources Branch. Halifax, NS

Nova Scotia Lands and Forestry (2020a) Forest Inventory- Third round aged forward. Forestry division. Truro, NS.

Nova Scotia Lands and Forestry (2020b) Winter 2020 Cape Breton moose survey. Wildlife division. Kentville NS. moose-survey-summary-winter-2020.pdf (novascotia.ca). Accessed September 10, 2021

Nova Scotia Department of Natural Resources and Renewables (2021) Recovery plan for the moose (*Alces alces Americana*) in mainland Nova Scotia. Nova Scotia Endangered Species Act Recovery Plan Series

Parks Canada. 2020a. Cape Breton Highlands Aerial Moose Survey 2020 – Organization and Field Methods. Internal Report. Cape Breton Highlands National Park, Ingonish Beach, NS.

Parks Canada. 2020b. Aerial Moose Survey 2020 - Reference Guide for Data Recorders. Internal Report. Cape Breton Highlands National Park, Ingonish Beach, NS.

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

Quayle, J. F., MacHutchon, A. G., & Jury, D. N. (2001) Modeling moose sightability in south-central British Columbia. Alces, 37:43-55.

R Core Team (2021) R: A language and environment for statistical computing. Version 4.0.4. R Foundation for Statistical Computing, Vienna, Austria.

Smith, R (2016). Cape Breton Highlands Aerial Moose Survey – 2015 Report. Internal Report. Cape Breton Highlands National Park, Ingonish Beach, NS.

Sollmann, R., Gardner, B., Williams, K. A., Gilbert, A. T., & Veit, R. R. (2016). A hierarchical distance sampling model to estimate abundance and covariate associations of species and communities. Methods in Ecology and Evolution, 7: 529-537.

Valente, A. M., Marques, T. A., Fonseca, C., & Torres, R. T. (2016). A new insight for monitoring ungulates: Density surface modelling of roe deer in a Mediterranean habitat. European Journal of Wildlife Research. 62: 577-587.

Wood, S. (2017) Generalized additive models: An introduction with R, 2nd ed. Chapman and Hall/CRC press. Bristol, England.