

Sightability Correction for Moose Population Surveys

Aaron Christ



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Cover Photo: A moose and calf utilizing a snow well under a spruce in Soutcentral Alaska.
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Summary

Simulated GSPE (Geo-Statistical Population Estimate) surveys were conducted on radiocollared moose in GMU 16. Quadrats with previously located moose were surveyed by teams who were not informed of the known locations. These teams subsequently radiotracked groups to verify whether or not they were observed during the survey flight. Because collared moose were the target, we could conclusively determine whether specific moose were seen or missed. Various environmental covariates were recorded for each sighting or missed sighting with the intent to create a general sightability model applicable to future surveys. The resulting model determined an association between sightability and total group size with the percent habitat cover in the 10 meter radius around the moose, but homogeneity within many of the collected covariates precluded their potential importance to sightability for this data. Therefore, the model has applicability only to surveys conducted in similar conditions, which limits its use.

It is assumed that once groups are located, enumeration of animals within those groups is complete and without error, but this assumption was shown to be violated. Almost 7% of groups observed were improperly enumerated. Collared calves bedded in tree wells were a notable proportion of missed moose. Only collared moose could be definitively located, so there were undoubtedly more moose missed. Improper enumeration not only negatively biases the population estimate, but could also adversely impact demographic ratios if certain cohorts are disproportionately missed.

Key words: Moose, *Alces alces*, population estimation, GSPE, sightability, SCF, enumeration.

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I. Background

Intensive management of moose (*Alces alces*) requires accurate population estimates. Current methods for population estimation (GSPE, Geo-Statistical Population Estimate) assume perfect sightability, or utilize random intensive counting to get an average estimate for the sightability correction factor (SCF).

The reasons for differential sightability are numerous, but can be basically categorized as environmentally based or observer based. Environmental covariates could include vegetative cover, snow cover, light conditions, etc. Observer covariates could include experience, fatigue, speed of survey, method of flying survey units (from simple transects to repeated circling), etc.

The goal of this study was to evaluate models connecting environmental and observer covariates to sightability of moose under common survey conditions as an alternative to a simple SCF.

II. Study Area

The study area is located in the central portion of 16B and the SW portion of 16A roughly bounded by the following landmarks: south of Willow Mountain, north of Beluga Lake, west of the Deshka River, and east of the confluence of Happy River and the Skwentna River. See Appendix F for maps of the study area. This location was chosen to take advantage of collared moose from another ongoing study.

III. Methods

A grid based on the standard GSPE grid was created for the area encompassing 102 collared moose (17 collared cows had collared calves). By using collared moose we could definitively say whether specific moose were sighted. Simply double counting a study unit wouldn't guarantee the same moose were observed by multiple observers. Moreover, double counting could assign environmental covariates to specific moose, but couldn't specify which of those moose was missed. Unlike running an actual population survey, the timing of data collection was not a factor beyond how it affected covariates. We could collect data from several disjoint periods and still have valid data for model estimation. Multiple years of data could be combined to increase the precision of the model. See Appendix A for details on the required assumptions for maintaining a valid survey.

Any model generated would only be applicable for the common search pattern used. Pilots who fly different patterns may have different sightability and thus require a different model. Unidentified covariates could reduce model precision. Cognitive covariates such as airsickness or boredom likely have a marked impact on sightability, but are hard to include in a model because they are often correlated with how many moose are being observed. Assuming relatively high sightability, insufficient replications could lead to estimates biased toward higher sightability because too few non-sightings are observed.

Data to develop a covariate model could be collected during surveys, but the number of replicates necessary for model estimation as well as time constraints of an actual survey make this impractical. Conditions, and therefore covariates, should be similar to those potentially experienced in surveys.

Because these were not actual population surveys, we altered the protocol in order to increase the number of resighting samples. Any alterations, however, could only be in terms of logistics and not in a way that might bias the represented covariates. Alterations included:

1. Subdividing quadrats into 4 sub-sections in order to reduce the amount of time spent looking at areas where no collared moose are present.
2. Resampling quadrats with different observer planes, or even with the same observer plane after an appropriate period of time has elapsed.
3. Having observers also fly quadrats in which no collared moose were present to reduce bias from increased diligence (by knowing that a collar must be in each quadrat surveyed)

A coordinating plane located the collared moose and noted the coordinates of each on the study area map. To save effort, the location was assumed to be unchanged on the following day. Moose did move between study days, so there were instances where the moose moved to an adjacent quadrat. This resulted in an empty quadrat being surveyed, but subsequent tracking allowed other observer planes to run the trial in the correct quadrat for the rest of that day.

Survey planes were assigned units following normal survey protocol with possible alterations noted above. During the sampling of each sub-quadrat, observers made specific note of collared moose and the covariate values for the point where they saw the first moose, that is, the moose which caused them to switch to high intensity circling in search of associated moose. Upon completing each sub-quadrat, they contacted the coordinating plane and were told the frequencies of moose in the recently finished sub-quadrat. The observer planes then radio-located these moose and either verified that those moose were indeed seen, or noted that they were missed and recorded the associated covariate values.

Covariates were chosen based on conversations with ADF&G biologists as well as from literature (Putera and Drummer 2004, McCorquodale 2001, Quayle et al 2001, Drummer and Aho 1998, Cogan and Diefenbach 1998, Anderson and Lindzey 1996, Bisset and Rempel 1991, Unsworth et al 1990, Samuel et al 1987)

Covariates Collected (see Appendix D for sample survey form)

Light conditions:

Type: bright / flat

Intensity: H / M / L

Snow conditions:

Age: Fresh / <1 week / >1 week

Cover: complete cover / low veg. showing / bare ground showing

% Vegetative cover (within 10 meter radius):

0,10,20,30,40,50,60,70,80 (based on comparison to example sheet, see Appendix E)

Habitat type of first observed moose in group:

1. Open lower elevation, predominantly shrub, riparian, or wetland
2. Mixed Open Forest with some shrub understory
3. Dense Spruce Forest
4. Dense Deciduous Forest Birch, Aspen, etc. Few Shrubs
5. Subalpine Shrub
6. Burn

Spruce within 10m of moose (yes/no)

Moose Activity: Up (Standing or moving) / Down (Lying)

Additional conditions noted that may have affected the quality of the search:

- Classification Errors
- Low Clouds or Fog
- Poor Light
- Poor Visibility/Snow on Trees
- Inadequate Snow Cover
- Windy/Turbulent
- Problems finding SU Boundaries
- Inadequate Search Effort
- Short on Fuel
- Inexperienced Pilot
- Uncooperative Pilot
- Inexperienced Observer
- Observer Sleeping
- Observer Airsick
- Other

Power estimation

Using the rule of thumb from Hosmer & Lemeshow (2000, p. 346), we would need roughly 10 observations per number of parameters plus 1 (i.e. $10 \times [\text{param}+1]$) for the least frequent outcome. So for a model with 6 variables we would need about 70 missed moose, which translates to 700 groups needed at 90% sightability, 350 groups at 80% sightability, 234 groups at 70% sightability, 175 groups at 60% sightability or 140 groups at 50% sightability.

IV. Results

Conducting GSPE-type moose surveys in unit 16 have potentially differing issues depending on which time of year they are being conducted. Fall surveys are becoming increasingly rare due to changing weather patterns. We have fewer sufficiently deep snow events in the late fall before day lengths become too short. Simply conducting a survey is not possible, irrespective of any sightability issues. Conversely, in the spring we encounter plenty of snow, but there is much more use of snow wells under spruce making some moose difficult, if not impossible to observe. (Note that there is no data from the fall, but the differing amount of snow as well as the better physical condition of the moose might lead one to think it is much less of an issue). This is more than a simple sightability issue, because we end up violating a key assumption: groups can be completely and correctly enumerated once they are observed.

Because we were only able to conduct surveys in the spring, this project investigated problems with surveys at that time. At the moment it is not clear how 'groups' of single animals should be treated with regard to 'missingness correction', i.e. are they not seen because of simple sightability (happened to not see them), or not seen because they are in the category of unobservable moose. Another weakness is

the very small amount of information regarding the modeling of missingness. Simulation studies could be used to look into ways to deal with this. We are in the unfortunate position of knowing there's a problem, but having little to no data to estimate it without a large variance in the final estimate.

One more shortcoming of the data is that we had two years of nearly identical spring weather. If surveys will always have these weather conditions, then a model from this data is applicable. If we stray far from these conditions the model will not be applicable. The homogeneity of the sightability conditions resulted in a very simplistic model, only including total group size and percent vegetative cover. There were many covariates which were essentially collinear with the intercept, and therefore could not be included in the model. The department could certainly spend a lot more time and money to get different flying and weather conditions as long as we have collared moose available to observe. Budget and personnel time will require a very large initial investment beyond what's been done to make this idea remotely useable.

Unfortunately, gathering sightability data is not really conducive to running concurrently with actual surveys because of the immediacy of uncertain weather windows, not to mention logistical constraints of keeping track of which moose should have been seen, and tracking ones that may have been missed. Should the region make it a priority, more can certainly be done to create an improved model. I would advise that it will be cost prohibitive at this point. Simply spending another \$50-60k will not markedly improve the model to widely varying conditions, and there will be additional costs in attempting to estimate rates of missingness.

We still need to offer a viable solution to the need for population estimates. FY09 and FY10 surveys conducted an SCF estimate for individual surveys, and I would encourage this again in the future. We are left with only estimating 'observable moose' because there will still be some moose that are impossible to visually observe under any conditions. There is insufficient data at this time to begin estimating moose that are not observable.

Sightability model (ignoring improper enumeration)

104 and 183 moose groups were encountered in 2007 and 2008 respectively. Ten were missing most covariate information due to reporting errors. Several others were missing only one or two covariates, so had to be omitted in analyses involving those covariates.

Using forward selection with an inclusion criterion of $P \leq .1$, the best fitting model included only total group size and percent vegetative cover. This is not to say the remaining covariates aren't involved in sightability. Because many of the environmental covariates were the same between years, there was not enough variation in them to be helpful in explaining sightability for this particular data.

Parameter	DF	Estimate	Error	Chi-Square	Pr > ChiSq	Exp(Est)	95% Confidence Limits	
Intercept	1	-0.0806	0.5533	0.0212	0.8841	0.923		
total	1	0.9212	0.2283	16.2765	<.0001	2.512	1.682	4.120
p_cover10	1	-0.1805	0.0825	4.7833	0.0287	0.835	0.708	0.980

So for every additional moose in the group, the odds of being seen go up by $e^{.9212} = 2.51$ times (95% CI 1.68 to 4.12). Likewise, for every 10% increase in cover the odds of being seen go down by $e^{-0.18} = .835$ (95% CI 0.71 to 0.98) times, in other words a 16.5% (29% to 2%) reduction in odds for every 10% increase in cover.

Recall that $odds = p(\text{something happens})/p(\text{something doesn't happen})$, so it's interpreted differently than probabilities. For example, if a moose group has a probability of being seen of .8, the odds would be $\frac{.8}{.2} = 4$. Increase that group size by 1 and the odds would then be $4 * 2.5 = 10$, so the probability would be $\frac{10}{1+10} = 0.91$. Increase that group size by 2 and the odds would be $4 * 2.5^2 = 25$ so the probability would be $\frac{25}{1+25} = 0.96$. It wouldn't take many additional moose in a group before the probability quickly approaches 1. Likewise, the aforementioned group would go from probability .8 to .7 with a 30% increase of cover. Appendix B contains mathematical details for the estimation of the sightability model.

Incorrect enumeration

19 (out of 287) or 6.6% of groups had bad enumeration. Two moose were missed on 3 occasions; otherwise it was only single moose that were missed. This number is likely low for two reasons: singletons that were missed could only be counted as not seen and not counted as bad enumeration. Second, the bad enumeration can only reflect our missing collared moose in the group—there may have been other missed moose without collars that still went uncounted. The most common comment from observers is that they were underneath spruce trees. Often, it was a bedded calf that was missed (5/19 times reported).

Group Size	1	2	3	4	5	6	7	8	9	10+
seen	47	52	19	17	15	9	5	4	1	9
not seen	47	23	1	2	0	0	0	0	0	0
Bad enumeration (observed count)	2	2	6	0	2	3	1	2	0	1
Bad enumeration (corrected count)	N/A	2	2	5	1	2	3	1	1	2
% of total groups with bad enum. (observed count)	N/A	2.7	30	0	13	33	20	50	0	11

A little caution should be used when interpreting this chart. Collared moose were observed multiple times by multiple aircraft on multiple days. In that sense, there is an extreme lack of independence and the totals have no association with the population total. If we can assume collared moose were randomly distributed among the population, then we could potentially say the ratios would reflect those of the population. The two rows labeled 'bad enumeration' reflect the originally observed count and the count corrected after radio-tracking of collared moose occurred. (Note again that we have no way of identifying non-sightable groups of 1 in the count of non-sighted groups of 1.) Although the distribution of group sizes with bad enumeration looks pretty similar across all sizes, we see the rate is actually much higher for medium sized groups after we account for the number of each group size, keeping in mind there is very little data. Despite appearing to have more problems with bad enumeration, none of the 43 moderate to large groups was missed due to sightability. Appendix C contains some potential options of how to model incorrect enumeration.

V. Discussion

Sightability models vs. Sightability Correction Factors

When conditions match those found in this sightability study, this final model would be applicable. However, conditions in the future could easily be quite different. The cost of collecting more sightability data should be considered in determining whether this model should be refined further. It may be more cost effective to add SCFs to each survey, although estimates resulting from using SCFs will not have the same precision as a good sightability model. Collecting smaller amounts of sightability data over a span of several years could help expand the applicability of this model to more varying conditions.

Potential bias in composition data

Collared calves were missed in the initial group count and later observed bedded under spruce trees. There were only 17 calves with collars, so many more calves could have been missed when counting groups. If late winter conditions lead calves to be more likely to use tree wells for protective cover there could be serious negative bias introduced in the calf-cow ratio.

Adherence to quadrat boundaries

Search patterns at the edges of quadrats should be better defined. At the beginning of this project, pilots asked whether they should make turns within the boundaries or just after leaving the quadrat boundaries. The benefits and liabilities of each method could be compared, but in viewing the GPS recorded flight paths, there were several instances of groups being counted when the plane was actually outside of the quadrat boundary. Various factors such as screen resolution and the pilot's primary focus of keeping the plane airborne make such errors completely understandable. Error in the georeferenced base maps could not completely explain tracks and groups outside quadrat boundaries, because they occurred on all 4 boundaries of a quadrat. Reducing quadrats to a quarter of their normal size may have had some effect, however. If this were an actual survey and extra counting was happening with any consistency, the survey estimate would be higher than the true value because we are artificially increasing the density of moose in the surveyed quadrats, by erroneously including moose from adjacent quadrats.

With the ubiquity of GPS devices able to track a day's worth of flying, it might be worthwhile to have surveyors mark each group with a GPS waypoint and compare the stored tracks along with the waypoints to a base map of the quadrats. The tracks and waypoints would need to be downloaded each night after the surveys are finished so as not to be overwritten the next day. The actual comparison would not need to be done in the field, but could be done back at the office using standard GIS software. It would be a fairly easy way of post-processing to increase data quality and survey consistency.

Support staff

The pilots and assistants were all of great help both in the air and on the ground. Every evening there was a lot of work to be done downloading data from GPS units and cameras, reassigning collared moose to correct quadrats and updating flight assignments for the following day. It was more than one person could reasonably handle and were such a study to be repeated, an additional person with GPS and GIS familiarity who could complete these tasks in the evening would be highly recommended. Several

recording errors could have been caught while still fresh in the memory of pilots and observers, and the overall quality of the data could have been markedly improved.

Conclusion

The intent of this study was to create a model to estimate sightability as an alternative to conducting SCF correction flights for each survey. Due to homogeneity within many of the anticipated predictors, a model with only limited applicability could be developed. Continuing to collect sightability data and expanding the applicability of this model is a possibility, albeit a costly one. In areas where sightability is known to be an issue GSPE surveys should not be conducted without some form of correction, so area managers should strongly consider committing additional resources to flying SCF flights if no other alternatives are available. Region III has been working on corrections using remotely sensed habitat data within the GSPE framework to estimate sightability correction, but as of publication it has not been completed. Other methods for estimation of moose population, such as line transect, exist but may have other technical and logistical issues that preclude their use.

Enumeration of moose groups is an issue in need of further study. The use of tree wells in late winter, especially by calves, could bias not only the population estimate but also other important demographic measures. As managers need to move to late winter surveys due to weather and light conditions, this issue becomes more prominent.

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VIII. Appendices

Appendix A: Required assumptions for population survey validity

- 1) The population is closed
As long as the survey is conducted quickly and without long pauses, we can fairly safely assume the populations are closed. This can be a tricky issue due to aggregations toward the end of the year.
- 2) Groups are observed independently
There is no reason observing one group would increase or decrease the chances of seeing another group. It could be possible, however, that the circling of a group represents a marked change in sightability due to the change in flight pattern and nearby groups have more chance of being observed.
- 3) Observed groups are completely observed and not double-counted.
With sufficient circling, groups should be completely counted and as in assumption 1, as long as surveys are conducted in a timely manner, moose should not have the opportunity to travel between survey units except in rare cases.
- 4) The probability of choosing a unit to be surveyed can be enumerated.
This is fairly simple depending on how the units were sampled. Most of the time (under simple random sampling) units will all have the same probability of being chosen: $(\# \text{ units surveyed})/(\# \text{ units in study area})$. If there is reason to do restricted sampling, by blocks for example, units can have different probabilities of being surveyed. This doesn't break the assumptions, but must be accounted for in both sightability correction and variance calculations.
- 5) The probability of observing a group is known or can be estimated.
We will either estimate the sightability via logistic regression, or will use an existing sightability model estimated from previously collected data.

Appendix B: Estimation using logistic regression (LR) model ASSUMING PERFECT ENUMERATION.

The following notation follows directly from Steinhorst and Samuel (1989), where additional intermediate details can be found.

Let

l = the number of survey units sampled,

L = the total number of survey units in the study area,

n_k = the number of moose groups observed in the k th survey unit,

N_k = the actual number of moose groups observed in the k th survey unit,

$m_{i(k)}$ = the number of moose in the i th group in the k th survey unit,

τ = the total population,

T = an estimator for τ ,

p_k = the probability of the k th survey unit being sampled (for SRS, $p_k = 1/L$),

$\pi_{i(k)}$ = the probability of sighting the i th group in the k th survey unit, and

$\mathbf{x}_{i(k)}$ = the vector of covariates associated with the i th group in the k th survey unit.

For sampled quadrats $k = 1, \dots, l$ we observe moose groups $i = 1, \dots, n_k$. The probability of sighting can then be modeled using logistic regression (LR)

$$\hat{\pi}_{i(k)} = \frac{e^{\mathbf{x}_{i(k)}^t \hat{\boldsymbol{\beta}}}}{1 + e^{\mathbf{x}_{i(k)}^t \hat{\boldsymbol{\beta}}}}$$

where $\mathbf{x}_{i(k)}$ is the vector of covariates and $\hat{\boldsymbol{\beta}}$ is the vector of coefficients to be estimated using standard software packages such as SAS or R.

The sightability corrected population total can then be estimated by

$$T_{LR} = \sum_{k=1}^l \frac{1}{p_k} \sum_{i=1}^{n_k} \frac{m_{i(k)}}{\hat{\pi}_{i(k)}},$$

where $\hat{\pi}_{i(k)}$ is the estimated probability of sighting from the LR model.

For the case of simple random sampling, this simplifies to

$$T_{LR} = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}}{\hat{\pi}_{i(k)}}.$$

Let

$$\hat{M}_k = \sum_{i=1}^{n_k} \frac{m_{i(k)}}{\hat{\pi}_{i(k)}} = \sum_{i=1}^{n_k} m_{i(k)} \hat{\Theta}_{i(k)},$$

where an unbiased estimate for $1/\pi_{i(k)}$ is

$$\hat{\Theta}_{i(k)} = 1 + e^{-\mathbf{x}_{i(k)}^t \hat{\boldsymbol{\beta}} - \mathbf{x}_{i(k)}^t \hat{\boldsymbol{\Sigma}} \mathbf{x}_{i(k)} / 2}.$$

where $\hat{\boldsymbol{\Sigma}}$ is the estimated information matrix for $\hat{\boldsymbol{\beta}}$ and noting

$$s_{\hat{\Theta}_{i(k)}}^2 = e^{-2\mathbf{x}_{i(k)}^t \hat{\boldsymbol{\beta}} - \mathbf{x}_{i(k)}^t \hat{\boldsymbol{\Sigma}} \mathbf{x}_{i(k)}} \left(e^{\mathbf{x}_{i(k)}^t \hat{\boldsymbol{\Sigma}} \mathbf{x}_{i(k)}} - 1 \right) \text{ and}$$

$$s_{\hat{\Theta}_1, \hat{\Theta}_2} = e^{-(\mathbf{x}_1 + \mathbf{x}_2)^t \hat{\boldsymbol{\beta}} - (\mathbf{x}_1 + \mathbf{x}_2)^t \hat{\boldsymbol{\Sigma}} (\mathbf{x}_1 + \mathbf{x}_2)/2} \left(e^{\mathbf{x}_1^t \hat{\boldsymbol{\Sigma}} \mathbf{x}_2} - 1 \right),$$

the variance of this estimator can also be calculated as

$$s_{T_{LR}}^2 = \sum_{k=1}^l \frac{1-p_k}{p_k} \hat{M}_k^2 + \sum_{k \neq k'} \frac{p_{kk'} - p_k p_{k'}}{p_{kk'} p_k p_{k'}} \hat{M}_k^2 \hat{M}_{k'}^2 + \sum_{k=1}^l \frac{1}{p_k^2} \sum_{i=1}^{n_k} \left(1 - \frac{1}{\hat{\Theta}_{i(k)}} \right) m_{i(k)}^2 \hat{\Theta}_{i(k)}^2$$

$$+ \sum_j \sum_{j'} a_j a_{j'} s_{\hat{\Theta}_j \hat{\Theta}_{j'}},$$

where j indexes all $i(k)$ and where $a_j = \sum_{i(k) \in j} m_{i(k)} p_k$.

Under SRS this simplifies to

$$s_{T_{LR}}^2 = \frac{L-l}{l} \sum_{k=1}^l \hat{M}_k^2 + \frac{L(l-L)}{l^2(l-1)} \sum_{k \neq k'} \hat{M}_k^2 \hat{M}_{k'}^2 + \frac{L^2}{l^2} \sum_{k=1}^l \sum_{i=1}^{n_k} \left(1 - \frac{1}{\hat{\Theta}_{i(k)}} \right) m_{i(k)}^2 \hat{\Theta}_{i(k)}^2 + \sum_j \sum_{j'} a_j a_{j'} s_{\hat{\Theta}_j \hat{\Theta}_{j'}},$$

Appendix C: Some options for dealing with improper enumeration

For simplicity, we will assume SRS.

Assuming perfect enumeration of groups:

$$T = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}}{\hat{\pi}_{i(k)}}$$

But we observe $m_{i(k)}^* \leq m_{i(k)}$, i.e some count not including possible missing (hidden and unobservable) moose. (Note: if group size is a covariate for sightability, then it is actually *observed* group size)

We need to look at the distribution of group sizes with uncounted moose. Also, what should be done about “groups” of size 1. Are they missed, simply unobservable, or some mixture of the two?

Could: 1. Adjust total and/or sightability

$$T = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \frac{\tilde{m}_{i(k)}}{\hat{\pi}_{i(k)}}$$

or

$$T = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}^*}{\tilde{\pi}_{i(k)}}$$

2. Estimate missing and add to total

$$T = \frac{L}{l} \left(\sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}^*}{\hat{\pi}_{i(k)}} + \sum_{k=1}^l \sum_{i=1}^{n_k} d_{i(k)} \right)$$

where $d_{i(k)} = m_{i(k)} - m_{i(k)}^*$. Note this is not $T = \frac{L}{l} \left(\sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}^* + d_{i(k)}}{\hat{\pi}_{i(k)}} \right)$ because the unobserved moose aren't seen, so how are they ‘adjusted’ for sightability? Probably need more structure on the $d_{i(k)}$ since we have to estimate it, however.

3. Add adjustment based on observed group sizes and their probability of containing unenumerated moose

$$T = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \left(\frac{m_{i(k)}^*}{\hat{\pi}_{i(k)}} + \frac{m_{i(k)}}{\delta_{i(k)}} \right)$$

where $\delta_{i(k)}$ is an adjustment for observed group size $m_{i(k)}^*$, and if $m_{i(k)}^* = m_{i'(k')}$ then $\delta_{i(k)} = \delta_{i'(k')}$. For this we would need to estimate a distribution for δ based on group size.

4. Add adjustment based on probability that exactly one moose was missed, i.e. assumes no more than one moose can be missed (See note for 2, however)

$$T = \frac{L}{l} \sum_{k=1}^l \sum_{i=1}^{n_k} \frac{m_{i(k)}^* + \gamma m_{i(k)}}{\hat{\pi}_{i(k)}}$$

where $\gamma_{m_{i(k)}}$ is the probability of a group sized $m_{i(k)}$ containing a missed moose, noting that

$$\frac{\gamma_{m_{i(k)}}(m_{i(k)}^* + 1)}{\hat{\pi}_{i(k)}} + \frac{(1 - \gamma_{m_{i(k)}})m_{i(k)}^*}{\hat{\pi}_{i(k)}} = \frac{m_{i(k)}^* + \gamma_{m_{i(k)}}}{\hat{\pi}_{i(k)}}.$$

Using results from Walsh et al 2009, we can get a closed form estimate for the variance of this estimator

$$\begin{aligned} Var(T) = & \frac{L-l}{l} \sum_{k=1}^L m_k^{*2} + \frac{L(l-L)}{l^2(l-1)} \sum_{k \neq k'}^L \sum_{k'}^L m_k^* m_{k'}^* \\ & + \frac{L}{l} \sum_{k=1}^L \sum_{i=1}^{N_k} \frac{1 - \pi_{i(k)}}{\pi_{i(k)}} (m_{i(k)}^* + \gamma_{m_{i(k)}}) \\ & + \frac{L}{l} \sum_{k=1}^L \sum_{i=1}^{N_k} \frac{\gamma_{m_{i(k)}} (1 - \gamma_{m_{i(k)}})}{\pi_{i(k)}} \end{aligned}$$

where $m_k^* = \sum_{i=1}^{N_k} (m_{i(k)}^* + \gamma_{m_{i(k)}})$ and assuming SRS.

Number 4 is a seemingly good option considering the data we have show generally only on moose missing, but recall that we are only have data on collared moose that are missing, not on collarless moose that were not seen, so there may have actually been multiple moose not enumerated. The only fool-proof way to get that number is with a population of completely collared moose. Although the estimate would still be negatively biased, it should be less biased than if we ignore improper enumeration.

Appendix D: Sample survey form

[SAMPLE]

MOOSE CENSUS FORM—Sightability Study

Page 1 of 1 Form SS1 1/17/07

SEARCH IDENTIFICATION

Date: 2-1-07 SU #: 115 / SW
 GMU: 16BN
 Location: Yonina River
 Observer: A Christ
 Pilot: B Dale
 Aircraft Type: Scout Temp (F) 25

SEARCH TIMES
(in minutes)
 Stop@ 11:55
 Start@ 11:18
 Elapsed 37

OVERALL SURVEY RATING: ☐ Excellent ☒ Good ☐ Fair ☐ Poor

SEARCH CONDITIONS			
SNOW AGE <input type="checkbox"/> 1. Fresh <input checked="" type="checkbox"/> 2. < 1 week <input type="checkbox"/> 3. > 1 week LIGHT TYPE <input checked="" type="checkbox"/> 1. Bright <input type="checkbox"/> 2. Flat	SNOW COVER <input checked="" type="checkbox"/> 1. Complete <input type="checkbox"/> 2. Some Low veg Showing <input type="checkbox"/> 3. Bare Ground Showing LIGHT INTENSITY <input type="checkbox"/> 1. High <input type="checkbox"/> 2. Medium <input checked="" type="checkbox"/> 3. Low	HABITAT TYPE FOR FIRST OBS MOOSE <input type="checkbox"/> 1. Open lower elevation, predom shrub, riparian, or wetland <input type="checkbox"/> 2. Mixed Open Forest with some shrub understory <input type="checkbox"/> 3. Dense Spruce Forest <input type="checkbox"/> 4. Dense Deciduous Forest Birch, Aspen, etc. Few Shrubs <input type="checkbox"/> 5. Subalpine Shrub <input type="checkbox"/> 6. Burn	MOOSE ACTIVITY (WHEN FIRST OBS) <input type="checkbox"/> U. Up (Standing/moving) <input type="checkbox"/> D. Down (Lying)

CHECK ADDITIONAL CONDITIONS THAT MAY HAVE AFFECTED THE QUALITY OF THE SEARCH

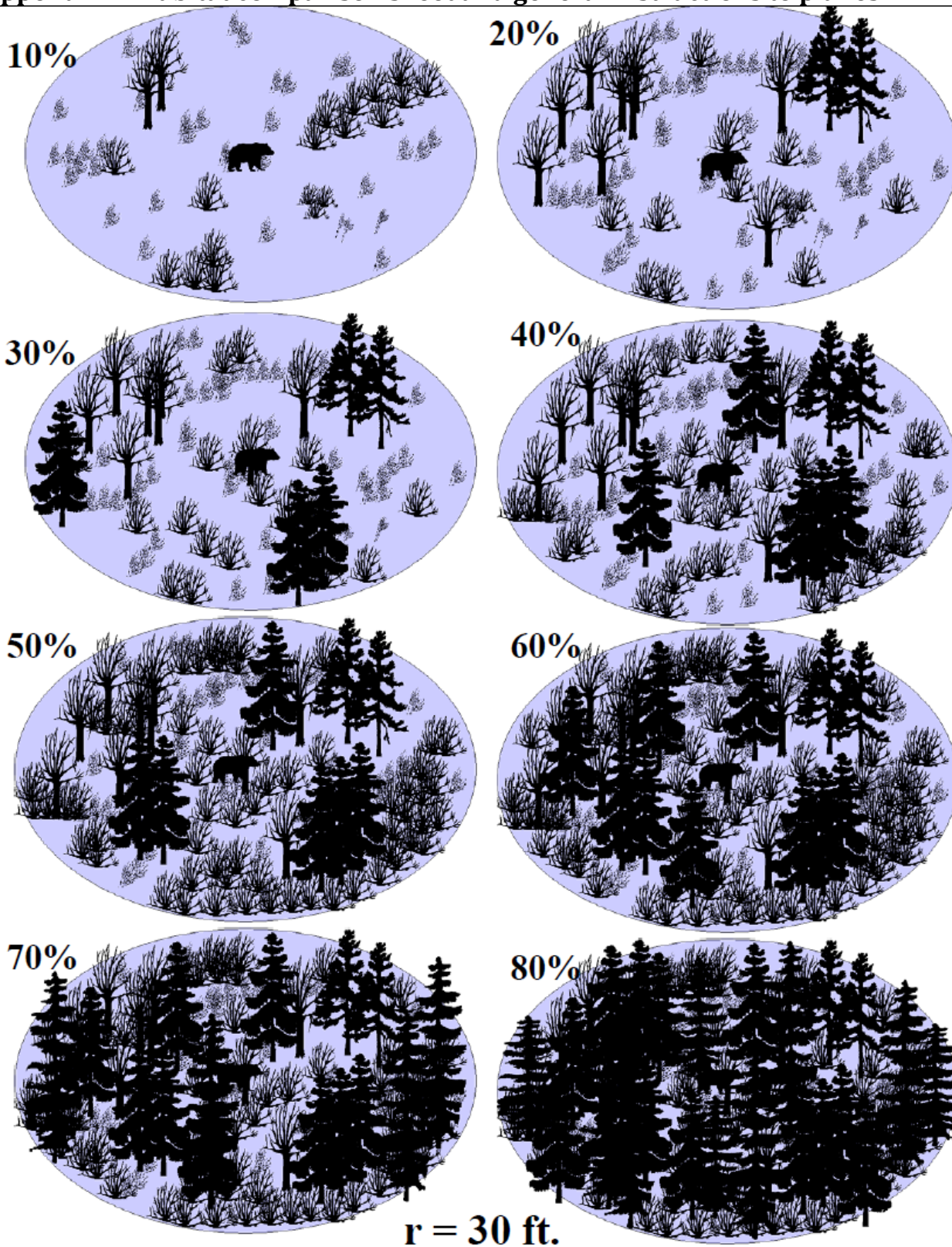
<input type="checkbox"/> Classification Errors	<input type="checkbox"/> Low Clouds or Fog	<input type="checkbox"/> Inexperienced Pilot	<input type="checkbox"/>
<input type="checkbox"/> Poor Light	<input type="checkbox"/> Poor Visibility/Snow on Trees	<input type="checkbox"/> Uncooperative Pilot	<input type="checkbox"/>
<input type="checkbox"/> Inadequate Search Effort	<input type="checkbox"/> Problems finding SU	<input type="checkbox"/> Inexperienced Observer	<input type="checkbox"/>
<input type="checkbox"/> Short on Fuel	<input type="checkbox"/> Boundaries	<input type="checkbox"/> Observer Sleeping	<input type="checkbox"/>
<input type="checkbox"/> Windy/Turbulent	<input type="checkbox"/> Inadequate Snow Cover	<input type="checkbox"/> Observer Airsick	<input type="checkbox"/>
<input type="checkbox"/> Other (Explain):			

#Obs. Collars	Group No.	Adults	Calves	Unk.	Total Moose	Hab Type	%hab cover	Spruce <10m	Moose Activity	Trench ?	Remarks
1	1	1		1	2	2	60	✓	U/D	<input type="checkbox"/>	WP 027
2	2	3	2		5	2	40	✓	U/D	<input type="checkbox"/>	WP 028 Fresh tracks
									U/D	<input type="checkbox"/>	led us to group
4	1			1	2	3	80	✓	U/D	<input type="checkbox"/>	WP 029
5	1111		11		6	3	60	✓	U/D	<input type="checkbox"/>	WP 030
6									U/D	<input type="checkbox"/>	
7									U/D	<input type="checkbox"/>	8520/9810 cow/calf
8									U/D	<input type="checkbox"/>	*WAS with grp 5, but not counted 9700 (WAS UNDER SPRUCE)
9									U/D	<input type="checkbox"/>	OUT OF AREA 8550
10	1	1			2	3	80	✓	U/D	<input type="checkbox"/>	9990 missed group
11									U/D	<input type="checkbox"/>	WP 031
12									U/D	<input type="checkbox"/>	
13									U/D	<input type="checkbox"/>	note: Moose 9700 not reflected
14									U/D	<input type="checkbox"/>	in count for group 5
15									U/D	<input type="checkbox"/>	
16									U/D	<input type="checkbox"/>	
17									U/D	<input type="checkbox"/>	
18									U/D	<input type="checkbox"/>	
19									U/D	<input type="checkbox"/>	
20									U/D	<input type="checkbox"/>	

Draw line under last group observed before follow-up radiotracking
 Additional Lines on Back of Sheet if Needed

[SAMPLE]

Appendix E: Habitat comparison sheet and general instructions to planes



Objective:

We are trying to evaluate how certain covariates relate to the sightability of moose during a population survey. Moose **groups** are surveyed and enumerated. Because we need to be able to ascertain the presence of a moose in a specific location we must rely on radio collars to uniquely identify individual moose, although it is the group we are actually identifying. Covariates are related to the group and are represented by the first moose seen (not necessarily the collared moose).

Flight pattern

Flight patterns and speeds need to replicate a standard survey. One exception is that there is no fixed time for surveying a unit. As vegetation or topography cause sightlines to be diminished, we need to decrease the spacing between adjacent passes. For example, wide open muskeg has a very wide sight distance, so the flight paths will be spaced farther apart. Tall spruce has a very short sight distance and will require tighter spacing between adjacent passes. The goal is to actually see all the area, but remain as efficient as possible. For terrain that switches between wide open and closed it may be necessary to depart from the normal straight passes and add extra time only in the difficult sighting areas.

When a group is encountered:

Mark GPS location for the group

Collect covariate information for **first** moose seen

Switch to a more intensive search pattern (circling).

Search for other moose noting how many collars are seen in the group

Radio tracking 'missed' moose

Sometimes you will be given frequencies to track. If upon tracking you find that you saw the collared moose's group but did not notice the collar, simply make a note by the group you had previously seen. If you indeed missed the group, simply record the count and covariate information on the data sheet. **DO NOT FORGET TO RECORD COVARIATES FOR 'MISSED' MOOSE!**

SPECIAL CASE If you find that you missed a collared moose but already saw the group it was in, we need to make a special note. This could happen when the collared moose was resting underneath a spruce while all others were more in the open. This is **only** when you failed to include the collared moose in the group count on the original observation. These cases are extremely important to note because they violate standard assumptions made for this type of surveying.

Time spent for follow-up radio tracking

The goal is to locate missed groups from the survey. Moose that have moved outside of the particular quadrat are not counted as missed because they were not there to be observed in the first place. As soon as you determine that the signal is coming from outside the quadrat you just surveyed, you can abort the radio locating and notify the coordinating aircraft so we can locate the collar. We do NOT need a specific location for moose that have moved out of the quadrat, but if it is easy to determine which quadrat it moved to, that would be helpful to know. **DO NOT SPEND A LOT OF TIME TRACKING A MOOSE THAT YOU KNOW HAS LEFT THE QUADRAT!**

If you can locate a moose, but not make a visual verification (e.g. really hidden in the trees) make your best guess as to where it is and note on the survey form that you could not make visual verification. **RECORD COVARIATES!**

What happens if something unexpected comes up? Please get on the radio and ask for help. **DO NOT ASSUME!** There are specific assumptions that need to be met, and I need to be sure we still meet those assumptions.

Appendix F: Maps of the study area

