Wolf Census in three boreal caribou ranges in British Columbia; results from 2015

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EXECUTIVE SUMMARY

Developing a cost-effective and accurate method of counting wolves in boreal forests of western Canada is important for the management and conservation of woodland caribou. If such a method can be implemented, then the degree to which anthropogenic habitat disturbance affects predator- prey relationships, relative to other factors (e.g., natural habitat, climate) can be formally evaluated. Given this context, we divided this project into proximate and ultimate objectives. The proximate objective was to develop and test the method to count wolves, to help realize the ultimate objective of evaluating the relative influence of human footprint, natural habitat, and climate on caribou dynamics.

Developing the method involved three components: conducting a power analysis to guide aerial survey intensity, piloting the method in the field, and validating the findings based on a sample of radio marked wolves. The power analysis was based on simulating systematic transect spacing from 2 to 7 km, and varying the length of time over which wolf locations were included (simulating tracks since last snowfall) from 1 to 5 days. This way the relative interplay of space and time could be evaluated. Our results showed that time was highly important, indicating large benefits to waiting 3 days following large snowfall events. The effect of transect spacing was less dramatic, but showed a clear negative relationship between transect spacing and the probability of detection.

We piloted the method by sampling portions of 3 boreal caribou ranges in northeast British Columbia; the entire Calendar and Parker Ranges, and a portion of the Chinchaga range that roughly corresponded to the Chinchaga Resource Review Area. The survey design consisted of flying 3-km belt transects with a Cessna L-19 Bird Dog fixed wing aircraft in order to encounter wolf tracks; encountered wolf tracks were then tracked to assess pack size.

There was a combined effort of ~ 3100 km encounter transects flown among the three survey areas. We counted the most wolves (8 packs, 52-61 wolves estimated) in the Chinchaga RRA survey area, and this area was calculated to have the highest density of wolves: 13.3 - 15.6 wolves / 1000 km^2. By comparison, we calculated a density of 6.4 – 7.0 wolves / 1000 km^2 at Calendar (5 packs, 32 to 35 wolves estimated). At the relatively small Parker survey area, we located one pack of 6 wolves. Four recent wolf kill sites were observed, all with wolves seen nearby. During the surveys 77, 15 and 41 moose were observed incidentally in Calendar, Parker and Chinchaga RRA respectively, and 37, 9 and 3 caribou were observed incidentally in Calendar, Parker and Chinchaga RRA respectively. In total, the three surveys required 66.5 hours of fixed wing flying, with 44.7 hours being logged as survey hours within the survey areas. We estimated that approximately 60% of the survey hours were used deviating from the encounter transects to assess tracks, and for tracking wolves. Owing to a lack of collared wolves in the survey areas, the validation of the census counts could not be made during the 2015 surveys.

The field component of this study revealed three important findings: (1) the survey was logistically feasible using a fixed wing in very remote regions; (2) wolf densities were about 6 to 7 times higher than expected (based on moose densities) in the Calendar and Chinchaga RRA survey areas; and (3) relative trends between moose and wolf abundance among ranges matched expectations.

We recommend that future surveys should expand in scope to census additional survey areas in order to capture natural variation in ungulate densities, and variation in the footprint of human disturbance. We also recommend that surveys should specifically take place in areas where there is sufficient number of collared wolves to validate the estimate of the census method being used. Finally, we recommend that the simulation exercise is repeated with more precise wolf tracking data (e.g., with hourly fix rate data instead of daily fix rates).

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INTRODUCTION

Apparent competition (Holt 1977) is implicated as a key mechanism in the decline of boreal caribou. The process of apparent competition involves increases to the abundance of moose and deer, which causes predator numbers to increase and caribou to decline because they are less fecund and perhaps more vulnerable to predation compared to other ungulates. It is commonly reported that increased moose and deer abundance is directly caused by human disturbance thereby linking human development to caribou decline (Schwartz and Franzmann 1991; Rempel et al. 1997; Serrouya et al. 2011). Yet the apparent competition between these ungulates and caribou is undoubtedly influenced by other non-disturbance factors such as climate change, weather patterns, or natural habitat attributes that also affect moose and deer distributions across the landscape.

To disentangle the degree to which disturbance contributes to caribou decline, several conditions must be achieved: 1) a study must include sufficient variability in human footprint and habitat conditions; and 2) a reliable method is required to track the abundance (either relative or absolute) of wolves and their prey. The former condition is increasingly challenged by the advancing human footprint, but near pristine conditions still exist in some parts of British Columbia and southern Northwest Territories. Some undisturbed areas have considerable variability in natural moose populations that could be used to understand causal mechanisms. Several approaches have been attempted to enumerate wolves in forested ecosystems, including intensive radio-collaring efforts followed by flights to count numbers within each pack (Latham et al. 2011), detecting tracks in defined survey units (Patterson et al. 2004), and complete censuses (van Oort and Bird 2011; Serrouya 2013). The radio-collaring approach has been successfully used in boreal forests, but is very expensive due to the need to radio collar each pack and it usually takes several years to acquire the sample needed to obtain an estimate. In contrast, censuses where all habitats are covered may not be possible in the boreal forest where study areas are usually too large to cover in detail.

The proximate objective of our project was to develop a cost-effective and accurate method to count wolves in the boreal forest. This objective consists of three components: conducting a power analysis to guide survey intensity, implementing the result of the power analysis with surveys in the field, and conducting a post-hoc assessment on the accuracy of the method. The ultimate objective of this work is to address the relative influence of human footprint, climate, and natural habitat composition on the abundance of moose, wolves, and caribou. In this report we primarily address the proximate objective of developing the method, but we also touch on the ultimate objective, which is necessarily brief because sampling was conducted over one winter.

METHODS

Study Areas

Three study areas were defined, each located within different recognized caribou ranges – Calendar, Parker and Chinchaga (Environment Canada 2012) – and chosen because of the range of moose densities that had previously been estimated (Thiessen 2010). The Calendar study area was previously determined to have a relatively low moose density (0.018 moose/km^2), compared with the Chinchaga RRA and Parker study areas with densities of 0.15 and 0.25 moose/km^2 respectively (Thiessen 2010, McNay et al. 2013). All three study areas had relatively high levels of disturbance primarily in the form of seismic lines, but also as a result of resource roads, natural gas extraction facilities and infrastructure, and pipeline right-of-ways.

The Calendar study area (4973 km^2) was the BC portion of the Calendar caribou range, extending approximately from the Petitot River at its southwest border, to the northeast corner of BC. The Canadian Natural Resources Ltd. (CNRL) Helmut camp, positioned just south of the study area, served as a fueling station for the aircraft. Near Fort Nelson, the Parker study area was defined as the entire range of the Parker Caribou herd (752 km^2). The 3900 km^2 Chinchaga Resource Review Area (RRA) study area was a section of the northwest corner of the Chinchaga range bounded on its western edge by the Sikanni River. While the survey area was based on the previously delineated RRA management polygon, we modified the boundary slightly to make a more practical survey area.

Survey Design

Our goal was to conduct a complete census of each of the three study areas. These study areas were in landscapes with low topographic relief and no natural barriers to wolf movement; consequently, we opted to use an encounter transect/belt survey methodology to assure even and controlled search effort across the study areas. The spacing between the transects that we selected (3 km) was informed by a simulation study utilizing winter GPS location data from 11 wolves collared in the study region as part of the University of Alberta and SCEK research programs. The GPS collars were programmed to obtain a fix 1 to 4 times per day, depending on the collar. Data used for the analysis ranged from January 1 to March 31 in 2013 and 2014.

The simulation clarified the trade-off between how wide transect spacing could be in relation to how much a wolf travels over a given window of time. Presumably, the longer wolves have to track a landscape following a snowfall, the wider apart transects could be. Therefore, two factors were varied; transect spacing and the window of time that empirical wolf movements would encompass. Transect spacing was set at 2, 4, 5 and 7 km, and the time window was set at 1, 2, 3, 4 and 5 days.

For each iteration within the simulation, a random longitude was selected within the study area, and the rest of the study area was then populated with simulated transects spaced at one of the four distances specified above. Transects were always oriented North-South. Similarly, a random start date was selected, then all wolf locations within the specified time window, beginning with the start date, were extracted and plotted on the GIS. The number of crossings that occurred across the simulated transect was tabulated for each wolf and time period. This process was repeated 3500 times for each wolf so that every combination of transect spacing and time window was adequately populated.

The response metric for each iteration of these simulations was whether or not the wolf path intercepted transects at least once – this event was considered a detection. Our simulations assume that every time the empirical wolf path crosses a simulated transect, the path is detected by the aircraft. Clearly this is incorrect, but we make the further assumption that any level of detectability will affect each simulation scenario (i.e., each combination of transect spacing and time window) in the same fashion. All programming for the simulation was conducted in R using the following packages: rgdal, lubridate, plyr, reshape, and ggplot2.

The simulation served as a relative measure of how the sampling process was influenced by time and space. Based on the simulation results, we opted to use a 3-km transect spacing for these surveys (see Results and Discussion). In practice, we treated the 3-km spaced transect lines not as a fight paths, but rather, as the dividing lines between parallel 3-km wide corridors, which we surveyed via meandering flight lines. The flight paths included considerable looping to check out tracks, and meandered to survey habitat that was optimal for maximizing detections (e.g., by flying over open habitats, frozen lakes, roads, seismic lines, wetlands, etc., and avoiding heavily timbered habitats).

Prior to the surveys, a deep (~40 – 100 cm) snowpack covered 100% of the survey areas. A complete census was conducted at each of the three study areas, each completed in relatively short time periods (7, 1, and 11 days for Calendar, Parker, and Chinchaga RRA respectively). In all surveys, the survey advanced across the study area progressively (e.g., from east to west, or north to south etc.) so that wolves previously counted were less likely to be counted twice as a result of movements from surveyed regions into regions of the study area not yet surveyed. Such movements were also very likely to be detected, and the surveyor's awareness of the current pack locations in the recently surveyed area was used to assure that wolf movements did not result in a double counting scenario.

The aerial survey was conducted with a Cessna L-19 Bird Dog. The pilot and the biologists were highly experienced with conducting aerial wolf surveys. The crew navigated with the pilot's dash-mounted GPS, which was uploaded with mapping files to display the 3-km transect lines. Tracklogs and coordinates of wolf sign were recorded using hand-held GPS units (Garmen Map76csx). Additionally, we counted and took coordinates for all visual observations of moose, caribou, and evidence of wolf kills. For half of the Parker range, a Bell 206 Jet Ranger was utilized. The Jet Ranger and the L-19 were both used in order to train additional observers. The Jet Ranger was useful as it seated multiple passengers, and could hover over tracks during the training session.

Wolf pack sizes were estimated with varying degrees of certainty. A minimum wolf pack size was an objective minimum count derived from tracking evidence such as clear splitting of tracks, from visual observations of the pack, or from tracking the animals on a shallow snow surface such as lake ice, where individual wolf tracks could be separated. We also recorded an "upper estimate" when the total group size was thought to be greater than the minimum count; these more subjective estimates were based on the observers' opinion based on the overall amount of sign, circumstances, and tracking conditions. In some cases only minimum counts were possible (e.g., if three wolves were seen at the edge of timber, and no other evidence of pack size was observed). Sometimes, we were certain that we counted the whole pack, and provided an upper estimate that was identical to the minimum estimate. During this survey and numerous previous wolf surveys, there have been many opportunities where upper estimates have been validated once the tracking led to a visual observation of the pack; it has been the experience of the pilot and biologist (van Oort) in these situations that upper estimates are most often accurate within 1 wolf.

Total population size estimate ranges were calculated by summing minimum counts (lower total estimate) and by summing the upper estimates (upper total estimate). Wolf density ranges were calculated for survey areas where more than one pack was detected by dividing the total number of wolves by the survey area. We used units of 1000 km^2 for this calculation (e.g., wolves per 1000 km^2).

Survey Chronology and Conditions

Depending on snowfall events, snow track surveys vary in terms of the distribution of track ages or 'vintage.' In some cases there may be only fresh tracks, while in other cases there may be two or more vintages. In the current three surveys, the snowfall history presented multi-vintage tracks on the landscape, which gave the observers good confidence in determining regions of wolf activity; that is, a lack of fresh track detections was typically coupled with a lack of older track detections, giving confidence that fresh tracks were not being missed due to a short time period since last snowfall.

The Calendar survey began on January 28, *c*. 2 days since the previous snowfall (a light skiff of snow). Approximate temperatures ranged from -24 to -15°C during the Calendar survey, completed from January 28, through February 3, 2015. The Calendar survey was completed over 5 days not including a 2-day recess (January 30-31) during which suboptimal weather conditions prevented survey work, but deposited 5-10 cm of fresh snow throughout the study area. Tracking conditions were considered adequate to good during the Calendar survey, with fresh tracks being discernable on snow surfaces that were between 1 and 3 day old, and lighting being bright, or filtered.

The Parker survey was completed in one day on February 4, 2015, *c.* 4 days after the previous snowfall (10-20 cm, locally deep). The survey took place during an approximate temperature of -15 °C. Snow tracking conditions during the Parker survey were excellent, with fresh tracks being discernable on the 4 day old snow surface; lighting conditions were initially excellent (bright/filtered), but became progressively darker during the day as a storm cell advanced into the study area.

A major snowfall commenced on 5 February, ending in the evening of February 6 followed by minor flurries throughout February 7. This single snowfall event served as the most recent tracking layer throughout the Chinchaga survey, with the final transects being flown approximately 8 days post-snowfall. The survey began on February 9. Approximate temperatures ranged from -17 to -10°C during the Chinchaga survey. The survey was completed on February 15 with two 1 day recesses (February 10, 13) due to suboptimal lighting conditions. The snow tracking conditions were excellent during this survey although tracking became challenging later in the survey owing to the aging tracking surface (too many tracks). Lighting conditions were relatively poor during the early phase of the Chinchaga survey due to a low overcast sky, but improved by the later part of the survey. Consequently, spotting tracks was relatively challenging early in the survey (mostly for tracks to the side of the aircraft), while our ability to separate tracks was potentially affected later in the survey. Both these conditions (poor lighting, old track surfaces) could have potentially caused our survey to underestimate the Chinchaga population.

RESULTS

Simulation

Simulations revealed a pronounced increase in detections of wolves as the time window increased from one to two days. There was much less benefit transitioning from 3 to 4 or 4 to 5 days (Fig. 1). Realistically, once a survey period begins, it will likely continue for 3 to 4 days, further increasing the amount of tracks on the landscape and consequently increasing the number of wolf detections. Starting later than three days after a snowfall results in a slightly increased probability of detection, but as the extent of tracking increases, longer search times to locate and enumerate packs may be required and confidence in pack size counts may decline. The relationship between the time window and proportion of wolves detected suggests that waiting about 3 days after a snowfall is a good guideline for when to begin a period of aerial sampling.

When considering the 3-day time window, detections diminished considerably as transect spacing increased from 2 to 7 km apart. There was not a clear break point between transect spacing and wolf detections, but transect spacing of about 3 km could be expected to detect approximately 75% of the wolf tracks (Fig. 1).

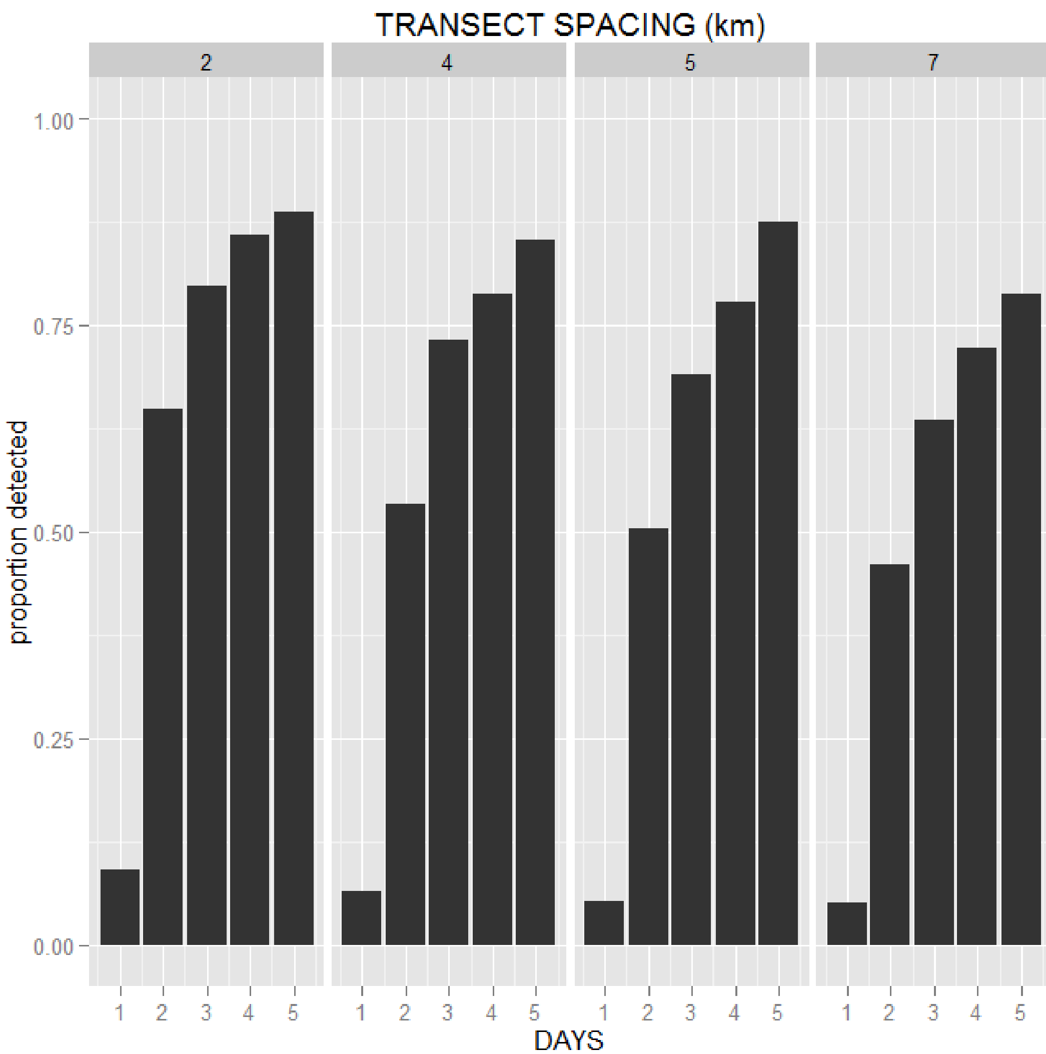

Figure 1. Proportion of individual wolves detected as a function of simulated transect spacing and empirical wolf movements over the course of discrete time windows (i.e., the space a wolf covers across 1, 2, 3, 4, or 5 days). Empirical data was obtained from northeast British Columbia as part of ongoing research from the University of Alberta and SCEK.

Survey Effort

Three-kilometer transect spacing meant that ~ 3100 km of transects needed to be flown to cover the three study areas (not including ferry distances). Prior to the survey, ferry times were estimated to require ~ 26 hours of air travel, and the total time required to fly the transects was estimated at 27.8 hours (Table 1), assuming a flight speed of 110 km/h using a Piper Super Cub (not necessarily accurate). The survey was completed with a more powerful aircraft capable of cruising speeds of 220 km/hr which diminished the ferry times considerably (Table 1). Transect flying speed was realized at approximately 180 km/hr using the Cessna L-19, which diminished the basic transect flying time calculation to 17 hours for all three study areas. However, the realized total time spent in the study areas amounted to 44.7 hours; hence, we estimate that 38% of the time in the study area was required for transect flying, and that 62% of the survey time was required for the additional meandering nature of the flight paths, for checking tracks, and in particular, for tracking wolves after tracks were detected. Ferry times to Calendar from Fort Nelson varied between 40 and 60 minutes. Ferry times to the Parker and Chinchaga RRA were approximately 10 and 30 - 40 minutes respectively.

Table 1. Estimate of linear km that must be flown assuming 3-km transect spacing in each of three boreal caribou ranges. Note that these flight hours do not include backtracking wolf tracks to location wolf packs.

Study area	Transect distance	Predicted transect hours (110 km/hr)	Predicted time for ferry and fuel up	Realized survey time (~180 km/hr)	Realized time for ferry and fuel up*
Calendar	1654	15	12	19.9	8.7
Chinchaga RRA	1159	10.5	12	20.8	7.1
Parker	254	2.3	2	4	1

* Not included are the 1.6 hour flights repositioning the aircraft between Watson Lake and Fort Nelson or a training flight.

Survey Results

Wolf survey results are shown in Table 2, Table 3, and Figure 2. We counted the most wolves in the Chinchaga RRA survey area, and this area was calculated to have the highest density of wolves: 13.3 - 15.6 wolves / 1000 km^2. By comparison, we calculated a density of 6.4 – 7.0 wolves / 1000 km^2 in Calendar.

Four recent wolf kill sites were observed, all with wolves observed nearby. Two moose kills were found in the western part of the Calendar study area, both completely consumed. A pack was observed with two moose kills in southwestern part of the Chinchaga RRA. Judging by the size of each kill (one completely consumed, one partially), the observers thought that the two killed moose were both adult, rather than a cow/calf combination. No evidence of old kills was observed in any survey area.

During the surveys 77, 15 and 41 moose were observed incidentally in Calendar, Parker and Chinchaga RRA respectively, and 37, 9 and 3 caribou were observed incidentally in Calendar, Parker and Chinchaga RRA respectively (Figure 3, Table 2). Flight lines of the survey are shown in Appendix 1.

Table 2. Results from three wolf surveys at three survey areas conducted from 28 January through 15 February, 2015.

Survey area	No. of wolf packs	No. of wolves	No. of caribou observed	No. of moose observed
Calendar	5	32 to 35	37	77
Parker	1	6	9	15
Chinchaga RRA	8	52 to 61	3	41

Table 3. Notes regarding each of the wolf pack observations.

Survey area	Pack	Minimum count	Upper estimate	Notes
Calendar	1	6	8	Estimated from tracks. One animal spotted at a later date during capture.
	2	6	6	Estimated from tracks. Lots of tracking along, but no animals observed.
	3	8	8	Tracked over good distance. Gained upper estimate of 8 from tracks. Observed pack of 8 in open area.
	4	5	NA	Spotted 3 running into timber, but counted minimum five from tracks on Petitot ice – a pack that may commonly hunt from the Petitot ice way during winter?
	5	7	8	Tracked over good distance from recent kill. Definitely observed 7 (photographed); possibly 8. Not more than 8.
Parker	1	6	6	4 seen on ice, but good track evidence of 6 animals. Seen later in forest, and two people thought they saw 5 or 6 at that time.
Chinchaga RRA	1	10	17	Linked two separately detected track sets, both followed over a long distance. Clearly counted 10 at one location. Tracking was confusing because movement directions merged together, allowing possibility that two groups came together (10 + 7 more); otherwise there was likely some confusion caused by wolves backtracking themselves.
	2	4	4	Had several indications of 4 animals during long tracking. Observed two wolves (one huge) on ice; we were both certain that 2 must have been lagging behind.
	3	1	NA	Could not get an estimate on how many animals made this track - short track segment. Edge case. Could not figure it out.
	4	9	9	9 animals seen on the Sikanni ice. Two were curled up in the same bed. Tracked up and down the Sikanni – a pack that patrols this river ice during winter?

Survey area	Pack	Minimum count	Upper estimate	Notes
	5	8	8	Estimated from tracking. We assumed it was the same group that came/went off the rails (obliterated tracking on rail bed) which was observed at two locations along the rail bed.
	6	8	NA	Tracks throughout a vast area, with several vintages. Observed one animal enter thick forest nears some big den-like holes in the snow near a small creek. Tracks suggested 8 minimum.
	7	7	NA	Minimum 7 counted from tracks.
	8	5	7	Observed 5 animals. Gained a convincing track count of 7 at one location. Were observed at a partially consumed moose kill. Another recent moose kill nearby.

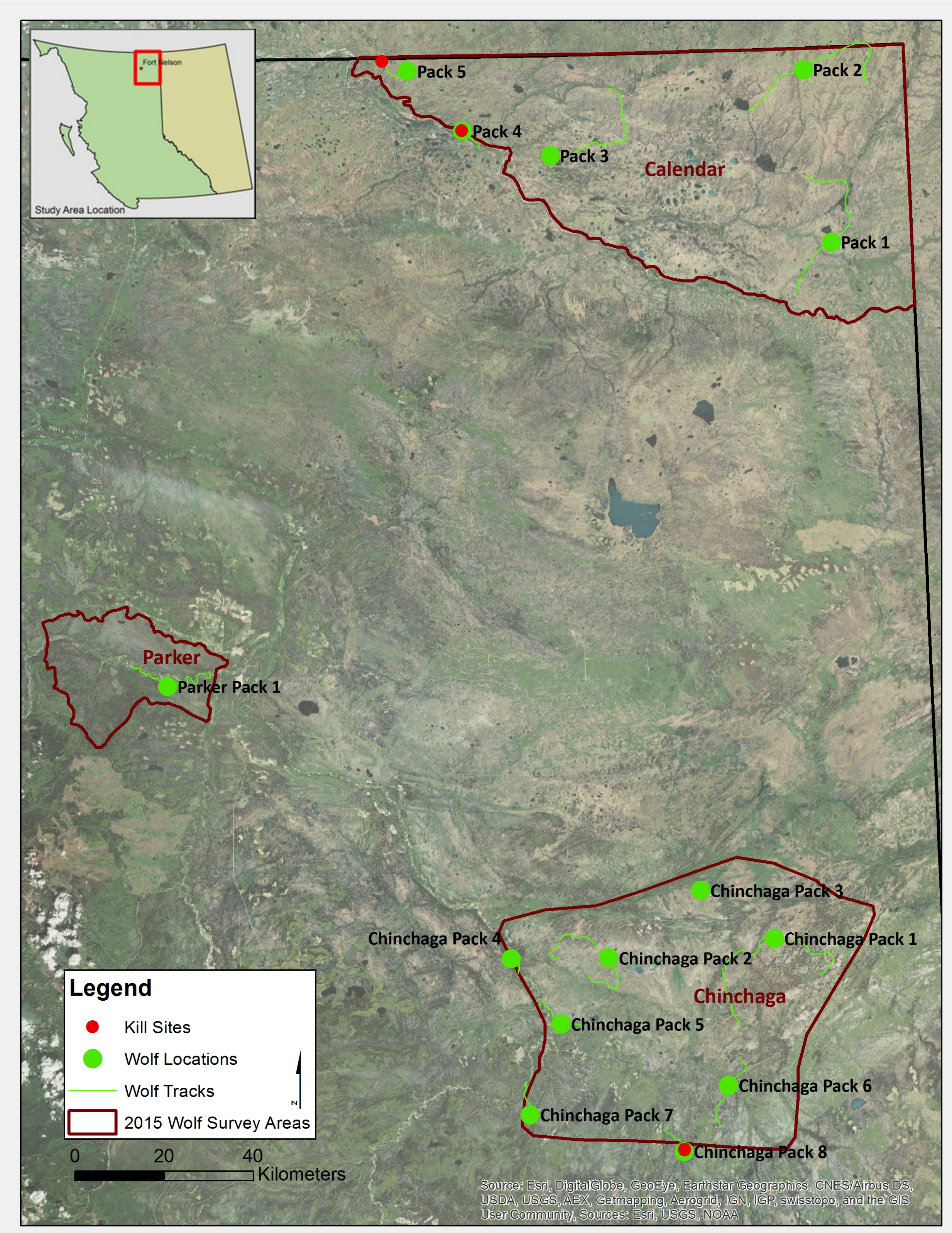

Figure 2. Map showing the track locations from wolf packs in the Calendar, Parker, and Chinchaga RRA survey areas.

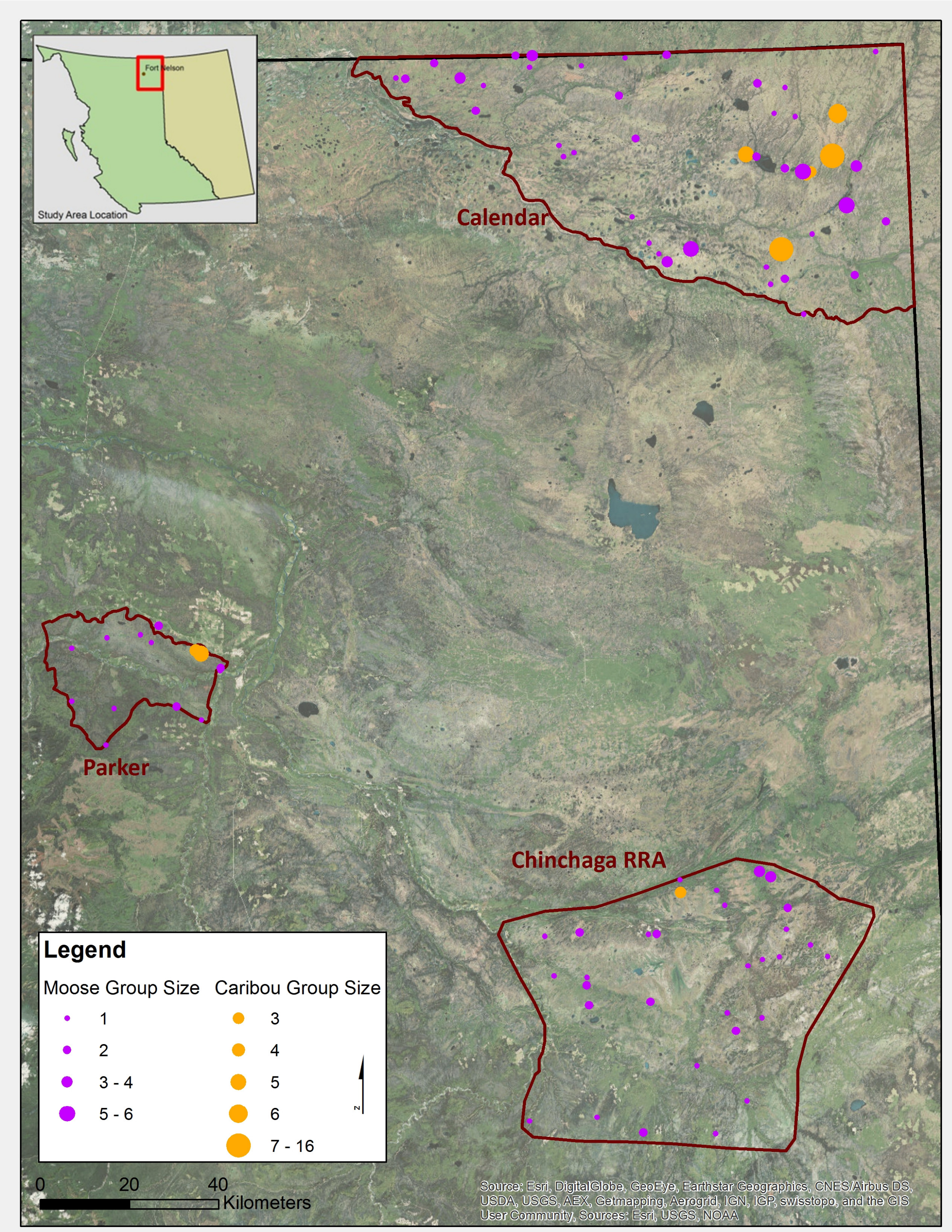

Figure 3. Map showing the locations of ungulate observations in the Calendar, Parker, and Chinchaga RRA survey areas.

DISCUSSION

The proximate objective of this study was to develop a method to count wolves in the boreal forest of western Canada, and this objective consisted of 3 components: (1) the power analysis to determine sampling intensity, followed by (2) the implementation of the surveys, and (3) an evaluation of accuracy based on radio-marked wolves.

Based on the power analysis, we recommended that transect spacing should be no greater than 3 km apart, and to wait two or three days after a large snowfall event before initiating the survey. The 3-km spacing resulted in an estimated 17 hours of transect flying for the L-19 aircraft surveying at 180 km/h, not including time to check tracks and locate wolves once their tracks were encountered. Overall we used 66.5 hours of flying; 44.7 hours were flown within the survey areas, and the remaining time was used for aircraft transfer, ferrying to the study area, and for training purposes. Roughly 60% of the flying time within the survey areas was spent off transect, primarily following wolf tracks. One weakness of the power analysis was that it utilized wolf data with relatively low fix rates (e.g., daily fix data). Utilizing more precise fix rate data (e.g., hourly) would capture a great deal more wolf movement, and potentially increase the simulated encounter rates, depending upon how tortuous the wolf paths are. At the time of our study, more precise wolf location data were not available.

The field component of this study revealed three important findings. First, the survey was logistically feasible using a fixed wing aircraft in very remote geography, and tracks were readily seen despite the forested conditions. Soft, fresh snow is a primary requirement for this method to be successful because tracks are much more difficult to locate on a crusted snowpack. In some climates, the requirement for adequate tracking conditions is rarely achieved. We found excellent tracking conditions on a complete snowpack throughout this study. The major limitation was lighting conditions during our survey. The remote nature of the survey areas was potentially a problem, but we solved this by using the L-19 Bird Dog. This was the first time for both the pilot and the observers using the L-19. In general, we found the L-19 to be an excellent choice for surveying these remote areas. The machine had a visibility profile for observers that was similar to a Piper Super Cub, but it was capable of flying at much greater speeds allowing us to minimize the ferry times at these remote survey areas. Fast travel was especially important during winter when good lighting was restricted to the middle half of the already short daylight period. A drawback to the L-19 was that it could not fly as slowly as the Super Cub while surveying. Spotting tracks or tracking wolves did not seem to be challenged by the high survey ground speed; rather, the time available for observing tracks was diminished, which meant that it was necessary to double back and check tracks more often. Utilizing the CNRL Helmut airstrip also provided a major advantage in allowing us to minimize ferry times. In future Calendar surveys, accommodation for the crew at the Helmut camp would be highly beneficial if possible.

The second major finding was that wolf densities were about 6 to 7 times higher than expected in the Calendar and Chinchaga RRA survey areas. In the Calendar Range the 2010 density estimate for moose was 0.018 /km^2, equating to approximately 85 moose in that area (Thiessen 2010). Based on this moose estimate, and using equations that convert moose biomass to wolf abundance (Messier 1994; Fuller et al. 2003; Cariappa et al. 2011), we expected fewer than 5 wolves in the Calendar Range, but found 32 as a minimum estimate. Similarly in the Chinchaga area we expected fewer than 7 wolves, but found at least 52.

Why were the wolf estimates so high in our study areas? It could be that moose numbers were underestimated during the 2010 survey, at least in the Calendar Range. This survey had high uncertainty (CV = 42%), with the upper estimate (95 % CI) at 0.04 /km^2 (195 moose) (Thiessen 2010), but even at this higher density, we would expect only 6 wolves. Assuming the moose population increased at 10%/yr, a starting population of 195 in 2010 would grow to 314 in 2015, yet predicted wolf numbers would still be fewer than 7. Another indication that moose numbers may be higher than the 2010 estimate is that we incidentally saw 77 different moose from the fixed-wing aircraft during the wolf census. This number (77) is almost as high as the actual moose estimate from Calendar (85), which was based on a survey specifically designed to count moose.

It is also possible that wolves are being sustained by another food source that we have not accounted for. Given the very low density of caribou in these ranges, it is not possible that caribou abundance can explain the discrepancy outlined above. Wolf diet analyses could reveal if other prey should be included the biomass conversion equations we are using (e.g., Fuller et al. 2003). It is also plausible that double counting of wolves occurred, but we took steps to minimize this risk. These included surveying a steady progression of the study area and completing the survey in a short time frame. As well, the most certain approach to avoid double counting is to backtrack each new set of tracks to ensure that they are not connected to other sets of tracks previously documented. This was a key component that we focused on, and placed much survey effort at bounding each set of tracks. Several of these issues could be resolved by surveying in areas where a sample of GPS-collared wolves are located. This way pack movements, and missed individuals, could be used to calibrate our estimates.

A final consideration of the high wolf density was the inclusion of all edge packs in our final estimate (i.e., the inclusion of all packs whose tracks straddled the survey area border), though edge effects will decrease with larger survey areas. The Calendar and Chinchaga RRA survey areas were very large, but still contained only 5 to 8 packs, so the edge effects may have been considerable. Nonetheless, it is important to note that including edge packs, which straddle the survey area boundary, is presumably offset by not counting a proportionately equal number of packs that straddle the boundary, but that were not detected because they were just outside the survey boundary during the census. We surmise that there may be at least one reason why this logic might be flawed. If some wolf packs (e.g., pack 4 in Calendar and packs 4 and 5 in Chinchaga) make a living foraging near the banks of major rivers that define the boundary of a survey area, they might be more likely to be detected on the river ice, than other packs, which straddle a boundary in upland habitats, because of their frequent use of the river ice, and the ease in which these tracks are detected. This would mean that certain boundary packs would have a high probability of being detected in the study area, therefore inflating density estimates. One option to correct this problem would be to add some buffer habitat around river boundaries (e.g., west of the Sikanni River); alternatively, it may be wise to not use major river systems as survey area boundaries. In general, the survey conditions were less ideal during the Chinchaga survey, and we were more suspicious that tracks were missed due to poor lighting, or, later on, due to an inability to separate tracks made by more than one pack. As such, it was our opinion that the survey results were conservative with respect to the counting process. Furthermore, even by excluding all edge packs, wolf numbers were still at least 5 times higher than expected in both ranges.

The third major finding from the field surveys was that *relative* trends between moose and wolf abundance among ranges matched expectations. In the Chinchaga RRA, where the estimated moose density was highest (0.15/km^2), the wolf density was also highest (wolves at 13.3 – 15.6/km^2), whereas wolf densities were about half as high in Calendar where there were fewer moose. We did not include the Parker range in this comparison because it was small and would be highly influenced by edge effects.

Survey Accuracy: simulation vs reality

Three assumptions made by the simulation made its results conservative: (1) the assumption that linear flight lines were followed; (2) that wolf tracks had to be intersected by flight lines in order to be successfully detected; and (3), that wolves move in linear paths between the GPS locations. In practice, we expect that detection rates would be higher because wolves often make considerable non-linear movements within a day, and their tracks are often detected to the side of the aircraft. More importantly, we treated the 3-km spaced transect lines not as a fight paths, but rather, as the dividing lines between parallel 3-km wide corridors, which we surveyed via meandering flight lines. The meandering nature of the flight lines would have increased detections simply by increasing the area surveyed.

Conversely, the simulation assumed 100% detections of intersected tracks, which is unrealistic. Tracks are undoubtedly missed at times due to dense timber/cover, poor lighting conditions, tracking conditions (e.g., wind, other tracks), or due to observer error (mis-identification, fatigue, distraction etc.). This factor is unavoidable, but is remedied to a high degree by the sheer number of tracks that can be laid down by wolves. As the simulation demonstrated, missing tracks is a much larger issue shortly after a large snowfall event when there are few tracks, which could be missed by the survey crew because they were not intersected, or also, because they happen to be in dense timber. There were multiple vintages of tracks during our surveys, allowing some idea of how often fresh tracks might have been missed. Old tracks were found to be clustered, and always associated with fresh tracks in our surveys.

In general, we found the conditions and survey design to be appropriate for gaining a good census count for all three surveys. We have suggested that there were more challenging track/pack detection issues during the Chinchaga RRA survey, due to poor lighting conditions, and later, as a result of possible confusion as to how many packs were involved in making a large cluster of tracks. Detection rates in wolf surveys are poorly understood, largely because surveys of areas with collared wolves have typically utilized the collars to help locate the packs. We had planned to use collars as a validation tool, without using the radio signals to help locate and detect animals. Unfortunately, the validation component of our study was not realized because there were insufficient radio collars (n = 1) in the survey area. Of significance, Brad Culling used our survey results to help capture and collar wolves from our pack 6, near July Lake in the Calendar survey area on February 9, shortly after we had surveyed the area. We were certain that there were at least 6 animals in this group, and we gave an upper estimate of 8.

Observations of the collared pack later confirmed that there were 7 animals (Brad Culling *personal communication July 14, 2015*).

Recommendations for future work

The large discrepancy between expected and observed wolf abundance warrants further investigation. At a minimum, the moose survey results should be updated, and perhaps other ecological investigations including diet content of wolves to determine if there is a prey source that is not being accounted for.

Although we made linkages between moose and wolf abundance in this report, we did not extend these linkages to the ultimate objective of this research: examining the relative effect of human footprint vs. natural habitat attributes on the abundance of moose and wolves. However, it is clear that there are major differences in the underlying habitat in the Chinchaga RRA compared to the Calendar range (Appendix 2; fens and bogs account for 69% of the habitat in Calendar compared to 43% in Chinchaga RRA), and this effect on moose abundance should be contrasted against the effect of human footprint. Our next scope of work will be to address these comparisons, but doing so will require extending the range of wolf sampling into areas that have little human footprint, and areas that have increased variation in habitat. Ideally these 2 factors will be spatially decoupled to avoid confounding effects.

Wolves commonly make many non-linear movements, and we suspect that the simulation underestimates true encounter rates when fine scale movements cannot be captured. We recommend that the simulation is repeated with wolf data that has more frequent locations (e.g., hourly) in order to better account for the nature of wolf movements to improve the predictability of the results.

We also see potential for using data of observed moose and caribou collected during wolf census surveys to estimate the relative abundance of these ungulates. We recommend that this potential is considered prior to future surveys; it may be possible to use a distance sampling protocol to enhance these data.

Finally, we recommend that surveys should specifically take place in areas where there is sufficient number of radio-collared wolves to validate the encounter success and total estimate of the census method being used.

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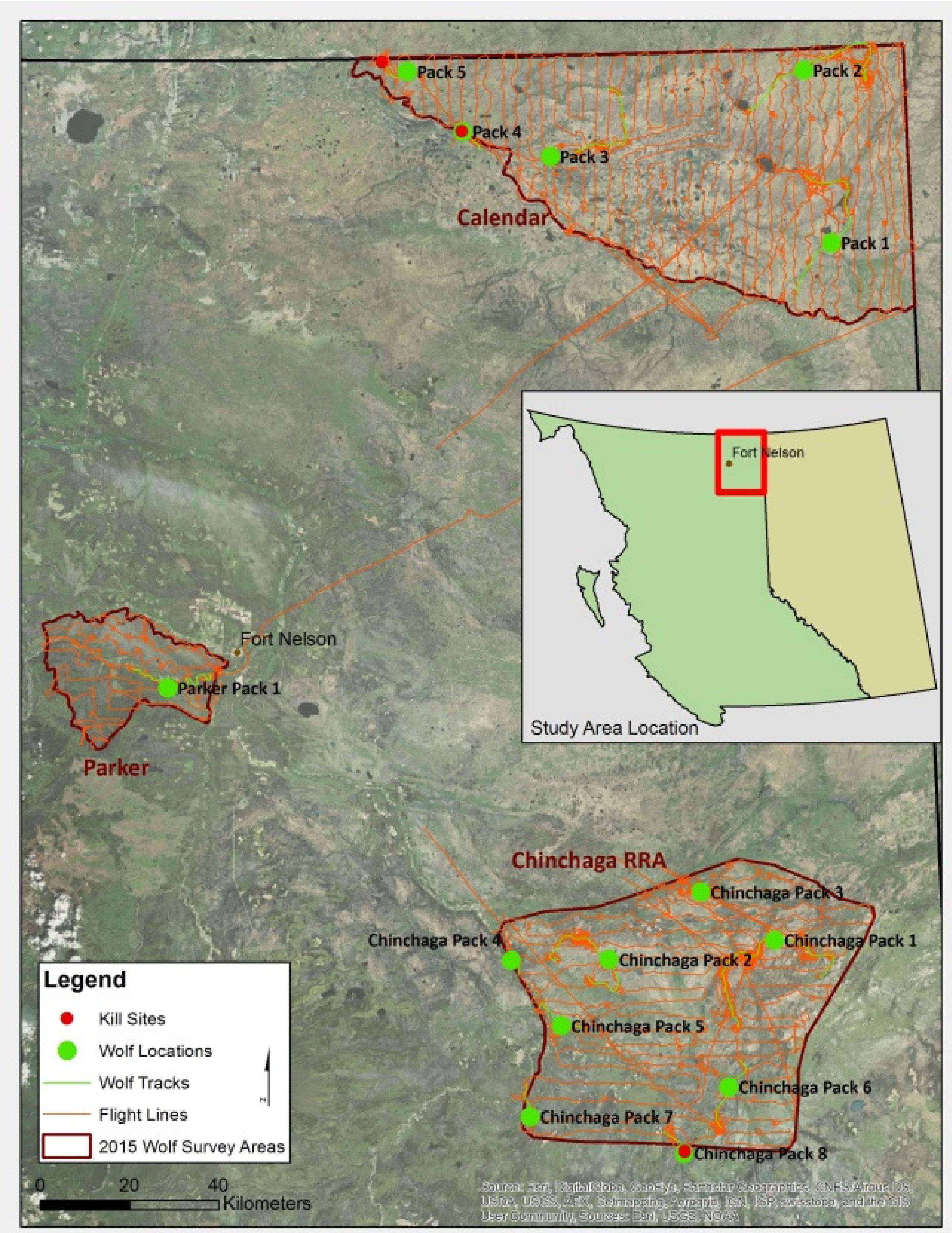
Appendix 1. Flight lines used during the wolf census. Areas with high concentrations of lines correspond to where wolves were being tracked, whereas the parallel lines represent the 3-km transect spacing.



Appendix 2. Map of broad habitats in the 3 survey areas.