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Nicholas J. Armstrong

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ABSTRACT

Armstrong, Nicholas. 2020. Methods for finding wolf (*Canis lupus*) kill sites using location clusters: A study in Grand Portage Indian Reservation, Minnesota.

Wolves have profound effects on the ecosystems around them. As large carnivores, they can significantly manipulate ecosystems by controlling potentially overabundant ungulate populations. This study attempts to find predation sites to help understand wolf prey selection, seasonal preference, and frequency of kill within the Grand Portage Reservation. We developed and tested three methods to identify wolf kill sites using GPS location clusters from collared wolves in Grand Portage Indian Reservation. During October 2019 to January 2020, we identified location clusters using the program R to analyze GPS locations gathered from Vectronic Vertex Plus Iridium collars attached to seven local wolves. Search teams then visited the location clusters to determine why the cluster occurred and if there was a predation event. We tested three methods, including Method One: Stratified Random Sampling, in which a subsets of location clusters were chosen randomly in a stratified approach; Method Two: Census of Clusters Produced by One Wolf or Pack, in which clusters were chosen from a singular wolf pack and all sites from that pack were visited when possible; and Method Three: Hand Picking Clusters, in which clusters were handpicked by search teams based on criteria and trends from past experience. After visiting 30 sites from 240 (11 %) clusters produced by the algorithm, the search team concluded that each of the three methods had pros and cons. Method Three was the most effective method tested, as it produced the highest likelihood of finding a predation event, given the resources allocated to the study.

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INTRODUCTION

Gray wolves have profound effects on the ecosystems around them. As large carnivores, they can significantly manipulate ecosystems through controlling potentially overabundant ungulate populations (Smith et al., 2003). However, there is still debate over whether wolves are limiting populations or acting as natural regulators (Webb et al., 2008). The grey wolf has historically been found throughout the northern hemisphere, excluding deserts and mountain tops (Mech, 1974). However, in the past 100 years, the geographic range of the grey wolf has been dramatically reduced (Larivière et al., 1999). The grey wolf has faced persecution by humans in most of its range because of wild food competition and predation on livestock (Mech et al., 2019).

To understand how wolves influence and control their ecosystems, knowledge of both diet and foraging ecology is necessary (Stahler et al., 2006). The method most often used in foraging ecology is scat analysis. There are limitations to this method, however, primarily in the limited detection of prey size and age, and of frequency of kills (Kermish-Wells et al., 2017). An alternative of using GPS collar data points to find and visit potential kill sites can fill in this additional information.

The main prey species for wolves varies throughout North America. For example, in Banff National Park, wolves prey primarily on elk (*Cervus canadensis*), with limited numbers of other ungulate species (Huggard, 1992). In Quebec, diet is mainly composed of white-tailed deer (*Odocoileus virginianus*) in the winter months, shifting to moose (*Alces alces*) and beaver (*Castor canadensis*), which can comprise 75% of their total diet, in the summer months (Potvin et al., 1988). Based on a scat study done in Grand Portage Indian Reservation, the main prey species included white-tailed deer, moose, and beaver (Chenaux-Ibrahim, 2015). Prey populations change in their relationships with predators based on local food habits and availability as in Algonquin Park, Ontario, where a large percentage of wolves' diet is moose, white-tailed deer and beaver, but moose carcasses were primarily scavenged during winter months (Forbes & Theberge, 1996).

Grand Portage Indian Reservation is part of the 1854 Authority Treaty Area in northeastern Minnesota (Grand Portage Band of Lake Superior Chippewa n.d.). The size of the reservation is approximately 192 km^2, consisting of shoreline along Lake Superior, urban areas, and forests. Activities that take place on the reservation include logging, hunting, trapping, fishing, hiking, and snowmobiling (Tiller, 1996). The interior of the reservation has little to no human structures, but has ample amounts of secondary road and snowmobile trails (Jones, 2000). The wolves in the study area comprise three packs. The wolves that are currently collared have no known pack association.

The purpose of this study is to explore methods for the selection of potential kill sites from GPS location clusters from seven GPS-collared wolves on the Grand Portage Indian Reservation, identified using an algorithm written in the program R. The goal is to determine the best way to find kill sites using these clusters along with considerations of available resources on the reservation and effectiveness of the algorithm.

LITERATURE REVIEW

PREY SELECTION

To explore prey selection and kill frequency of grey wolves throughout North America, a table was constructed for a better visual representation of data over varying studies (Table 1). Close attention was paid to primary and secondary prey species, the season in which the study was completed, the kill frequency, and the age and sex of the primary prey species. From this summary, some of the main species selected by grey wolves were white-tailed deer and mule deer (*Odocoileus hemionus*), which together consisted of about 35% of the diet, where elk consisted of 29% of the wolf diets , with moose at 29%, caribou (*Rangifer tarandus*) at 11%, and beaver at 5% of there diet, while the remainder of their diet consisted of muskrat (*Ondatra zibethicus*) and other small mammals and birds. Most studies were from the western areas of North America. In studies relevant to Minnesota (11 and 17), the main prey species was white-tailed deer. Prey selectivity is determined by season. The Minnesota studies were both done in the summer months, and prey selection might change in the winter. In the summer months, wolves in the Quebec study (3) preyed on moose, while in the winter they preyed on deer as the main staple. Of the studies which included the age or condition of the prey, 80% stated that the prey targeted first were the young, sick, or old. In the spring, according to study 16, wolves particularly target the young, sick, or old.

Table 1. Studies on wolf diet and frequency in North America

Reference	Study area	Method	Primary prey species	Secondary prey species	Season	Kill frequency	Primary sex/age class
Smith et al., 2000, 2003, 2004 (1)	Yellowstone National Park	Radio Collars and Airplanes	Elk	Moose and Bison	Year-round	1.9 kills per wolf per month	Mostly calves & females (79%)
Huggard, 1992 (2)	Banff National Park	Scat and winter track survey	Elk and deer	Moose	Year-round	N/A	N/A
Potvin et al., 1988 (3)	Outaouais - Laurentides region in Quebec	Scat survey	Summer-moose; winter-deer	Summer-beaver winter - moose	Year-round	N/A	N/A
Ballard, et al., 1987 (4)	South-central Alaska	Scat, aerial observations	Moose	Caribou	Year-round	1 kill every 8.3 days	Calves
Carbyn, 1983 (5)	Riding Mountain National Park	Aerial observations with ground checks	Elk	Deer, moose	Year-round	1 elk every 15 days	N/A
Hayes et al., 1999 (6)	Yukon	Radio collars and aerial observation	Moose	Caribou	Year-round	0.045 moose per day per wolf	Calves

Table 1, continued

Reference	Study area	Method	Primary prey species	Secondary prey species	Season	Kill frequency	Primary sex/age class
Kolenosky, 1972 (7)	East Central Ontario	Aerial and ground observations	White-tailed deer	N/A	Winter	3.2 deer per week	Fawns
Voigt et al., 1976 (8)	Central Ontario	Scat survey	Beaver	White-tailed deer	Summer	N/A	N/A
Thompson, 1952 (9)	Wisconsin	Scat survey	White-tailed deer	Small mammals	Year-round	N/A	Fawns
Dale et al., 1995 (10)	Gates of the Arctic National Park	Radio collar and aerial survey	Caribou	Moose	Spring	0-8 days per kill	N/A
Chavez & Gese, 2005 (11)	North-western Minnesota	Scat survey	Deer species	Muskrat	Summer	N/A	Adults
Milakovic & Parker, 2011 (12)	Northern British Columbia	Scat survey	Moose	N/A	Summer-fall	N/A	N/A

Table. 1, continued

Reference	Study area	Method	Primary prey species	Secondary prey species	Season	Kill frequency	Primary sex/age class
Milakovic & Parker, 2011 (13)	Northern British Columbia	Scat survey	Elk	N/A	Year-round	N/A	N/A
Milakovic & Parker, 2011 (13)	Northern British Columbia (Western pack)	Scat survey	Caribou	Stone’s sheep	Winter-spring	N/A	N/A
Arjo et al., 2002 (14)	Northwestern Montana	Scat survey	Deer species	Elk	Year-round	N/A	Adults
Popp et al., 2018 (15)	South of Sudbury, Ontario	Scat survey	Elk	Moose, white-tailed deer	Spring-summer	N/A	Young
Fuller & Keith, 1980 (16)	Fort McKay	Aerial survey and scat survey	Moose	Beaver	Year-round	1 moose every 4.7 days	Young, old or sick
Gable et al., 2018 (17)	North-central Kabetogama State Forest, Minnesota	Scat survey	Deer (Fawn)	Berries	Summer	N/A	Fawns

KILL RATE

The kill rate is how often wolves make a kill. Based on the reviewed studies, I found a variety of ways it was expressed. The most common method was the number of days between kills, but it was also expressed as number of kills per month, number of kills per month per wolf, and the number of kills per day per wolf. To make a comparison easier, 3.2 deer per week is approximately 1 kill every 2 days. Throughout North America, wolves have a kill frequency ranging from as low as one every 15 days in Riding Mountain National Park (study 5) to one every other day in Gates of the Artic National Park (study 10).

Factors affecting hunting success and kill rates

There are many factors that can affect wolf kill rates, including prey density, wolf density, prey survival tactics, type and quality of alternate food sources, and the effectiveness and type of predator (i.e., is the hunt in a pack, solitary, by ambush or chase; Pimlott, 1967). According to Hebblewhite and Pletscher (2002), prey that can be found easier tend to have higher predation rates. As herd size increases, the chance of a wolf encounter and subsequent death are higher. Another factor that can affect kill rate is snow depth Hunting success of wolves on Isle Royale, Michigan (Peterson, 1977). increased when snow depths were over 75 cm. Prey species such as moose have higher foot loads and this causes them to sink into the snow, but wolves have a lower foot load and can be supported by snow crust. Sand et al. (2005) found that age of breeding males in a pack can affect how successful a hunt is; breeding males five and a half years and up had the best success hunting moose.

CHARACTERISTICS OF WOLF KILL SITES

Wolf kill sites are the areas where wolves make a kill. In Wyoming, wolves were shown to use open terrain and riparian terrain most often as kill sites (Woodruff et al., 2018). On Isle Royale wolves killed moose within their prime more often near shorelines, under higher canopy cover, and in lower conifer levels, while they killed moose past their prime more often in higher elevations, under less canopy cover, and in areas with a higher amount of conifer trees present (Montgomery et al., 2014). Wolves near Glacier National Park in Montana killed in the winter in areas of high stalking cover and lower slope, close to water, while travel to kill sites occurred more in valley bottoms and ravines; white-tailed deer were especially killed on flat terrain (Kunkel & Pletscher, 2001).

MATERIALS AND METHODS

GENERAL APPROACH

I used GPS wolf collar data currently being collected by Grand Portage Indian Reservation and ran the location data thought an algorithm in the R program that generated “location clusters,”. Search teams then visited the center of the cluster locations to determine whether it was a kill site. The Vectrontic Vertex Plus Iridium collars were set to send a signal every 4.5 hours, which included a time stamp, the location of the wolf, and whether the collar is in mortality mode. The algorithm to generate clusters was adapted to be used on Isle Royale National Park by graduate student Nicholas Fowler, from an algorithm used to detect possible kill sites of bobcats (*Lynx rufus*) in the upper peninsula of Michigan (Svoboda et al., 2012). It used the following “rule” to generate clusters: a minimum of two points within 50 m in a continuous 24-hour period.

CLUSTER SELECTION METHODS

I used three different methods to select subsets of location clusters for search teams to visit and investigate. In all cases, the clusters were displayed on ArcMap and Google Earth. When visiting a cluster, search teams used a Garmin handheld GPS unit (Garmin® GPSMAP® 78S) to locate the centre of the cluster as the start point. In Methods One and Two, search teams walked around the cluster centre point in circles at intervals of 5 to 10 m depending on visibility, following Webb et al. (2008), out to 50 m, following Svoboda et al. (2012). When completing these circles, any signs of a kill, such as blood, fur, guts, bones, and carcass, were recorded. In the cases of only small signs or blood being spotted, such areas were tracked if possible, and if nothing more was found, the circles around the centre point continued. Any evidence of a kill found in a 50-m radius around the cluster center was recorded and input into a shared Excel spreadsheet for record-keeping. Records included prey species, age if possible (based on tooth wear), age of kill site (old, fresh), site description and location type as described in Table 2.

Table 2. Descriptions of wolf location types classified in this study.

Location type	Description of site
Kill site	A site with evidence such as blood, hair, and body parts at the location; "fresh" if still fresh, with blood on the snow or ground.
Scavenged carcass	A site with evidence of wolves feeding on a carcass that they did not kill; such evidence included presence of maggots (DeVault et al., 2003) and lack of sign of any struggle, such as broken branches and other disturbance.
Bed/rest site	A site with an obvious "bed" or indent in the snow where a wolf has been laying; hair or tracks may occur in the "bed"
Old kill/scavenge site	A site where bones were found that did not appear "fresh," e.g., green in colour; a site where it is not possible to determine if it is a kill or scavenge.
Rendezvous site	A site with evidence of wolves spending a lot of time with scat and tracks very present (Ausband et al., 2010); other signs included evidence of frequent visits and broken paths.
Human influence site	A site with evidence of attractants, such as bear bait, hunter or roadkill carcasses (broken bones or saw marks in bones).
Unknown	Sites where the search team was unable to determine location type due to lack of scat, beds, kills, etc.

METHOD ONE: STRATIFIED RANDOM SAMPLING

In Method 1, subsets of location clusters were chosen randomly in a stratified approach, such that they were in areas that were accessible to the search team, near roads or other access points. This method reflected the fact that many areas identified by location clusters were not reasonably accessible by foot or vehicle.

METHOD TWO: TRACKING CLUSTERS PRODUCED BY ONE WOLF PACK

In Method 2, clusters were chosen from a singular wolf or wolf pack. The algorithm was run once a week and all sites from that pack were visited in that same week when possible. When a kill site was found, the algorithm was switched to another singular wolf of a different wolf pack.

METHOD THREE: “HANDPICKING” CLUSTERS

In Method 3, the search team together viewed all location clusters on ArcMap and Google Earth to find trends and similarities from previous kill sites to “handpick” areas to visit. The criteria and trends considered included vicinity of location clusters to each other, number of location points within a cluster. The criteria and trends used were: two location clusters falling within 100 m of each other, one with four to six locations, the second with two to three locations. From previous experience, the cluster with fewer location points was usually the kill site.

RESULTS

METHOD ONE: STRATIFIED RANDOM SAMPLING

Method One was used from October 21 to November 31, 2019. During this period, a total of 143 clusters were produced using the location algorithm, while four additional sites were visited before the R script became available. The locations were from all seven collared wolves, and each wolf produced a varied number of clusters (Table 3). The search teams were able to visit and classify 16 sites using this method (Figure 1). Among the 16 sites visited there was only one kill site, this being an adult

Table 3. Clusters produced and visited based on each wolf collared (Method One) in the Grand Portage Indian Reservation.

Collar number	Clusters produced	Clusters visited
37744	26	4
37745	23	0
37747	26	4
37748	16	2
37749	14	0
37752	18	1
37753	24	5
Total	147	16

white-tailed deer. However, locating this site did not actually use the prescribed search methodology, as the bones were found outside the 50-m search radius. Another site contained a scavenged carcass of an American black bear (*Ursus americanus*). The scavenged site had signs of wolf activity, including scat and tracks around the area, but the site and the carcass had maggots, indicating the bear was likely wounded and scavenged by wolves. Two sites were believed to be from a past kill or

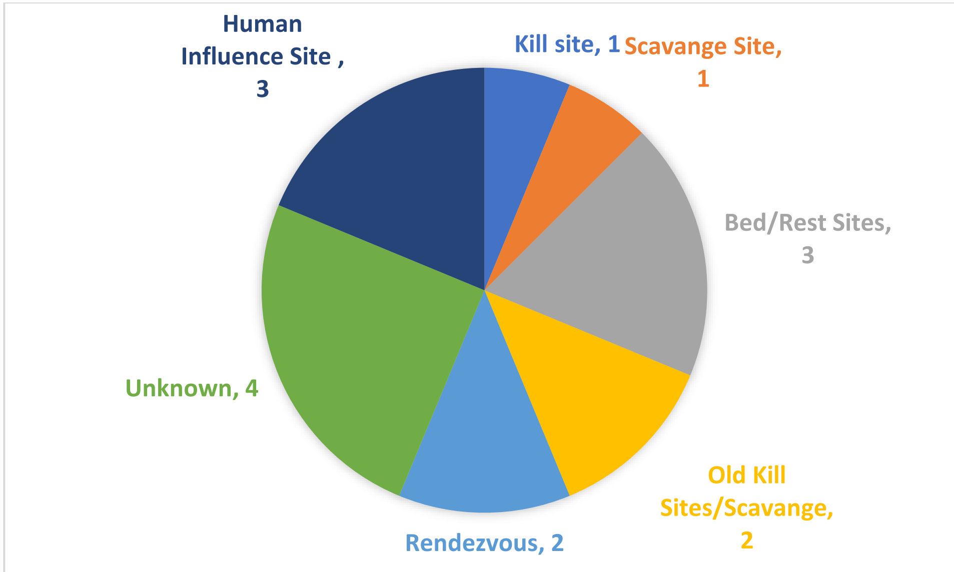

Figure 1. Site types found while investigating potential wolf predation sites using Method One in Grand Portage Reservation ($N = 16$).

scavenge. The bones found were from two different white-tailed deer (one at each site), which included shoulder blades, vertebrae, and lower mandibles. At the singularly identified rendezvous site, the search time found locations from two collared wolves that were believed to be part of the same pack (collar numbers 37744 and 37753), but the algorithm identified two different location clusters. At this site, there were significant signs of wolf activity, including scat, trails and tracks around the area.

There were three occurrences each of human influence and bed/rest sites (Figure 1). In the first case, the search team found sites where they believed human influence explained why the wolves visited the area: two sites contained black bear bait piles, where bear hunting had previously occurred during the spring, as well as bags and barrels, which were believed to once contain food; the third site was a place where hunter-killed carcasses had been dropped off, with signs that included bones from both white-tailed deer and moose, lacking antlers and showing signs of cutting and saw marks. In the other case, evidence to support the Bed/Rest Sites was increased activity in the area and 1-6 “beds” at the sites.

METHOD TWO: CLUSTERS PRODUCED BY ONE WOLF OR WOLF PACK

Method Two was implemented from December 3 to 11, 2019 and was planned to take place over two weeks to apply the search effort required to the location clusters produced by the first identified wolf pack, which included two collared wolves (37744 and 37753). Of a total of 22 clusters produced from these wolves’ locations between November 28 and December 1, 2019, the search team was able to visit only 10 sites, owing to the availability of the search team members and the weather during the search period (Table 4). Of these, only eight sites were searched from December 3 to 10, 2019, but when two were visited on December 11, one was a kill site and the method was thus discontinued. The kill site included legs, spine and head of a white-tailed deer, all with flesh still attached, and a pelt still at the site along with the deer’s stomach. The other location types classified were six bed/rest sites and three unknown site types (Figure 2). The cluster centre produced using Method Two was very accurate to the locations of blood, fur and limbs of the white-tailed deer carcass. Signs of the kill were seen at varying distances from the centre. These ranged from as close as 0 m away to the main signs, such as blood, and body parts all located between 0 and 20 m, to about 80 m away, where a small trail of blood was found. The beds at the bed/rest sites had one and seven beds present, excluding the third site that was located close to the kill site, where an accurate count of beds was unable to be completed because of the area having been packed down to a large degree from the activity of the wolf pack.

Table 4. Clusters produced and visited based on selected packs (Method Two) in the Grand Portage Indian Reservation.

Collar number	Sites produced	Sites visited
37744	11	5
37753	11	5
Total	22	10

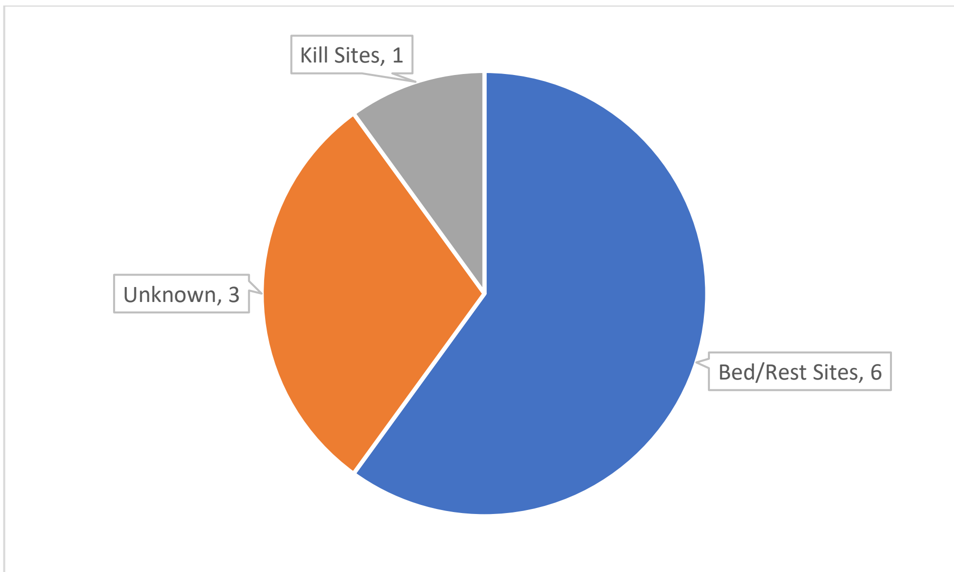

Figure 2. Site types found while investigating potential wolf predation sites using Method Two in Grand Portage Reservation ($N = 10$).

METHOD THREE: "HANDPICKING" CLUSTERS

The third method of cluster selection occurred from December 12 -17, 2019, and on January 24, 2020. During implementation of Method Three, the collars on wolves 37744 and 37747 stopped working, limiting the number of functioning collars from seven collars to six and then five. During the first period, there were 29 clusters produced by the algorithm, and three were visited by the search team (Table 5). On the final day, 20 clusters were produced and one site visited (Table 6). We attempted to visit one other site, but it was inaccessible.

Table 5. Clusters produced and visited during December 12 to 17, 2019, and January, 24, 2020 based on Method Three in the Grand Portage Indian Reservation.

Collar #	Clusters produced	Clusters Visited
37745	10	2
37747	8	0
37748	8	1
37749	10	0
37752	7	0
37753	6	1
Total	29	3

During the first period, the three sites that were visited included one kill site and two human influence sites (Figure 3). At the kill site, the search team found an adult female white-tailed deer carcass under some balsam fir trees. At the human influence sites, moose bones were found, but they contained saw marks. The distance to roads, piles of bones on the roadside, and the location of these sites inside the Fort William First Nation reserve led the search party to conclude human influence. The wolf in the area had apparently taken the bones and spread them around the forested areas near an old road near Canadian National Railway property. On January 24, 2020, the final site visited did not show any evidence of a wolf kill; thus, it was listed as an unknown site type, largely because the night before it had snowed about 10 cm, ultimately covering most tracks and any possible beds in the area.

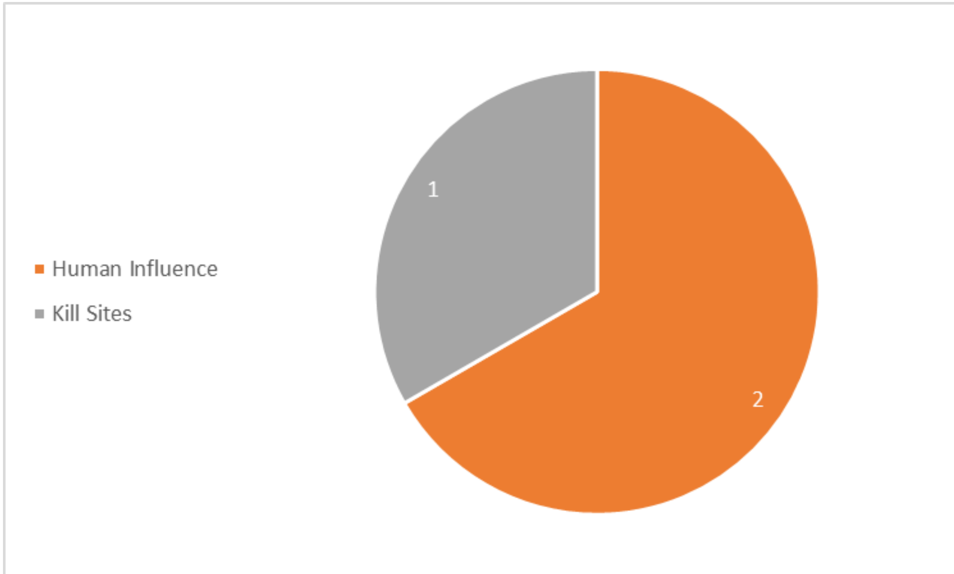

Figure 3. Site types found while investigating potential wolf predation sites using Method Three in Grand Portage Reservation from December 11 to 17, 2019 ($N = 3$).

OVERALL RESULTS

The number of sites that were produced by the location cluster algorithm over the entirety of this study was 240 from October 25, 2019 to January 21, 2020. Search teams visited 30 sites or 11% of all generated cluster locations (Figure 4). The 30 sites included three kill sites, one scavenged site, nine bed/rest sites, eight unknown sites, two old kill/scavenge sites, two rendezvous sites, and five human influence sites (Figure 5). The method that produced the highest results in terms of the percentage of potential sites that were classified as kill sites was Method Three, with 25% of the sites searched being kill sites. The second highest percentage of kill sites found over sites visited was Method Two.

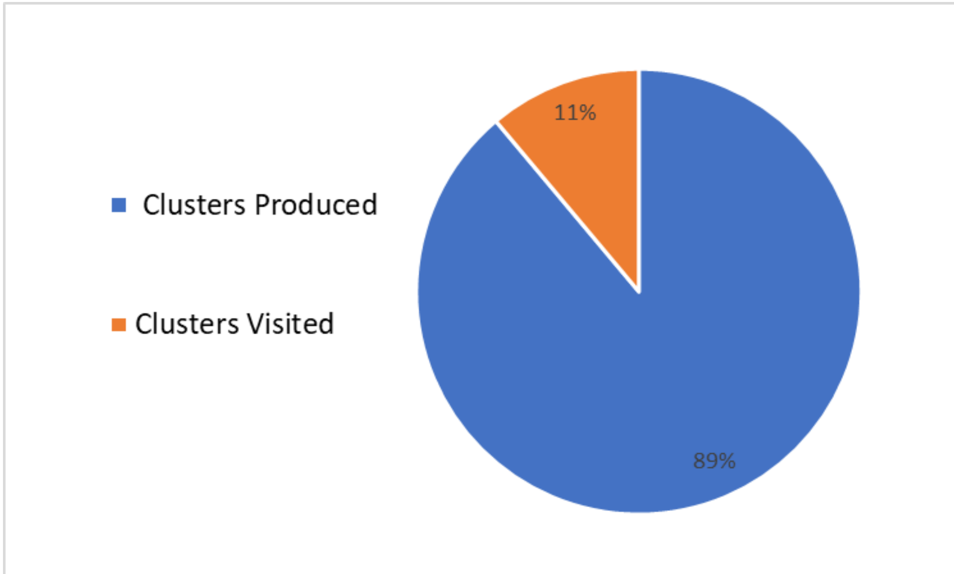

Figure 4. Percent of potential wolf-kill location clusters visited relative to the number of clusters produced by the algorithm.

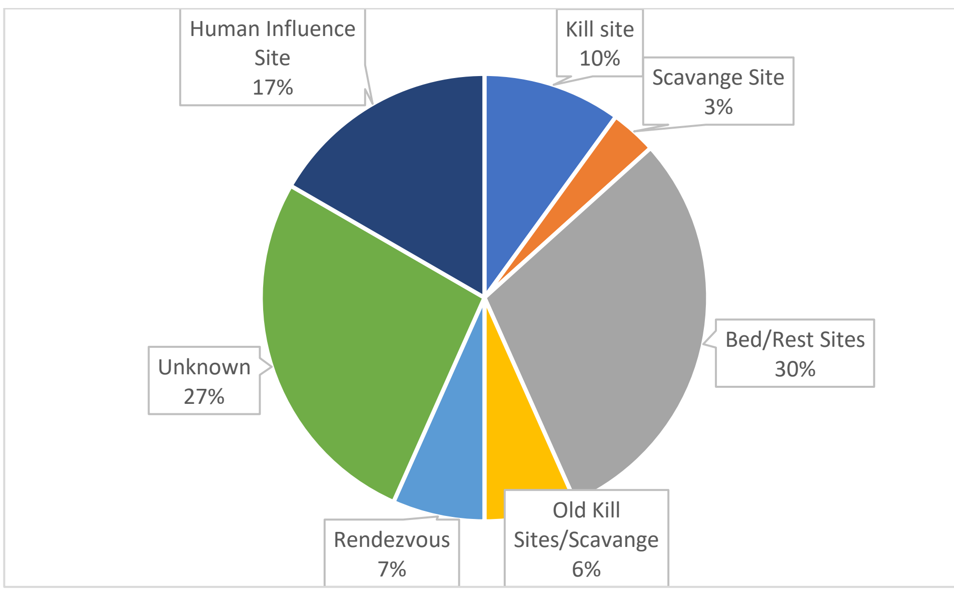

Figure 5. Location types classified during the study in Grand Portage Reservation over the study period.

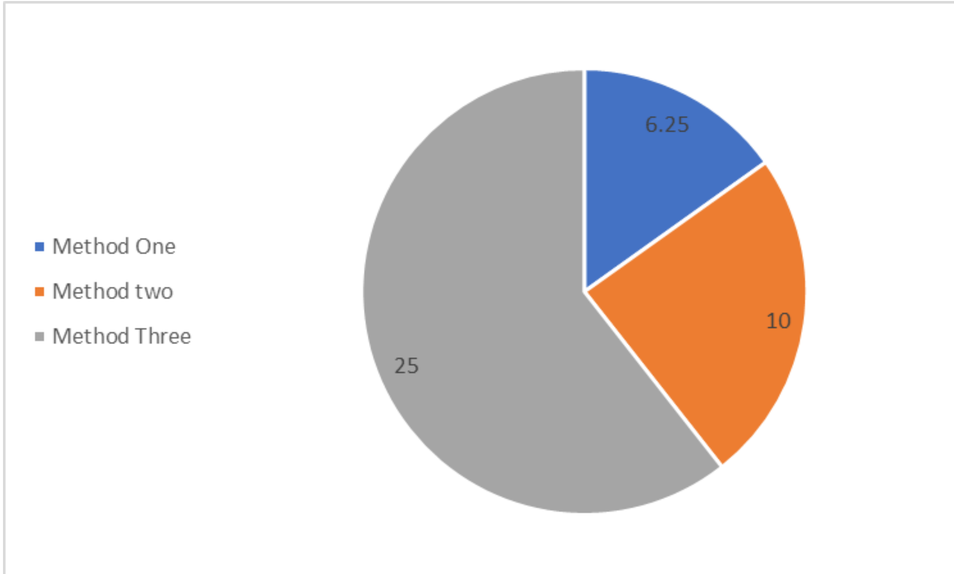

Figure 6. Percent of potential sites that were kill sites for each selection method.

For each of the three methods tested, there were both associated pros and cons (Table 7). With the first method, the search team noticed how time-consuming the selection process and the search were. There were also problems with the large number of clusters produced, even with the team randomly selecting the clusters among those stratified to have a reasonable accessibility, the likelihood of finding kill sites was low. Another issue was a strong bias toward selecting only accessible points. Employment of Method One did force a search with high coverage of the site when the area was searched. The major con associated Method Two was that there was little to no coverage of non-focal packs in the study area, so there was a high chance of missing kills from these other packs. Pros for this method included very good coverage of the focal pack and a high chance of finding a kill site for the pack. For the focal-pack method, Method Two, the number of location clusters produced was very manageable to visit. The major con with Method Three was also a chance to miss possible kill sites, but this time because of selection bias, depending on the skills of the search team.

Table 6. Comparison of pros and cons between methods explored during this study.

	Pros	Cons
Method One	High number of potential and realized kill sites	Time consuming searches Many location clusters produced and not visited Many false kill sites High bias
Method Two	Full coverage of potential sites attributed to a pack	Limited coverage of non-focal packs
	Higher chance to find kill sites	Time consuming searches
	Manageable number of location clusters produced	High chance to miss kill sites of non-focal packs
Method Three	Very manageable number of location clusters to visit	Chance to miss kill sites
	Highly selective of the best sites	Some sites extremely difficult to visit
	High chance to find kill sites	Potential for high bias
	Less time needed for search	Very dependant on selector skill set in creating search criteria

NON-METHOD RELATED COMPLICATIONS

During the study period, there were a variety of complications in finding location clusters and searching potential kill sites that were unrelated to the methods. They included errors in the R program, staffing problems, time limitations, and weather. The error in the R program was that, while two locations within 50 m in a continuous 24-hour period were defined as a cluster, the script was not set up to produce a shapefile from two points and did not leave a record on ArcMap or Google Earth. Staff time for this project was unfunded as it was considered experimental, leading to low availability of staff for it. Time was clearly required of staff to select the subset of clusters to visit, travel to and from the sites, with search time in some cases allowing only one or two site visits in a day. The biggest issue faced during this study was the weather, as snow made searching for kills or other wolf signs at a site difficult and sometimes unfeasible.

DISCUSSION

Examining wolf diets and kill frequency can lead researchers and scientists to better understand wolf ecology, as well as the concept of predator-prey relationships in general. Management strategies for predators like wolves and the prey that they feed on require information on diet and kill frequency (Hosseini-Zavarei et al., 2013). However, using GPS collars and location clusters to locate winter kills turned out to be very challenging in the Grand Portage Indian Reservation. Over time, search teams found solutions to improve efficiencies, and the methods allowed them to become more time effective, less resource-demanding, and increasingly likely to find a kill site.

A major change was the dropping of the strict site search methodology. The time it took to complete circles in dense brush and deep snow was unreasonable. In some search areas, there were obstacles such as fallen trees, ponds, swamps, and rocky outcrops, requiring searchers to go around them for safety reasons. The prescribed circular paths as a result ended up overlapping and requiring even more time to complete. Overall, the protocol for searches introduced a higher risk to staff and limited the number of sites that could be visited. A second change by the end of the study period was in simplifying the methods to select clusters to visit. With limited resources and staff time, it was ineffective to randomly select sites that ultimately would be unlikely to contain a kill. Focusing time on a single wolf or wolf pack (Method Two) was simpler. Gradually, effectiveness improved as it became clear that learning the trends in finding the previous kill sites allowed for selecting sites based on these learned criteria, and for Method Three to be born. This third method was not sufficiently tested to confirm its effectiveness, as most of the collared wolves had left the study area by January, crossing international borders or travelling south to areas of private land. However, it did appear to be a much better system, as it was more time effective. Remaining issues included problems in differentiating kill sites, sites with human influence, and scavenge sites. These three location types appeared the same on the cluster maps.

Bias

Throughout this study, a major concern was bias in the results we gathered. Even using Method One, we discovered the bias associated with locating clusters to be reasonably accessible by vehicle and thus near roads. Search teams believed that likely kill sites were missed that were further from the roads. Method Two was believed to be the least biased, because all the potential kill sites for a specified wolf or wolf pack were being searched, regardless of site accessibility. However, here bias was due to only one pack being searched, with the others neglected. Searching one wolf or wolf pack was the necessary compromise with limited resources. Method Three was the most biased, because all of the clusters selected were based on what was discovered from previous kill sites and relied on the experience and skills of those doing the selection. Given limited resources, this third method has promise in eliminating some bias because continued learning about new kill sites should adjust the selection criteria and produce more reliable selection in the future. The approach to subsampling wolf kills will never be completely unbiased, as the amount of time and resources needed to complete a census would not be expected.

Terrain

Terrain in the study area consisted of rocky hills and dense forest with lakes and swamps scattered throughout. Terrain was limiting to the number of clusters that could be visited, first because some of the potential kill sites were in very rough areas or far from roads, making the time required to search and get to all selected clusters limiting. The second reason terrain was limiting was safety. However, terrain is not a factor that can be controlled and must always be taken into consideration.

Wolf dispersal

Dispersal of young wolves is common; wolves usually disperse at about 11 to 12 months of ages, and adult dispersal is rarer (Gese & Mech, 1991). It usually occurs in the months of February to April and October to November. This dispersal timeline matched closely with the wolves leaving the Grand Portage Indian Reservation study area, and collared wolves moved south to Grand Marais and north to Thunder Bay. As the wolves collared were only classified as adult or pup it is hard to tell if this dispersal was age related. Some of the collared wolves may have had territory outside of the Reservation. This dispersal led to a reduced number of wolf location to draw from in the study area in the cluster selection.

Territory

Wolf packs have a mean territory size of about 170 km^2 (Gese & Mech, 1991). Thus, natural territory size adds to the problem of wolves leaving the study area. From 2016–2017, five wolf packs patrolled most of the area in the Grand Portage Indian Reservation, but the northern packs had almost half of their territory outside in other parts of Minnesota or in Canada (Appendix 1). By 2018, territory maps showed more territory outside of the Reservation boundaries, with the southern pack's territory expanding south out of the Reservation (Appendix 2). Local and international borders that dissect the territories made this study challenging. The wolves are free to pass borders with ease, but researchers face challenges to visit sites that cross into private properties and over international borders.

Weather

Weather issues arose often. Snow was the biggest issue during this study. Snow made visiting potential kill sites harder by covering up tracks and other evidence of wolves at a site. When a significant amount of snow fell, search teams had to hit a "reset" on which clusters were planned to be visited.

Collar Functionality

Collar functionality was an issue later in the study, with two GPS collars ceasing to function. This led to a reduced number of collars from which to gather wolf locations. The collar malfunctions, along with wolf deaths, are an unpredictable variable with no solutions.

CONCLUSION

Among the three methods tested to find wolf kill sites, Method Three is the best due to its likeliness to produce results. This statement, however, must be confirmed with further testing and ideally comparing the results of other studies. In planning studies that have the objective to identify wolf kill sites, more thought should be put into variables that are uncontrollable, such as weather and wolf survival. Improvements to collar functionality should be investigated to find ways to limit them from going offline unexpectedly.

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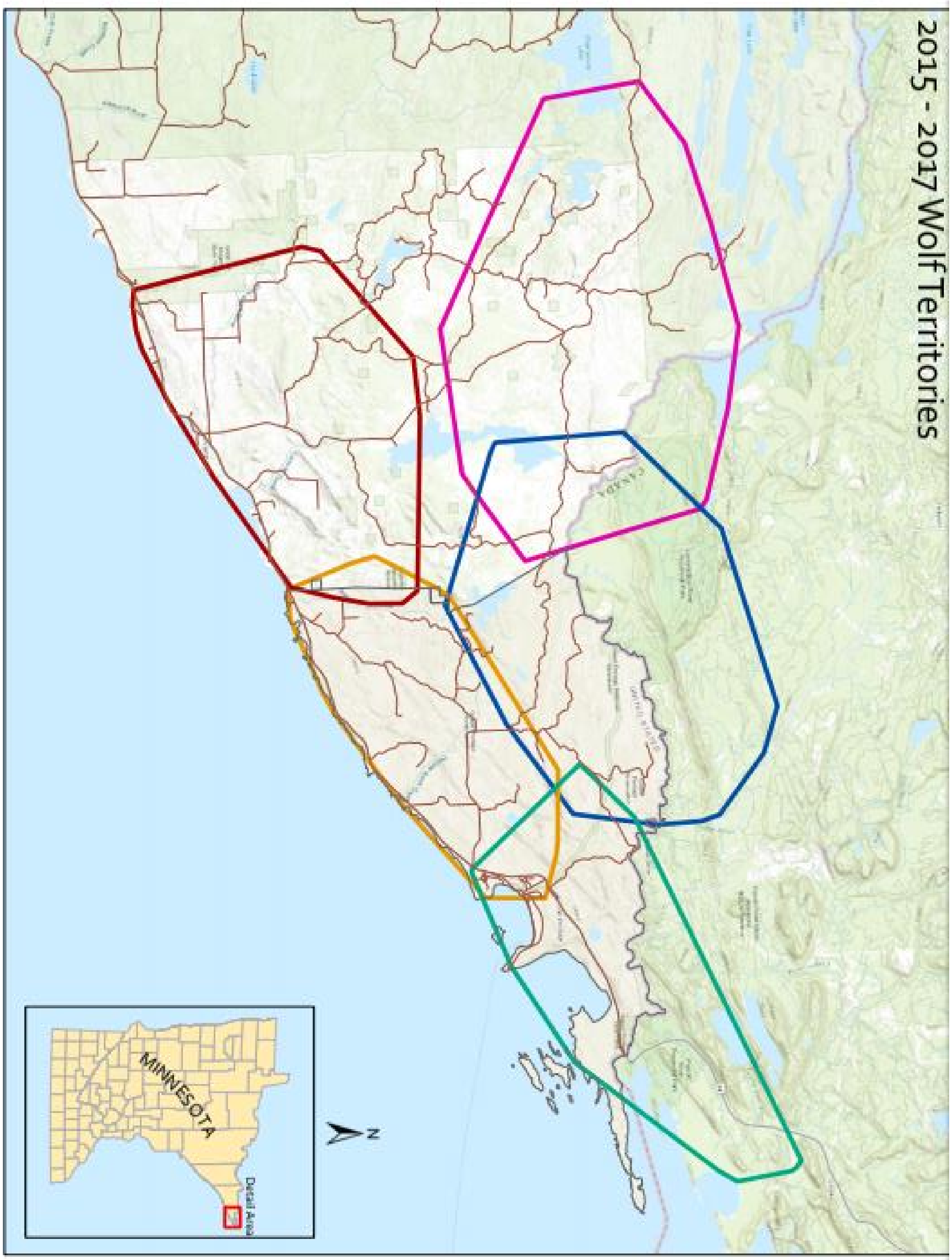
APPENDICES


2015 - 2017 Wolf Territories
MINNESOTA
Detail Area
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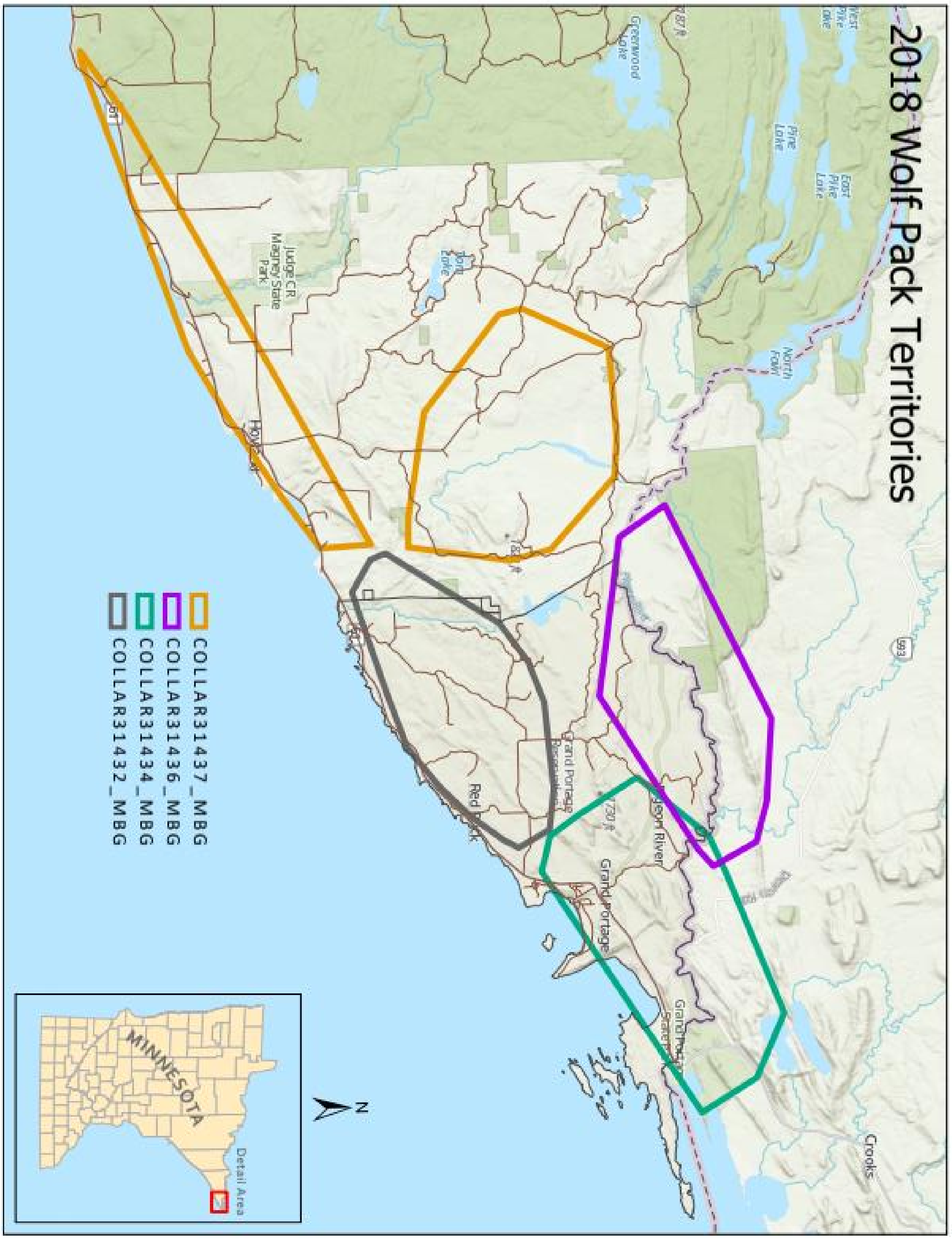
2018 Wolf Pack Territories
COLLAR31437_MBG
COLLAR31436_MBG
COLLAR31434_MBG
COLLAR31432_MBG
MINNESOTA
Detail Area
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Judge CR Magney State Park
Grand Portage
Crooks