2022-2023

GREATER VOYAGEURS ECOSYSTEM WOLF POPULATION REPORT

by Thomas Gable, Austin Homkes, and Joseph Bump

VOYAGEURS WOLF PROJECT

ACKNOWLEDGEMENTS

We first and foremost thank Liv Coletta and Sophie Heny who were our first winter field technicians on the project. Liv and Sophie worked diligently through all sorts of conditions this winter to make sure our trail cameras were working to ensure we could get sufficient footage of all 20 wolf packs in the Greater Voyageurs Ecosystem. Their efforts were a big reason why our 2022-2023 population survey was our most successful effort to date!

We also thank our 2022 summer field crew—Izzy Evavold, Maeve Tuley, Rudi Boekschoeten, Dani Freund, Mark Belew, Clara Dawson, Rose Newell, and Liv Coletta—whose hard work and effort from April 2022 to November 2022 also contributed to the findings detailed in this report.

We are very grateful to Anthony Souffle who has generously volunteered his time to join us in the field and photograph our work and the wolves we study. Many of the photographs in this report, in particular the ones of wolves and/or people, were taken by Anthony.

Lastly, we thank all Voyageurs National Park staff and collaborators who have dedicated their time, effort, and resources to studying the wolves of the Greater Voyageurs Ecosystem since 1975.

FUNDING AND SUPPORT

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We are thankful to the many organizations and institutions that have and/or are currently supporting our project including the University of Minnesota, International Wolf Center, Northern Michigan University, Van Sloun Foundation, Voyageurs Conservancy, Voyageurs National Park, Wolf Conservation Center, The 06 Legacy, National Wolfwatcher Coalition, Minnesota Department of Iron Range Resources & Rehabilitation, Wildlife Science Center, Rainy Lake Conservancy, Vectronic-Aerospace, International Wildlife Coexistence Network, The Big Bad Project, NatureSpy, and Arc'teryx.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

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Report designed by Kimberly Boustead

WOLF POPULATION ESTIMATE: 2022-2023

OVERVIEW OF METHODS

During April 2022-April 2023, we studied the wolf population in the Greater Voyageurs Ecosystem (GVE), Minnesota in an effort to understand wolf population dynamics and how changes in population dynamics are connected to or influence predation behavior, wolf pup survival, and changes in prey density. Although our primary objective was to estimate wolf population density, we also wanted to estimate key population parameters including pack size, pack composition, recruitment of wolf pups, and territory size.

Our primary tools to study the wolf population were GPS-collars and remote trail cameras. We used data from GPS-collared wolves to collect data on the size and distribution of wolf territories in the GVE. More specifically, we used GPS-collar data from May to October 2022 to estimate territory size because this is when our GPS-collars recorded intensive GPS-collar data (locations every 20 mins). Additionally, wolf pack territory boundaries appear, in general, more stable in summer compared to winter when wolves are jostling for territory with neighboring packs and often following deer to wintering habitats. After delineating the territories of numerous packs in the GVE, we then calculated how much wolf pack territories overlap one another and how many neighboring packs, on average, surround a single pack's territory.

To estimate pack size, pack composition, and the number of surviving pups in each pack, we deployed >200 trail cameras across the GVE from December 1, 2022 to April 10, 2023—we refer to this timeframe as our "winter survey period"—to capture repeated video observations of wolf packs during winter. In particular, we sought to obtain repeated independent observations of the same pack at the same size during the monitoring period. We considered observations to be independent if they were on a different day than any other observations of that pack. Multiple independent observations of the same size for each pack provides highly-reliable and accurate pack size estimates (Gable et al. 2022).

Our objective during Winter 2022-2023 was to deploy cameras in every wolf pack territory (20 packs) in the GVE to get detailed data on each pack that occupies the GVE. We had not attempted this before given the time, effort, and resources required to do so. For perspective, our largest survey prior to this year was in 2021-2022 when we studied

14 packs (Fig. 1). Fortunately, due to the generous support of thousands of donors, we had a field crew this past winter for the first time, which increased our logistical capacity and allowed us to study all 20 packs in the GVE (Fig. 2).

The detailed data on wolf pack territories and wolf pack size were then used to estimate wolf population density (wolves/1000 km²) for 2022-2023. For a detailed description of how we calculated density and the other methods we briefly described above, please see the methods section at the end of this report, which provides a more technical description of our approach.

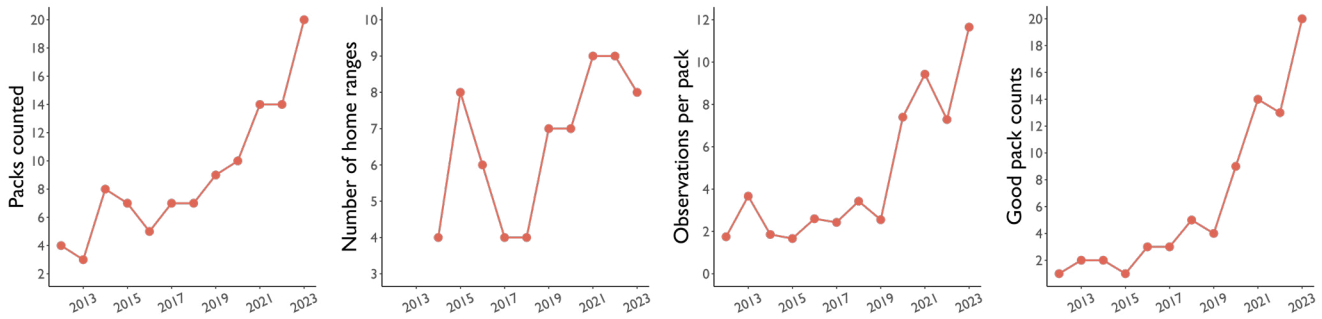
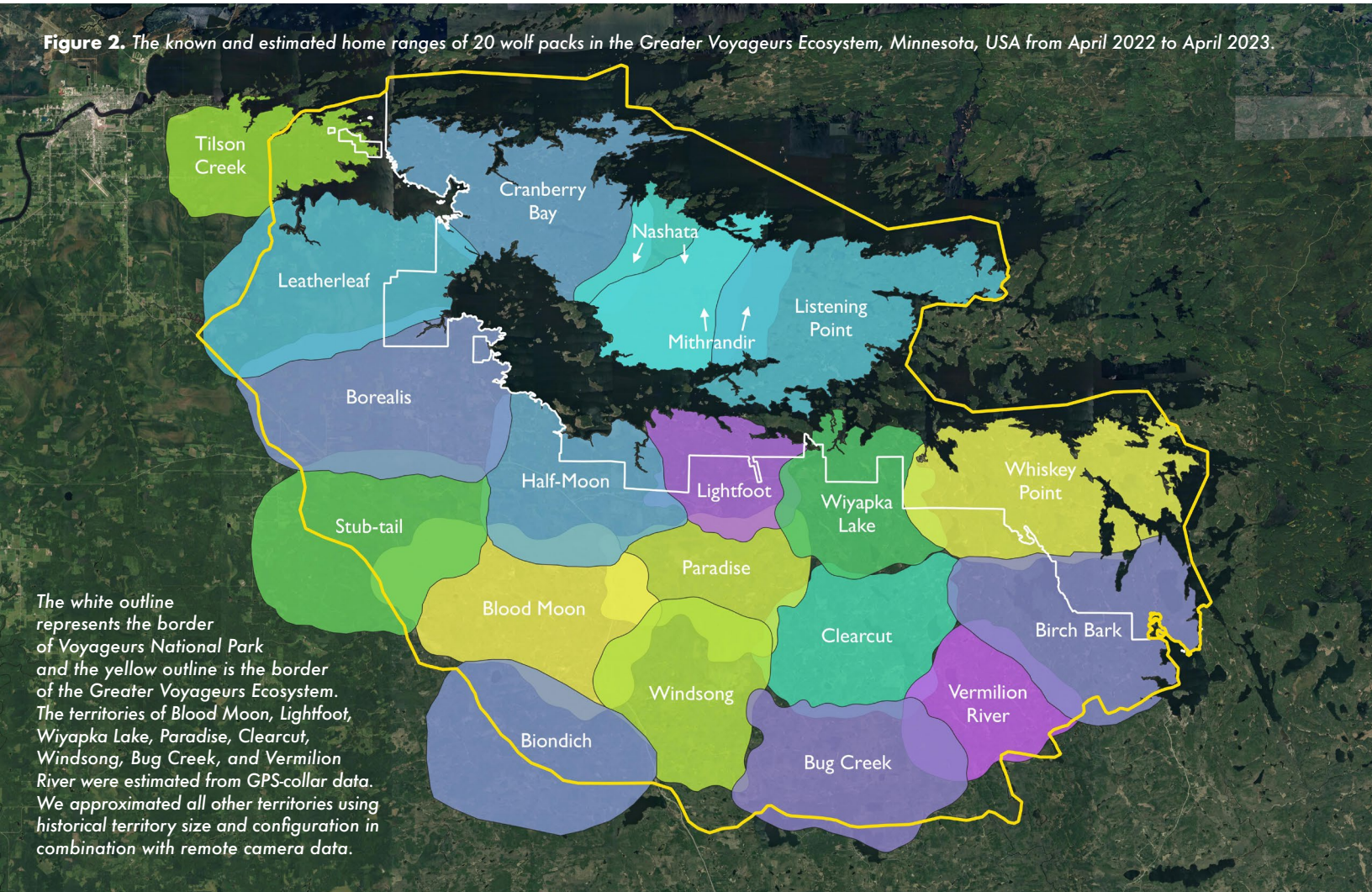


Figure 1. *The number of wolf packs (far left) and pack home ranges (middle left) studied during 2012-2023 in the Greater Voyageurs Ecosystem, Minnesota, USA. We also included indicators of the quality of wolf pack size estimates during this time (right two graphs). The number of observations per pack (middle right) refers to the number of independent observations of each pack at a given size (e.g., a value of 11.6 in 2023 indicates that, on average, we had 11.6 independent observations of each pack at their estimated size). We considered a "good pack count" to be when we had 3 or more independent observations of a specific pack at their estimated size.*

Figure 2. *The known and estimated home ranges of 20 wolf packs in the Greater Voyageurs Ecosystem, Minnesota, USA from April 2022 to April 2023.*



The white outline represents the border of Voyageurs National Park and the yellow outline is the border of the Greater Voyageurs Ecosystem. The territories of Blood Moon, Lightfoot, Wiyapka Lake, Paradise, Clearcut, Windsong, Bug Creek, and Vermilion River were estimated from GPS-collar data. We approximated all other territories using historical territory size and configuration in combination with remote camera data.

2022-2023 WOLF POPULATION SUMMARY

During April 2022-April 2023, we estimated the area of 8 wolf pack home ranges/territories and estimated the size of 20 wolf packs based on an average of 11.7 independent observations of each pack at the estimated size (i.e., the number of wolves we determined were in a given pack). In total, we recorded 606 observations of 2 or more wolves traveling together during the winter survey period. The 2022-2023 survey effort was the most intensive survey effort to date in the Greater Voyageurs Ecosystem, Minnesota (Fig. 1). Further, this year marks the 4th consecutive year of a sustained, intensive effort to collect data on more wolf packs, obtain better estimates of pack size, and understand the wolf population of the GVE in more detail.

We estimate that wolf population density in the Greater Voyageurs Ecosystem in 2022-2023 was 65.2 wolves/1000 km^2 (95% confidence interval: 53.7-87.8 wolves/1000 km^2), indicating that wolf density remained unchanged from 2021-2022 (65.7 wolves/1000 km^2; Fig. 3). Average wolf pack size decreased by 10% in 2022-2023 (4.2 wolves/pack) compared to 2021-2022 (4.7 wolves/pack) due to reduced wolf pup recruitment (Fig. 4), which was driven by a decrease in wolf

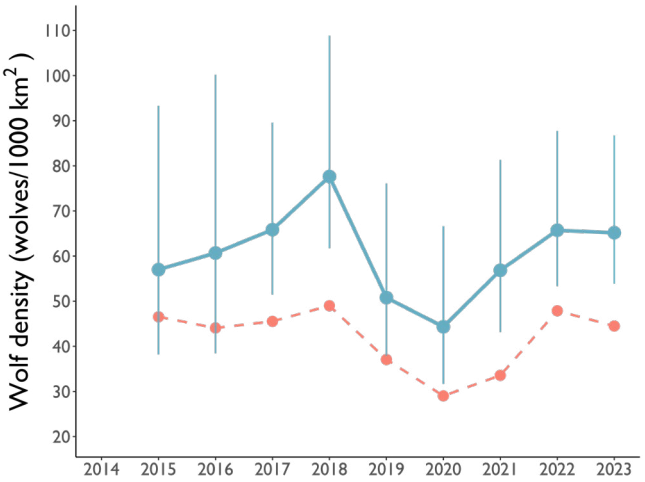


Figure 3. *Wolf density estimates (blue points) for the Greater Voyageurs Ecosystem, Minnesota, USA from 2015 to 2023. The error bars represent 95% confidence intervals. The red points and dashed red line represent wolf pack density if density was calculated solely by dividing mean wolf pack size by mean home range size (i.e., if density estimates did not account for pack home range overlap or lone wolves).*

Table 1. *Pack size and pup recruitment estimates for all wolf packs in the Greater Voyageurs Ecosystem, Minnesota, USA during our 2022-2023 winter survey period. The number of independent observations indicates the number of different days we observed a given pack at their estimated size during our winter survey period (Dec.1 to Apr. 10). For example, we observed 4 wolves together in the Paradise Pack on 32 different days during our winter survey period. The territory estimate column indicates whether we had sufficient GPS-collar data to estimate that pack's territory/home range.*

Pack	Pack size	Pups Recruited[1]	Number of Independent Observations	Territory Estimate
Biondich	2	0[1]	3	
Birch Bark	4	1	4	
Blood Moon	2	0[2]	17	Yes
Borealis	6	UNK[3]	2	
Bug Creek	9	5	4	Yes
Clearcut	3	0[1]	11	Yes
Cranberry Bay	3	2	21	
Half-Moon	7	5	3	
Leatherleaf	6	4	2	
Lightfoot	4	0[2]	9	Yes
Listening Point	3	0[1]	11	
Mithrandir	4	NA[4]	18	
Nashata	3	0	8	
Paradise	4	1	32	Yes
Stub-tail	4	2	7	
Tilson Creek	4	2	13	
Vermilion River	3	NA[4]	19	Yes
Whiskey Point	2	0	5	
Windsong	7	5	26	Yes
Wiyapka Lake	5	2	18	Yes

1 indicates the pack did not have any pups alive during the winter survey period but we are unsure whether the pack produced pups in Spring 2022

2 indicates the pack did not produce pups in Spring 2022

3 indicates the pack did recruit pups but we are unsure of the number recruited

4 indicates the pack formed in Fall or Winter, and therefore did not rear pups

pup survival and a few packs that did not produce a litter of pups (Table 1). On average, wolf packs only successfully raised (i.e., "recruited") 1.7 pups per pack in 2022-2023, which was a 26% reduction in recruitment relative to 2021-2022 when recruitment was 2.3 pups/pack. Of the 17 packs for which we could determine whether reproduction occurred, 18% (n=3) did not produce a litter of pups in Spring 2022. This stands in contrast to 2020-2021 where 100% of packs studied produced a litter.

Even among packs that did produce pups in 2022-2023, recruitment was lower than the previous year (2.3 pups/pack in 2021-2022 and 1.9 pups/pack in 2022-2023) almost certainly due to decreased pup survival. Although recruitment and subsequently pack size decreased in 2022-2023, a small decrease in wolf pack territory size and a small increase in territory overlap amongst packs from the previous year offset any change to wolf density that would have otherwise occurred due to smaller pack sizes (Fig. 5 and Fig. 6).

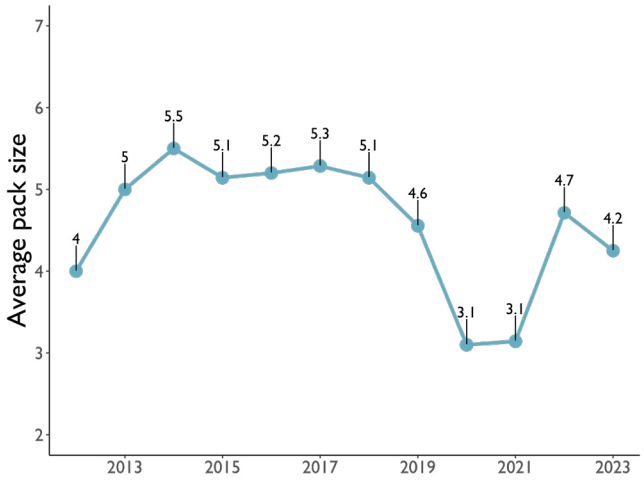


Figure 4. *Wolf pack size estimates for the Greater Voyageurs Ecosystem, Minnesota, USA from 2012 to 2023.*

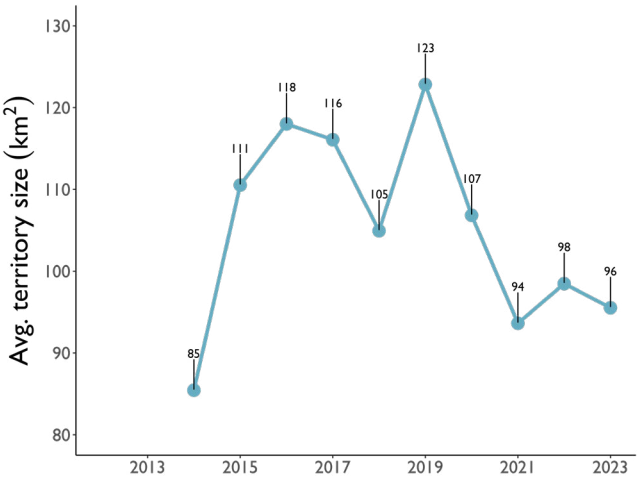


Figure 5. *Wolf home range size estimates for the Greater Voyageurs Ecosystem, Minnesota, USA from 2012 to 2023.*

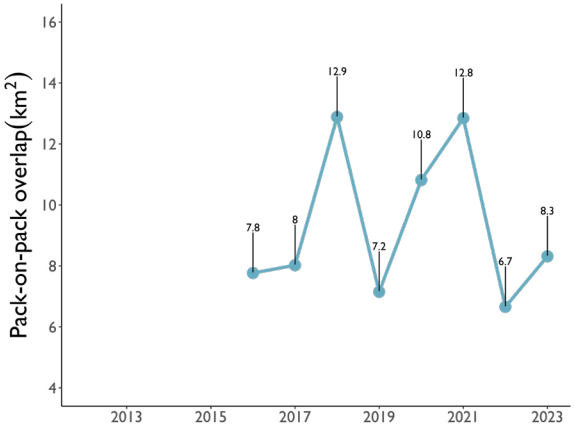


Figure 6. *Wolf pack overlap estimates for the Greater Voyageurs Ecosystem, Minnesota, USA from 2012 to 2023. We considered pack-on-pack overlap to be the average territory overlap of each wolf pack territory with each neighboring pack. For instance, in 2022-2023, each wolf pack territory overlapped each neighboring pack territory by 8.3 km². Quantifying the overlap of wolf pack territories is crucial for deriving accurate wolf population density estimates.*

POPULATION TREND, ASSUMPTIONS, AND LONE WOLVES

Although wolf density has varied annually in the GVE since 2015, there is no indication that wolf density has increased or decreased with time (Fig. 3). In other words, the population has remained relatively stable and current population density (65.2 wolves/1000 km^2) is close to the average population density (60.4 wolves/1000 km^2) over the past 9 years (2015-2023) in the GVE. Notably, the average density of wolves in the GVE during this period represents some of the highest sustained densities of gray wolves reported (Mech and Barber-Meyer 2015, Gable et al. 2022).

In our population report last year (see Gable et al. 2022), we included an estimate of wolf density for 2014-2015. Although we lacked sufficient data on several important population parameters during this year, we made some generous assumptions to derive a density estimate for 2014-2015 and in doing so we arrived at an incredibly high wolf density estimate (94 wolves/1000 km^2). After re-examining our assumptions and the quality of the data, we do not think this estimate is reliable. As such, we have removed it from this year's assessment/report and will do so for all future assessments, analyses, and reports.

We also re-examined an important assumption we made last year when calculating wolf population density: the prevalence of lone wolves in the population. Estimating the abundance of lone wolves in any population is a challenging task because lone wolves are transient, and are therefore difficult to count or census, and their social status (lone vs. pack wolf) can change quickly. Thus, estimating the abundance of lone wolves during winter is chasing a moving target. Because of these challenges, many researchers and state agencies make assumptions about what percent of a population are lone wolves. For instance, the Minnesota Department of Natural Resources assumes that lone wolves constitute 15% of the state's annual wolf population when calculating annual population estimates (Erb and Humpal 2022). Similarly, previous research in the Greater Voyageurs Ecosystem determined lone wolves composed a minimum of 10% of the population (Gogan et al. 2004). However, based on other studies, the researchers assumed lone wolves likely constituted 15% of the population in the GVE (Fuller 1989, Gogan et al. 2004). Based on the previous researchers' approaches and reasoning (e.g., Erb and Humpal 2022, Gogan et al. 2004, Fuller 1989), we assumed lone wolves were 15% of the wolf population in the GVE when deriving annual population density estimates from 2014-2022 for the GVE in our report last year (see Gable et al. 2022). Although this was not a rigorous estimate of lone wolf abundance, we surmised that it was likely close to the actual abundance.

However, we became interested in independently estimating, and therefore verifying, whether this was a valid assumption because: 1) it was based on research from >20-30 years ago (the 15% estimate is based on Fuller 1989) and prior to GPS-collar technology, remote trail cameras, and genetic information, and 2) it assumes that the percent of lone wolves in the population remains constant across years. Thus, we used two different approaches to estimate the abundance of lone wolves. The first approach entailed determining the percent of collared wolves that were lone

wolves during each winter survey period (December 1 to April 10), and the second approach entailed determining the number of distinct lone wolves observed on remote cameras during the winter survey period.

Data on collared wolves is likely the best method for estimating the prevalence of lone wolves. If collared wolves are a representative sample of the population, then the percent of collared wolves that are lone wolves should, with sufficient sample size, approximate the frequency of lone wolves in the larger population. We think that collared wolves are likely a representative sample—or as close as one could get to a representative sample. Part of our reasoning is that the social status of a wolf when it is initially collared in spring or early summer is not necessarily reflective of a wolf's social status during the following winter. We have had many pack wolves, both breeding and subordinate wolves, that were pack wolves during spring/summer but by winter were lone wolves and vice versa. Thus, even if collared wolves are not a random sample of the larger wolf population during Spring/Summer—which is very challenging to assess—we think that collared wolves are likely close to a representative sample by winter (6-10 months later) given the amount and frequency of change in wolf social structures.

In total, we had 82 wolves collared during winter study periods from 2014-2023, and 19.5% (16 wolves) were lone wolves (Table 2). Annual estimates of lone wolves in the population varied from 0% to 29% with a mean of 15.2%. However, the annual estimates of 0% were from 2016-2017 and 2017-2018 when only 2 and 3 wolves, respectively, were collared during the winter study period. If we remove those years because of the small sample sizes, annual estimates of lone wolves in the population varied between 10-28% with an average of 19.6%.

One of the biggest limitations of using collared wolves to estimate the annual abundance of lone wolves in the GVE is sample size. The largest number of collared wolves we had in any winter survey period was 14 and we averaged 11 collared wolves per winter study period (not including data from 2016-2018). These small sample sizes make it difficult to detect biologically meaningful differences in lone wolf prevalence from one year to the next, and more importantly, to know whether observed differences between years represents an actual difference in lone wolf prevalence. Because increasing the number of collared wolves during the winter survey is not logistically feasible, we think the best approaches for incorporating these data into population estimates is to either use the long-term average from collar data (19.6%) or to use a 2-3 year moving average to account for variability from year-to-year. For instance, using a 2-year moving average to estimate the annual prevalence of lone wolves in the population indicates that lone wolves constituted 18-25% of the population annually during the 2014-2023 period, suggesting that the prevalence of lone wolves in the population has been relatively similar throughout this 9-year period.

Year	Lone wolves that were collared during winter period	Total wolves collared during winter period	Percent of collared wolves that were lone wolves	Unique lone wolves observed on camera during winter period	Number of pack wolves observed on camera during winter period	Minimum percent of population that are lone wolves based on cameras
2014-2015	4	14	28.6			
2015-2016	1	9	11.1			
2016-2017	0	2	0.0			
2017-2018	0	3	0.0			
2018-2019	1	8	12.5			
2019-2020	3	12	25.0			
2020-2021	1	10	10.0			
2021-2022	3	12	25.0			
2022-2023	3	12	25.0	9	85	9.6
TOTAL	16	82	19.5			

Table 2. *Prevalence of lone wolves in the Greater Voyageurs Ecosystem, Minnesota, USA during our winter survey period (Dec. 1 to Apr. 10) based on collared wolves and remote cameras. We did not have a sufficient number of remote cameras deployed during 2014-2022 to estimate number of lone wolves using this approach.*

The second approach we used to estimate the prevalence of lone wolves were remote cameras. Specifically, we used trail cameras to provide a minimum estimate of the number of lone wolves in the GVE during the winter survey period. To be counted as a lone wolf, we had to observe a wolf multiple times over the survey period, be able to readily identify the wolf based on physical characteristics, and be confident a wolf was not part of any pack in the GVE. Because of these criteria, there were likely several lone wolves that we did not "count" via this approach, i.e. this approach is conservative. Furthermore, our ability to detect lone wolves was likely not consistent across the GVE because our cameras were not systematically distributed. As a result, we would have been much more likely to detect lone wolves in areas with a high-density of cameras and less likely to detect lone wolves in areas with very low density of cameras (e.g., Leatherleaf, Stub-tail, and Borealis Pack territories). For these reasons, our trail camera approach only yielded a minimum estimate of lone wolves in the population.

During the 2022-2023 winter survey period, we could confidently identify 9 lone wolves in the GVE (Table 2). Because we censused the number of wolves in all 20 packs in the GVE (85 wolves), we were able to determine that lone wolves constituted at least 10% of the wolf population in the GVE (9 lone wolves/[9 lone wolves + 85 pack wolves]*100). Unfortunately, we are not able to use this approach to estimate lone wolf prevalence in any year other than 2022-2023 because of insufficient camera data.

What does the minimum estimate of lone wolves from trail cameras tell us? Most importantly, that lone wolves almost certainly constituted more than 15% of the wolf population in the GVE during the winter survey effort. If lone wolves composed 15% of the population, as we had assumed last year, then there were only 3 lone wolves we were unable to confidently identify on remote cameras during this year 's survey. We think that scenario is highly improbable. Instead, we are confident that we underestimated the number of lone wolves by a fair margin given the low density of cameras in large proportions of the GVE during the winter survey period and the fact that there were many videos of single wolves in low and high-density camera areas for which we could not determine if the wolf was a lone or pack animal (e.g., night time videos, videos of a running wolf). We think it likely that the actual number of lone wolves in the GVE was >50-100% (5-10 wolves) higher than our minimum estimate, which would indicate that lone wolves could have constituted >15-20% of the population—figures that are relatively consistent with the prevalence of lone wolves when using data from GPS-collared wolves.

Figure 7. *Mean wolf pack size in the Greater Voyageurs Ecosystem (GVE), Minnesota, USA from 1976 to 2023. Historical data on wolf pack sizes in the GVE were from 1976-1978 (Hardwig 1978), 1985-1986 (archived map by Voyageurs National Park biologist Glen Cole), 1987-1991 (Gogan et al. 2004), 1998-2001 (Fox et al. 2001), 2005 (Fox 2006), and 2008 (Ethier and Sayers 2008).*

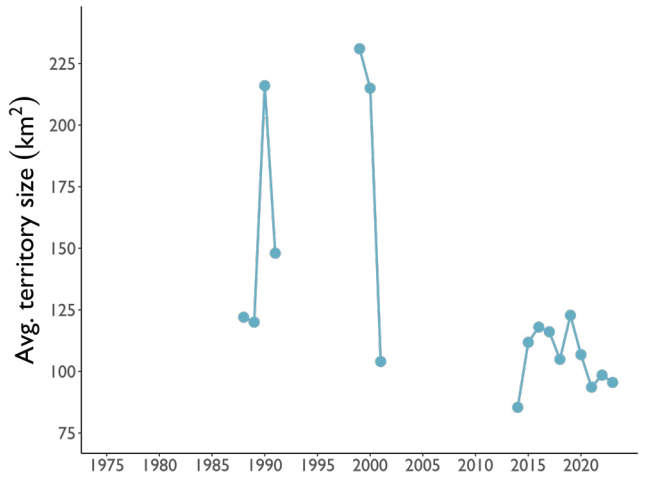


Figure 8. *Mean home range size in the Greater Voyageurs Ecosystem, Minnesota, USA from 1975 to 2023. Data from 1987-1991 and 1998-2001 are from Gogan et al. (2004) and Fox et al. (2001), respectively. Home ranges from 1987 to 2001 were estimated using telemetry data and minimum convex polygons whereas home ranges from 2014-2022 were estimated using GPS-location data and kernel density estimators.*

Based on this information, we do not think it is correct to assume that lone wolves constitute 15% of the population in the GVE (and possibly similar ecosystems). Instead, both of our methods suggest that lone wolves, on average, compose a larger proportion of the population in the GVE than we had assumed, likely around ~20% each year. As such, when calculating our density estimates this year, we assumed lone wolves made up 19.6% of the wolf population in the GVE. Admittedly, this might seem a trivial discussion because whether we assume 15 or 20% makes very little difference in our assessment of population trends. However, over the past two years, our objective has been to estimate the wolf population in the GVE in the most rigorous and defensible way possible. To that end, we have made a concerted effort to re-think, re-assess, and refine how we estimate every facet of the wolf population to ensure our assumptions are valid and that we collect rigorous data, where possible, on important population parameters (see Gable et al. 2022). We realized that our assumptions about the prevalence of lone wolves was the weakest assumption in our estimates and wanted to find a way to improve. The discussion above outlines this process of re-thinking and refining.

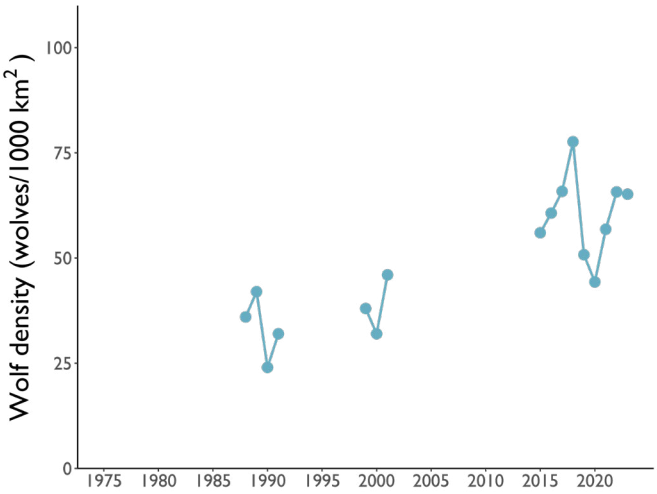


Figure 9. *Wolf density in the Greater Voyageurs Ecosystem, Minnesota, USA from 1975 to 2023. Data from 1987-1991 and 1998-2001 are from Gogan et al. (2004) and Fox et al. (2001), respectively. Although wolf density during 2015-2022 was substantially higher than that reported in previous studies, we do not think wolf population density has increased–or at least increased substantially– over the past 35 years. Instead, the disparity in density from previous studies and ours likely stems from the coarser survey methods used in previous studies. For detailed discussion, see Gable et al. (2022).*

INDIVIDUAL WOLF PACK SUMMARIES

The following pages are individual summaries regarding the data collected on each wolf pack studied during the 2022-2023 winter survey period. The summaries provide an explanation of the size of each pack, pack composition, and any other pertinent details on that pack during 2022-2023. When possible, we refer to known wolves by their ID. Known wolves are either those we have tagged and collared or those that have distinctive physical appearances that allow us to identify them when they are recorded on our remote cameras. Collared and ear-tagged wolves have IDs that either begin with a "V" (e.g., V085) or are a three digit code (e.g., "Y1T" or "B2L"). Wolves that we have identified solely based on physical appearance have IDs based on their pack affiliation when first identified on camera (e.g., CB = Cranberry Bay, LP = Listening Point) and social status (e.g., BM = breeding male, BF = breeding female, SUB = subordinate). For instance, the breeding female of the Stub-tail Pack, who has never been collared but has a distinctive short tail from which we can easily identify her on camera, was assigned the ID: ST_BF.

The breeding female of the Biondich Pack in April 2023. Her distended nipples indicate she was nursing pups at this time.

BIONDICH

Prior to this past year, we had not studied the pack that occupied the Biondich territory (Fig. 2). However, in our effort to survey all packs in the GVE, we started studying wolves in this area this past winter. Even so, we had poor data on the Biondich Pack this winter relative to other packs in the GVE, in part because we had few trail cameras in the pack's territory and because the few cameras that we did have deployed were plagued by drifting snow, malfunctions, and in one instance, a stolen SD card. Nonetheless, we were able to get 4 independent observations during the winter survey period of two wolves traveling together in this pack. In late April 2023, after our winter survey period, we had two separate observations of the Biondich breeding female (BD_BF) where she was clearly lactating, indicating she had given birth and was nursing pups. We are not precisely certain where the Biondich territory boundaries are but hope additional trail cameras this fall and winter will help us to clarify this to an extent.

BIRCH BARK

This was the first year we surveyed the pack in the area that we now know is occupied by the Birch Bark Pack. Much of the Birch Bark territory is remote and difficult to access, which created some difficulties in observing the pack. Additionally, we deployed relatively few cameras in this territory relative to others. Despite this, we still observed the pack on camera several times and captured 4 observations of four wolves traveling together. All other observations were of smaller groups within the pack during winter (e.g., the breeding pair traveling together)

The Birch Bark breeding pair (BB_BM and BB_BF) are clearly older wolves and might have occupied their territory several years. The other two pack members appear to be a 2-3 year-old subordinate wolf and a pup born in Spring 2022. Although we do not know exactly where the Birch Bark Pack's territory boundaries are, we do know that their territory extends from the Vermilion River all the way into Voyageurs National Park. We had a few observations of these wolves on the snowmobile trails north and south of Mukooda Lake, indicating that they are the pack directly south of the Whiskey Point Pack.

1 The breeding male of the Birch Bark Pack in early April 2023 on the snowmobile trail just south of Mukooda Lake in Voyageurs National Park. 2 The breeding male of the Birch Bark Pack in March 2023.

BLOOD MOON

The Blood Moon Pack took over the Moonshadow territory in January 2022 and was composed of a breeding male (now dubbed "Y1T" after we collared him in May 2022), breeding female, and two pups. Although we need genetic evidence to confirm, we suspect that the breeding female and both pups in Blood Moon were members of the Moonshadow Pack and Y1T simply ousted Wolf V079, the breeding male of Moonshadow last winter. This is based on the fact that the breeding female of Blood Moon looks very similar to the former breeding female of Moonshadow. However, we cannot say with 100% certainty that she is the same wolf but hope genetic assessments might help to determine this one way or the other.

Regardless, the Blood Moon Pack did not produce a litter of pups in Spring 2022—the female was never clearly pregnant— and the two subordinate pack members dispersed or died sometime during Summer 2022. Thus, the pack was down to the breeding pair by Fall 2022 when we had numerous observations of Y1T and his mate traveling together throughout fall. Unsurprisingly, the pack remained 2 wolves into and through the winter and we had 24 independent observations of two wolves in the Blood Moon Pack. We had one very interesting observation, however, in mid-winter in which Y1T and his mate were accompanied by a lone wolf (dubbed LW_2022_01). This lone wolf was easy to identify because he could not use his front left leg/foot and limped around. Although we had numerous observations of this lone wolf from October 2022 through April 2023, this instance was the only one where he was traveling with other wolves. For whatever reason, he and the Blood Moon Pack seemed to part ways shortly after this observation.

One interesting behavior from Y1T this winter was his proclivity to travel large distances outside of the Blood Moon Pack territory. In particular, Y1T, and presumably his mate, spent a substantial portion of the winter 4-6 miles south of the territory in and around an old growth cedar complex, which we suspect was a deer yard. Loggers clear-cut some large tracts of forest a short distance from this cedar complex this winter and one cabin owner in the area who we spoke to in May stated that he saw at least 100 deer in the cut shortly after the timber was harvested. Unsurprisingly, Y1T spent time in and around these large clear-cuts this winter, and we suspect his extra-territorial movements were driven by where deer were congregated for the winter. As spring arrived, Y1T returned to the Blood Moon territory and remained there with the exception of brief extra-territorial forays.

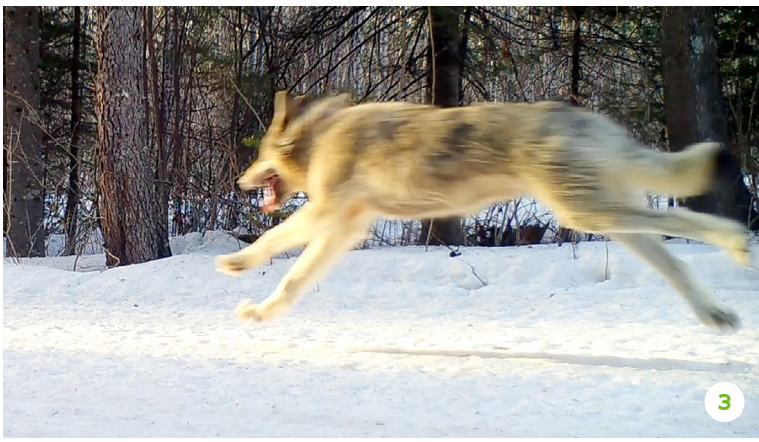
Wolf Y1T, the breeding male of the Blood Moon Pack, in December 2022.

BOREALIS

Going into Winter 2022-2023, we knew little about the Borealis Pack, which occupied the territory to the west of the Half-Moon Pack (Fig. 3). We deployed cameras in the territory in early February but despite having numerous cameras deployed on obvious travel corridors in what we presumed to be the territory, we did not have many observations of this pack. In July 2023, we collared the breeding male of the Borealis Pack (Wolf R4D) and learned that our problem lay in the fact that we only had cameras deployed in about a quarter of the actual Borealis territory—and in portions of the territory that the pack does not appear to use frequently. Indeed, we learned that the Borealis territory goes from the western edge of the town of Kabetogama to the area northwest of Ray between Highway 53 and Lake Kabetogama–a much larger territory than we previously estimated. The last time a wolf was collared in this area of the GVE was in 2013-2014 and that wolf had a very small territory. We incorrectly assumed that the pack still maintained a very small territory when deploying cameras.

Although we had limited observations, we did record two independent observations of 6 wolves on March 26 and April 3. From these observations, we determined that the pack was comprised of six wolves; the breeding male (now dubbed R4D), the breeding female, and four subordinates that consisted of at least two pups. It is possible that three or all four of the subordinates were pups but video footage was not of sufficient quality to make a determination.

1 Two pups from the Borealis Pack checking out a trail camera in early 2023. 2 Two Borealis pack members in March 2023. 3 A wolf in the Borealis Pack running down a snowmobile trail in April 2023.



BUG CREEK

The Bug Creek Pack was the largest pack that we documented this winter with 9 members who remained in the pack through early spring. In total, we had 4 observations of 9 wolves together this winter and 6 observations of 8 wolves. Initially, we waffled on whether to consider this pack 8 or 9 wolves during the winter. However, we captured an observation of all 9 pack members in mid-April, shortly after our winter survey period, so we think a count of 9 is the most accurate and representative.

The Bug Creek Pack consisted of the breeding male (B5E), the breeding female (BC_BF), two subordinates that were at least 2 years old (BC_SUB1 and BC_SUB2), and 5 pups born in Spring 2022. The pack spent much of the winter months in and around the cedar swamps in the southern portion of their territory where deer are known to yard up during the winter. This did present some challenges for getting observations of the pack during winter because the pack did not move around the territory as much as other packs and because there are few clear travel corridors (roads and trails) through the cedar lowlands where the pack spent much of its time. Despite all of this, we still had high-quality data on both the size and composition of the pack.

1 Two subordinate wolves from the Bug Creek Pack playing in early April 2023. The wolf facing the camera is a subordinate female that is almost 2 years old. The other wolf is a pup born in Spring 2022. 2 Three Bug Creek Pack wolves in early 2023. The first and last wolf are subordinate females (almost 2 years old) and the middle wolf is a pup born in Spring 2022.

CLEARCUT/BLUEBIRD LAKE

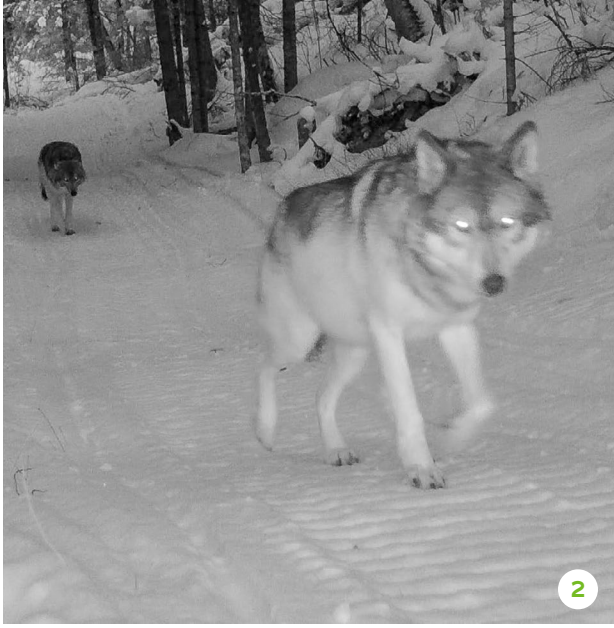
The Bluebird Lake Pack was 3 wolves in fall and early winter: the breeding male (P0C), the breeding female (P3S), and a subordinate female (now dubbed Wolf B6T). Although the pack had a litter of 6 pups in April 2022, none of the pups survived past August 2022. It seems the death of the pups was an omen of things to come for Bluebird Lake.

On January 20, 2023, P3S was killed by two unknown wolves. We captured some of P3S's final moments on a trail camera. In the video, P3S is running full speed down a trail past our camera chased by two pursing wolves lagging behind by only a few seconds. P3S died within hours of that video and about 200 m from where that trail camera was located. A little over a week later, P0C was attacked by other wolves near the center of the Bluebird Lake territory and died from his injuries a few days later. The breeding pair of Bluebird Lake had been eliminated in a matter of days and the pack effectively ended.

Starting in early January, prior to P0C and P3S's deaths, we began observing a different pack of 3 wolves roaming the Bluebird Lake Pack territory. We suspect this pack was likely responsible for the death of P0C and quite possibly P3S as well. Either way, this new pack, who we named the Clearcut pack after the extensive logging operations within the territory, was now clearly occupying the former Bluebird Lake territory. The Clearcut Pack consisted of a breeding male (CC_BM), breeding female (CC_BF), and a subordinate male.

From the time the Clearcut Pack took over the territory through early spring, we captured consistent footage of the 3 pack members traveling together. However, scattered throughout the winter, we also captured 11 instances of the Clearcut breeding male (CC_BM) traveling with B6T, the sole surviving member of the overthrown Bluebird Lake Pack. Fortuitously, we collared B6T this spring and she continues to occupy and remain in the Clearcut Pack despite the death of her parents. We did not consider B6T part of the Clearcut Pack during Winter 2022-2023 but the fact that she continues to occupy and live in the Clearcut territory suggests she might have joined the pack in Spring or Summer 2023. We are very interested to see what transpires with B6T and the Clearcut Pack in the coming year.

1 Wolf B6T was a subordinate female wolf in the Bluebird Lake Pack until both her parents were killed by other wolves in January 2023. This event marked the end of the Bluebird Lake Pack and the Clearcut Pack took over the Bluebird Lake territory at this time. Despite this, B6T remained in the territory and she appears to have joined the Clearcut Pack this spring or summer. 2 The breeding pair of the Clearcut Pack in early 2023. The breeding female is on the right and the breeding male on the left. 3 The breeding female of the Clearcut Pack. She is easily identified by the missing portion of her right ear.



1 Wolf V083 (left) crossing a frozen beaver pond with a subordinate Cranberry Bay Pack member (right). This photograph was taken in early December 2022 just days before the Cranberry Bay Pack split. 2 The breeding pair of the Cranberry Bay Pack in early 2023. Wolf V084, the breeding female, is in front and is followed by her new mate.

CRANBERRY BAY

The Cranberry Bay Pack was eight members strong in early December. At this time, the pack consisted of the breeding pair (Wolves V083 and V084), four subordinates at least 1-2 years old, and two pups born in 2022. However, around December 5th or 6th something happened that caused the Cranberry Bay Pack to split up into two distinct groups/packs. We suspect that "something" was the death of the breeding male of the Nashata Pack, the pack bordering Cranberry to the east (Fig. 3).

The breeding male (NS_BM) of the Nashata Pack had been seen on camera regularly prior to December 5-6 but was never observed after that period. We did, however, observe the breeding female of Nashata (NS_BF) many times during the winter survey period as well as the yearling female from Nashata (NS_SUB1). Furthermore, the Nashata breeding female had a different mate by mid-winter. The last video of the Nashata breeding male was on December 3 and in that video he looked healthy, mobile, and dominant. Given all the evidence, we think it most likely that this breeding male was killed by other wolves (likely Cranberry) around December 5-6. His death set several things in motion.

Around December 7, V083, the breeding male of Cranberry, left the Cranberry Bay Pack along with two subordinates from the pack and these 3 wolves formed a pack with the subordinate female (NS_SUB1) from Nashata. We call this new pack the Mithrandir Pack (see below). Simultaneously, one of the subordinate males (CB_BM) from the Cranberry Bay Pack paired with V084 and became the new breeding male. We assume this male joined the pack at some point during 2022 and was not related to V084. The new breeding male can be seen traveling with V083, V084, and the rest of the Cranberry Bay Pack prior to the split. Notably, this wolf's posture and demeanor was that of dominance (e.g., tail always held up in the air or parallel to the ground) and unlike the other subordinates in the pack.

After the split occurred, the Cranberry Bay Pack was 3 wolves: Wolf V084, the new breeding male (CB_BM), and a pup. We did have a few observations in early winter, shortly after the split, where there were 5 wolves in Cranberry Bay. We suspect the extra 2 wolves were subordinate wolves that were going back and forth between Mithrandir and Cranberry for a while. However, by mid-winter, the Cranberry Bay Pack was only 3 wolves and we had 21 independent observations of the pack at this size.

In late April 2023, V084 was clearly pregnant and traveling around with her new mate. Thus, the Cranberry Bay Pack lives on. Notably, the split of the Cranberry Bay Pack in December ushered in a new era in Voyageurs National Park with 4 packs—Cranberry Bay, Mithrandir, Nashata, and Listening Point— occupying the Kabetogama Peninsula simultaneously, something that has not been observed in our study or in previous studies of the wolves in Voyageurs National Park.

HALF-MOON

Estimating the size of the Half-Moon Pack this winter was more challenging than expected, which has been the trend for the past few years. Despite being one of the most accessible territories in the GVE, the pack is one of the most difficult to capture on camera. They appear to avoid most of the roads and trails in their territory for most of the winter so getting repeated observations is difficult. Nonetheless, we were able to collect enough evidence to be pretty confident in our pack size estimate.

In total, we had 3 observations of 7 wolves traveling together in the Half-Moon territory. Two observations were in January 2023 and one was in March 2023. In Fall 2022, we, along with two different landowners in Kabetogama, had several observations of 7-8 wolves in the territory, including a few observations of 6 pups with 1-2 adults. And in April 2023, after our winter survey period, we had an observation of 4 yearlings in the territory indicating the pack was at least 6 wolves in April (4 yearling plus the breeding pair) and very possibly 7. Given all of this information, we feel confident the pack was 7 wolves in winter.

The pack underwent an interesting transition throughout 2022-2023. In Spring 2022, the Half-Moon breeding female (HM_BF), who had been the mate of the breeding male (V094) since the pack formed in late 2019, gave birth to a litter of pups. Interestingly, however, a subordinate female in the pack (Pup 2217)—the third and only other pack member in Winter 2021-2022—gave birth to a litter of pups as well. We only learned of this from remote trail camera footage in which Pup 2217 was clearly pregnant and then clearly nursing pups. In one informative sequence during mid-April 2022, V094 was traveling with the breeding female of the Half-Moon Pack (HM_BF), who had already given birth and was lactating, as well as Pup 2217 who had not given birth yet but was incredibly pregnant. A few weeks later, we observed Pup 2217 on camera and she was clearly lactating.

We strongly suspect that V094 was the father of both litters but are not able to say with certainty as of right now. However, we are awaiting genetic analyses which we hope will shed light on this. Either way, as summer progressed into fall, it was apparent that the breeding female of the Half-Moon Pack (HM_BF) was being replaced by Pup 2217. We rarely observed HM_BF traveling with V094 or other members of the Half-Moon Pack during this time and we did not observe her on camera after November 4, 2022. We did, however, observe Pup 2217 frequently travel with V094 and some or all of the surviving pups in the pack. All of this indicated that Pup 2217 was now the new breeding female of the Half-Moon Pack. By late March 2023, Pup 2217 was clearly pregnant once again and V094 clearly her mate.

The Half-Moon Pack successfully raised 5 pups last year, though we do not know how many pups were born between both litters. We know at least 6 pups were born as we have trail camera footage showing 6 pups in fall but that is the extent of our knowledge. We were later able to collar two of these pups (O5E and O6C) in May 2023—we hope we can use their DNA to determine who their father and mother was.

The Half-Moon Pack in late April 2022. In this photo, the breeding male, Wolf V094, is in the middle. On the right is the breeding female of the Half-Moon Pack (HM_BF) who had just given birth to pups. This female had been the breeding female since 2020. On the left is Pup 2217 who is clearly pregnant in this image and who gave birth to pups a few days after this image. Thus, the Half-Moon Pack produced two litters of pups in April 2022, and we are fairly certain that V094 was the father of both litters.

LEATHERLEAF

This was the first year we surveyed the wolves in the Leatherleaf Pack. The pack was named for bog-dwelling plant that dominates most peat bogs in the Northwoods: leatherleaf. The Leatherleaf territory includes the expansive bog that forms much of the East Rat Root River Peatland Scientific and Natural Area (Fig. 3). Like the neighboring Tilson Creek Pack, the Leatherleaf Pack had an older breeding female (LL_BF), a younger breeding male (LL_BM), and pups.

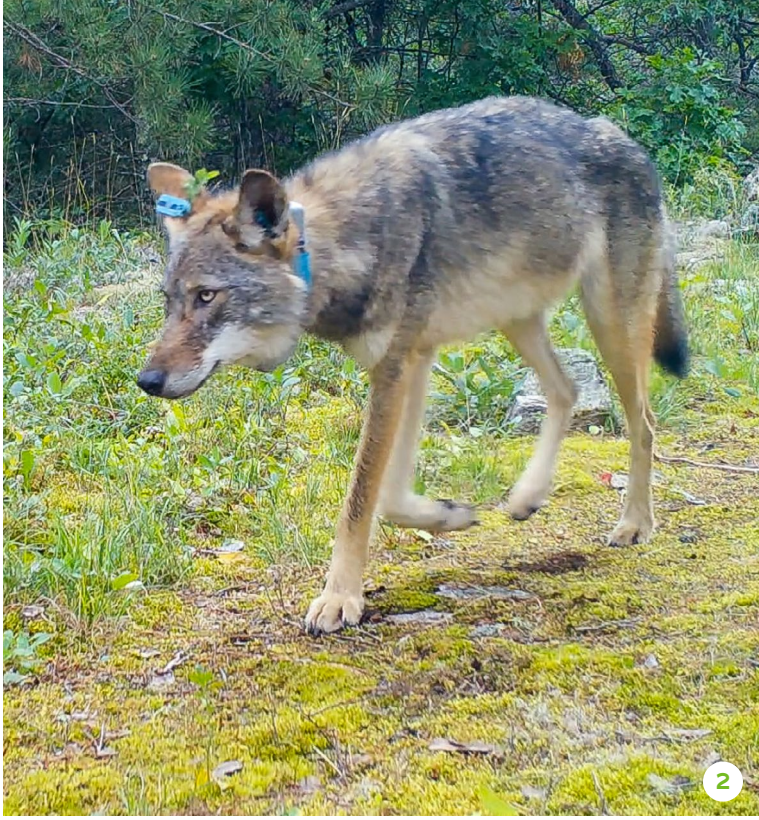
Unfortunately, we did not have cameras deployed in the Leatherleaf territory for much of the winter and as a result, we have poor data on pack size relative to other packs. Nonetheless, we can confidently say that the pack had somewhere between 5-7 wolves in it. On December 27, we observed 5 Leatherleaf wolves—the breeding pair and 3 pups— trespassing in the Cranberry Bay territory near the Locator Lake trailhead. Then on March 4, we observed 7 wolves—the breeding pair and 5 pups—together. We had numerous observations of 2-4 wolves from the pack traveling throughout March, and then another observation of 5 wolves on April 2, which consisted of the breeding pair and 3 pups.

Given the relatively scant observations of the entire pack, we had to decide what pack size was the most appropriate and best represented the size of the pack. We decided the best approach was to split the difference and assume a pack size of 6 wolves. Clearly, the pack was 7 wolves at one point in late winter but whether all 7 wolves were part of the pack for most of the winter is unknown.

Also worth noting, although our trail cameras were not systematically spread throughout the area, the Leatherleaf Pack was never captured on cameras north of the tributary that flows from Rat Root Lake into Black Bay. However, the pack was routinely captured on camera south of Black Bay as far south as the southern edge of the peatland area.

The Leatherleaf breeding female was clearly pregnant at the end of the winter and gave birth to an unknown number of pups in the spring. However, in mid-July 2023 she was struck and killed by a vehicle on Highway 53 just southeast of Ericsburg. We will be curious to see if and how her death affects the rest of the pack in the coming months.

A pup in the Leatherleaf Pack in December 2022. Several of the wolves in the Leatherleaf Pack, including this pup, appeared to have mange in Winter 2022-2023.



LIGHTFOOT

In January 2022, the breeding male of the Lightfoot Pack, Wolf V071, was killed by other wolves. The pack seemed to persist through the winter, though members of the pack appeared to be only loosely associated with one another and the pack did not produce pups in Spring 2022. As of early Spring 2022, we were uncertain if the Lightfoot Pack was still a social group or if the pack had completed dissolved. Then, in May and June 2022, we captured and collared three yearlings from the Lightfoot Pack (Wolves P2L, B3S, and B4D; Wolves P2L and B4D had PIT-tags from when they were tagged as pups). Wolf P2L died in July 2022 due to unknown causes but Wolf B3S and B4D remained in the Lightfoot territory through Winter 2022-2023.

The GPS-collar data from these two wolves along with trail camera data clearly indicated that the Lightfoot Pack was still in existence during Winter 2022-2023. Indeed, the Lightfoot Pack was 4 wolves strong—Wolf B3S, Wolf B4D, a younger male, and an older-looking female—and we had 9 independent observations of the pack at this size throughout the winter survey period.

Interestingly, for much of the winter, Wolf B4D remained in the Lightfoot territory but rarely associated with other pack members. Then, in March 2023, B4D dispersed northward into Canada and left the pack. However, the other 3 pack members associated with one another often based on trail camera footage.

We surmise that the younger uncollared male in the pack was the sibling of B3S, B4D, and P2L, and it is very likely that the older female is the mother of all these wolves and V071's former mate. The Lightfoot Pack did not produce a litter of pups in Spring 2023 for the second year in a row and there was never any indication that any females in the pack were pregnant. This supports our assessment regarding the social composition of the pack (a mother and her offspring). Otherwise, we would have expected the young male to mate with one of the females in the pack.

In May 2023, we collared the young male in the pack, who is now dubbed Wolf Y4D. Y4D has been made several long forays away from the Lightfoot territory throughout the summer and will almost certainly leave the territory for good in the near future—more evidence that he is a subordinate young male and the offspring of the older female in the pack. Otherwise, if he was unrelated, it would be hard to imagine that he, as the only male in the pack, would leave in search of another mate and vacant territory when he already had both.

1 *Two yearling wolves of the Lightfoot Pack on a frozen beaver pond in March 2023. Wolf B3S, a yearling female, is staring at the camera and the other wolf is her brother, Wolf Y4D, who we collared in May 2023.* 2 *Wolf B4D, a yearling female of the Lightfoot Pack, in August 2022.*

LISTENING POINT

Sometime during Spring to Fall 2022, the Listening Point Pack took over the former Shoepack Lake territory on the eastern portion of the Kabetogama Peninsula. This part of Voyageurs National Park is very remote and getting substantial footage of wolves in this area is quite difficult. As a result, we are not certain of exactly what occurred here (e.g., did the Listening Point Pack oust Shoepack Lake? Did V036, the Shoepack Lake breeding female die, and the Shoepack Lake Pack dissolve?).

However, we collected good data on the size of the Listening Point Pack this past winter. The pack was 3 wolves and we had 11 independent observations of the pack at this size. The pack appeared to consist of a breeding pair and a younger subordinate wolf. Notably, this subordinate did not look to be a pup.

The pack appeared to be larger in December than it was the rest of the winter as we had two observations of 5 wolves and one observation of 4 in December. However, all other observations during January to April were of 3 wolves except for one observation on March 11, 2023. Given this, we think it is clear that the pack was 3 wolves for the vast majority of our winter survey period.

In late March and early April 2023, the breeding female of Listening Point (LP_BF) was clearly pregnant indicating the pack produced its first litter of pups in their current territory in April 2023.

1 The Listening Point Pack in early January 2023. The pack was 3 wolves for most of the winter but we had a few observations in early winter—including this observation—showing 4 or 5 wolves in the pack, indicating the pack was larger in early winter but had decreased in size by mid-winter. 2 The breeding female of the Listening Point Pack.

MITHRANDIR

Sometime around December 4-6, 2022, Wolf V083, the breeding male of Cranberry Bay from 2019 to 2022, voluntarily left or was forced out of the Cranberry Bay Pack, just a few short days after the breeding male of the Nashata Pack disappeared and presumably died (see summary of Cranberry Bay Pack and Nashata Pack).

V083 promptly formed the Mithrandir Pack on December 6 or 7, 2022 which consisted of two subordinate wolves from the Cranberry Bay Pack and the yearling female from the Nashata Pack (NS_SUB1). We had 18 observations of these 4 wolves traveling together throughout the remainder of the winter survey period. All observations of the Mithrandir Pack were in or on the periphery of the Nashata Pack territory, and we did not have any observations of this pack in the interior of the Cranberry Bay territory.

As such, the Mithrandir and Nashata Packs had substantial spatial overlap during the winter survey period and we often observed both packs using the same areas, though it appeared Mithrandir's territory expanded eastward more than Nashata's. Perhaps Nashata tolerated Mithrandir's presence because the yearling female from Nashata was part of Mithrandir, and two presumably Cranberry Bay subordinates—and likely offspring of V083— were part of Nashata.

Interestingly, the Mithrandir Pack did not produce a litter of pups in Spring 2023, though it was apparent that V083 and NS_SUB1 were a pair. Contrastingly, Nashata did have a litter of pups in Spring 2023 and we would suspect that Nashata will likely be the dominant pack in this territory going forward.

1 The dominant female of the Mithrandir Pack who was a yearling subordinate wolf in the Nashata Pack until December 2022 when she paired with Wolf V083 and formed the Mithrandir Pack. 2 A subordinate wolf in the Mithrandir Pack traveling shortly after a snowstorm in late December 2022. 3 The dominant pair of the newly-formed Mithrandir Pack: Wolf V083 (left), the former breeding male of the Cranberry Bay Pack, and the yearling female from the Nashata Pack (right).

NASHATA

Up until December 4, 2022, the Nashata Pack consisted of the original breeding pair (NS_BF and NS_BM) and a yearling female (NS_SUB1). We had this trio on camera numerous times throughout the summer and fall. However, sometime during December 4-6 the breeding male of Nashata disappeared. The last video of the Nashata breeding male was on December 3 and in that video he looked healthy, mobile, and dominant. Given all the evidence, we think it most likely that this breeding male was killed by other wolves (likely Cranberry) around December 4-6. His death set large changes in motion (see Cranberry Bay and Mithrandir summaries).

By December 7, the yearling female of Nashata had left and joined the Mithrandir Pack. The breeding female disappeared temporarily but then re-appeared on February 21 and resumed patrolling the Nashata territory with two other wolves, who were very likely former Cranberry Bay subordinates. We had a total of 8 independent observations of these three wolves traveling together from February 21 to April 10. All signs indicate that the re-configured Nashata Pack is still occupying the same territory as the pack has in the past.

The breeding female of Nashata was clearly pregnant in late March and early April. Additional observations in May and June show she had distended nipples and was lactating, indicating she was nursing her third litter of pups as the Nashata breeding female (she produced pups in 2021, 2022, and 2023).

1 The Nashata Pack in November 2022 just weeks before we think the breeding male of the Nashata Pack was killed by other wolves. In this photo, the breeding female is on the right, the subordinate yearling female in the middle, and the breeding male on the left. 2 The breeding female of the Nashata Pack in May 2023 with a subordinate pack member in the background. The breeding female is easily identified by her unique coat coloration and the distinctive notch in her left ear. 3 The yearling subordinate female of the Nashata Pack jumping over a creek in November 2022 with the breeding female in the background. The yearling female left the Nashata Pack a few weeks after this photo and formed the Mithrandir Pack with Wolf V083, the former breeding male of the Cranberry Bay Pack.

PARADISE

The Paradise Pack was 4 wolves strong this past winter: the breeding male (V077) and female (V085), a subordinate yearling male (W2L) and a pup. We are very confident in the size of this pack as we had 32 independent observations of 4 wolves during our winter survey period—the most of any pack we studied. The Paradise Pack had 5 pups in Spring 2022 based on fortuitous trail camera footage we captured of the pack moving the pups. However, only one of those pups survived and trail camera evidence suggests the other 4 pups died by June or early July 2022.

Curiously, Wolf V085 disappeared in late winter and the last observation we had of her was on March 25 when she was traveling with V077 and the pup. In that video, she appeared to be pregnant with her 4th litter as the Paradise breeding female and appeared to be in good physical condition. After March 25, we had numerous videos of V077, W2L, and the pups providing strong evidence that V085's absence was due her genuine disappearance and not a lack of detection on cameras (i.e., that she was around but we just did not happen to catch her on camera).

Given all of this, we think it highly likely that V085 was either killed by other wolves or died due to human-causes (e.g. vehicle strike, illegal killing). Despite her absence, the Paradise Pack appears to persist with V077 continuing to patrol and maintain the territory, though W2L dispersed from the pack in Summer 2023. There is even some evidence suggesting that V077 might have found a new mate but time will tell if this is indeed the case.

1 The only pup from the Paradise Pack's 2022 litter that survived. This photo is from April 2023. 2 Wolf V085, the breeding female of Paradise Pack, in March 2023. We believe V085 died shortly after this observation as she has not been captured on any camera since late March 2023. 3 Wolf W2L, a yearling male in the Paradise Pack, in December 2022.

1

STUB-TAIL

The Stub-tail breeding pair successfully raised three pups to Fall 2022, however, by early winter the pack was down to four members: the breeding male (ST_BM), the breeding female (ST_BF, aka Stub Tail), and two pups (ST_SUB1 and ST_SUB2). We had 7 independent observations of 4 wolves in this territory during the winter and did not have any observations of more than 4 wolves during the winter survey period. We do not know what became of the third pup that survived to the fall. As an interesting anecdote, we captured many observations of the breeding female traveling by herself during winter, which seemed unusual relative to other packs. However, the pack clearly was still a cohesive unit by early spring and the breeding female was clearly pregnant and then nursing in April.

2

3

1 The breeding female of the Stub-tail Pack in early 2023. The pack was named after this breeding female's deformed, "stubby" tail. 2 The breeding male of the Stub-tail Pack (left) with a pup (right) in April 2023. 3 The Stub-tail Pack in November 2022. The breeding female scent-rolled while one of her pups stood nearby and investigated. The pack had 5 members in November 2022 but by mid-winter was down to 4 members.

The breeding female of the Tilson Creek Pack in March 2023.

TILSON CREEK

This was the first year we surveyed the Tilson Creek Pack with trail cameras. In previous years, we had opportunistically counted tracks while cross-country skiing but we had not made any attempts to rigorously study the pack. We had a late start documenting this pack due to camera failure issues and were only able to deploy cameras in the territory starting in late February. Despite this, we were able to capture over 20 observations of the pack and 13 independent observations of 4 wolves traveling together. Given that this was our first year studying this pack, we know very little about these four members or how long the pack has existed.

We were able to determine from trail camera observations that the pack consisted of a breeding pair and two pups, born in Spring 2022. The breeding female of the pack (TC_BF) appears to be an older wolf, particularly relative to the breeding male (TC_BM). The breeding male may have suffered from a mild case of mange in late winter and had very short fur above the shoulder blades. This combined with the wolf's long guard hairs on the back of the neck gave him a sort of lion's mane appearance towards the end of March. The next generation of the Tilson Creek Pack were likely born this spring as the breeding female was clearly pregnant towards the end of the winter.

VERMILION RIVER

The breeding male of the Vermilion River Pack, Wolf B2L, was a subordinate member of the Bug Creek Pack in 2022. For much of Summer 2022, B2L was only loosely associated with Bug Creek. From time to time he would associate with other pack members such as Wolf B5E, the breeding male of Bug Creek, but for much of the time he remained around the territory periphery or just outside of the Bug Creek territory. By Fall 2022, he somehow became the breeding male of the pack/territory easterly adjacent to the Bug Creek territory. We do not know how this happened. Did he oust another breeding male and take his mate? Did he meet a lone female and settle in a vacant territory? We will never know the answer.

Either way, B2L is now leading the Vermilion River Pack which was three wolves strong this past winter: B2L, the breeding female (VR_BF), and a subordinate 1-2 year old male (VR_SUB1; clearly not a pup). We had 19 independent observations of these three wolves during the survey period this year and no observations of more than 3 wolves traveling together. All this to say, we had surprisingly good data on this "new" pack that occupies a remote part of the GVE.

1 The breeding female of Vermilion River in mid-winter. She has a distinctive dark marking on the left side of her muzzle, which make her easy to identify. 2 *The breeding pair of the Vermilion River Pack in late April 2023. In front is Wolf B2L, the breeding male, and in the background the breeding female, who was clearly nursing pups at this point based on her distended nipples.*

1

WHISKEY POINT

The Whiskey Point Pack has been a rather difficult pack for which to collect substantive data. Their territory occupies one of the more inaccessible areas in the GVE and there are only a few short human trails through the territory. As such, there are not many places to deploy cameras. Nonetheless, we were able to get sufficient data on the pack this winter to determine pack size. The Whiskey Point Pack was down to just two wolves, a breeding pair, this past winter. We had 5 independent observations of the pack at this size. We had several observations of this pack in the fall where the breeding pair was accompanied by a younger subordinate, likely a 1.5-2.5 year old wolf. However, that third wolf was not around by the onset of the winter survey period. The breeding female of Whiskey Point (WP_BF), who is easily identifiable because she is missing the tip of one of her ears, was clearly pregnant in late March, indicating the pack produced a litter of pups in Spring 2023.

2

1 *The breeding pair of the Whiskey Point Pack crossing a frozen beaver dam and pond in late March 2023. The breeding male is on the left and the breeding female on the right.* 2 *A yearling wolf from the Whiskey Point Pack that remained with the pack until late summer or early fall in 2022. This wolf was not observed with the pack during Winter 2022-2023.*

WINDSONG

The Windsong Pack lost 3 of its 5 members—two subordinate yearlings (Pup59 and Pup60) and a subordinate 2-year-old wolf O0C—in Spring and Summer 2022 for depredation management reasons on the Sheep Ranch. The only two remaining members were the breeding male and female (Wolves V087 and O4D, respectively) and their new litter of pups born in Spring 2022. We visited the Windsong Den in May 2022 and counted/tagged 4 pups. However, the pups were not in a traditional den when we found them but rather just laying around in an extremely dense balsam fir stand so we thought it likely there were some pups that evaded detection.

That intuition was correct as the Windsong Pack was 7 wolves this past winter: the breeding pair and 5 pups. We had exceptional data on this pack with 26 independent observations of these wolves during our winter survey period. We also had several observations in Fall 2022 of 5 pups traveling together and then all 7 wolves together too.

In Spring 2023, we collared 3 of these 5 pups who were now yearling wolves (Wolves O3S, B7D, and O7T). Only 1 of the 3 wolves had been tagged as a pup which indicates the pack produced a minimum of 6 pups in Spring 2022 (we tagged 4 as pups and then collared 2 that were untagged). Supporting this assessment is an observation from Wes Johnson, owner of the Sheep Ranch, who said he saw a dead wolf pup along Sheep Ranch Road roughly 2 miles east of the Sheep Ranch—right in the center of the Windsong territory— in September 2022. This pup appeared to have been hit by a vehicle.

The Windsong Pack gave birth to another litter of pups in Spring 2023, which is not surprising as Wolf O4D was clearly pregnant in late winter. This was the third litter of pups she and Wolf V087 have produced.

1 Three Windsong Pack pups in early 2023. 2 Wolf V087, the breeding male of the Windsong Pack, in early 2023. 3 Three Windsong Pack members in early Winter 2022-2023: Wolf V087– the breeding male– and two pups. Wolf V087 is the wolf staring at the camera.

WIYAPKA LAKE

The Wiyapka Lake Pack started out in early winter with 6 members: the breeding male (WL_BM), the breeding female (V076, whom we've studied intensively in the past), a 1.5-year-old subordinate, two pups (WL_SUB1 and WL_SUB2), and an older female (WL_OF) who seems to have joined the pack sometime in the last year. WL_OF was a surprising addition as older wolves rarely join established packs like Wiyapka Lake. Interestingly, we had two observations of this older female submitting to both WL_BM and V076 during the winter. Clearly, she is a subordinate member but her history and backstory are unknown.

By early-to-mid December, the 1.5-year-old subordinate wolf likely dispersed like his littermates, Wolves R1T and R2L, did a few months earlier. Although the wolf could have died, we suspect dispersal is much more likely as this subordinate wolf only appeared to be traveling with the pack periodically throughout fall and early winter. Indeed, we had numerous observations of the pack during this time without this wolf.

Regardless, the pack decreased to 5 wolves in early winter and remained 5 wolves for the rest of the winter. We had 18 independent observations of the pack at 5 wolves throughout the winter survey period. By late March, V076 was clearly pregnant and subsequent footage in April and May confirmed that she had given birth and was nursing pups.

1 All 5 members of the Wiyapka Lake Pack. 2 The breeding male of the Wiyapka Lake Pack carrying a deer leg back to the den in April 2023.

METHODS

Pack Size

We estimated pack size using remote trail cameras during our winter monitoring period which we defined as December 1 to April 11. We considered the end of the winter monitoring period as April 11 because that is average parturition date for wolves in the GVE and when we would generally expect packs to stop traveling as a cohesive social group. Our objective was to get repeated independent observations of the same pack at the same size during the monitoring period. We considered observations to be independent if they were on a different day than any other observations of that pack. Multiple independent observations of the same size for each pack provides highly-reliable and accurate pack size estimates. Generally, we considered $\geq$3 independent observations of the same size to be a reliable pack count.

Estimating home ranges

To estimate home ranges, we caught wolves via rubber-padded foothold traps and fit them with GPS-collars. All capture and handling of wolves was approved by the National Park Service's and University of Minnesota's Institutional Animal Care and Use Committee (protocols: UMN 1905-37051A).

We primarily estimated home range size for wolf packs using GPS-collar data from May 1 to October 31. Wolf pack home ranges in the GVE appear more stable in summer (the ice-free period) than they are in winter. During winter, wolf home ranges in the GVE are prone to small shifts and changes and are less stable than they are in the summer, likely because wolf movements change based on where deer congregate and on intraspecific pressures from neighboring packs. Wolf home ranges appear to stabilize during spring to fall because deer are likely more dispersed across their territory and intraspecific competition is lowest during the summer (Mech and Barber-Meyer 2017)

Furthermore, most wolves studied during summer are fitted with GPS-collars that take locations every 20 minutes during the summer period before the collars switch to taking 6 hour locations. Wolves fitted with collars that take 20-min fixes yield high-resolution GPS-collar data on wolf movements during summer, which is ideal for estimating home ranges and certainly superior to using longer fix-interval GPS data from the winter. That said, GPS-location data was limited for some wolves during summer for a variety of reasons including fall capture dates and collars with sustained low fix rates (12 or 24 hr). In these scenarios, we estimated home ranges using winter locations or a combination of summer and winter locations.

We used locations from GPS-collared wolves to estimate kernel home ranges for each pack (Fig. 2). More specifically, we used 99% kernel home ranges for wolves with 20-min-fix-interval GPS-collars and then 95% kernel home ranges for wolves with GPS-collars that had longer fix intervals (most others had 4, 6, or 12 hr-fix-interval collars). We calculated home ranges differently because the data from wolves with 20-min-fix-intervals had substantially higher resolution than collars with longer fix intervals. Thus, the periphery of territories was much clearer because of the amount of GPS-location data (~2,180 locations/month). As a result, kernel density home ranges fit the location data exceptionally well and a 99% kernel home range was more representative of than a 95% home range. With longer fix-intervals, however, there was more uncertainty due to substantially fewer GPS-locations and we decided a 95% kernel home range was more appropriate. We removed locations associated with extra-territorial forays prior to developing kernel density home ranges (Burch et al. 2005, Powell and Mitchell 2012, Mancinelli and Ciucci 2018).

We removed the area of kernel home ranges that overlapped the 4 large lakes—Kabetogama, Rainy, Namakan, and Sand Point— in the Greater Voyageurs Ecosystem (Fig. 2). Wolves do not use the large lakes as part of their home range during the ice-free periods (~April to November) and rarely, if ever, swim out to the islands in these large lakes. Thus, these lakes are hard territorial boundaries for most of these packs for the majority of the year (~April to November). Even when ice forms, wolves spend relatively little time out on the ice with most activity on the ice near the shorelines of these major lakes or on the small islands close to the mainland. As such, removing any territory overlap with these major lakes seems more logical than including territory that overlaps the lakes. Notably, we did not remove the area of smaller lakes that were entirely contained within pack territories.

Quantifying home range overlap

Although wolves are highly territorial, wolf pack home ranges frequently overlap to some extent (Fig 2). When using metrics such as mean pack and home range size to estimate density, quantifying home range overlap is necessary to avoid underestimating density (Erb and Humpal 2020). However, for most wolf pack home ranges, we only had partial knowledge of neighboring packs (i.e., we did not have current home range data for each pack every year) so we used an approach that allowed us to account for overlap when estimating density without having perfect knowledge of all home range overlap in our study area (Gable et al. 2022).

Our approach consisted of calculating the average spatial overlap of one home range on another using all available home range data for a given year (we refer to this metric as 'pack-on-pack overlap' hereafter). We then estimated the number of neighbors that known wolf pack home ranges likely had using a combination of known and historical wolf pack territory locations. We then multiplied pack-on-pack overlap by the average number of neighboring packs to yield the average home range area that a typical wolf pack overlaps with other wolf packs. To incorporate this into density estimates, we divided the spatial overlap by two (i.e., because two packs shared the area of overlap) and subtracted the result from the average home range size (see equation below). In a few instances, 3 pack home ranges overlapped but the area of the overlap was minor (<1-2 km^2) so we were not concerned about incorporating this into our estimates as it would have little-to-no effect (Fig. 2).

Calculating density

We calculated wolf density (wolves/1000 km^2) using data on pack size, home range size, and pack-on-pack overlap. Specifically, we used the following equation:

$$Density = \frac{PS \div \left(HR - \left(\frac{Ovlp * Nb}{2}\right)\right)}{0.85} * 1000$$

where PS is mean pack size, HR is mean home range size, Ovlp is mean pack-on-pack overlap, and Nb is the mean estimated number of neighboring packs that a typical wolf pack has. We estimated that lone wolves constituted 19.6% of the population (see detailed discussion above) and thus divided the density of pack wolves (which is calculated via the numerator in the equation above) by 0.804 to yield overall wolf density (Gogan et al. 2004, Erb and Humpal 2020).

We used a non-parametric bootstrapping approach to obtain 95% confidence intervals for our density estimates (Fieberg et al. 2020)that residuals are Normally distributed, have constant variance, and cases are independent. To do this, we generated 1,000 plausible values, given the data collected, for each parameter (HR, PS, Ovlp, Nb) by doing 1,000 bootstrapping iterations (i.e., resampling with replacement). We calculated density using the values generated during each bootstrap iteration to yield 1,000 plausible density estimates. We then selected the 2.5% and 97.5% highest density values for our 95% confidence interval (Gable et al. 2020). We used simple linear regression to assess whether there was any trend or change in annual pack size, home range size, or density with time during 2012-2023.

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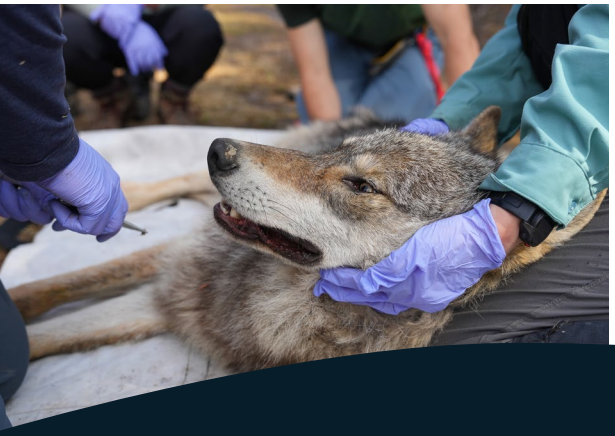

2023 VOYAGEURS WOLF PROJECT