DISTRIBUTION AND ABUNDANCE OF WOLVES IN MINNESOTA, 2024-25

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At the time wolves were federally protected in the mid-1970s, Minnesota contained the only known reproducing wolf population in the lower 48 states, except for that on Isle Royale. Over the years, much attention has been focused on studying and monitoring Minnesota's wolves. Research efforts began in the mid-1930s (Olson 1938) and continued with few lapses to this day. Efforts to delineate wolf distribution and enumerate populations have also been made at various times over the last 50 years (Erb and DonCarlos 2009, Erb et al. 2018).

Early estimates of Minnesota's wolf population, often derived from bounty records and anecdotal information, were by necessity subjective. With the advent of radiotelemetry, geographic information systems (GIS), and global positioning systems (GPS), more detailed monitoring and mapping of wolf populations have been possible. However, financial and logistical considerations often limit intensive monitoring to small study areas.

Enumerating elusive carnivore populations over large areas remains a difficult task, particularly in forested landscapes (Kunkel et al. 2005). Complete territory mapping (Fuller and Snow 1988, Burch et al. 2005) is usually not possible over large areas, though various sampling designs can be considered (Potvin et al. 2005). Use of standard mark-recapture methods may not be practical given the difficulties of capturing and recapturing sufficient samples. However, genetic mark-recapture methods have recently been applied to wolves (Marucco et al. 2009) but may also be impractical over large areas. Population estimation approaches based on prey or habitat assessments (e.g., Fuller 1989, Boyce and Waller 2003, Cariappa et al. 2011) may be useful for estimating potential abundance of large carnivores but may not always match realized abundance due to other time-varying factors that may limit populations (e.g., disease, weather, lagged responses to changes in prey). Aerial sampling methods exist (Becker et al. 1998, Patterson et al. 2004) but may be logistically challenging when applied to broad expanses of dense forest. Initial evaluation of these aerial snow-tracking methods in Minnesota was not promising (J.E., unpublished data). Increasingly, remote trail cameras are being used to assist in monitoring carnivores at large scales, with recent (Ianarilli et al. 2021) and ongoing research in Minnesota exploring expanded adoption of these methods.

Since the late-1970s Minnesota has monitored its statewide wolf population using an approach that combines attributes of territory mapping with an *ad hoc* approach to determine the total area occupied by pack wolves. The methods employed have changed only slightly during this time. During 1978-1998, surveys were conducted at 10-year intervals. During 1998-2012, surveys were conducted at approximately 5-year intervals, in part for consistency with the survey timeline specified in the Minnesota Wolf Management Plan (first and fifth year after delisting; Minnesota Department of Natural Resources 2001). Results indicated a geographically and numerically expanding population through the 1997-98 survey, with little geographic expansion from 1998 to 2007 (Erb and DonCarlos 2009) and only slight geographic expansion between 2007 and 2018 (Erb et al. 2018). These results have been coarsely consistent with separate wolf population trend indicators in Minnesota (i.e., annual scent station survey, winter track survey, and number of verified depredations).

In 2012, wolves in the Great Lakes Distinct Population Segment were removed as a listed species under the federal Endangered Species Act (ESA). From 2012 to 2014, a regulated public harvest of wolves was allowed, with annual harvests in Minnesota ranging from 238 to 413 wolves. As a result of a court ruling in late-2014, ESA protections were reinstated on wolves in the Great Lakes and no public harvest of wolves has since occurred in Minnesota. Beginning in 2012, the Minnesota Department of Natural Resources (DNR), with assistance from numerous collaborators, began deriving wolf population estimates annually. However, one component of the surveys - delineation of total and pack-occupied wolf range (defined below) - is still being re-assessed only at ~5-year intervals, as was the case from 1998 to 2018. Winter 2024-25 marks the 7th year since wolf range has been re-assessed, and re-assessment of wolf range was included in this winter's wolf survey.

METHODS

The approach we used to delineate wolf distribution and estimate population size was essentially identical to the previous 6 wolf range surveys (Fuller et al. 1992, Berg and Benson 1998, Erb and Benson 2004, Erb 2008, Erb and Sampson 2013, Erb et al. 2018), and conceptually like the 1978-79 wolf range survey (Berg and Kuehn 1982). Primary cooperators were similar to previous wolf range surveys and included natural resources staff within: 1) MNDNR; 2) U.S. Forest Service; 3) U.S. Fish and Wildlife Service; 4) U.S. Department of Agriculture - Wildlife Services; 5) U.S. Geological Survey; 6) Tribal and Treaty resource authorities; 7) County Land Departments; 8) Camp Ripley Military Facility; 9) Voyageurs National Park; and 10) various University collaborators and research projects.

We mailed instructions to participants in October 2024 and asked them to record a location and group size estimate for all wolf sign (e.g., visual, track, scat) observed during normal work duties from November 2024 until snowmelt the following spring (~ mid-May 2025). Participants could provide locations on paper forms or maps, but most data were entered directly by participants in a web-based GIS survey application. As in previous wolf range surveys, we used the Public Land Survey township (~93 km^2, with some exceptions) as the spatial scale for assessing pack-occupied range.

Although recorded estimates of wolf group size are not used directly for population enumeration, the assessment of township-specific wolf occupancy, as discussed below, treats observations of single wolves differently than pack (>1 wolf) detections. We conservatively assumed group size to be 1 in situations where wolf sign was recorded but no group size was noted, or where a range was recorded that included 1 (e.g., 1-2 wolves). If group size was recorded as 'numerous', it was set to 2 (i.e., a pack). We then combined this database with wolf observations recorded on other wildlife surveys during 2024-25 (e.g., carnivore scent station survey, furbearer winter track survey, moose/deer/elk surveys, trail camera projects, 2024 wolf depredation removal data, etc.). This combined database is hereafter referred to as 'WISUR25'. Wolf detections from these same sources, but from 2020-23, were also consulted for purposes of delineating total wolf range, but they were not used in any assessment of townships currently occupied by wolf packs and are not part of the WISUR25 database.

Delineation of both total range and occupied range includes, but is not limited to, consideration of whether townships meet human and road density criteria defined by Fuller et al. (1992; i.e., townships within wolf range are presumed to be occupied by wolves if road density is <0.7 km/km^2 and human density is <4/km^2, or if road density is <0.5 km/km^2 and human density is <8/km^2; hereafter termed 'modeled' townships). As in previous surveys, human density was calculated using the most recent (i.e., 2020) U.S. Census Data as incorporated into the 2020 Minor Civil Divisions (MCDs) GIS layer produced by the Minnesota Legislative Coordinating Commission. Because census population data are reported by MCDs rather than public land survey townships, population values for MCDs intersecting multiple townships were evenly divided among all intersecting townships. Road density calculations were based on the Minnesota Department of Transportation's 1:24,000 GIS roads layer, excluding forest roads based on route system classifications, and summarized within each township as kilometers of road per square kilometer. These density metrics were subsequently used to classify townships according to established wolf habitat suitability thresholds.

Delineation of total wolf range is intended to encompass those areas within the state where consistent or sufficient wolf detections occur (either singles or packs) more than might be expected from 'random' temporally irregular dispersals. Total wolf range depicts the coarse distribution of wolves within the state and is useful for documenting larger-scale expansions or contractions of wolf range. Although Minnesota's wolf range has expanded south and west since the 1970s, it has remained essentially contiguous with the Canadian border to the north and Lake Superior and Wisconsin to the east. Because systematic searches for wolf sign are not conducted and much of the southern and western periphery of wolf range in Minnesota is private land, there is some subjectivity in the approach used to delineate the south and west boundary. Using the previously delineated boundary as the reference point, we re-evaluated the south and west border based on the following data: 1) all WISUR25 observations; 2) modeled townships; 3) land use and cover; and 4) other detections or knowledge of wolf activity in the area from 2020-23 (e.g., wolf depredation sites, track survey detections). While maintaining a contiguous total wolf range, the overall approach is designed to maximize inclusion of areas with periodic (since last survey) or recently abundant wolf observations and modeled townships, while minimizing inclusion of areas that neither fit the model nor contained numerous or consistent wolf observations.

We computed occupied range by subtracting from the total range all townships that contained neither current observations of a pack (defined as >1 animal) nor fit the human-road density model criteria. We also fully excluded lakes larger than 200 km^2 (n = 5) from calculations of both total and occupied range.

To radio-collar wolves for use in estimation of territory and pack sizes, we and various collaborators captured wolves using foothold traps (LPC # 4, LPC #4 EZ Grip, or LPC #7 EZ Grip) approved as part of research conducted under the Association of Fish and Wildlife Agencies Best Management Practices for trapping program. In addition, numerous wolves were captured using live-restraining neck snares during winter (Gese et al. 2019). Wolves were typically immobilized using a mixture of either Ketamine:Xylazine or Telazol:Xylazine. After various project-specific wolf samples and measurements were obtained, the antagonist Yohimbine was typically administered to animals prior to release. Various models of radio-collars were deployed depending on study area and collar availability. GPS radio-collars were programmed to take a minimum of 4 locations per day.

To estimate average territory size, we delineated territories of radio-collared packs using minimum convex polygons (MCP) for consistency with previous surveys. Prior to delineating wolf pack territories, we removed 'outlier' radiolocations, which loosely included 1) individual locations >5 km from other locations (Fuller 1989); 2) movement paths if the animal did not travel to that area on multiple occasions and if use of the path would have resulted in excessive inclusion of unused areas in the MCP; and 3) for consistency with the way in which the data is used (i.e., to estimate number of packs under the assumption of minimal overlap), locations that result in notable overlap with adjacent territories. Additional subjective deviations were made when deemed biologically appropriate by the collaborator monitoring the specific pack.

In past surveys where many territories were delineated using VHF radiolocations, territory sizes were increased 37% to account for the average amount of interstitial space between wolf pack territories as estimated from several Minnesota studies (Fuller et al. 1992:50) where the number of radiolocations per pack typically averaged 30-60. Interstitial spaces are a combination of small voids created by landscape geometry and wolf behavior but are much more likely to be an artifact of territory underestimation when there are comparatively sparse radiolocations. Hence, for packs with <100 radiolocations, our current methods still multiply the area of each estimated territory by 1.37 as in the past. However, during the current survey, all packs (n=42) had >100 locations (mean number of radiolocations = 2,649) and all territories were assumed to be fully delineated and were not re-scaled.

To estimate the number of packs within occupied wolf range, the area of pack-occupied range is divided by average scaled territory size. The estimated number of packs is then multiplied by average mid-

winter pack size to produce an estimate of pack-associated wolves, which is then divided by 0.85 to account for an estimated 15% lone wolves in the population (Fuller et al. 1992:46, Fuller et al. 2003:170). Specifically,

N = [(km^2 of occupied range/mean scaled territory size)*mean pack size]/0.85.

Using the accelerated bias-corrected percentile method (Manly 1997), the 90% confidence interval for population size was generated from 9,999 bootstrapped re-samples of the pack and territory size data and does not incorporate uncertainty in the estimates of occupied range or percent lone wolves.

RESULTS

A total of 947 opportunistic wolf sign observations were recorded during the winter 2024-25 wolf range survey (Figure 1), 41% fewer than in 2017-18. Observations consisted of 54% tracks, 10% visuals, 8% scats, and 28% other (howls, deer kills, depredation sites, agency trail cameras, etc.).

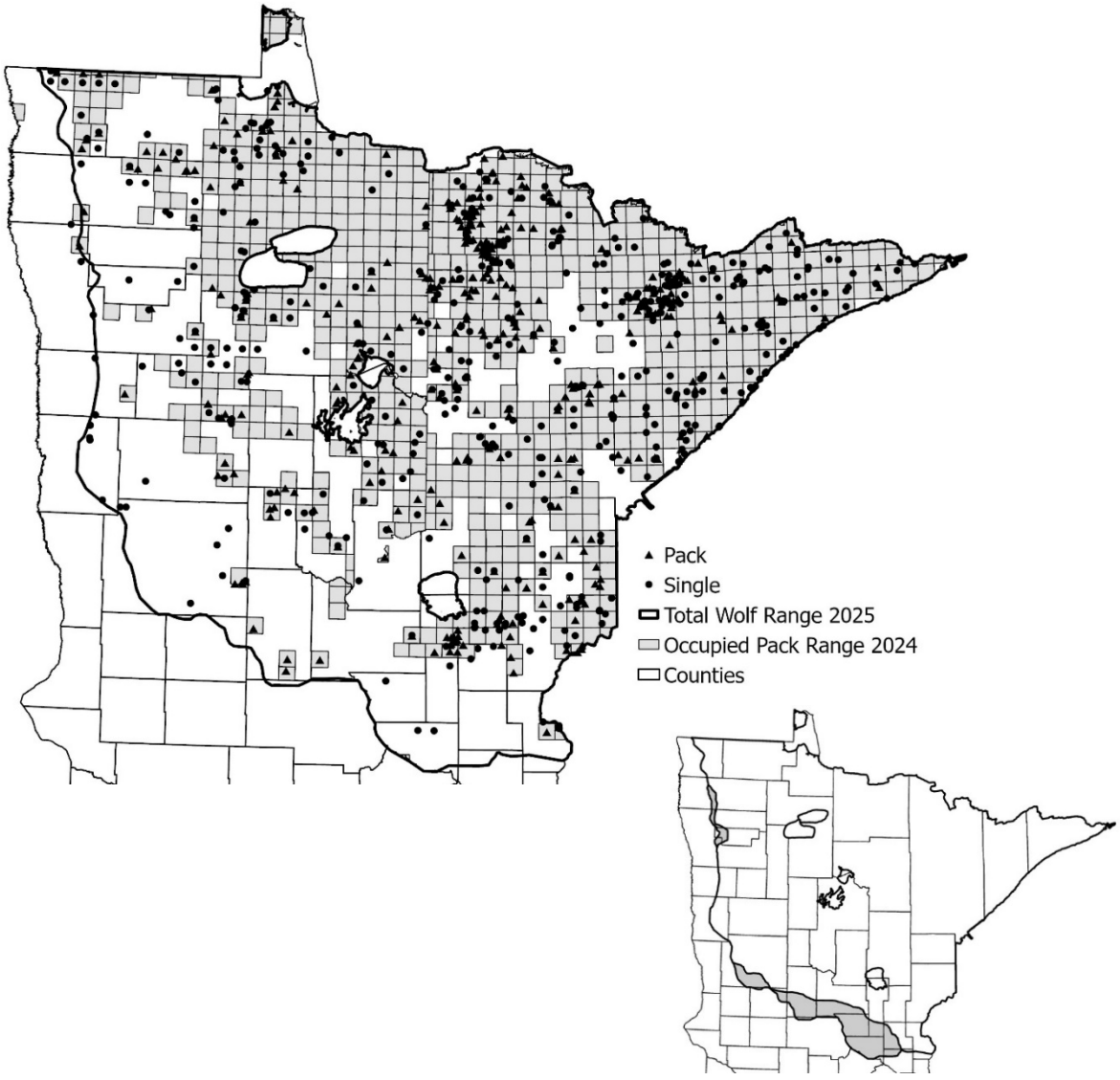

Figure 1. Wolf sign observations, total wolf range, and occupied townships delineated as part of the 2024-25 winter wolf survey in Minnesota. Gray area in smaller inset highlights new area included in total wolf range since 2018.

Distribution

We evaluated potential shifts in total wolf range by examining available information near the southern and western edge of the previously delineated wolf range boundary. Though only a small percentage of the observations were outside the previously delineated range, we opted to extend the range line in a couple areas, particularly in central Minnesota, to include areas where multiple packs were detected this winter. Revised total wolf range was estimated to be 118,612 km^2, an increase of 6% from 2018 (Figure 1, Table 1).

After removing townships within the revised total range that neither met human-road density model criteria nor contained pack observations this winter, estimated pack-occupied range was 67,464 km^2 (Fig. 1), an ~9% decrease from the 2017-18 survey (Figure 1, Table 1). Of the total estimated pack-occupied range, 43% was confirmed to be occupied based on pack detection in the township, and 57% was presumed to contain packs because of low human and road density (i.e., modeled townships; Table 1). Of all the townships in wolf range that contained current pack detections, 30% had higher human and/or road density than the thresholds in the road-human density model currently used (Table 1).

Table 1. Comparison of Minnesota wolf range assessments, 1988 – 2025.

	1988/89	1997/98	2003/04	2007/08	2012/13	2017/18	2024/25
Total Wolf Range (km^2)	60,229	88,325	88,325	88,325	95,098	111,862	118,612
Occupied Range (km^2)	53,100	73,920	67,852	71,514	70,579	73,972	67,464
% Pack-Occupied Range confirmed by pack detection in township	55	84	54	68	70	66	43
% Pack-Occupied area with pack detection that exceeds human/road density thresholds [a]	11	17	19	20	30	27	30
Wolf Population Density (wolves/100 km^2)	2.9	3.3	4.5	4.1	3.1	3.6	3.4

[a] thresholds from Fuller et al. (1992)

Pack and Territory Size

We obtained sufficient location data to generate territories for 42 packs (Figure 2); their collective territory area represented 9% of pack-occupied wolf range. Winter pack size counts were obtained for 34 of those packs. A land cover comparison using the 2019 National Land Cover Database suggests that the location of collared packs this winter reasonably represented cover types in overall pack-occupied range, with the most deviation stemming from collared packs occurring in areas with more deciduous forest and less hay/pasture/cropland (Table 2).

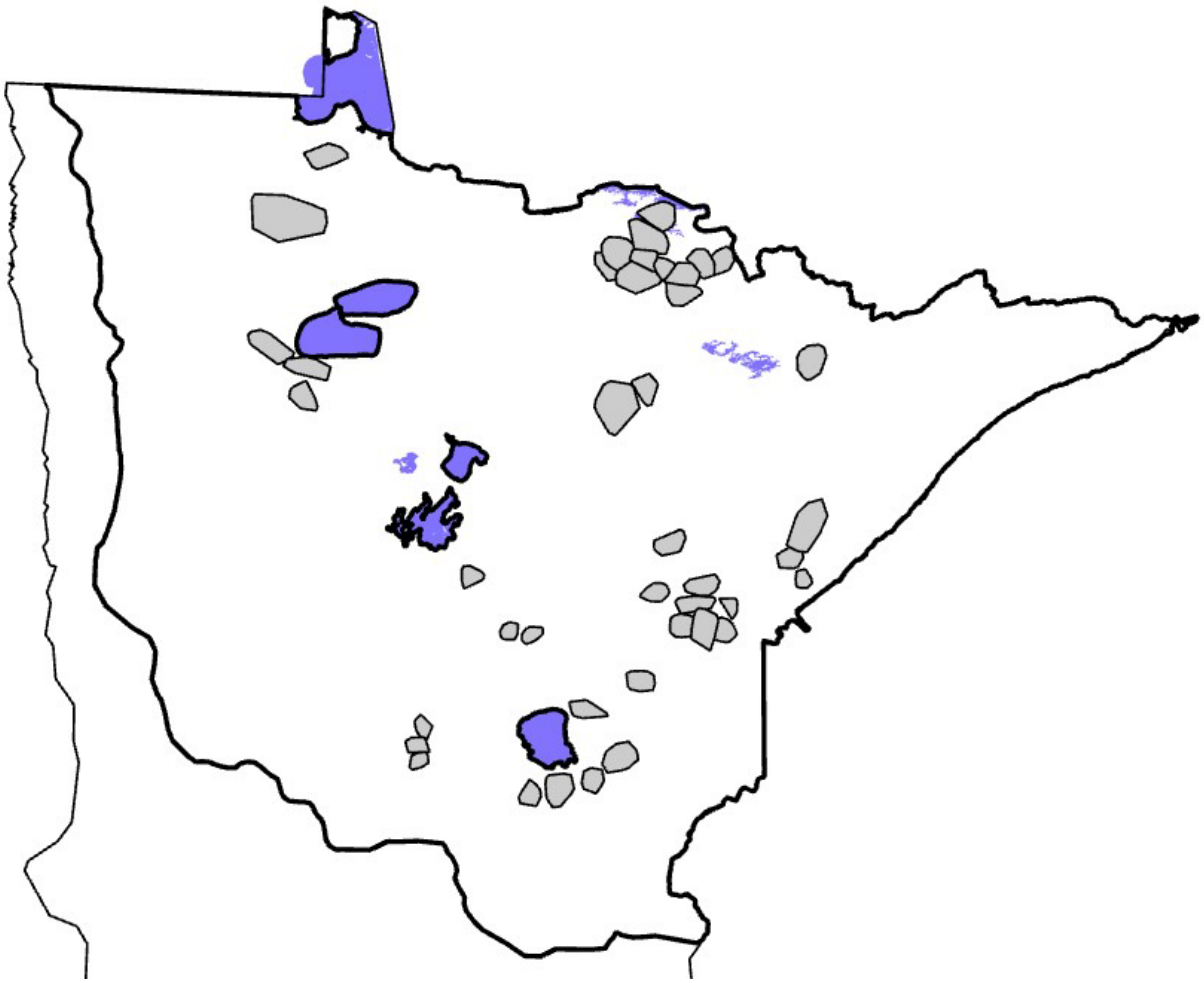

Figure 2. Location of radio-marked wolf packs in Minnesota from which data on territory and pack size were derived during the 2024-25 survey.

Table 2. Comparison of land cover[a] in territories of radio-collared wolf packs during winter 2024-25 with land cover in all pack-occupied wolf range in Minnesota.

	Overall Occupied Wolf range	Radio-collared Wolf Territories
Land Cover Category	% Area	% Area
Woody Wetlands	39.6	41.6
Deciduous Forest	16.7	20.3
Emergent Herbaceous Wetlands	10.8	10.1
Mixed Forest	11.7	12.1
Evergreen Forest	5.6	4.1
Open Water	4.7	4.0
Shrub/Scrub	1.8	2.2
Pasture/Hay/Grassland/Crops	6.9	3.8
Developed, All	2.1	1.9

[a] Land cover data derived from the 2019 National Land Cover Database

Average territory size for radio-marked packs was 145.67 km^2 (Figure 3), higher than 3 of the 4 previous years but near the average over the past decade. Average winter pack size was 4.21 wolves (Figure 4).

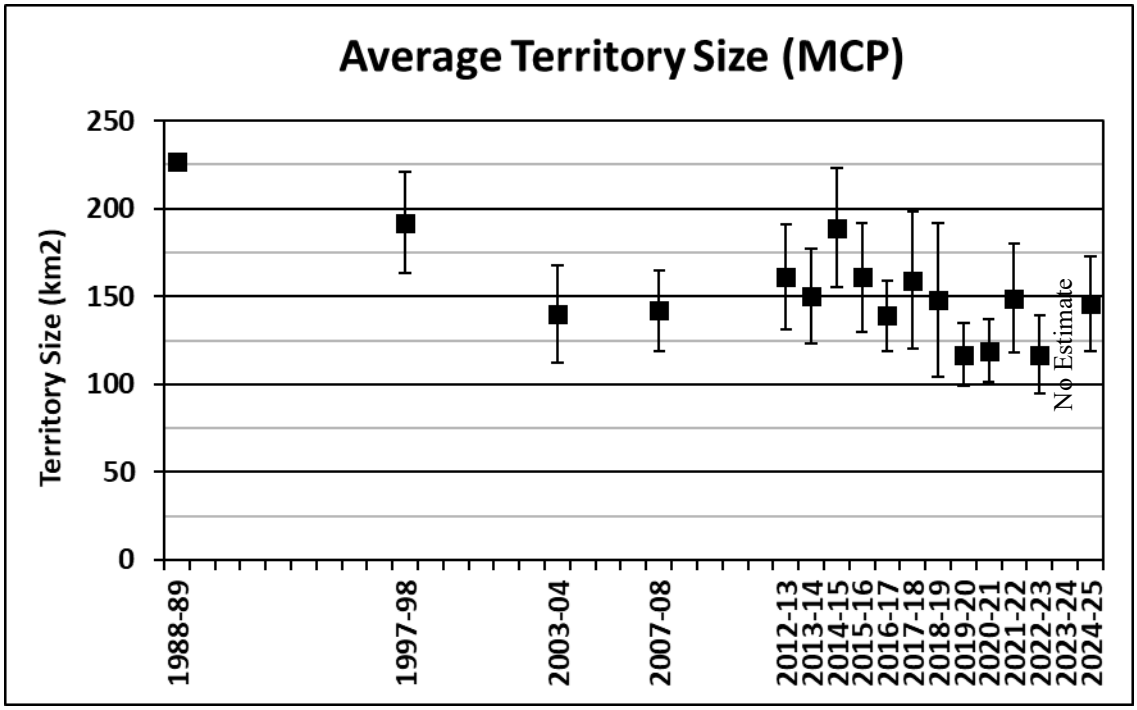

Figure 3. Average scaled territory size for radio-marked wolf packs in Minnesota from 1989 to 2025.

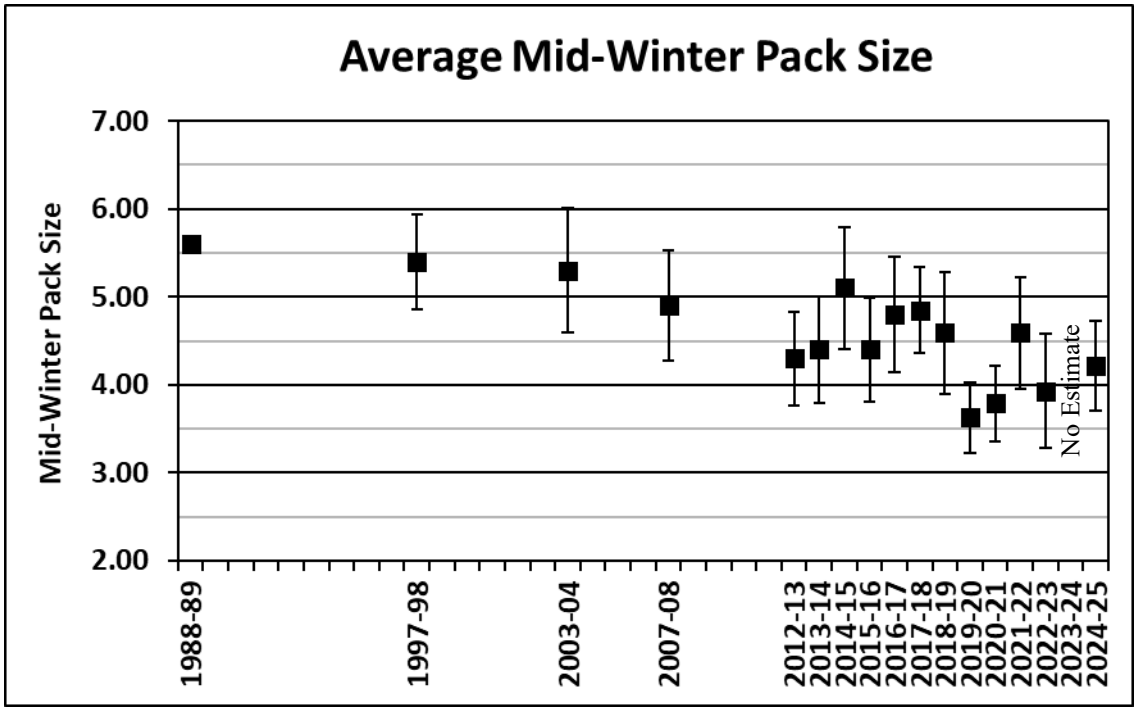

Figure 4. Average mid-winter pack size for radio-marked wolf packs in Minnesota from 1989 to 2025.

Wolf Numbers

Dividing estimated occupied range (67,464 km^2) by average territory size (145.67 km^2) results in an estimate of 463 wolf packs in Minnesota (Figure 5). Multiplying by average pack size (4.21) and accounting for an estimated 15% lone wolves yields a population point estimate of 2,294 wolves (Figure 6), or 3.4 wolves per 100 km^2 of occupied range (Table1). The 90% confidence interval ranges from 1,862 wolves to 2,670 wolves (Figure 6).

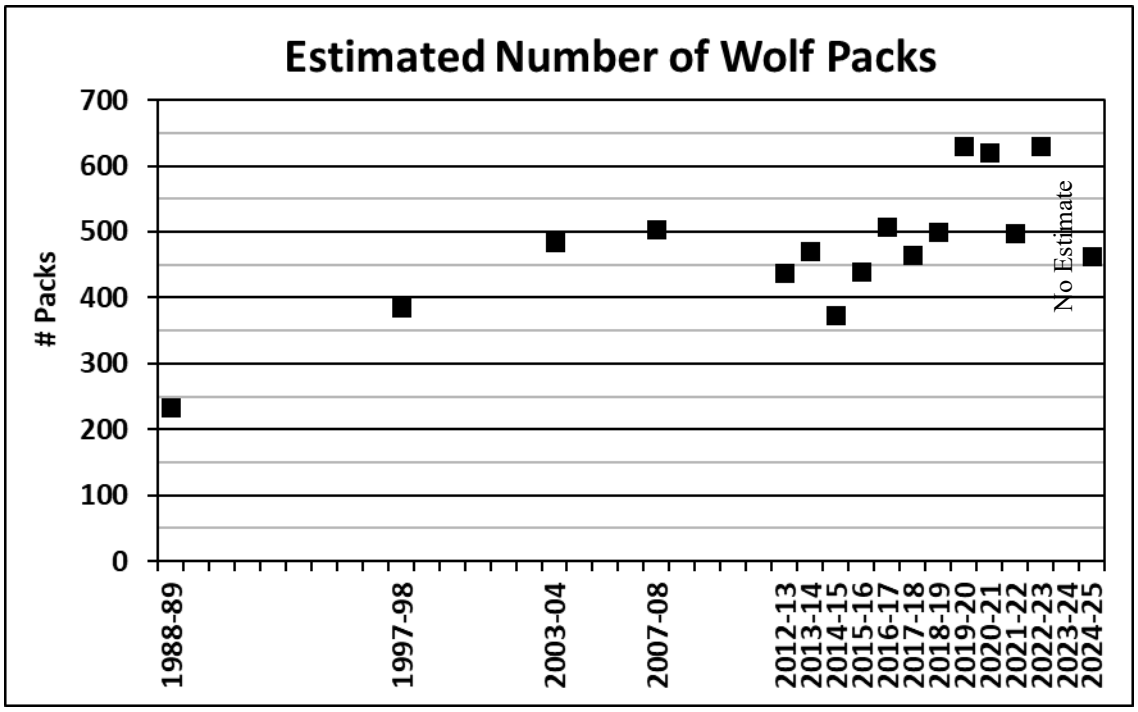

Figure 5. Estimated number of wolf packs in Minnesota at periodic intervals from 1989 to 2025.

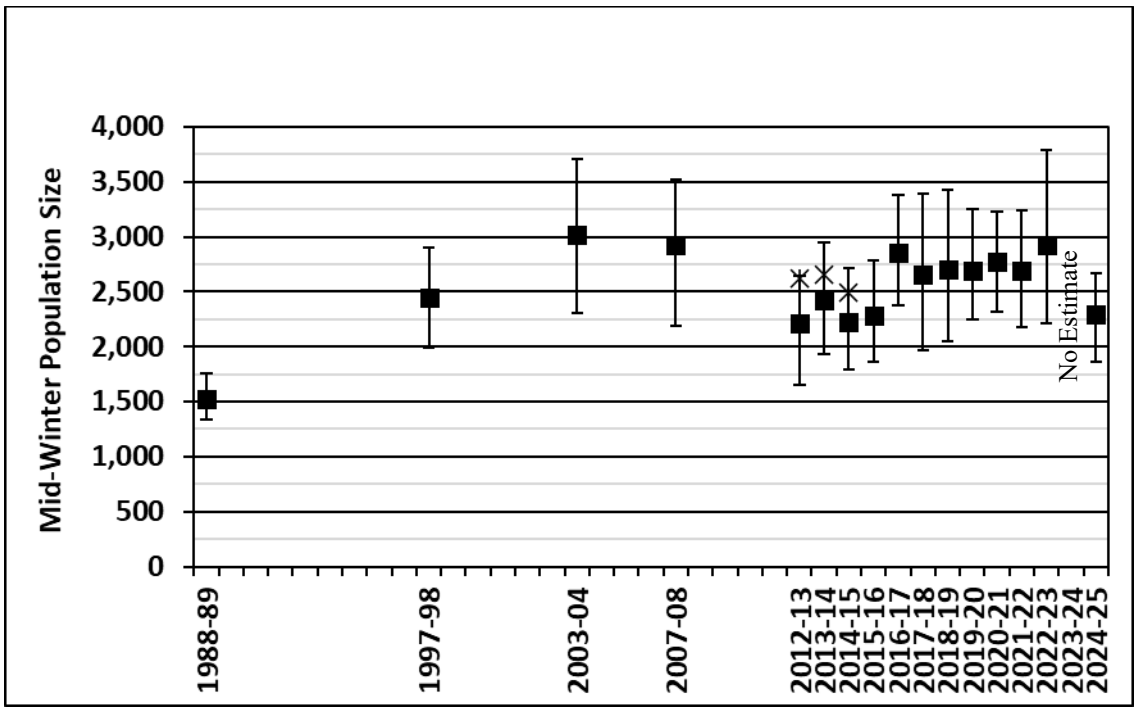

Figure 6. Wolf population estimates from periodic standardized surveys in Minnesota, 1989 to 2025.

DISCUSSION

Available information since the 2017 survey indicates that total wolf range has slightly expanded, primarily in the southcentral portion of the range; we repositioned the wolf range line after considering multiple data sources, resulting in a 6% increase in wolf range to 118,612 km^2. Nevertheless, most of the expansion area was not deemed to be pack-occupied, resulting in negligible effects on the population estimate.

Approximately 57% of total wolf range, or 67,464 km^2, was estimated to be occupied by wolf packs during winter 2024-25, a 9% decrease since the 2017-18 wolf range survey; the 5 recent estimates of pack-occupied range have fluctuated between ~67,000 and 74,000 km^2. The 9% decline is partly influenced by the decision to expand total wolf range; while adding some townships that were deemed to be pack occupied, it added more that were not. Additionally, because delineation of wolf range relies in part on opportunistic wolf sign observations, effort or tracking opportunity across surveys likely varies because of snow (tracking) conditions, fluctuations in the number of personnel able to contribute wolf sign observations, or the number of hours spent afield by survey participants. Although we cannot comprehensively quantify opportunistic effort or spatially explicit metrics of suitable tracking opportunity, for the current survey we believe that both effort and tracking opportunity were notably reduced compared to the 2017-18 range survey. For example, although the average number of opportunistic observations provided per contributing individual was ~7 in both surveys, in winter 2017-18 we received observations from 192 individuals compared to only 92 in the current survey. Various snow metrics (e.g., overall winter severity, # of days with a snowfall of ≥1") suggest that snow tracking opportunities were also likely reduced in the 2024-25 survey, and the percent of the total winter observations that were (snow) tracks was the lowest since the surveys began, 11 percentage points lower (65% versus 54%) than in winter 2017-18. Hence, although we cannot quantify how much of the estimated decline in pack-occupied range is real versus attributable to declines in sign-recording effort or opportunity, we strongly believe that a notable portion is attributable to effort and opportunity reductions.

Because 57% of the townships, the highest to date, were deemed pack occupied based only on low human/road density (i.e., not via pack detections) this winter, potential for occupied range to be overestimated may be higher. However, in addition to the apparent reduction in effort and tracking opportunity this past winter, in many cases a lack of pack detections likely reflects low sampling effort (in all survey years) rather than a lack of wolves. For example, wolves occupy many remote areas (e.g., the BWCAW) and are unlikely to be opportunistically detected in any winter, and notable amounts of private land, particularly in the southern and western portion of the range, are also unlikely to be opportunistically detected in most years. The latter is highlighted by ongoing research (to be fully presented in a separate report) in which trail cameras were deployed in 32 townships across 2 study areas in fall 2024 near the periphery of wolf range. Opportunistic winter 2024-25 sign observations confirmed pack occupancy in 4 of those 32 townships, whereas trail cameras confirmed pack occupancy in 13; the magnitude of this difference may only apply to the periphery of wolf range and be exaggerated based on apparent reductions in sign-recording effort and opportunity this past winter, but it highlights the apparent underestimation in some areas. Finally, the percentage of township area containing pack observations but exceeding the 1988-89 road-human density occupancy model thresholds increased from 11% (1989) to ~30% (2012-2025; Table 1), indicating that this model-based component of assessing pack occupancy is also underestimating results in many areas. Conversely, some 'model-occupied townships', such as landscapes with extensive bog area, may lack adequate forest cover or deer density to sustain wolf packs and thus result in an overestimation of pack occupancy in those areas, though we believe underestimation of pack-occupied range is the overall net effect of these current range delineation limitations. Recent published regional analyses of wolf habitat selection (e.g., van den Bosch et al. 2023) along with results of ongoing trail camera research are being considered in discussions regarding future improvement to methods for quantifying pack-occupied range and may be used to recalculate occupied range and population estimates from previous surveys. Though most of this suggested underestimation would apply across all surveys previously conducted and thus affect absolute numbers but not trends, only the apparent reduction in effort and tracking opportunity during winter 2024-

25 is likely to be a contributor specifically to the current estimated decline in pack occupancy (winter 2017-18 versus 2024-25) and abundance (winter 2022-23 versus winter 2024-25).

Average territory size had declined in the early years of the survey (Figure 3), likely owing to increasing pack competition in an increasingly saturated wolf range (e.g., Fritts and Mech 1981, Hayes and Harestad 2000) and the generally negative correlation (Mech and Boitani 2003, Fuller et al. 2003) between territory size and prey density (i.e., the increasing deer density in northern Minnesota from the 1980's through the mid 2000's). However, since 2003 our estimates of average territory size have been comparatively stable, with fluctuations in point estimates likely driven by sampling variability and the direct or lagged influence of shorter-term deer density fluctuations or winter severity.

Average mid-winter pack size as estimated from radio-marked packs was approximately 4.2 and has generally exhibited only minor fluctuations over time. The correlation between winter pack size and prey density is not as strong as the correlation between prey density and wolf territory size, though prey density certainly has an influence on pack size, particularly via changes in pup survival (Fuller et al. 2003). Our estimates of winter pack size likely underestimate true pack sizes on average, though we suspect not substantially so. Underestimation results from the difficulties of obtaining counts at times when the full pack is together, and in locations and conditions in which all are detectable from the air or ground.

Accuracy in estimates of average territory and pack size is dependent, in part, on radio-collaring a representative sample of wolf packs. Because it is not feasible to identify and stratify all wolf packs to employ true random sampling, our efforts have focused on identifying study areas for radio-collaring that are believed to be collectively representative of overall wolf range, particularly with respect to land cover and deer density. Even so, annual capture success in those areas varies, some collared wolves die or disperse, and some radio-collars prematurely fail. This creates annual variability in the degree to which collared packs are representative of the entire population. Examination of land cover data suggests the location of collared packs this winter provided a reasonable representation of land cover types found throughout the entirety of pack-occupied range.

The most recent previous estimate of abundance was in winter 2022-23 (2,919 +/- ~800), as inadequate snow conditions for obtaining counts on collared packs prevented abundance estimation in winter 2023-24. Using the observed estimate for pack-occupied range in winter 2024-25, the current population of wolves was estimated to be 2,294 (+/- ~ 400), or 3.4 wolves/100 km^2. For comparison given the likelihood that pack-occupied range was underestimated in the most recent survey, using the 2017-18 estimate of pack-occupied range results in an estimate of 2,515 (+/- ~450) wolves during winter 2024-25. Hence, approximately two-thirds of the decline in the current population point estimate was attributable to the estimated decline in pack-occupied range between winters 2017-18 and 2024-25, with the remainder largely attributable to increased average territory size compared to winter 2022-23. Although use of either the 2017-18 or 2024-25 estimate of pack-occupied range results in a decline in the population point estimate since winter 2022-23, the degree of confidence interval overlap in either case does not support a conclusion that the change was statistically significant. Nevertheless, the preponderance of evidence, including expert opinion and a statistically significant decline in wolf track indices between winter 2023-24 and winter 2024-25 on the separate furbearer winter track survey, suggests wolf numbers have recently declined, though likely not to the degree suggested by this survey due to greater underestimation of pack-occupied wolf range in winter 2024-25.

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