DISTRIBUTION AND ABUNDANCE OF WOLVES IN MINNESOTA, 2017-18

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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 with few lapses continue 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).

Early estimates of Minnesota's wolf population, often derived from bounty records and anecdotal information, were by necessity subjective. With the advent of radio-telemetry, geographic information systems (GIS), and global positioning systems (GPS), more detailed monitoring and mapping of wolf populations has 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). Newer 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 Initial evaluation of these aerial snow-tracking methods in Minnesota was not promising (J.E., unpublished data). Further evaluation may be needed, including a cost-benefit analysis, but many assumptions of the method appear difficult to meet in Minnesota's forested landscape with moderate to high deer abundance.

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 2012 (Erb and Sampson 2013). 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 occupied wolf range (defined below) - is still being re-assessed only at 5-year intervals, as was the case from 1998 to 2012. Winter 2017-18 marks the 5^{th} 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 5 wolf range surveys (Fuller et al. 1992, Berg and Benson 1998, Erb and Benson 2004, Erb 2008, Erb and Sampson 2013), and conceptually similar to 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) DNR; 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 2017 and asked them to record a location and group size estimate for all wolf sign (e.g., visual, track, scat) observed during the course of normal work duties from November 2017 until snowmelt the following spring (~ mid-May 2018). Participants could record locations on forms or maps then provided to us for later data entry, 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 classifying wolf observations.

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 sign was recorded but no group size was noted. 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 2017-18 (e.g., carnivore scent station survey, furbearer winter track survey, moose/deer/elk surveys, etc.). This combined database is hereafter referred to as 'WISUR18'. Locations of verified wolf depredations from 2013 to 2018, as well as locations of wolves harvested during the 2012-2014 regulated wolf seasons, 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 WISUR18 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, <u>or</u> 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., 2010) U.S. Census Data as incorporated into the 2010 Minor Civil Divisions GIS layer produced by the Minnesota Legislative Coordinating Commission. Road density calculations are based on the Minnesota Department of Transportation's 1:24,000 GIS roads layer (excluding 'forest roads') and summarized within each township as the number of kilometers of road per km^2.

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 WISUR18 observations; 2) modeled townships; 3) land use and cover; and 4) knowledge of wolf activities in the area since the last survey (e.g., wolf depredation sites, 2012-14 wolf harvest locations). 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 neither contained 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. 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 and an antibiotic were typically administered to animals prior to release. Various models of radio-collars were deployed depending on study area and collar availability. Most GPS radio-collars were programmed to take 3-6 locations per day, while wolves fitted with VHF-only radio-collars were relocated at approximately 7- to 10-day intervals throughout the year, or in some cases primarily from early winter through spring.

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 using the following guidelines, though subjective deviations were made in some cases as deemed biologically appropriate: 1) for wolves with approximately weekly VHF radiolocations only, locations >5 km from other locations were excluded as extraterritorial forays (Fuller 1989); 2) for GPS-collared wolves with temporally fine-scale movement information, we removed obvious movement paths if the animal did not travel to that area on multiple occasions and if use of the path would have resulted in overly-excessive inclusion of obviously 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), points that result in notable overlap with adjacent territories are removed.

In past surveys where the majority of 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 (n = 9; mean number of radiolocations = 38) we multiplied the area of each estimated territory by 1.37 as in the past. For packs with >100 radiolocations (n = 36; mean number of radiolocations = 1,301), 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 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 estimates of occupied range or percent lone wolves.

RESULTS

A total of 1,601 opportunistic wolf sign observations were recorded during the 2017-18 wolf range survey (Figure 1). Observations consisted of 65% tracks, 15% visuals, 4% scats, and 16% other (howls, deer kills, depredation sites, etc.).

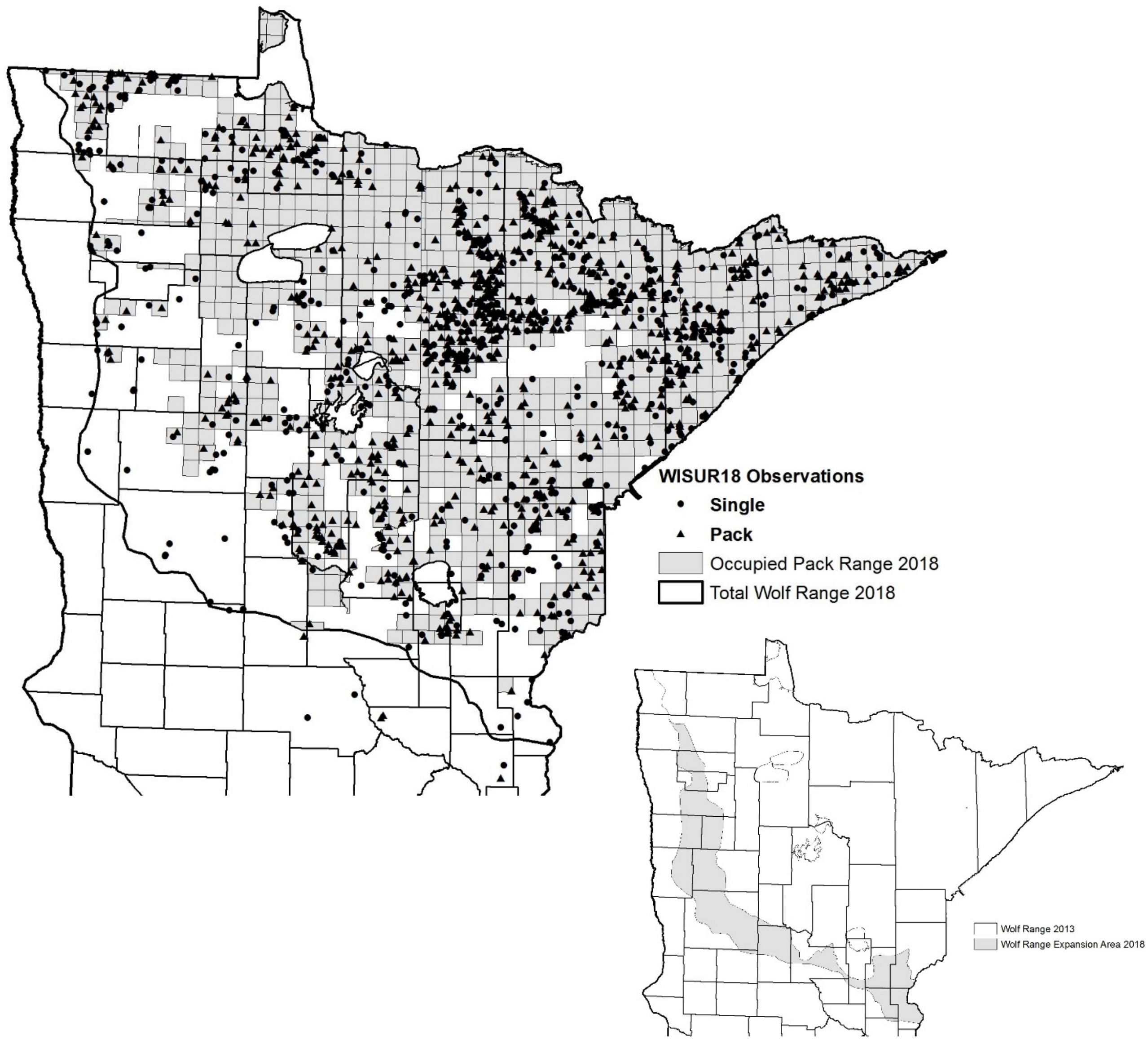

Figure 1. Wolf sign observations, total wolf range, and occupied townships delineated as part of the 2017-18 winter wolf survey in Minnesota. Small inset highlights area of range expansion since 2012.

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. After considering the totality of information (see Methods), we concluded that sufficient data existed to extend the previous wolf range line in numerous areas along the southern and western periphery. Revised total wolf range was estimated to be 111,862 km^2, an increase of ~18% from 2012 (Figure 1, Table 1).

After removing townships within the revised total range that neither met human-road model criteria nor contained WISUR18 pack observations, estimated occupied range was 73,972 km^2 (Fig. 1), a 4.8% increase from the 2012 survey (Figure 1, Table 1). Of the total estimated occupied range, 66% was confirmed to be occupied based on pack detection in the township, and 34% 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 pack observations, 27% had higher human and/or road density than the thresholds in the road-human density model previously developed (Table 1).

Table 1. Comparison of Minnesota wolf range assessments, 1988 – 2018.

	1988/89	1997/98	2003/04	2007/08	2012/13	2017/18
Total Wolf Range (km^2)	60,229	88,325	88,325	88,325	95,098	111,862
Occupied Range (km^2)	53,100	73,920	67,852	71,514	70,579	73,972
% Occupied Range confirmed by pack detection in township	55	84	54	68	70	66
% occupied area with pack detection that exceeds human/road density thresholds [a]	11	17	19	20	30	27
Wolf Population Density (wolves/100 km^2)	2.86	3.31	4.45	4.08	3.13	3.59

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

Pack and Territory Size

We obtained sufficient location data to generate territories for 45 packs (Figure 2); their collective territory area represented 10% of occupied wolf range. Winter pack size counts were obtained for 41 packs, including 6 packs with insufficient location data for territory delineation.

A land cover comparison using the 2011 National Land Cover Database suggests that the location of collared packs this winter led to some over-representation of habitat classified as woody wetlands and under-representation of deciduous forest (Table 2), likely a combined result of more collared packs (and with large territories) near Red Lake and fewer collared packs in our southwest study area. In addition, collared pack territories under-represented, as is typically the case, areas in occupied range classified as hay/pasture/cropland, largely a result of these areas being on private land where less wolf collaring is undertaken. Average spring 2017 deer density in the larger deer permit areas within which the wolf territories were situated, weighted by the number of radio-marked wolf packs within a given permit area, was 11.1 deer/mi^2. In comparison, spring deer density for the forest zone of Minnesota, a close approximation of wolf range, was 13.3 deer/mi^2 in spring 2017. Considering this collective information, we suspect that the sample of collared packs this winter might be slightly biased towards areas of lower quality wolf habitat compared to last winter.

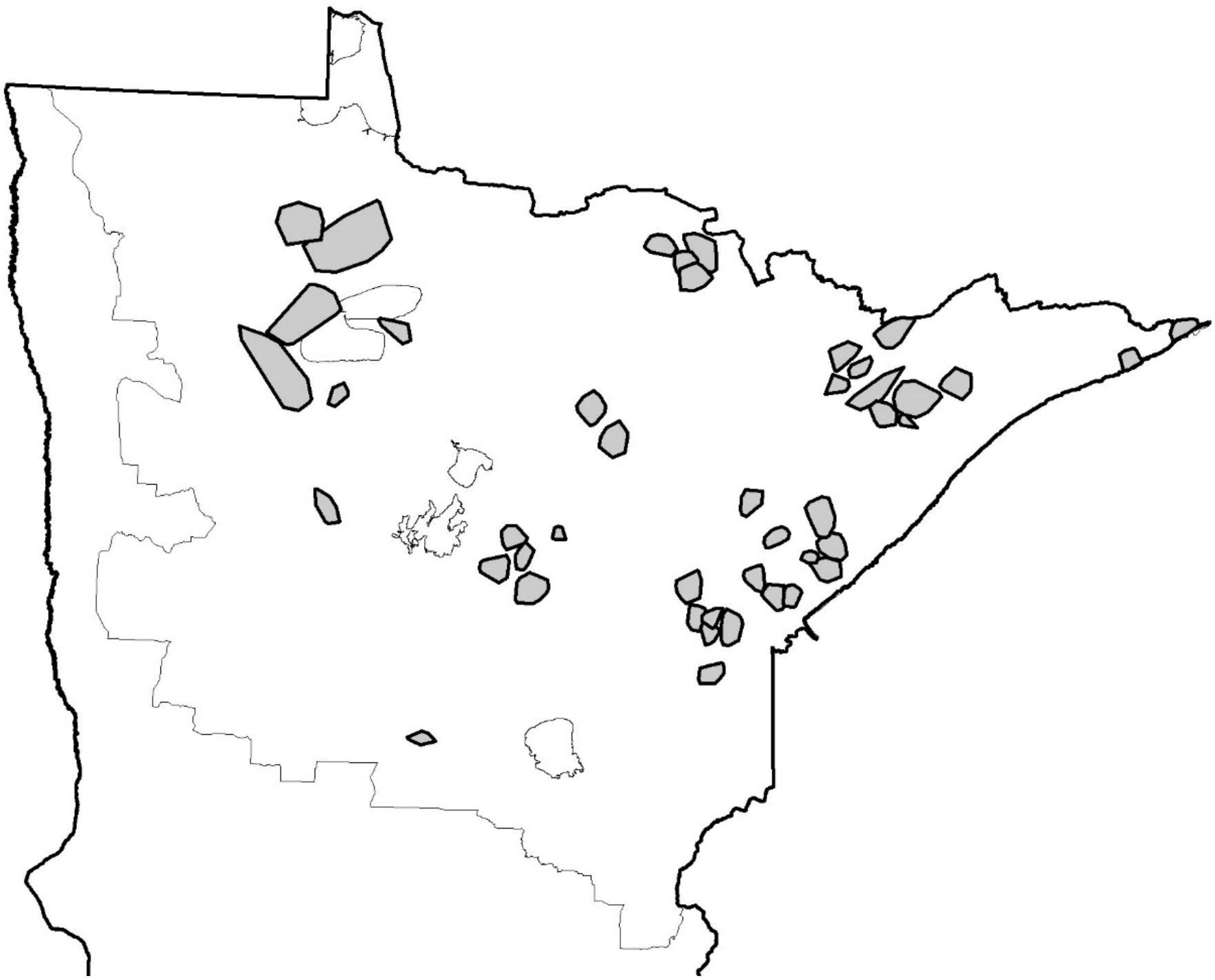

Figure 2. Location of radio-marked wolf packs in Minnesota from which data on territory and pack size were derived during the 2017-18 survey.

Table 2. Comparison of land cover[a] in territories of radio-collared wolf packs during winter 2017-18 with land cover in all of occupied wolf range in Minnesota.

	Overall Occupied Wolf range	Radio-collared Wolf Territories
Land Cover Category	% Area	% Area
Woody Wetlands	31.9	37.2
Deciduous Forest	23.1	18.1
Emergent Herbaceous Wetlands	10.1	13.2
Mixed Forest	6.9	7.1
Evergreen Forest	6.7	8.5
Open Water	5.2	4.5
Shrub/Scrub	4.5	4.8
Pasture/Hay/Grassland/Crops	9.3	4.9
Developed, All	2.4	1.8

[a] Land cover data derived from the 2011 National Land Cover Database

After applying the 'interstitial scaling factors' discussed in the Methods, average territory size for radio-marked packs was 158.97 km^2 (Figure 3). Average winter pack size was 4.85 wolves (Figure 4).

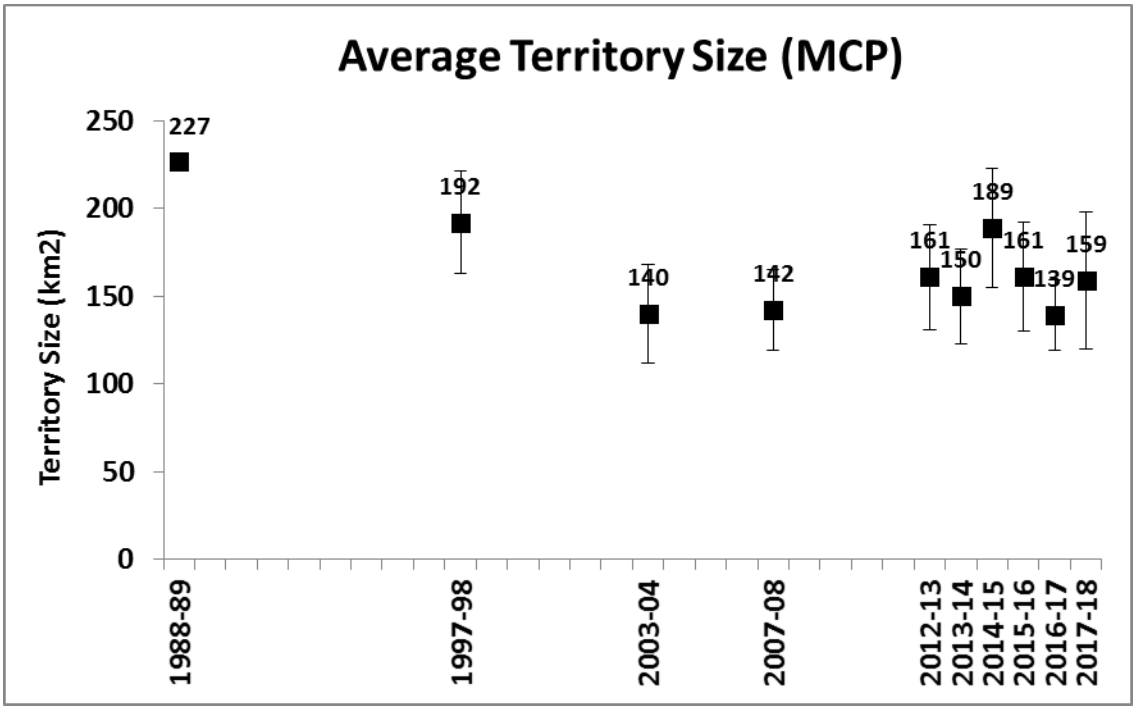

Figure 3. Average scaled territory size for radio-marked wolf packs in Minnesota from 1989 to 2018.

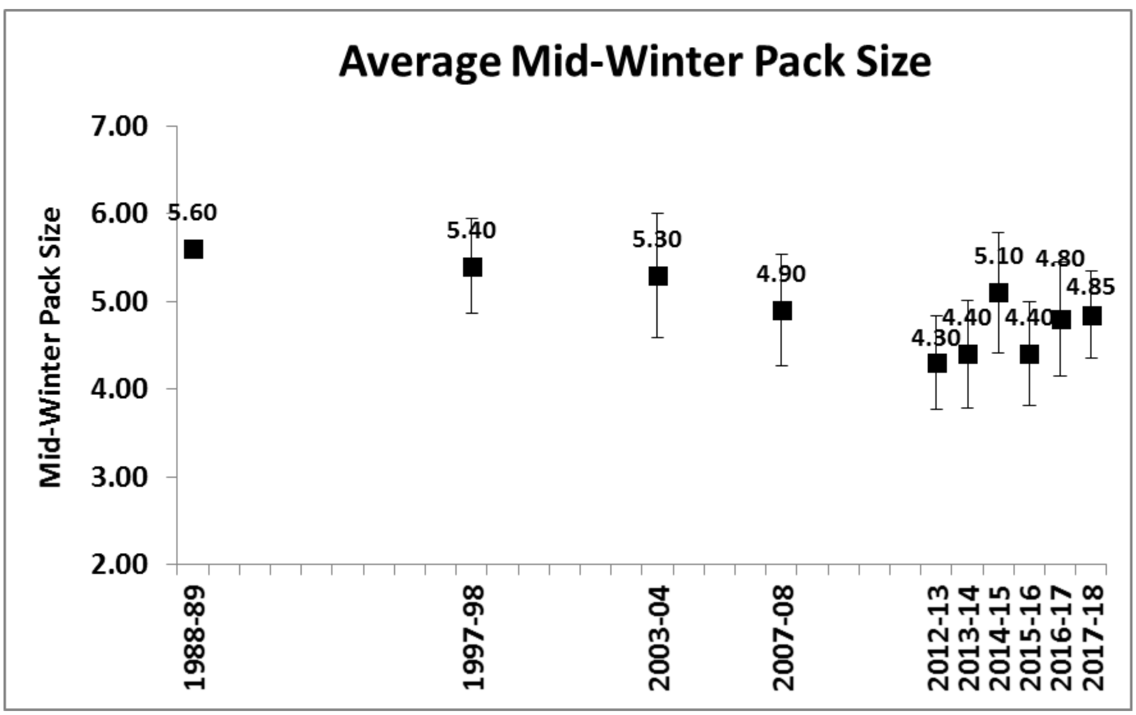

Figure 4. Average mid-winter pack size for radio-marked wolf packs in Minnesota from 1989 to 2018.

Wolf Numbers

Dividing estimated occupied range (73,972 km^2) by average territory size (158.97 km^2) results in an estimate of 465 wolf packs in Minnesota (Figure 5). Multiplying by average pack size (4.85) and accounting for an estimated 15% lone wolves yields a population point estimate of 2,655 wolves (Figure 6), or 3.6 wolves per 100 km^2 of occupied range (Table1). The 90% confidence interval ranges from 1,972 wolves to 3,387 wolves (Figure 6).

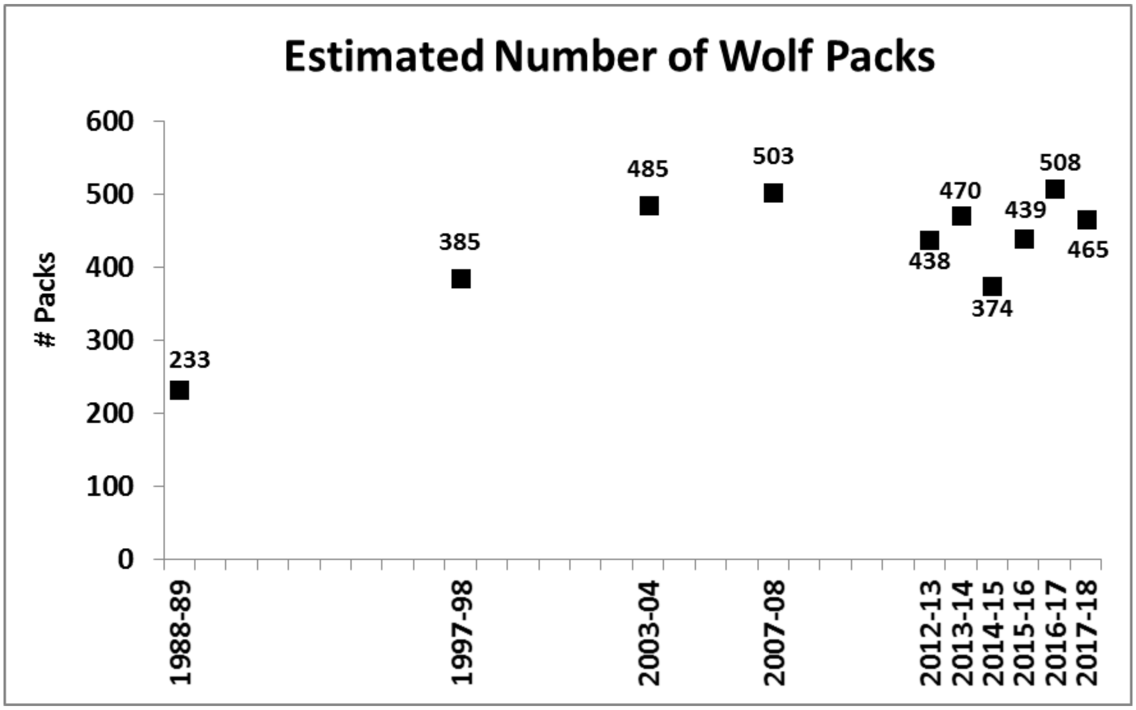

Figure 5. Estimated number of wolf packs in Minnesota at periodic intervals from 1989 to 2018.

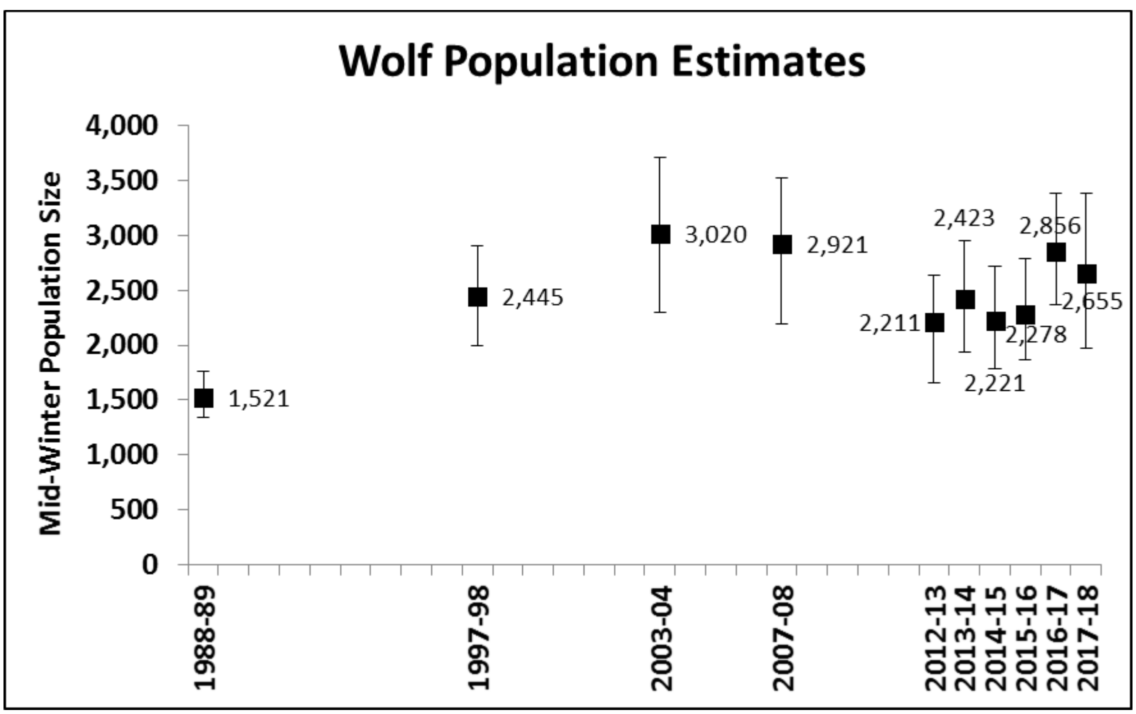

Figure 6. Wolf population estimates from periodic standardized surveys in Minnesota, 1989 to 2018.

DISCUSSION

Available information since the 2012 survey indicates that wolf range has expanded in several areas along the southern and western periphery. In these areas, we repositioned the wolf range line after considering multiple data sources, resulting in an 18% increase in wolf range to 111,862 km^2. Although much of the area of expansion was not concluded to be occupied by packs based on either the human-road density model or pack detections, and hence was not included in occupied range, we felt sufficient confirmations have occurred in these areas since the last survey to justify range expansion. It is also likely that wolves remain under-detected by survey participants in these areas during winter due to private ownership of much of the land.

Approximately two-thirds of total wolf range, or 73,972 km^2, was estimated to be occupied by wolf packs during winter 2017-18. This represents an approximately 5% increase in occupied range since the 2012-13 wolf range survey; the 4 estimates of occupied wolf range since then have fluctuated between approximately 68,000 and 74,000 km^2. Because delineation of wolf range relies on opportunistic wolf sign observations, effort across surveys likely varies as a result of fluctuations in the number of personnel able to contribute wolf sign observations or the number of hours spent afield by survey participants. Hence, we can't rule out sampling variation as the cause of slight changes in the estimate of occupied range, though changes in wolf demographics likely contribute to the fluctuations as well. Since 1998, there has been no consistent increasing or decreasing trend in the amount of occupied range.

Because 34% of the townships were deemed occupied based only on 'low' human/road density (i.e., not via pack detections), it remains possible that occupied range could be overestimated. However, in a majority of cases a lack of pack detections likely reflects a lack of sampling effort rather than a lack of wolves. Some wolves occupy remote areas (e.g., the BWCAW) and are unlikely to be opportunistically detected, and notable amounts of private land, particularly in the southern and western portion of the range, are also unlikely to be opportunistically surveyed. Stated differently, pack detection probability is undoubtedly less than 1 in many areas. Finally, while prey- or habitat-based models have some potential to overestimate occupancy at any given time, the 1988-89 human-road density model (Fuller et al. 1992) utilized in our methodology has generally been a conservative descriptor of wolf 'habitat' in Minnesota. The percentage of township area containing pack observations but exceeding the occupancy thresholds in the 1988-89 road-human density model had increased from 1988 (17%) to 2012 (30%), but may now have stabilized; results from the 2017-18 survey indicate that 27% of the townships in which wolf packs were confirmed have human-road densities that exceed the thresholds.

From 1988 to 2003, wolf pack territory sizes declined in Minnesota. Although numerous factors can influence territory size, we believe 2 largely explain this pattern. First, expanding wolf populations (or portions thereof) that compose a significant number of colonizing packs have been shown to exhibit declines in average pack territory size as the population becomes more established or available range more saturated (Fritts and Mech 1981, Hayes and Harestad 2000), a characterization that applies to the Minnesota wolf population from early recovery up to approximately 2003. Second, territory size is negatively correlated with prey density (Mech and Boitani 2003, Fuller et al. 2003), and Minnesota's deer population exhibited an increasing trend during much of wolf recovery in Minnesota. 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 deer density fluctuations.

Average mid-winter pack size as estimated from radio-marked packs was approximately 4.9 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 are highly likely to underestimate true pack sizes, 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 and deer density data from this past winter suggests that location of collared packs may have been somewhat biased towards less productive areas, with the potential result being a population point estimate biased low. Nonetheless, confidence intervals for the past 2 surveys widely overlap (Figure 6), indicating no significant population change from last year.

We estimate the current population of wolves to be 2,655 (+/- ~ 700), or 3.6 wolves/100 km^2. We estimate total wolf range to have increased by an estimated 18% since 2012, while occupied range was estimated to have increased ~5%. Since wolf population estimates have been derived annually (2012–present), wolf population estimates appear to coarsely track changes in deer density (Figure 7), and wolves remain widely distributed throughout Minnesota's forest zone.

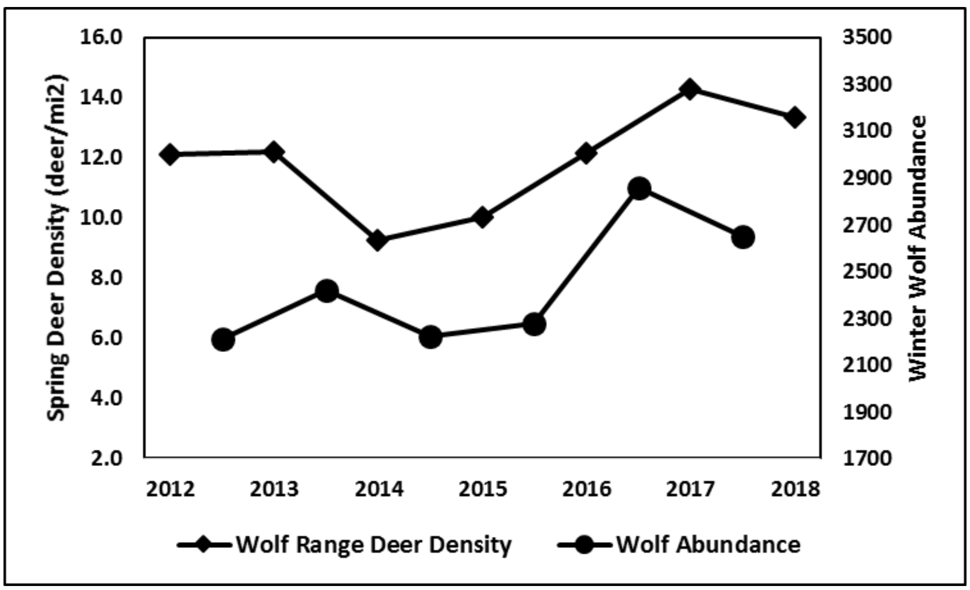

Figure 7. Comparison of estimated pre-fawn deer density in wolf range with winter wolf abundance in Minnesota, 2012-2018.

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