



Estimates of White-tailed Deer Density in Voyageurs National Park

1989–2016

Natural Resource Report NPS/VOYA/NRR—2017/1427



ON THE COVER

White-tailed deer in marsh grass.

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Abstract

White-tailed deer (*Odocoileus virginianus*) are an important component of southern boreal ecosystems, including those within and adjacent to Voyageurs National Park (VOYA), Minnesota. Voyageurs National Park staff has employed aerial and pellet-based methods of deer population monitoring for several periods from 1989 to present. Our objective for this report was to compile the results from these surveys, combine them with model-based estimates by the Minnesota Department of Natural Resources for areas adjacent to the park, and provide current and historical deer density estimates for VOYA and the adjacent areas. Deer pellet-count surveys were conducted during 1989, 1991, 1996, 1997, 2009–2011, 2015, and 2016 on randomly selected sampling units in and adjacent to VOYA in Minnesota and Ontario. Additionally, observations of white-tailed deer were recorded during aerial winter moose population surveys in 1992, 2009–2011, and 2013–2016. Based on pellet-count surveys, deer density has likely decreased during the period 1989 to 2016. We think the decrease in deer density in VOYA is likely due to changing forest composition and structure. VOYA was last logged in 1971, before the park was established, and little early successional habitat is available in the park, as natural disturbance is largely limited to small-scale events from beaver activity or wind throw. Density estimates based on aerial survey data were much lower than pellet-count density estimates for all years. We do not recommend using the estimates derived from aerial surveys as measures of either trends or abundance of deer in VOYA. Future aerial surveys for deer could be modified to improve accuracy and precision of estimates but such improvement may be cost-prohibitive. We suggest continued use of pellet-count-based estimates of deer density in VOYA as a low-cost, low effort method as an index to abundance and trends within the park.

Acknowledgments

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Introduction

White-tailed deer (*Odocoileus virginianus*) are an important component of southern boreal ecosystems, including those within and adjacent to Voyageurs National Park (VOYA), Minnesota. Moose (*Alces americanus*) and caribou (*Rangifer tarandus*) were the predominant native ungulates during the pre-settlement period (Heinselman 1973, Cole 1987). After European settlement in the area, unregulated hunting and drastic land-use changes resulted in the extirpation of caribou and a large decline in moose abundance by the early 20th century (Bergerud 1974). The resulting landscape conditions favored expansion by white-tailed deer, which is now the dominant ungulate species in the park in both numbers and biomass (Cole 1987).

The effects of white-tailed deer on forest ecosystems are significant. Foraging by individuals and populations of deer can affect vegetation composition and structure (Waller and Alverson 2006). Their foraging activities make them direct competitors of other ungulates like moose and caribou but they are also indirect competitors through the transmission of parasites and diseases, aka parasite-mediated competition (Jenks and Leslie 2011). Specifically, white-tailed deer are carriers of meningeal worm (*Parelaphostomus tenuis*) and liver fluke (*Fascioloides magna*), both which adversely impact moose populations through increased mortality and morbidity (Cole 1981, Murray et al. 2006, VanderWaal et al. 2014). White-tailed deer are also the primary prey of gray wolves (*Canis lupus*) in the park, and wolves subsist almost entirely on deer during the winter when other prey (e.g., beavers) are not available (Gogan et al. 2004, Cheneaux-Ibrahim 2015, Gable 2016). Because wolf density is predominantly a function of prey density (Fuller et al. 2003, McRoberts and Mech 2014), wolf density in and around VOYA is almost certainly affected by deer density. Additionally, deer fawns can be an important seasonal food source for several other forest predators including coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and black bears (*Ursus americanus*) (Kunkel and Mech 1994, Carstensen et al. 2009, Gable 2016). Deer carcasses provide an important food source for a multitude of scavenging birds and mammals (Jennelle et al. 2009). Thus, accurate estimates of deer densities are critical to proper management of park resources and helpful in understanding the complex relationships among VOYA's most charismatic wildlife.

Unfortunately, estimating white-tailed deer abundance in the southern boreal forest is notoriously difficult. Deer are smaller and lighter in color than moose, and when combined with the high conifer density in typical winter range for deer, detection from aircraft is often poor (DeYoung 2011). Fecal pellet-counts have been used to estimate deer (and other ungulate) density since the 1950s (e.g., Eberhardt and Van Etten 1956), but the assumptions behind the methodology are often untested (e.g., Fuller 1991, but see Forsyth et al. 2007 and deCalesta 2013). The Minnesota Department of Natural Resources (MNDNR) employs a modeling approach to estimate deer density in each Deer Permit Area (DPA) in the state, with annual harvest by sex and age class as key inputs into their model (D'Angelo and Giudice 2016). There is no legal harvest of deer on Federal lands in VOYA and thus estimates from the adjacent DPAs to VOYA may or may not be applicable.

Fortunately, VOYA staff has employed aerial and pellet-based methods of deer population monitoring periodically from 1989 to present. Our objective was to compile the results from these

surveys, and combine them with model-based estimates by the MNDNR for areas adjacent to the park, to estimate current and historical deer density for Voyageurs National Park and the adjacent areas.

Methods

Pellet-Counts

Deer pellets counts were conducted during April and May (1989, 1991, 2009–2011, and 2015–2016) on randomly selected 1 km² sampling units in and adjacent to VOYA in Minnesota and Ontario (Figures 1, 2, and 3). Though the pellet-count methodology was similar across all years, the number and distribution of sample units varied slightly between years (Table 1). Pellet-count surveys were conducted using a standardized protocol developed specifically for Voyageurs National Park (Appendix A). Each sampling unit had two parallel transect lines that were separated by 100 m. Each transect line was 800 m in length and consisted of four 79.2-m²-area plots at 200-m intervals. Sampling units containing >50% water cover (e.g., some units along large lake shorelines) were limited to one transect line. Each plot was intensively searched by walking along each side of cloth tape 22 m in length and counting all old and new pellet-groups within 1.8 m of the tape (i.e., the plots were 3.6 m wide). Pellet-groups were defined as those containing at least 30 individual pellets of the same age and size. Only pellet-groups where ≥50% of the pellet-group fell within the plot boundaries were counted. New pellets (i.e., those deposited in the winter that just ended) were easily distinguishable from old pellets (i.e., >1 year old) as they were typically on top of the leaf litter, shiny and dark colored, and free of moss or insect damage. We recorded how much of the sample plot was surveyed (to the nearest 10%) as occasionally portions of individual plots could not be completely surveyed because of standing water.

We calculated deer densities based on total new pellet-groups counted, mean pellet-group deposition rate (pellet-groups/day), deposition period (days), and the area sampled (m²) (Equation 1).

$$\text{Equation 1} \quad \text{Deer density (ind/km}^2\text{)} = \frac{\text{Pellet Groups Counted}}{\text{Pellet-Group Deposition Rate} \times \text{Deposition Period} \times \text{Sampling Unit Area (km}^2\text{)}}$$

We used a mean pellet-group deposition rate of 25 pellet-groups/deer/day, which is the average of white-tailed deer deposition rates from two northern forest locales: Nova Scotia (16 pellet-groups/deer/day, 1 Nov.–30 Apr.; Patterson et al. 2002) and northern Minnesota (34 pellet-groups/deer/day, 15 Oct.–30 Apr.; Rogers 1987). We estimated deposition period by calculating the number of days from a mean leaf-off date of 1 November (VOYA unpublished data) to when the survey was conducted. Unsampled plots were not included in the estimates of area sampled. Because we do not know the true pellet-group deposition rate for any year of sampling, we then estimated deer density using the 16 and 34 pellet-groups/deer/day from Patterson et al. 2002 and Rogers 1987, respectively, to see how different deposition rates (i.e., ± 35% of 25 pellet-groups/deer/day) affected our density estimates.

In 1996 and 1997, pellets were counted in 13 randomly selected survey grids with each grid containing five transects spaced 200 m apart (Figure 4). Each transect had four stations that were 40 m apart, and each station had three sampling plots (1 × 10 m) that were oriented at 0°, 120°, and 240°. The 1996 survey was conducted during February and March when snow-cover was present, while the 1997 survey was conducted during April and May. Pellet-count methodology within the individual

sample (i.e., the actual plot-based pellet-counts) plots followed the same method described above for all other years.

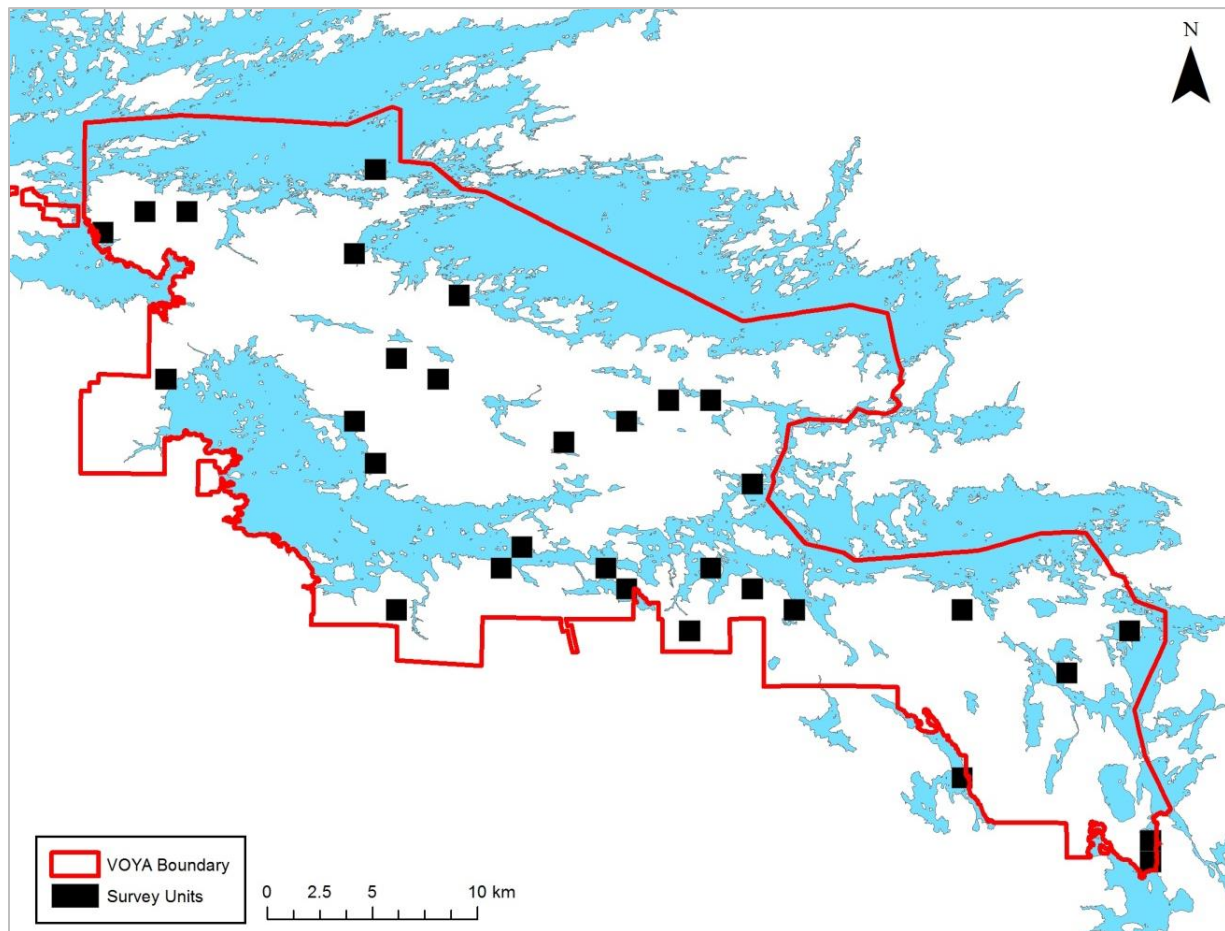


Figure 1. Location of white-tailed deer pellet-count surveys conducted in Voyageurs National Park, 1989–1991.

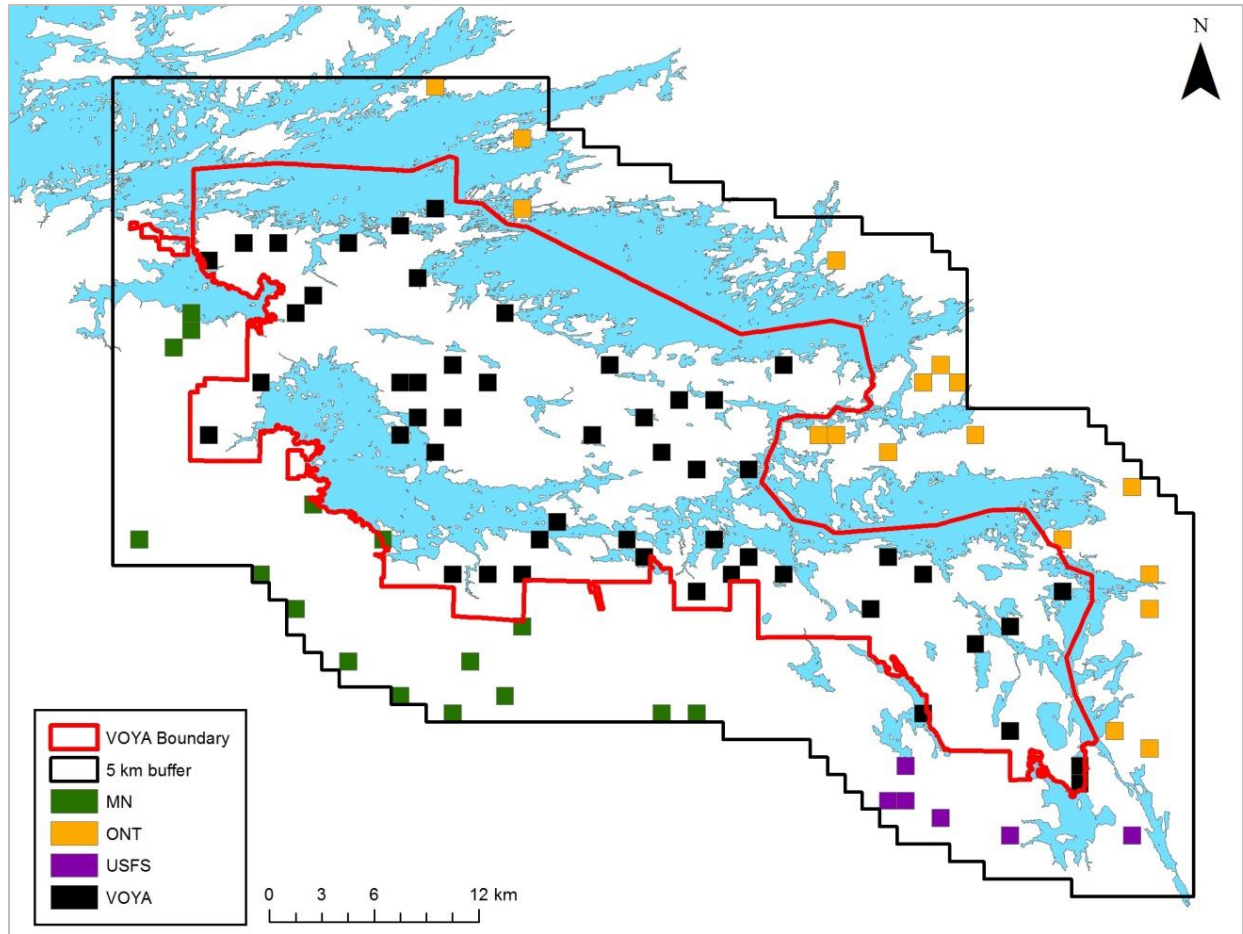


Figure 2. Location of white-tailed deer pellet-count surveys conducted in and adjacent to Voyageurs National Park, 2009–2011. Many of the units inside of the park were also sampled in 1989 and 1991. Survey units outside of the park were randomly placed within a 5 km buffer of the park (on land owned by Province of Ontario, United States Forest Service, and State of Minnesota) to determine if densities inside and outside of the park were similar. In 2011, only the survey units inside of the park were sampled.

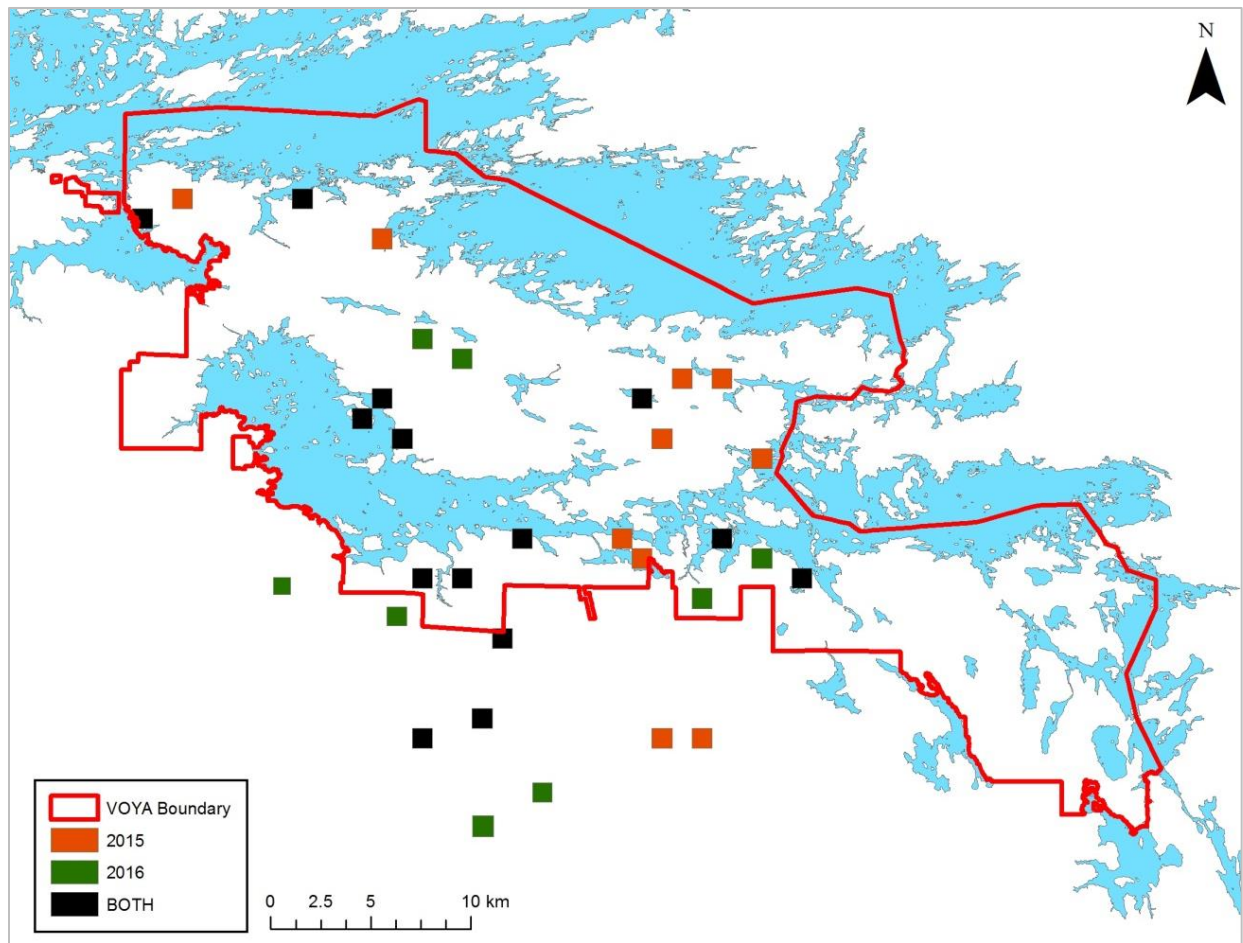


Figure 3. Location of white-tailed deer pellet-count surveys conducted in and adjacent to Voyageurs National Park, 2015–2016.

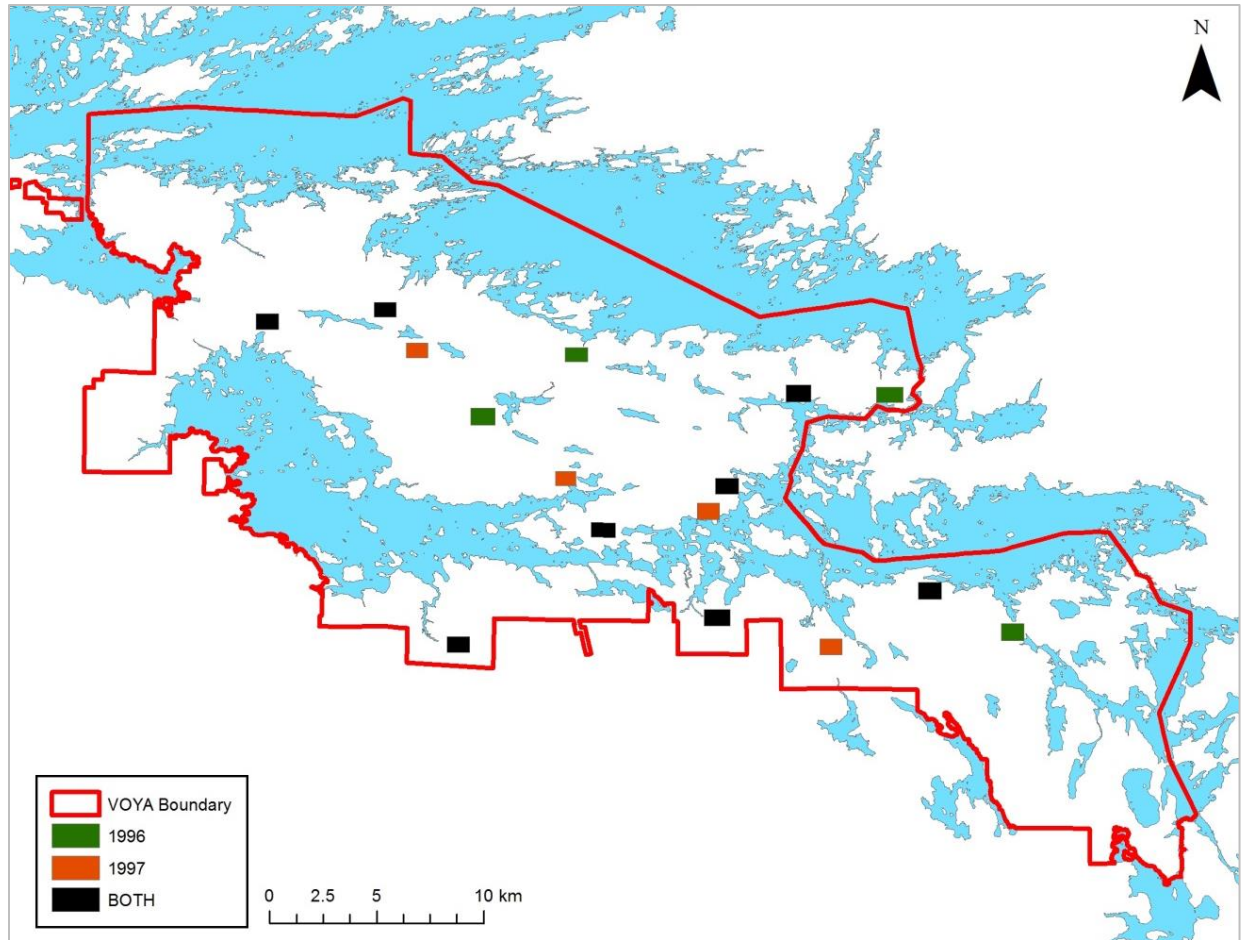


Figure 4. Location of white-tailed deer pellet-count surveys conducting in Voyageurs National Park, 1996 and 1997.

Aerial Surveys

Observations of white-tailed deer were recorded during winter moose population surveys in 2009–2011 and 2013–2016. During 2009–2011, we visited 33 survey units that were delineated for previous (1991–1998) moose surveys (Gogan et al. 1997). Survey units were also divided into two roughly equal halves and designated as subunit “a” or “b”. Because we wanted to more accurately update information on park-wide distribution of moose, we surveyed all 33 survey units in 2009–2010. In 2011, we focused survey efforts on the survey units in the park that represent the vast majority of moose range in the park (i.e., Survey Units 1–23). We used a deHaviland Beaver with a pilot and a minimum of three observers, flying at airspeeds between 125 and 145 km/hr and at an altitude of 150–215 m above ground level. Survey units were sampled by flying west-east transects spaced at 0.536 km intervals at an intensity of ca. 1.5 minutes/km². We recorded number and location of white-tailed deer seen during the first pass along a transect only (i.e., we did not circle back for deer). A random sample of sub-survey units where at least one deer was observed during the standard (transect) survey were reflight to calculate SCF_o, or Sightability Correction Factor (Gasaway et al. 1986). Sightability trials were flown at three times the standard search intensity (ca. 4.5 minutes/km²) in a haphazard pattern such that the entire subunit was searched with approximately the same

intensity. Data on deer locations were recorded similarly as on the standard survey, noting when individual deer were seen during both the standard and intensive survey. Deer population size was estimated using the formulas of Gasaway et al. (1986).

During 2013–2016, we also recorded observations of deer during our annual moose survey (Windels and Olson 2016). The survey area was limited to the Kabetogama Peninsula, a 305 km² roadless area in the center of the park where >90% of the park's moose population occurs. Surveys were conducted using a tandem seat, fixed-wing aircraft during which the pilot and observer searched for moose and deer while the plane flew in overlapping circles at an intensity of at least 3.5 min/km². We surveyed units 1–23 and recorded all observations of deer. We did not conduct sightability trials for deer during these years. Instead, we multiplied the total number of deer observed during the survey by the SCF_o (derived from the 2009–2011 survey) to give a point estimate of deer density for each survey year, acknowledging that the SCF was based on different methodology and conditions and therefore likely biased.

MNDNR Model-based Estimates

We used MNDNR model-based density estimates for Deer Permit Areas (DPA) adjacent to VOYA (D'Angelo and Giudice 2016) to compare our pellet-count and aerial survey density estimates. We used deer density estimates from 1989–1999 for DPA 115, as this DPA included all of the land that was south of VOYA and east of Highway 53 (Dexter 1999, Lenarz 2005). In the early 2000s, MNDNR DPA boundaries changed and the area south of VOYA and east of Highway 53 became DPA 119. Additionally, all pellet-count surveys that were outside of VOYA from 2009–2016 (excluding those in Ontario) were conducted in DPA 119.

Analysis

We compared our density estimates derived from pellet-counts and aerial surveys by VOYA staff with the MNDNR's model-based estimates. We used Pearson's correlation coefficient to compare trends in our pellet-count density estimates with the MNDNR model-based density estimates. Similarly, we used Pearson's correlation coefficient to compare trends from our aerial survey density estimates with those from our pellet-count-based and MNDNR model-based estimates. We compared density estimates from the Kabetogama Peninsula with density estimates from the southern portion of the park and state/federal lands outside of the park using Student's t-test. Similarly, we compared density estimates inside and outside of VOYA using Student's t-test. We used an $\alpha=0.05$ for all statistical tests.

Results

In 2009, deer density (based on pellet-counts) was 4.1 ± 0.5 (SE) deer/km², but declined to 1.71 ± 0.4 (SE) deer/km² by 2016 (Table 1, Figure 5). Mean deer density during the period 2009–2016 was $3.2 (\pm 0.4 \text{ SE})$ deer/km². There was no difference ($P > 0.05$) in deer density estimates inside and outside of VOYA during 2009, 2010, 2015, and 2016. Similarly, there was no difference ($P > 0.05$) in deer density estimates on the Kabetogama Peninsula and the area south of Kabetogama/Namakan Lake (i.e., southern portion of VOYA, and state/federal land south of VOYA). Deer density estimates for VOYA and for the combined area in and adjacent to VOYA were not significantly correlated ($r = 0.76$, $P = 0.13$ and $r = 0.85$, $P = 0.07$, respectively) with MNDNR density estimates during 2009–2011 and 2015–2016 (Figure 6), though low sample sizes likely contributed to lack of statistical power.

Pellet-counts from 1989 and 1991 resulted in deer density estimates of 12.3 ± 1.5 (SE) and 11.6 ± 1.3 (SE) deer/km², respectively, which are much higher than MNDNR estimates for the area adjacent to VOYA during those years (Figure 7). In 1996, mid-winter pellet-counts resulted in an estimate of 3.0 deer/km², which was lower than the 1996 MNDNR estimate (3.9 deer/km²) for the area adjacent to VOYA. However, in 1997 the pellet-count based deer density was 5.2 deer/km², which was ca. 50% higher than the MNDNR estimate for the area adjacent to VOYA (3.5 deer/km²; Figure 7).

The uncorrected number of deer observed during aerial surveys of the Kabetogama Peninsula ranged from as low as 98 in 2011 to as high as 388 in 1992 (mean = 220 ± 40 [SE]; Table 2). During the survey of the entire park, 177 and 236 deer were observed in 2009 and 2010, respectively. Aerial survey density estimates (i.e., calculated as observed numbers of deer multiplied by the SCF_o) from 2009–2016 were lower (densities = 0.7–1.9 deer/km²) than pellet-count density estimates for the corresponding year, and aerial density estimates increased slightly during the period 2009–2016 (Table 3). The 1992 aerial survey density estimate (2.9 deer/km²) was substantially lower than pellet-count based density estimate for 1991 (11.6 deer/km²) and for the model-based MNDNR estimate for 1992 (4.6 deer/km²) (Table 3, Figure 7). Aerial survey density estimates during 2009–2016 were negatively correlated with pellet-counts ($r = -0.89$, $P < 0.05$), but showed no significant trend with MNDNR density estimates ($r = -0.68$, $P = 0.18$).

Table 1. Density estimates of white-tailed deer from all pellet-count surveys conducted in and adjacent to Voyageurs National Park from 1989–2016. We adjusted the pellet-group deposition rate by 35% in both directions to yield low and high density estimates. Density estimates for 1989–1991 appear to be biased high and estimates from 1996–1997 are unreliable due to methodological issues. For conversion purposes, 1 km² = 0.386 mi². See Discussion for more details.

Year	Land Owner ^a	No. Pellet-groups	Units Sampled	Area Sampled (m ²)	Pellet-groups/m ²	Density Estimate (deer/km ²) ^d	SE (±) ^c	Low Density Estimate (deer/km ²) ^e	SE (±) ^c	High Density Estimate (deer/km ²) ^f	SE (±) ^c
1989	VOYA	798	28	14,256	0.055	12.3	1.5	9.1	1.1	19.2	3.6
1991	VOYA	854	31	16,157	0.052	11.6	1.3	8.5	1.0	18.2	3.2
1996	VOYA	54	13 ^b	7,590	0.007	3.0	0.7	2.2	0.5	4.7	1.0
1997	VOYA	337	12 ^b	14,400	0.023	5.2	–	3.8	–	8.1	–
2009	VOYA	543	46	27,221	0.020	4.1	0.5	3.0	0.4	6.4	0.9
	ONT	105	13	7,841	0.013	2.8	0.7	2.0	0.5	4.3	1.2
	MN	222	18	10,296	0.021	4.5	0.9	3.3	0.7	7.1	1.7
2010	VOYA	463	46	28,005	0.017	3.9	0.3	2.9	0.2	6.0	0.9
	ONT	99	12	7,603	0.013	3.0	0.5	2.2	0.3	4.6	1.3
	MN	211	18	11,326	0.019	4.4	0.5	3.2	0.4	6.8	1.6
2011	VOYA	260	27	16,204	0.016	3.3	0.6	2.4	0.5	5.0	0.98
2015	VOYA	161	19	12,038	0.013	2.8	0.4	2.1	0.3	4.4	1.0
	MN	33	5	3,168	0.010	2.2	0.6	1.6	0.4	3.5	1.5
2016	VOYA	72	15	9,346	0.008	1.7	0.4	1.3	0.3	2.7	0.7
	MN	54	7	4,435	0.012	2.7	0.7	2.0	0.5	4.2	1.6

^a VOYA= Voyageurs National Park, ONT = Ontario, MN= Land outside of the park in Minnesota

^b 1996 and 1997 surveys used random 'grid' units instead of the standard sample units used in the other pellet-count surveys.

^c Standard error.

^d Based on an average 25 pellet-groups/deer/day (Rogers 1987, Patterson et al. 2002).

^e Based on 16 pellet-groups/deer/day (i.e., 35% less than 25.0 pellet-groups/deer/day; Patterson et al. 2002).

^f Based on 34 pellet-groups/deer/day (i.e., 35% more than 25.0 pellet-groups/deer/day; Rogers 1987).

Table 2. Density estimates of white-tailed deer from aerial surveys conducted in 1992 (Gogan et al. 1997) and 2009–2016 in Voyageurs National Park.

Year	Dates	Location Surveyed	Area Sampled (km ²)	Deer Observed	SCF ^a	Density (deer/km ²)
1992	2/4–3/12	Kab. Peninsula	305	388	2.25	2.9
2009	1/16–1/27	Whole Park	529	177	2.45	0.8
2010	1/11–1/13	Whole Park	529	236	2.45	1.1
2011	1/18–1/20	Kab. Peninsula	305	98	2.45	0.8
2013	2/1–2/27	Kab. Peninsula	305	167	2.45	1.3
2014	1/27–3/13	Kab. Peninsula	305	208	2.45	1.7
2015	2/1–3/11	Kab. Peninsula	305	204	2.45	1.6
2016	2/4–3/3	Kab. Peninsula	305	253	2.45	2.0

^a Sightability correction factor

^b Density = (Deer Observed*SCF)/(Area Sampled)

Table 3. White-tailed deer density estimates (deer/km²) for the area in and adjacent to Voyageurs National Park, 1989–2016, from pellet-counts, aerial surveys, and model-based estimates from Minnesota Department of Natural Resources (MNDNR; D’Angelo and Giudice 2016). Pellet-based density estimates for 1989–1991 appear to be biased high, and estimates from 1996–1997 are unreliable due to methodological issues. See Discussion for more details.

Year	Pellet-Count Based Estimates			Aerial Survey	MNDNR Estimate
	VOYA	South of VOYA ^a	VOYA-Area ^b		
1989	12.3	–	–	–	3.9
1991	11.6	–	–	–	4.3
1992	–	–	–	2.9	4.6
1996	3.0	–	–	–	3.0
1997	5.2	–	–	–	3.0
2009	4.1	4.5	4.2	0.8	3.3
2010	3.9	4.4	4.0	1.1	3.3
2011	3.3	–	–	0.8	2.8
2012	–	–	–		3.2
2013	–	–	–	1.3	3.0
2014	–	–	–	1.7	2.0
2015	2.8	2.2	2.7	1.6	2.1
2016	1.7	2.7	2.0	2.0	2.5

^a State and federal lands adjacent to the southern border of VOYA

^b Density estimate for the area in and adjacent to VOYA (i.e., VOYA and area south of VOYA)

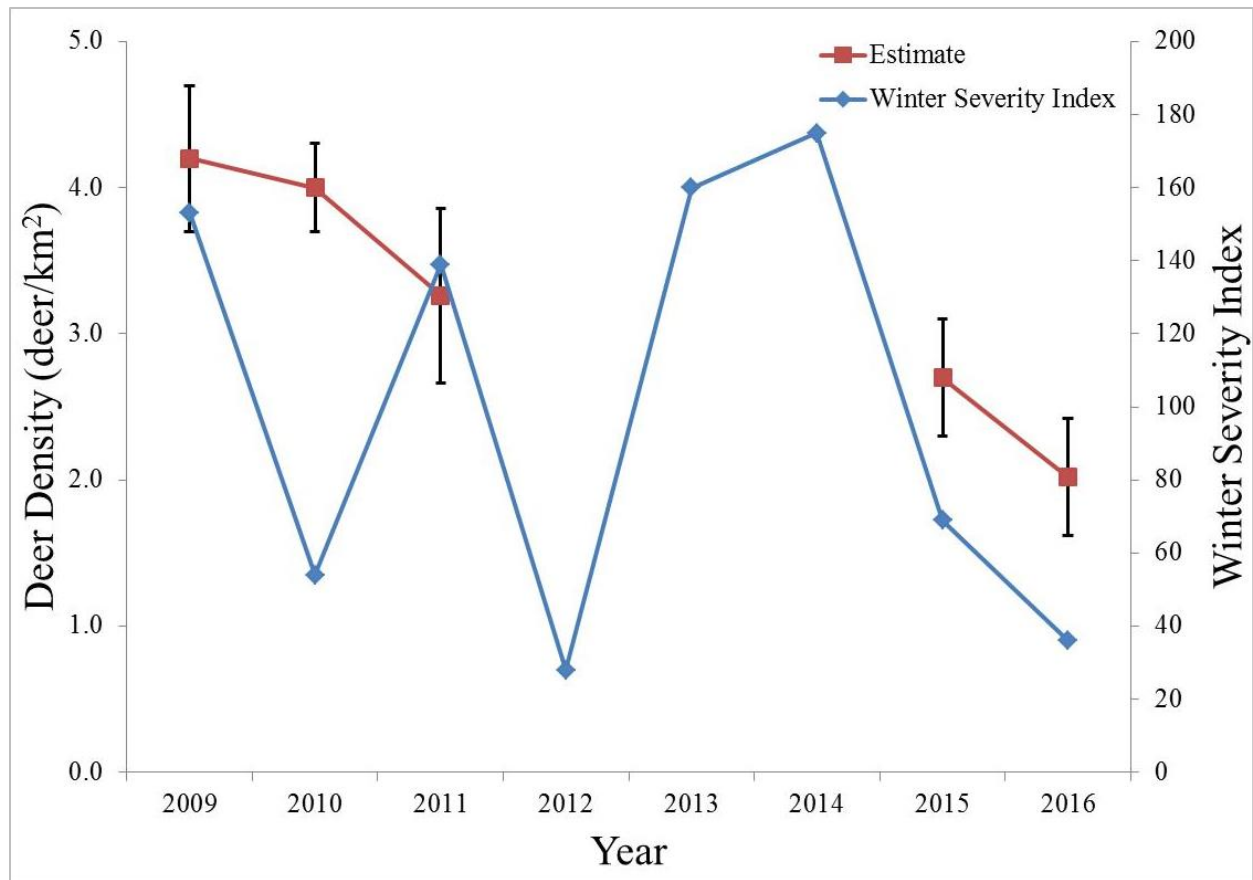


Figure 5. White-tailed deer density ($\pm$ SE) estimated via pellet-count surveys in Voyageurs National Park (MN), 2009–2016. MNDNR Winter Severity Index values are also shown during this period.

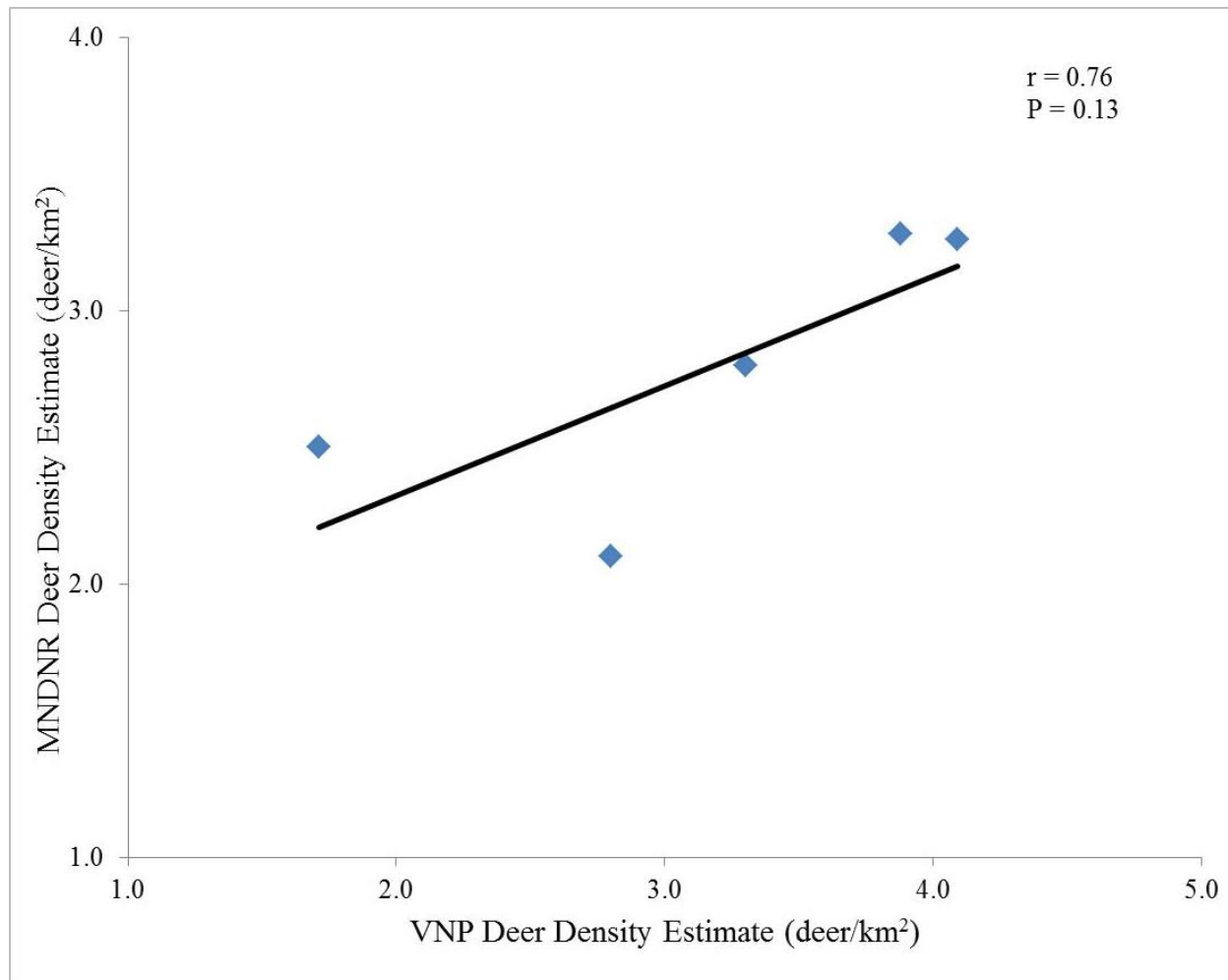


Figure 6. Correlation between pellet-count based estimates of white-tailed deer density for Voyageurs National Park (VOYA) and model-based estimates of deer density in areas adjacent to VOYA by Minnesota Department of Natural Resources (MNDNR; D'Angelo and Giudice 2016) for the five survey years of 2009–2011 and 2015–2016.

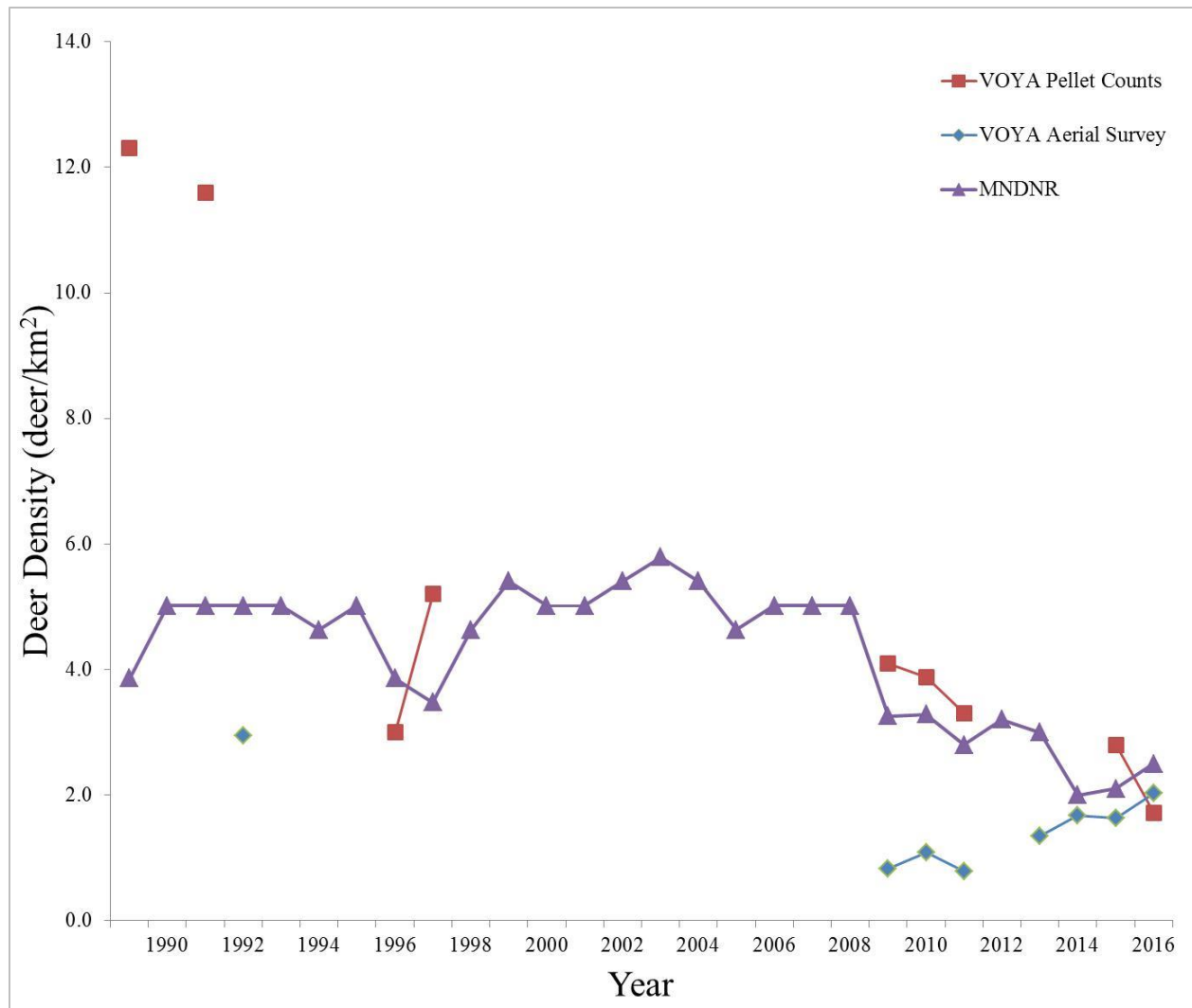


Figure 7. White-tailed deer density estimates based on pellet-counts and aerial surveys in Voyageurs National Park (VOYA), 1989–2016. Model-based estimates for deer in areas adjacent to the park are also shown (MNDNR; D’Angelo and Giudice 2016). Pellet-based density estimates for 1989–1991 appear to be biased high and estimates from 1996–1997 are unreliable due to methodological issues. See Discussion for more details.

Discussion

Accurate ungulate density estimates via pellet-count surveys are contingent upon having an accurate estimate of the pellet-group deposition rate (DeYoung 2011). We used a mean pellet-group deposition rate derived from estimates for white-tailed deer in northern Minnesota (Rogers 1987) and Nova Scotia (Patterson et al. 2002), as we thought those were most likely to be representative of deer in and adjacent to VOYA (see Table 1). Moreover, deCalesta et al. (2013), using the same deposition rate of 25 pellet-groups/deer/day, found a very close correspondence of deer density derived from a census of deer within fenced exclosures and estimates derived from pellet-counts.

To better understand how our estimates may have changed depending on the deposition rate, we estimated deer density using low and high deposition rates for deer in the boreal forest (Rogers 1987, Patterson et al. 2002), which demonstrated that changing the deposition rate by $\pm 35\%$ would correspond to a $\pm 35\%$ change in deer density estimates (see Table 1). We suggest a more conservative way to interpret our point estimates of deer density based on pellet-counts is to bound the uncertainty around the point estimates using the upper and lower estimates (while taking into account standard error around those estimates), which are derived by changing deposition rate by 35%. For example, we estimated deer density to be 1.7 deer/km² in 2016, but suggest true density likely is between 1.0 (lower estimate: 1.3 ± 0.3 deer/km²) and 3.4 deer/km² (upper estimate: 2.7 ± 0.7 deer/km²). However, even if an inaccurate estimate of pellet-group deposition rate is used in density calculations, pellet-count surveys can provide a valuable index to examine trends in deer abundance at different spatial and temporal scales for surveys conducted in a systematic manner (Forsyth et al. 2007). We do not have estimates of the power of our survey, i.e., whether our survey effort is adequate to estimate deer densities for all of VOYA. However, our pellet-count density estimates are primarily an index to track change over time. Given the similarity in trends of deer abundance from MNDNR model-based estimates and pellet-count based estimates (see below and Figure 6), we suggest our survey is likely adequate to accomplish this goal. Certainly, more intensive surveying would have yielded more precise estimates, but with limited time and resources this was not feasible given other management and research objectives at VOYA during this time.

Based on pellet-count surveys, deer density in 2016 (estimated at 1.7 deer/km²) in and adjacent to VOYA was lower than it was in 2009–2010. Winter severity is one of the most important factors impacting white-tailed deer density in northern Minnesota (DelGiudice et al. 2002, Heffelfinger 2011). The Winter Severity Index (WSI) developed by the MNDNR (DelGiudice et al. 2002) is based on the number of days below $\leq 0^\circ$ F and the number of days with ≥ 18 inches of snow on the ground. The WSI showed no significant trend during the periods 1989–2016 or 2009–2016 (see Figure 5), though it did vary substantially from year to year. Of particular note, two severe winters ending in 2013 and 2014 preceded the low deer density estimate of 2015, though we would have expected the 2016 deer density estimate to have been higher than 2015 based on the two mild winters of 2015 and 2016.

Year-round predation on adult deer and seasonal predation on deer fawns also affect deer density (Murphy 2011). As mentioned above, wolves are the primary predator of white-tailed deer in VOYA.

Wolf density in and around VOYA is high (40–60 wolves/1000 km²) and wolves consume adult deer throughout the year, but predation is highest from late fall to early spring as beavers (an important food source during the summer) become much less vulnerable when lakes and ponds are frozen. In late-May to mid-July, wolves in VOYA predate heavily on deer fawns until fawns are 7–8 weeks old and able to escape predation (Van Ballenberghe et al. 1975, Nelson and Woolf 1987, Gable 2016). Similarly, black bears, which are common in VOYA, can respond to the abundance of fawns in early summer and can be a large source of fawn mortality at this time (Kunkel and Mech 1994, Carstensen et al. 2009). In June 2016, we documented three instances where black bears had killed deer fawns (VOYA, unpublished data). However, we have no evidence that total predation on deer by wolves or bears has changed from 2009–2016 to coincide with the decline in deer abundance.

Forest composition and structure can also have an impact on deer populations by altering available forage and cover. VOYA was last logged in 1971 before the park was established, and little early successional habitat is available in the park because natural disturbance is largely limited to small-scale events from beaver activity or windthrow (Kirschbaum and Gafvert 2010). As a result, habitat quality for deer in VOYA has likely decreased as the forest has matured from 1975 to present (Adams and Hamilton 2011). Interestingly, deer densities inside and outside of VOYA do not appear to be different even though early successional habitat is much more abundant in the area just outside of VOYA due to active logging (Kirschbaum and Gafvert 2010). However, recreational hunting outside of VOYA is popular and likely results in a lower deer density than it would be if unharvested (DeYoung 2011).

Deer density estimates for VOYA based on pellet-counts from 1989 and 1991 (12.3 deer/km² and 11.6 deer/km², respectively) were extremely high. For example, these estimates are approximately 50% higher than the highest MNDNR estimate for areas adjacent to the park from 1976–present (i.e., 8.4 deer/km² in 1980 and 1983). We cannot fully explain why pellet-based density estimates were so high during 1989–1991, but it may have been due to methodological errors, such as incorrectly classifying old pellets as new ones, or random sampling errors, such as if several sample units fell within existing deer yards. Additionally, our pellet-based density estimates might be more accurate at lower deer densities than at higher ones. Nonetheless, it is possible that deer abundance in VOYA experienced a significant increase for a decade or so after the park was established in 1975, resulting from a combination of protection from legal hunting and a large pulse of early successional habitat created in the 1950–1960s. There are many examples of white-tailed deer populations experiencing a “release” when protected from hunting, but few of these examples also occur at northern extremes of white-tailed deer range where severe winters and a natural suite of predators (i.e., wolves, bears, coyotes, and bobcats) are significant regulators of deer abundance (Adams and Hamilton 2011). Anecdotal reports from VOYA staff present in the 1980s and 1990s suggest large deer yards and areas of overbrowsing existed at that time (B. Route, personal communication), though we do not see such evidence in the park at present.

MNDNR density estimates for the VOYA area were higher during the 1980s and 1990s than during 2009–2016. Moreover, even if pellet-count density estimates in 1989 and 1991 overestimated densities by 50%, deer densities in VOYA would still be higher than those during 2009–2016.

Additionally, the density estimate of the 1992 aerial survey was >30% higher than any aerial survey conducted from 2009–2016 (see Table 2). Our conclusion then is that while deer densities in VOYA in the 1980s and early 1990s were likely 1) greater than they are at present, and 2) greater than areas adjacent to the park that experienced deer hunting, they were not as extreme as those estimated by pellet-count methodology. The decline in density from 1989–present is likely due to changes in forest structure and composition inside the park, i.e., deer habitat quality has declined over time.

Alternative pellet-based methods for estimating deer density were attempted in 1996 and 1997 but both suffered from low sample sizes that resulted in relatively large variances around the estimates. The surveys were designed to improve precision of pellet-based density estimates, but we see no clear advantages over the more standard approach we used for 1989–1991 and 2009–2016 periods. The 1996 survey also differed in that it was completed during the winter. We do not recommend using this method in the future as only pellets visible on top of the existing snowpack can be counted and thus estimates should be biased low and variable snow conditions will make inter-annual comparisons difficult. Further, difficulties with winter access to most areas of VOYA will limit the number of sample units that can be surveyed in a given year.

Deer density estimates for VOYA derived from aerial surveys are lower than pellet-count and MNDNR density estimates during 2009–2016 (see Table 3). Moreover, aerial survey density estimates were negatively correlated to both pellet-count ($r = -0.89$) and MNDNR density estimates ($r = -0.38$). Based on this, we do not believe aerial surveys accurately reflect density estimates or trends in deer abundance through time. Indeed, DeYoung (2011) concluded that aerial deer surveys were best suited for relatively open environments and should be avoided in heavily forested habitats, which is found in much of VOYA. Additionally, accurate population estimates via aerial surveys are dependent on good visibility, observer experience, deer movements, and an accurate estimate of detection probability (Gasaway et al. 1986). Weather conditions such as snow depth and temperature ranged dramatically during our aerial surveys which likely affected deer behavior and detection probability. Research could be done to improve aerial survey-based density estimates in VOYA, primarily by refining aerial survey techniques and developing more rigorous estimates of detection probabilities under various conditions.

Pellet-count and model-based deer density estimates appear to reflect similar trends of deer density in and adjacent to Voyageurs National Park from 2009–present (see Figure 6), and it appears that both estimates can be used as indices to monitor white-tailed deer abundance in VOYA in the future. However, it should be noted that neither method has been independently validated against “known” deer densities, thus both could be providing biased estimates. Additionally, MNDNR model-based densities represent pre-fawn deer densities (i.e., the models take into account mortality during winter), whereas pellet-count surveys provide an average density estimate for the November–April/May period. Thus model-based density estimates should be lower than pellet-count estimates. Though model-based estimates of deer density adjacent to VOYA might be a useful proxy of deer density within VOYA, we suggest continued use of pellet-count based estimates (Appendix A) of deer density in VOYA as a low-cost, low effort method for more realistic estimates of abundance and trends within the park.

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Appendix A. White-tailed deer pellet count protocol for Voyageurs National Park, 2009–2016

Sampling Design

Two parallel transect lines will be established in each sampling unit, with at least 100 m separation between transect lines, using ArcGIS (or other GIS software) to ensure that transect lines fit within the sampling unit. Sampling units containing >50% water cover (e.g., some units along large lake shorelines; Sample Unit 43 in Figure A1) are limited to one transect line. Each transect line is 800 m in length and consists of four plots (22 m by 3.6 m) at 200-m intervals.

Establishing Transects

The following steps will be used to establish transect lines and sample plots in each sample unit:

- 1) Select a random number between 0 and 1000. The RANDBETWEEN() function in Excel works well for this; type in a cell “=RANDBETWEEN(0,1000)”. This is your random distance measurement to be used in Step 4.
- 2) Determine the best direction to orient transects (either N-S or E-W) based on limitations imposed by shorelines or other boundaries (see Figure A1).
- 3) Determine most accessible corner of the sampling unit, i.e., the corner of the plot easiest to travel to.
- 4) Starting from the most accessible corner, measure the random distance (the random number selected in Step 1) along the sample unit boundary in the direction perpendicular to the transect lines to determine the appropriate Easting or Northing of the transect line. If the random distance selected does not allow all of an 800-m transect to fall on land or inside the sample unit boundary, select another random distance between 0 and 1000. Label this transect using the following notation: “Sample Unit #A” (e.g., “4A” or “27A”).
- 5) Select a random number between 0 and 200. Starting where the transect line first intersects land, measure this random distance along the transect to the location of Plot 1 (Figure A1). Label plots using the following notation: “Sample Unit#Transect-Plot #” (e.g., “4A-1”). Record the UTM of this plot in an Excel spreadsheet.
- 6) Add the three remaining plots in the transect line by successively adding or subtracting 200 m to the appropriate UTM Easting or Northing (Figure A2). Label these plots and record the UTMs.
- 7) Repeat steps 1–6 for the second transect (“B”), if necessary.
- 8) Waypoints of sample plots can be loaded into GPS units (Garmin ETrex or Trimble).

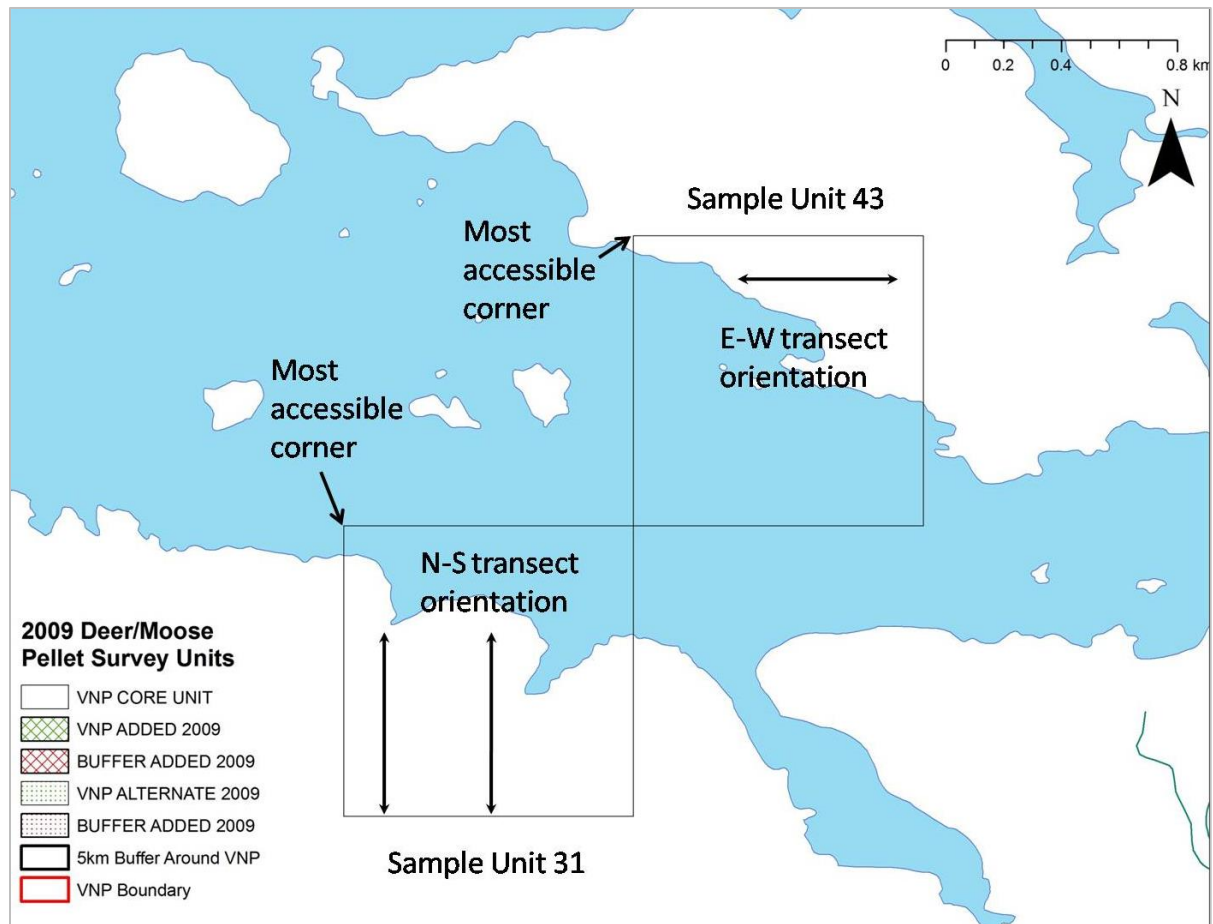


Figure A1. Examples of how to identify the most accessible corner, the best orientation for sample transects, and if the plot contains >50% lakes.

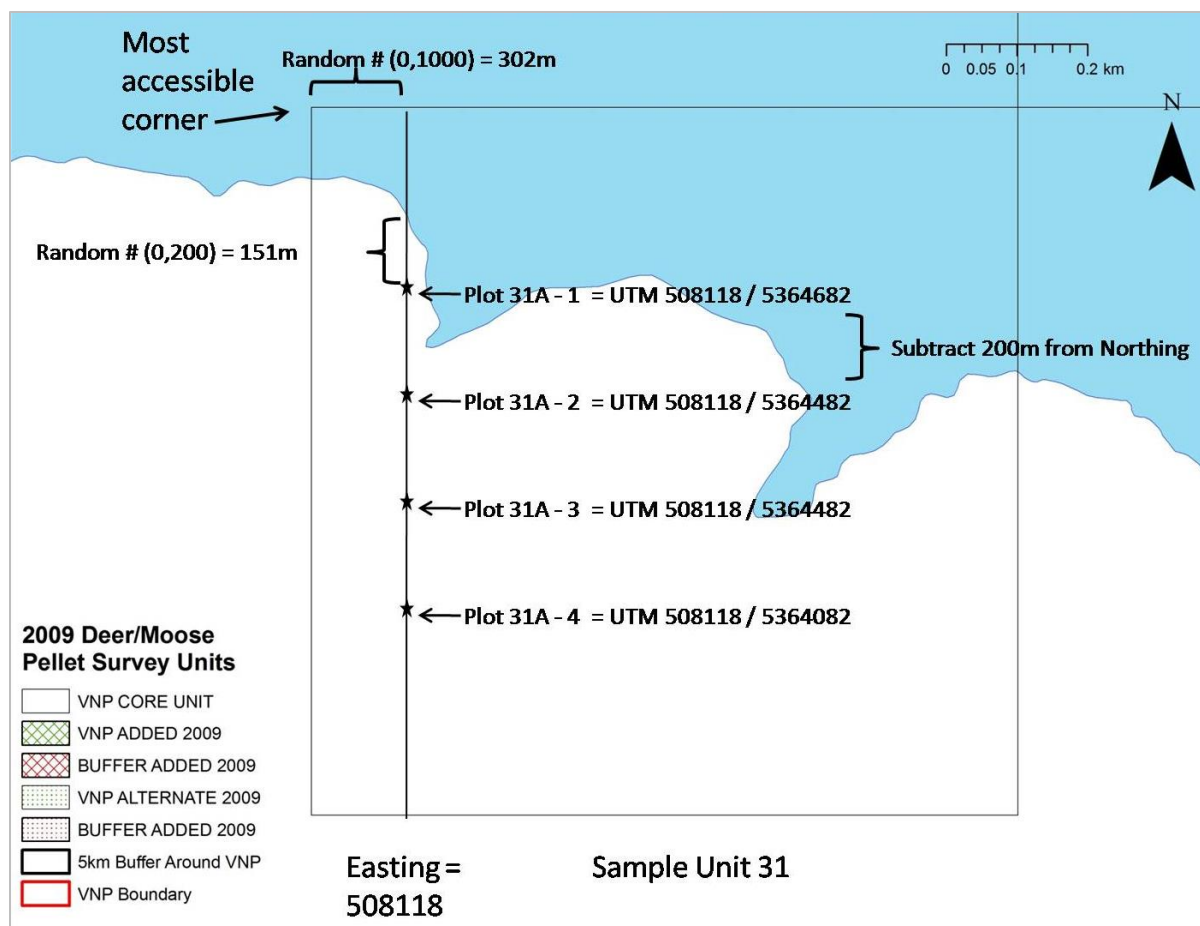


Figure A2. Examples of how to establish transect lines using random distance (0–1000 m), establish location of Plot 1 using random distance (0–200 m), and how to establish locations of Plots 2–4.

Pellet Data Collection

Rectangular sampling plots (3.6-m-wide by 22-m-long) will be sampled using the following steps:

- 1) The UTMs for each sample plot will be considered the plot “center.” Place the center stake in the ground, then move perpendicular (either East or North) to the sampling transect to stretch the 22 m rope from the stake and establish the center line of the rectangular plot (Figure A3). If part of the plot falls in habitat that is not able to be sampled (e.g., lake), you can move the plot according to the following rules in order of succession:
 - a. Move plot 22 m away in East or North direction from original plot center (i.e., 22 m farther away on same side of transect) (Figure A3).
 - b. Move plot to the opposite side of the transect (either West or South).
 - c. Move plot 22 m away in West or South direction from original plot center (i.e., 22 m farther away on the opposite side of the transect).

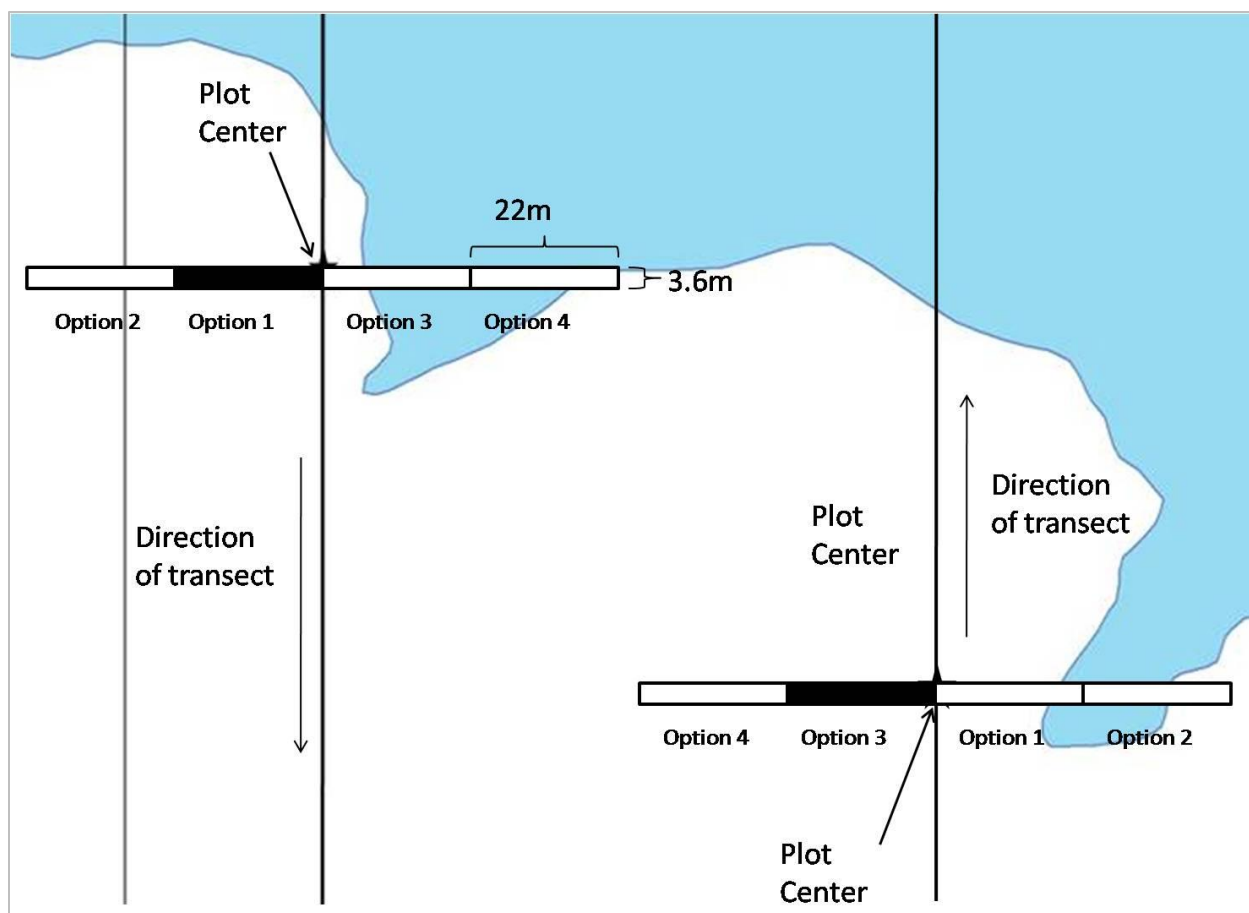


Figure A3. Examples of how to establish plot centers (black stars) and rectangular sample plots. Solid rectangles denote correct placement of plot. Note in the example on the right that options 1 and 2 resulted in plots falling in water, with option 3 the first available.

- 2) Use 1.8-m-long pole (collapsible tent pole) to measure 1.8 m on both sides of the center line to establish bounds of 3.6 m $\times$ 22-m-long plot.
- 3) All groups of white-tailed deer and moose pellets within each plot above the leaf litter from the previous fall will be identified to species and tallied.
 - a. Only count pellet-groups where $\geq 50\%$ of the pellet-group falls within the plot. Mean number of pellets per group for white-tailed deer pellet = 68.7 (range = 30–96 pellets; Rogers 1987) and for moose = 137 (P.A. Jordan, University of Minnesota, pers. comm.).
 - b. Pellet-groups that are difficult to age properly (i.e., are they 0–6 months old or >12 months old), are tallied separately on the data sheet. (Aging pellets can be difficult under dense conifer where litter does not accumulate rapidly.)
 - c. If you encounter a heavy concentration of pellets, estimate the number of groups present based on shape, size, color, and weathering.

- 4) If part of a plot cannot be counted due to snow cover, moving water, or standing water too murky or deep for seeing pellets (in clear water they can be seen down to 30–40 cm), the obscured area is estimated to the nearest 10% of the plot and recorded on the data sheet.

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