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Original Article

Deer Harvest Variation in Small and Large Management Units in Pennsylvania

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ABSTRACT Large game management units often lead to criticisms from hunters because they assume smaller units possess less variation in wildlife populations and more closely represent their local area. In 2003, Pennsylvania, USA, replaced smaller, socio-political county-based management units with larger wildlife management units (WMUs). We tested the hypothesis that smaller county units possessed less variation in antlered and antlerless white-tailed deer (*Odocoileus virginianus*) harvest densities among municipalities than did larger WMUs. Spatial variation, as measured by standard deviation and coefficient of variation of deer harvested per km^2 was similar for antlered deer (county units 0.44 SD, CV = 0.35; WMUs 0.43 SD, CV = 0.38) and antlerless deer (county units 0.71 SD, CV = 0.44; WMUs 0.84 SD, CV = 0.45). We found no support for the assumption that larger management units resulted in greater spatial variation in deer harvest density. © 2019 The Wildlife Society.

KEY WORDS county, harvest, management unit, municipality, *Odocoileus virginianus*, Pennsylvania, spatial variation, white-tailed deer.

Wildlife agencies delineate management units as areas possessing similar habitat and wildlife population characteristics. Biologically, management units should be large enough to contain the population of interest, delineate similar habitat conditions, and provide data sufficient to estimate population parameters with desired precision (Strickland et al. 1994, Rosenberry et al. 1999, Williams et al. 2002, McCoy et al. 2005). Socially, management units should delineate similarities in human-related factors that affect management actions, such as differences in human development, and be easily recognized by hunters (Strickland et al. 1994).

Spatial variation in biological and social characteristics within a management unit leads to questions of management unit effectiveness (Wisconsin Department of Natural Resources 2001, Wildlife Management Institute 2010). For example, in Wisconsin, USA, social concerns, such as hunters' interest in management units representing their local hunting locations, led to an increase in the number of white-tailed deer (*Odocoileus virginianus*) management units from 77 to 132 despite justification to maintain fewer and larger units for management decisions (Wisconsin Department of Natural Resources 2001). A recent review of Wisconsin's deer management program recommended increasing size of deer management units to increase sample sizes and improve reliability of deer management metrics at the unit level (Kroll et al. 2012).

In 2003, Pennsylvania, USA, changed its deer management units from 67 county management units to 22 wildlife management units (WMU). Thus, management unit size tripled on average. The lower number of WMUs, and subsequent increase in WMU size, was influenced by quantity of deer management data collected annually by the Game Commission. Public concerns about the size of WMUs led to an evaluation of WMU size in a legislatively sponsored review of Pennsylvania's deer management program (Wildlife Management Institute 2010). The legislature directed the reviewers to investigate whether smaller management units would improve deer management (HR642, 2007-08 Legislative Session). The review concluded that the WMU system represented a necessary compromise between deer management requirements for adequate data collection and deer habitat distributions and public desires for smaller management units (Wildlife Management Institute 2010).

Despite this conclusion, effectiveness of large WMUs continues to be questioned. In recent years, Pennsylvania legislators have proposed legislation to return to smaller, county-based deer management units (HB 2083, 2015-16 Legislative Session). Proponents of smaller, county management units question the ability of large WMUs to evenly distribute antlerless harvests and deer population abundance. For example, it is often assumed that antlerless harvest rates are greater on public lands than on private lands even though antlerless licenses can be used anywhere within a manage-

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ment unit. Proponents of smaller, county management units also question the ability of WMUs to maintain an evenly distributed deer population. Variation in landscape composition, the capacity of a landscape to support deer populations, and private and public landownership leads to perceptions that deer abundance varies more in large WMUs than in smaller county units. Proponents of smaller, county management units, perceive spatial variation of deer harvests is lower within smaller county-based deer management units than within large WMUs.

Although deer harvest variability between or within management units has been reported, to our knowledge, comparison of deer harvest variation within different-sized management unit systems has not been reported previously (Iverson and Iverson 1999, Nesslage and Porter 2001, Karns et al. 2016). We evaluated spatial variation of deer harvests within management units by estimating antlered and antlerless deer harvest densities for municipalities within counties and WMUs. Our objective was to test the hypothesis that smaller, county-based management units reduced spatial variation of deer management outcomes (i.e., antlerless harvest densities) and a public perception index of deer abundance (i.e., antlered harvest densities; Stout et al. 1996, West and Parkhurst 2002) compared with larger WMUs.

STUDY AREA

Prior to 2003, the Pennsylvania Game Commission used 67 county management units to manage deer populations. County management unit boundaries followed political boundaries that occasionally followed physical features (e.g., major rivers). County-management-unit land area averaged 1,751 km^2 (range = 342–3,222 km^2; Fig. 1).

In 2003, the Game Commission created a system of 22 WMUs for management of deer and other species. WMUs were created based on physiographic, habitat, and human factors (Rosenberry and Lovallo 2002). First, Pennsylvania was divided into physiographic units. The Ridge and Valley Province and Piedmont Province accounted for 2 of the units and the Appalachian Plateaus Province was divided into 3 units. These 5 physiographic units constrained further delineation of WMUs (Fig. 1). Division of physiographic units into WMUs followed similarities in landscape and human-related characteristics such as forest land (Loveland and Shaw 1996), public land areas of state and federal agencies, and human population density (2000 Census). Forest land, public land, and human population attributes were analyzed and plotted at high, medium, and low levels within 2.6-km^2 blocks across the state. The combination of physiography, forest cover, public land, and human density differentiated WMUs. Quantity of available wildlife harvest and population data informed decisions on size and number of WMUs. State, U.S., and interstate highways, as well as rivers, defined WMU boundaries. Wildlife Management Unit land area averaged 5,333 km^2 (range = 2,163–10,655 km^2).

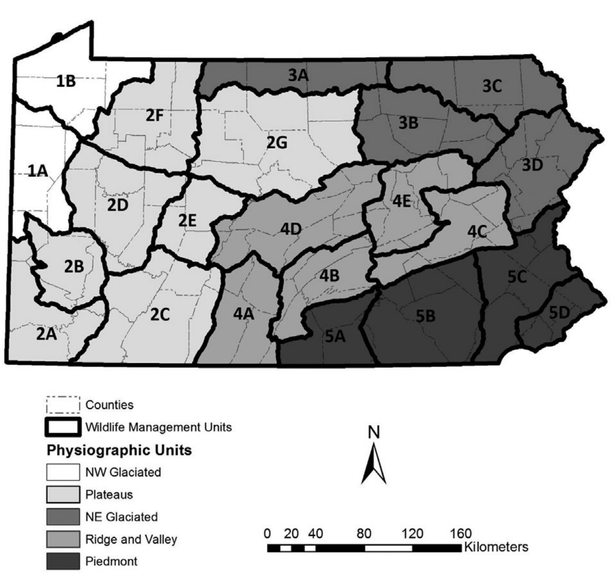

Figure 1. Physiographic provinces (shaded areas), 67 county boundaries and 22 wildlife management unit boundaries of Pennsylvania, USA.

METHODS

In Pennsylvania, buyers of general hunting licenses can harvest an antlered deer anywhere in the state within statewide antlered deer seasons. To harvest an antlerless deer, hunters must purchase an antlerless license for a specific management unit. Prior to 2003, the Game Commission issued antlerless licenses by county management units. After 2003, the Game Commission issued antlerless licenses by WMUs. Regulations required hunters to report deer harvests online, via telephone, or using postage-paid postcards within 10 days of harvest, indicating location of harvest (WMU, county, municipality), date of harvest, type of deer (antlered or antlerless), and hunting license number; these data are hereafter referred to as hunter-reported data. In Pennsylvania, a municipality includes cities, towns, boroughs, and townships. In addition, Game Commission personnel visited deer processors during the 12–15-day firearms season to field-check harvested deer and record type (antlered or antlerless), sex, age (6 months old, 18 months old, $\geq$30 months old), location of harvest (WMU, county, municipality), and hunter license number; these data are hereafter referred to as field-checked data. Game Commission personnel only check deer during the firearms season because most deer are harvested during this season, and variable reporting rates from other seasons have little effect on harvest estimates (Rosenberry et al. 2004). We then cross-tabulated field-checked harvest data with hunter-reported harvests to determine whether field-checked deer were reported by the hunter (Rosenberry et al. 2004).

We estimated deer harvests for municipalities or portions of municipalities (some municipalities were split by WMU boundaries) with a land area of $>$13 km^2. We excluded municipalities with a small land area ($\leq$13 km^2) because most were highly developed, provided limited hunting opportunity, and resulted in inflated harvest densities if deer harvests were reported in those municipalities. We pooled 3 years of field-checked data and hunter-reported harvest data to increase sample sizes when estimating municipality harvests.

To estimate harvest by municipality, we divided the annual average number of antlered or antlerless deer reported by hunters for each municipality by the respective reporting rate (Rosenberry et al. 2004). We developed a random-effects model using the glmer function in the package lme4 (https://cran.r-project.org/web/packages/lme4/index.html; Accessed 11 Sep 2018) in Program R (R Development Core Team 2016) to estimate reporting rate, where year and municipality were treated as random effects. The model was $\Pr(y_i = 1) = \text{logit}^{-1}\left(\beta_0 + \alpha_{j[i]} + \beta_{k[i]}\right)$ and

$$\alpha_j \sim N\left(0, \sigma_\alpha^2\right), j = 1, \ldots, J,$$

$$\beta_k \sim N\left(0, \sigma_\beta^2\right), k = 1, \ldots, K,$$

where i indexed field-checked deer, j was the municipality, β_0 was the intercept, α_j was the random effect for the jth municipality, and β_k was the random effect for the kth year. Both random effects had a mean of zero and σ_α^2 and σ_β^2 were the variance among municipality-specific and among year-specific random effects, respectively.

A random-effects model allowed us to estimate reporting rates for municipalities with sparse data because the model would estimate the reporting rate closer to the county or WMU average (i.e., the shrinkage effect of random-effect models). In addition, the model would account for annual variation in reporting rates but allowed us to use the average reporting rate across the 3 years, as well as assess the variability in reporting rates among years (Rosenberry et al. 2004). To compare spatial variation between county management units and WMUs, we used municipal harvests from 2 different time periods. To evaluate county spatial variation, we estimated municipal harvests from 1996 to 1998 when deer harvest regulations were applied by county management units. To evaluate WMU spatial variation, we estimated municipal harvests from 2012 to 2014 when deer harvest regulations were applied by WMU. These years represented periods of relatively consistent deer-harvest regulations applied at the unit of interest. The period from 1996 to 1998 represented years prior to substantial changes in deer hunting regulation. The years 2012 to 2014 represented a period about a decade after substantial changes in deer hunting regulations including implementation of antler point restrictions (2002) and WMUs (2003). One change did occur in 2013 when WMU 2H was created within the boundaries of WMU 2G. To maintain consistency in our data from 2012 to 2014, we included WMU 2H harvest data with WMU 2G. Our study required consistent deer-harvest regulations during the period of evaluation. Thus, we used 2 separate time periods when deer-harvest regulation boundaries corresponded to the management-unit boundaries of interest.

We tested the hypothesis that smaller county management units would exhibit less variation than WMUs using absolute (i.e., standard deviation, SD) and relative (i.e., coefficient of variation, CV) measures of variation of municipal harvests within counties and WMUs. Standard deviation provided an absolute measure of variation on a biologically meaningful scale of deer harvest per km^2. Coefficient of variation provided a relative measure of variation scaled to the point estimate. We rejected the hypothesis that smaller county-based management units reduced spatial variation of deer management outcomes such as antlerless harvest densities and a public perception index of deer abundance such as antlered harvest densities compared with larger WMUs if the variation in harvest density, as measured by SDs and CVs, was similar or smaller for WMUs than counties.

RESULTS

We estimated municipal deer harvests from a minimum of 43,000 hunter-reports and 8,000 field-checked deer each year. Average reporting rates ranged from 30% to 45%. Less than 3% of reported harvests could not be assigned to a WMU, or county, or municipality. Reporting rate varied little among years because the standard deviation was small among the random year effects for county units (Antlered SD: $\bar{x} = 0.023$; Antlerless SD: $\bar{x} = 0.005$) and WMUs (Antlered SD: $\bar{x} = 0.002$; Antlerless SD: $\bar{x} = 0.014$).

Spatial variation of antlered harvest densities did not differ between county management units and WMUs. Within county management units, antlered harvests averaged 1.34 ($\pm$0.44 SD, CV = 0.35; Fig. 2A) deer per km^2. Within WMUs, antlered harvests averaged 1.14 ($\pm$0.43 SD, CV = 0.38; Fig. 3A) deer per km^2. For antlered harvests, average absolute variation (SD) and average relative variation (CV) did not differ statistically because 95% CIs overlapped, and we did not consider the differences to be meaningful from a biological or management perspective (Table 1). In addition, distribution of antlered harvest density SD was similar for county management units and WMUs (Fig. 4A). Therefore, we rejected the hypothesis that smaller county management units reduced spatial variation of antlered harvest densities as a public perception index of deer abundance.

Spatial variation in antlerless-deer harvest densities was similar between county management units and WMUs. Within county management units, antlerless harvests averaged 1.71 ($\pm$0.71 SD, CV = 0.44; Fig. 2B) deer per km^2. Within WMUs, antlerless harvests averaged 1.86 ($\pm$0.84 SD, CV = 0.45; Fig. 3B) deer per km^2. For antlerless harvests, average absolute variation (SD) and average relative variation (CV) did not differ statistically because 95% CIs overlapped. We did not consider the differences to be meaningful from a biological or management perspective (Table 1). In addition, distribution of antlerless harvest density SD was similar for county management units and WMUs (Fig. 4B). Therefore, we rejected the hypothesis that smaller county management units reduced spatial variation in outcomes of management actions (i.e., antlerless harvest densities).

DISCUSSION

Smaller county units did not have less spatial variation in deer harvest densities compared with larger WMUs. Although WMUs were, on average, 3 times larger than counties,

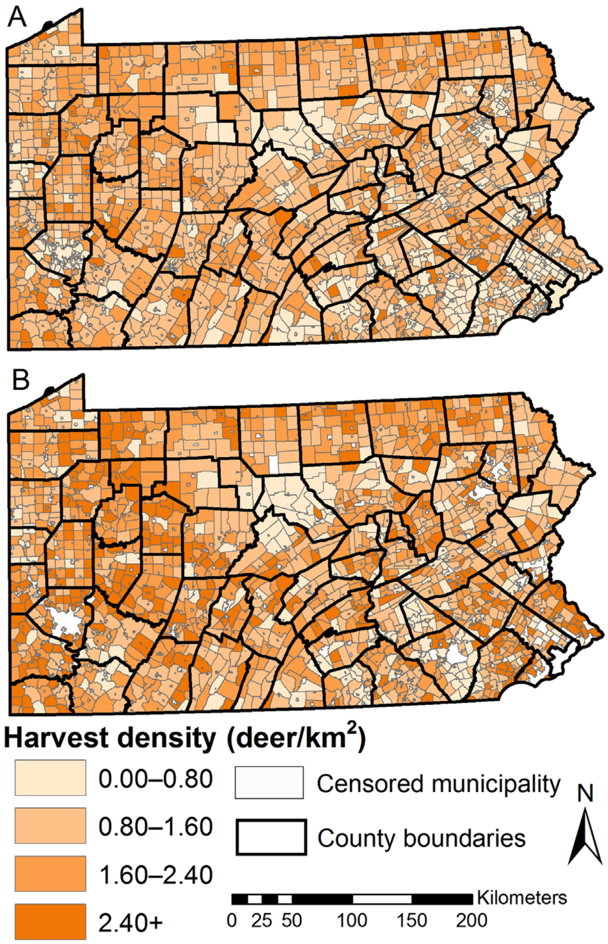

Figure 2. Estimated municipal antlered (A) and antlerless (B) white-tailed deer harvest densities (deer/km^2) within county management units, Pennsylvania, USA, 1996–1998.

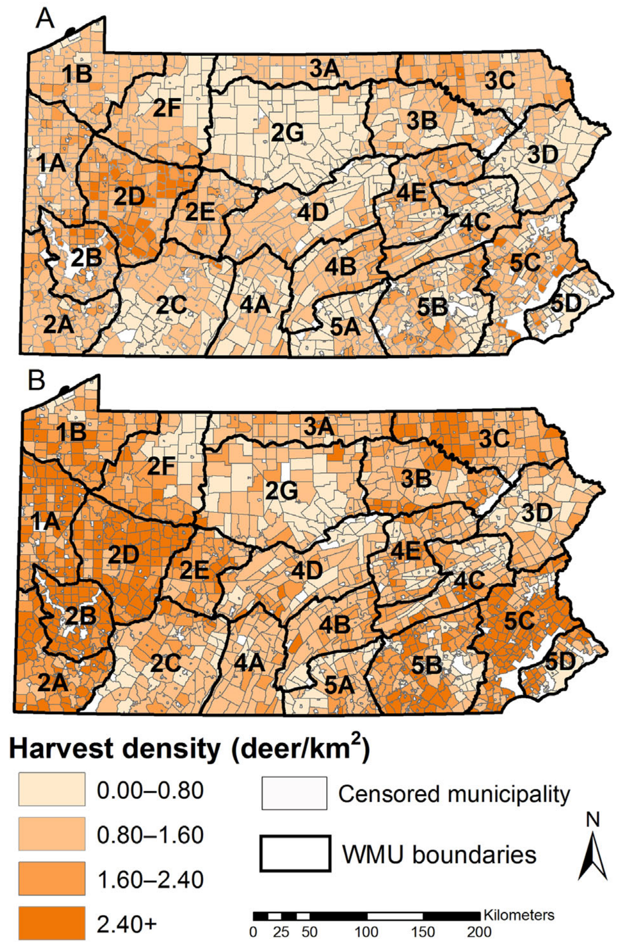

Figure 3. Estimated municipal antlered (A) and antlerless (B) white-tailed deer harvest densities (deer/km^2) within wildlife management units (WMU), Pennsylvania, USA, 2012–2014.

absolute and relative variation in antlered and antlerless harvest densities was similar. Cumulative distribution of absolute variation (i.e., SD) also showed a similar pattern. As a result, we conclude there are no differences in spatial variation of management outcomes as measured by antlerless harvest density, or deer population abundance as measured by the public perception index of antlered harvest density, between county units and WMUs.

Although increasing extent of an area may increase variability within the area, we did not detect an increase in deer harvest variation (Wiens 1989). This result is likely due to different objectives and outcomes for county management units and WMUs. Counties, as socio-political boundaries, are not designed to delineate similar ecological or human-related characteristics (Dallimer and Strange 2015). For example, Dauphin County extends from the Ridge and Valley Province into the Piedmont Province. Northern Dauphin County is primarily forested with large tracts of public land; whereas, southern Dauphin County encompasses the city of Harrisburg and surrounding communities. Unlike counties, WMUs delineated similarities in land cover (i.e., forest cover) and hunter-access (i.e., landownership, human density) factors that can affect deer harvests (Foster et al. 1997, Karns et al. 2016). The design of WMUs to encompass similar habitat and hunter-access factors appeared to compensate for their larger size when compared with smaller county units.

Larger size of WMUs and use of physical boundaries also may offset expected increase in variation. Small management units may not provide sufficient area to contain the population of interest (Rosenberry et al. 1999, McCoy et al. 2005, Webb et al. 2007). Widespread emigration and immigration of male white-tailed deer, in which >50% of yearling males disperse miles from their natal range, creates a dispersal edge surrounding management units (Rosenberry et al. 1999, Lancia et al. 2000, Long et al. 2005). Using an average dispersal distance of 7.5 km reported in Pennsylvania to define the width of the dispersal edge, a circle the size of the average county would contain 53% dispersal edge (Long et al. 2005). A circle the size of the average WMU would contain 33% dispersal edge. As a result, the influence of different deer population objectives in neighboring management units would have less effect on large WMUs than on small county units. In addition to the effect of unit size, use of roads and rivers as boundaries may act as semi-permeable barriers to emigration and immigration, further reducing the influence of emigration and immigration on overall

Table 1. Means and 95% confidence intervals (CI) of standard deviations (SD) and coefficients of variation (CV) of antlered and antlerless white-tailed deer harvest densities within counties and wildlife management units (WMU), Pennsylvania, USA, 1996–1998 and 2012–2014.

Type of deer	Unit	*n*	$\bar{x}$ of SD	95% CI for SD	$\bar{x}$ of CV	95% CI for CV
Antlered	County	66	0.44	0.40–0.47	0.35	0.31–0.38
	WMU	22	0.43	0.38–0.48	0.38	0.35–0.42
Antlerless	County	66	0.71	0.62–0.81	0.44	0.39–0.48
	WMU	22	0.84	0.66–1.01	0.45	0.41–0.49

population parameters within WMUs compared with county-based units (Rosenberry et al. 1999, McCoy et al. 2005, Long et al. 2010, Peterson et al. 2017). Wildlife management units may reduce expected variation by reducing the influence of neighboring management units due to larger area and semi-permeable nature of physical boundaries.

Regardless of management unit size, heterogeneity in deer harvest distribution will occur due to heterogeneity in landscape features—such as forested versus nonforested areas —and hunting activity—such as unhunted versus hunted properties—that exist at scales smaller than county units or WMUs. Our analysis demonstrated that larger management units, when designed to incorporate factors that affect deer and deer hunting, did not have greater spatial variation of deer harvests than did the smaller, county units. As a result, wildlife managers can consider other criteria—such as availability of data to provide reliable unit-level deer management metrics (Kroll et al. 2012) and boundary identification and location—when establishing deer management units.

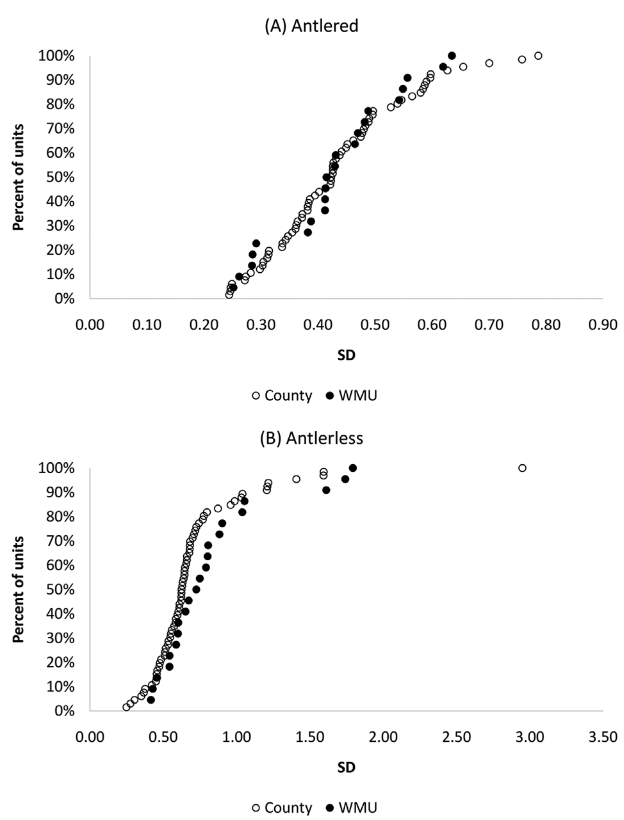

Figure 4. Cumulative distribution of the standard deviation (SD) of municipal antlered (A) and antlerless (B) white-tailed deer harvest densities within counties and wildlife management units (WMU), Pennsylvania, USA, 1996–1998 and 2012–2014.

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