Original Article

White-Tailed Deer Age Ratios as Herd Management and Predator Impact Measures in Pennsylvania

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ABSTRACT A review of the Pennsylvania Game Commission's (PGC) deer management program and public concern about predator impacts on deer (*Odocoileus virginianus*) populations compelled the PGC to investigate the role of age ratios in developing management recommendations. Age ratios, such as proportion of juveniles in the antlerless harvest, may provide an index to population productivity and predator impacts. We estimated proportion of juveniles in the antlerless harvest from hunter-killed deer, population trends using the Pennsylvania (USA) sex–age–kill model, and reproduction from road-killed females. Using these estimates and a simulation model, we concluded that no single age-ratio value would serve as a reliable measure of population status. Wildlife Management Unit-specific trends in proportion of juveniles in the antlerless harvest and population trends provided the most relevant management information. We also provide an example decision chart to guide management actions in response to declining age ratios in the harvest. Although predator management activities and juvenile survival studies are often desired by the public, our decision-chart example indicated a number of deer management options exist before investing resources in predator management activities and juvenile survival studies. Published 2011. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS age ratios, antlerless, black bears, coyotes, harvest, *Odocoileus virginianus*, Pennsylvania, predators, sex–age–kill model, white-tailed deer.

The value of age ratios for ungulate management depends on management objectives and availability of population trend data (Caughley 1974, McCullough 1994, Bender 2006). When used properly, age ratios may provide relevant management data such as adult and juvenile survival (Bender 2006). However, age ratios alone provide limited information on population demographics and their use in herd management decisions is risky (Caughley 1974, McCullough 1994). The Pennsylvania Game Commission's (PGC) deer management program (PA, USA) did not use age ratios alone for management recommendations for white-tailed deer (*Odocoileus virginianus*) but a legislatively sponsored, external review, and concerns about deer predation, compelled the PGC to investigate potential value of harvest age ratios to herd management.

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Intentional deer population reductions from 2000 to 2004 caused some sportsmen to express concern about deer population sustainability. Although controversy over PGC deer management is not new (Kosack 1995, Frye 2006), heightened discontent has led to greater legal and political involvement in deer management. Legally, a sportsmen group filed an injunction to stop the harvest of antlerless deer during the 2007–2008 hunting seasons because of concerns that the deer population was below its natural and sustainable level (The Unified Sportsmen of Pennsylvania v. The Pennsylvania Game Commission and the Commissioners of the Pennsylvania Game Commission, 2007). After 3 years, this case was dismissed in 2011. Other sportsmen are concerned that deer populations are not sustainable with current levels of predation. Public comments and presentations at Board of Game Commissioners meetings have requested reduced antlerless allocations to counter the perceived impact of predators on deer populations (Mulhollem 2010*a*). Predation concerns have led some members of the Board of Game Commissioners, the public, and politicians to promote reduced antlerless harvests, recommend juvenile survival studies, and promote bounties for predators (Crable 2010, Mulhollem 2010*b*). Politically, the legislature approved an independent review of the PGC deer management program motivated in part by sportsmen concerns over low deer numbers. In 2009, the Legislative Budget and Finance Committee selected the Wildlife Management Institute (WMI) to conduct an external review of the PGC's deer program (Wildlife Management Institute 2010).

Managing for a sustainable white-tailed deer population has been a part of the PGC's policy and deer management program for decades. Most recently, a facilitated meeting of public stakeholders independently identified maintaining a healthy deer population as a deer management goal. To measure progress toward the goal of a sustainable deer population, the PGC monitored population productivity (i.e., embryos/mature F [>1 yr of age]), disease prevalence, and population trends.

Following their review, WMI recommended replacing the measure of embryos per mature female or discontinuing deer herd productivity assessment (Wildlife Management Institute 2010). The WMI's most preferred alternative to replace the measure of embryos per mature female was proportion of juveniles (<1 yr of age) in the antlerless harvest (Wildlife Management Institute 2010). The reasons WMI recommended replacing or discontinuing use of embryos per mature female were that embryos per mature female did not appear sensitive to differences in deer population and habitat characteristics, and there were inadequate annual sample sizes for all age classes in 22 Wildlife Management Units (WMUs). As a result, the PGC assessed reproductive data using a 3-yr running average. Larger annual sample sizes for proportion of juveniles in the antlerless harvest were available by WMU, such that inadequate sample sizes were not an issue.

Proportion of juveniles in the antlerless harvest also may provide an index to predator impacts on deer populations (Williamson 2003, Kilgo et al. 2010). Predators kill most white-tailed deer during the first 3 months of life (Ballard et al. 2001). In Pennsylvania, coyotes (*Canis latrans*) and black bears (*Ursus americanus*) killed similar numbers of fawns, but predator-caused mortalities of deer older than 3 months were rarely observed (Vreeland et al. 2004, Keenan 2010, Norton et al. 2012). Consequently, collecting data on the proportion of juveniles in the antlerless harvest when deer are >3 months of age may provide an index to recruitment after most predator-caused mortalities have occurred.

Pennsylvania Game Commission staff annually evaluates progress toward management goals. Each management goal has a quantitative objective that defines goal achievement. For example, an average of 1.50 embryos per mature female was an objective for the deer health goal. Following field data analysis, PGC staff develops deer management recommendations. The primary method of adjusting deer populations is through a WMU-specific antlerless allocation that is distributed on a first-come, first-served basis. Staff recommendations are presented to a Board of Game Commissioners that has decision-making authority. The Board of Game Commissioners is not obligated to follow staff recommendations.

We evaluated proportion of juveniles in the antlerless harvest as a new decision criterion for deer management in Pennsylvania because of the program review by WMI and predation concerns expressed by the public. Our objectives were to: 1) identify an appropriate objective for proportion of juveniles in the antlerless harvest, and 2) describe how proportion of juveniles in the antlerless harvest could be used when making population management recommendations to address both biological and social considerations.

STUDY AREA

Pennsylvania was approximately 116,000 km^2. Pennsylvania's climate varied across the state with warm, humid summers and cold, snowy winters. Landcover, although variable, was predominantly forested with Appalachian oak forests in most areas and northern hardwood forests in the north. Forests were dominated by oak (*Quercus* spp.), maple (*Acer* spp.), birch (*Betula* spp.), American beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), and hickory (*Carya* spp.). Primary predators of white-tailed deer included coyotes (*Canis latrans*), black bears (*Ursus americanus*), and bobcats (*Lynx rufus*) (Vreeland et al. 2004). Deer management recommendations were based on data collected in 22 WMUs distributed among 5 physiographic provinces (Fig. 1). Within physiographic provinces, WMUs were areas with easily described boundaries and contained relatively homogeneous percent forest cover, percent public lands, and human population density. To achieve adequate samples size for data collected by WMU, such as harvest data, the number of WMUs was limited to 22. Wildlife Management Units ranged in area from 2,170 km^2 to 10,696 km^2. We limited our analysis to 19 WMUs because we did not estimate population size for 3 WMUs (2B, 5C, and 5D) that

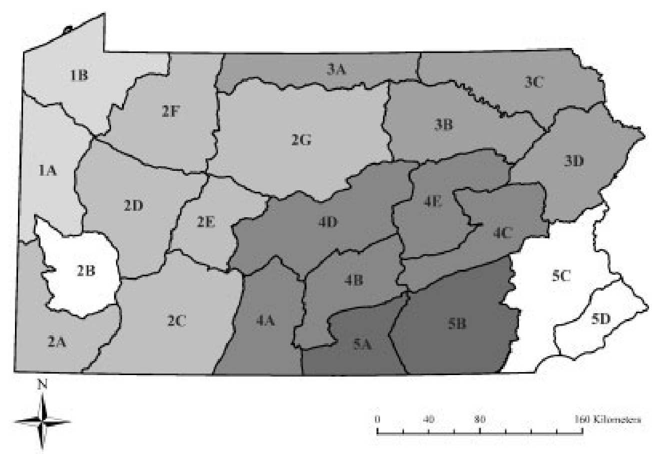

Figure 1. Pennsylvania's Wildlife Management Units (WMUs) in Pennsylvania, USA. WMUs 1A–B represent the northwest glaciated plateaus units. WMUs 2A–G represent the nonglaciated Allegheny plateaus units. WMUs 3A–D represent the northeast glaciated plateaus units. WMUs 4A–E represent the ridge and valley units. WMUs 5A–D represent the piedmont units. WMUs 2B, 5C, and 5D contain the cities and immediate suburbs of Pittsburgh and Philadelphia and were not included in this analysis.

encompassed Pittsburgh and Philadelphia and immediately surrounding areas (Norton et al. 2012).

METHODS

Proportion of Juveniles in the Antlerless Harvest

Annually, PGC personnel examined deer harvested by hunters during the 12-day modern firearms deer season and recorded sex, age, kill location (WMU, county, and township), and hunting license number. Data were collected by 33 teams of trained personnel that visited businesses throughout the state that processed deer. We used these data to estimate deer harvests and demographics of harvest (Rosenberry et al. 2004). During the hunting season, we aged deer as juveniles (<1 yr of age), subadult (1.5 yr of age), or adult (>1.5 yr of age) using tooth wear and replacement (Severinghaus 1949). To ensure accuracy of ages, PGC personnel completed training and testing every 3 yr.

We used these data to estimate the proportion of juveniles in the antlerless harvest ($\hat{p}_J$) as

$$\hat{p}_J = \frac{J}{J+F}$$

where J is the number of juveniles and F is the number of mature females (>1 yr of age).

Population Trends

We used population estimates from a modified sex–age–kill (SAK) model to monitor population trends. The Pennsylvania modification to the SAK model (hereafter, PASAK) differs from traditional SAK models when estimating the number of mature males (>1 yr of age) in the population. Because of selective antlered deer harvest, we estimated mature male populations using different harvest rates for subadult (1.5 yr of age) and adult (>1.5 yr of age) male deer (Norton et al. 2012). We estimated harvest rates from an empirical relationship between harvest rates and hunter effort statistics (Norton et al. 2012).

We estimated the adult male population ($\hat{N}_{\mathrm{AM}}$) as

$$\hat{N}_{\mathrm{AM}} = \frac{\hat{K}_{\mathrm{AM}}}{\hat{H}_{\mathrm{AM}}}$$

where $\hat{K}_{\mathrm{AM}}$ was the estimated adult male harvest and $\hat{H}_{\mathrm{AM}}$ was the estimated adult male harvest rate. We estimated the subadult male population as

$$\hat{N}_{\mathrm{YM}} = \frac{\hat{K}_{\mathrm{YM}}}{\hat{H}_{\mathrm{YM}}}$$

where $\hat{K}_{\mathrm{YM}}$ was the estimated subadult harvest and $\hat{H}_{\mathrm{YM}}$ was the estimated subadult harvest rate. We estimated the mature male population ($\hat{N}_{\mathrm{Antld}}$) as

$$\hat{N}_{\mathrm{Antld}} = \hat{N}_{\mathrm{AM}} + \hat{N}_{\mathrm{YM}}$$

We estimated sex- and age-specific deer harvests (K) for each WMU using a Lincoln–Petersen estimator corrected for small sample size (Chapman 1951),

$$\hat{K} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

where n_1 is the number of harvested deer checked in the field, n_2 is the number of harvested deer reported by hunters, and m_2 is the number of harvested deer checked by PGC personnel and reported by hunters (Rosenberry et al. 2004). Harvested deer were reported by hunters, who are required to report any legal deer harvest by mail or Internet.

After we estimated the mature male population, the PASAK model followed standard SAK methods. Specifically, we used mature female:mature male ratios ($\hat{p}_{\mathrm{F:M}}$) and juvenile:mature female ratios ($\hat{p}_{\mathrm{J:AF}}$) to estimate mature female ($\hat{N}_{\mathrm{F}}$) and juvenile ($\hat{N}_{\mathrm{J}}$) population sizes, respectively as:

$$\hat{N}_{\mathrm{F}} = \hat{N}_{\mathrm{Antld}} \times \hat{p}_{\mathrm{F:M}}$$

$$\hat{N}_{\mathrm{J}} = \hat{N}_{\mathrm{F}} \times \hat{p}_{\mathrm{J:F}}$$

where we estimated $\hat{p}_{\mathrm{F:M}}$ by dividing the proportion of subadult males in the mature male population ($\hat{p}_{\mathrm{YM:Antld}}$),

$$\hat{p}_{\mathrm{YM:Antld}} = \frac{\hat{N}_{\mathrm{YM}}}{\hat{N}_{\mathrm{AM}} + \hat{N}_{\mathrm{YM}}}$$

by the proportion of subadult females in the mature female population ($\hat{p}_{\mathrm{YF:F}}$) obtained from harvest data (Severinghaus and Maguire 1955):

$$\hat{p}_{\mathrm{F:M}} = \frac{\hat{p}_{\mathrm{YM:Antld}}}{\hat{p}_{\mathrm{YF:F}}}$$

We estimated the juvenile population using harvest juvenile: mature female ratios. This direct input was recommended by WMI (Wildlife Management Institute 2010) to replace a more complex correction-factor calculation (Norton 2010).

We quantified precision of the PASAK model using a Monte Carlo parametric bootstrapping method (Efron 1979) similar to Millspaugh et al. (2007). We conducted 1,000 Monte Carlo bootstraps of the empirical data to generate 1,000 population estimates from a random selection of the data taken with replacement. A fundamental assumption of the parametric bootstrap is that each parameter is assumed to have some underlying distribution with a specific mean and variance (Millspaugh et al. 2007). Because all PASAK model parameters were constrained between 0 and 1, we conducted the bootstrap using either a binomial distribution, $b(n,p)$, or a beta distribution, $beta(\mu,\delta^2)$, based on empirical data collected by the PGC (Norton 2010). Precision of population estimates was the standard deviation of the replicate simulation estimates of N and 90% confidence intervals were estimated from the 5th and 95th percentiles of simulation estimates of N. Also, we calculated the coefficient of variation (CV) as $\hat{\mathrm{S}}\mathrm{E}(\hat{N})/\hat{N} \times 100\%$. We used SAS (SAS Institute, Inc., Cary, NC) to estimate population size and precision for each WMU in Pennsylvania from 2004 to 2009.

Reproductive Data

Annually, PGC personnel examined female deer killed on highways or by other causes to determine pregnancy status and count fetuses from 1 February to 31 May. They recorded location (county, township, and WMU), date killed, cause of death, and number and sex of embryos for each doe on a form attached to a deer-jaw envelope. One side of the lower jaw was removed from each deer for age determination. We aged all jawbones using replacement-and-wear technique (Severinghaus 1949). From these data, we determined embryos per mature female including pregnant and nonpregnant females.

We selected a reproduction objective of 1.50 embryos per mature female. The value of 1.50 was chosen for a number of reasons. First, 1.50 embryos per mature female corresponds to a population at maximum sustained yield based on a Generalized Sustained Yield table derived by Downing and Guynn (1985). Second, other research studies support the conclusions based on the Generalized Sustained Yield table. Numerous studies from across the United States and Canada show that a value of 1.50 embryos per mature female represents the middle ground between deer with low and high nutrition (Cheatum and Severinghaus 1950, Verme 1969, McCullough 1979). Finally, a target of 1.50 embryos per mature female was achievable for WMUs in Pennsylvania. Studies used to assess the suitability of 1.50 embryos per mature female come from states including Michigan, Ohio, New York, and Pennsylvania (USA) and provinces including Manitoba (Canada; Cheatum and Severinghaus 1950, Ransom 1967, Verme 1969, McCullough 1979, Stoll and Parker 1986).

Establishing an Objective

An age ratio objective could be defined by a single threshold value or trend analysis of proportion of juveniles in the antlerless harvest. We used a simple model to evaluate the practicality of a single threshold value of proportion of juveniles in the antlerless harvest for all WMUs by estimating a critical value of proportion of juveniles in the antlerless harvest that resulted in a sustainable population. We limited our evaluation to mature females and juveniles because they met our definition of antlerless harvest. Our model began with the fawning season population of mature females and newborn fawns. We then calculated the prehunt population using fawning season population and survival rates. Next, we calculated the posthunt population using the prehunt population and harvest rates, and then calculated the next year's fawning season population using the posthunt population, survival rates, and reproductive data. We repeated these steps for a 5-yr period to evaluate population stability.

We used information from a generalized sustained yield table (Downing and Guynn 1985) and initiated the model using age and sex composition of a population at 60% of maximum abundance. We chose this level of population abundance because it was comparable to most WMUs in Pennsylvania based on mature female reproductive rates of 1.50 embryos per mature female (Rosenberry et al. 2010). We applied mature female survival rates proportionately across the year because we have observed little variation in monthly survival rates outside the hunting seasons (Norton 2010). For juveniles, we varied the summer survival rate from 0.10 to 1.00 in increments of 0.05. We also varied antlerless harvest rate, assumed to be equal for all antlerless deer, from 0.00 to 0.25. We chose these harvest rates because they represent a range of values consistent with those who want no antlerless hunting (0.00 harvest rate) and observed harvest rates from field studies in Pennsylvania under current regulations (Keenan 2010, Norton 2010). Prior to the start of the next year, we divided the juvenile population in half to represent a 50:50 sex ratio (PGC, unpublished data). Half of the juvenile population advanced into the subadult female class. Subadult males were removed from the simulation because they no longer met our definition of antlerless deer. Although male births may occur more frequently at this population level (Downing and Guynn 1985), male juveniles also occur more frequently in antlerless harvests (Rosenberry et al. 2010). We used the model to identify the point at which the population remained stable or increased above its initial level.

Data Analyses

For proportion of juveniles in the antlerless harvest, PASAK population estimates, and embryos per mature female, we estimated measures of precision (variance, SE, and coefficient of variation [CV]) for each WMU, 2004–2009. This 6-yr period is comparable to the time interval considered when assessing deer population trends for management purposes. We did not use the arcsine transformation because $\hat{p}_J$ ranged from 0.30 to 0.70 (Sokal and Rohlf 1987, Zar 1999). We evaluated trends using a nonparametric Mann–Kendall test (Thompson et al. 1998). Although the Mann–Kendall test may not be as efficient as parametric tests because it uses ranks instead of point estimates to calculate its test statistic (S), we chose to use it because 1) it does not require difficult assumptions found in regression methods (Thompson et al. 1998), and 2) it is a test used by PGC biologists when making management recommendations because it is simpler and easier to explain to the public and decision-makers. We use the term "stable" to indicate a trend in population estimates and proportions of juveniles in the antlerless harvest that is neither increasing nor decreasing. We assumed statistical significance when $\alpha \leq 0.05$.

To assess deer health, we compared observed embryos per mature female to our value of 1.50 embryos per mature female using a 2-tailed t-test (SAS UNIVARIATE; SAS Institute, Inc. 1989). We set $\alpha = 0.05$. Although count data with upper truncation—such as embryos per mature female that can only be 0, 1, 2, 3, or 4 embryos per mature female—may be assumed to follow a Poisson distribution, procedures based on normal distributions have performed satisfactorily in simulations (McDonald and White 2010). If mean embryos per mature female was $\geq$1.50, we considered female productivity to be acceptable. Likewise, if the mean embryos per mature female was <1.50, we considered female productivity to be unacceptable.

RESULTS

Harvest, Population Trends, and Reproduction

The proportion of juveniles in the antlerless harvest remained stable in all WMUs from 2004 to 2009 (Table 1). Annual sample sizes averaged 370 juveniles (range = 73–821) and 539 (range = 94–1,199) mature females in each WMU and provided precise estimates of the proportion of juveniles in the antlerless harvest (CV ≤ 10%; Fig. 2). Among WMUs, mean proportion of juveniles in the antlerless harvest ranged from 0.34 to 0.46 (Table 1). Deer population trends remained stable in all WMUs from 2004 to 2009 (Table 2). The majority of WMU deer population estimates possessed CVs of ≤20% (Fig. 3). Wildlife Management Unit deer populations achieved reproduction objectives from 2004 to 2009. During this time, we assessed 4 3-yr data sets. In 2 instances (WMU 2C in 2004–2006 and WMU 3D in 2007–2009), reproduction was significantly below the target of 1.50 embryos per mature female (Table 3). All other WMU reproductive assessments did not differ from, or exceeded, 1.50 embryos per mature female. Pooled estimates were precise for each WMU (Fig. 4).

Establishing an Objective

Based on our simulation model, a single value of proportion of juveniles in the antlerless harvest was inadequate as a measure of population status. With variable antlerless harvest rates and juvenile summer survival rates, the proportion of juveniles in the antlerless harvest needed to sustain a population varied from 0.23 to 0.51 (Table 4). If juvenile summer survival rate was held constant at 45%, which was similar to the lowest observed survival rate in Pennsylvania (i.e., 46%; Vreeland et al. 2004), the proportion of juveniles in the antlerless harvest also remained constant, but the population trend varied according to antlerless harvest rate. The population increased when antlerless harvest rate was ≤0.10. The population decreased when the antlerless harvest rate was ≥0.15.

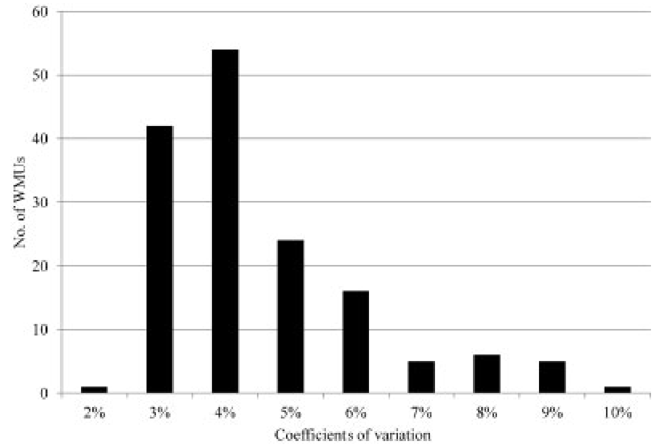

Figure 2. Distribution of coefficients of variation of Wildlife Management Unit (WMU) estimates of proportion of white-tailed deer fawns in the antlerless harvest for 6 yr, Pennsylvania, USA, 2004–2009.

DISCUSSION

A single objective value for proportion of juveniles in the antlerless harvest cannot be interpreted to suggest a particular management response. Depending on juvenile survival and antlerless harvest rates, the proportion of juveniles in a population with a stable trend could vary substantially, and a single threshold value of proportion of juveniles in the population could correspond to increasing, decreasing, or stable deer population trend. These results agree with previous studies that population trend information is needed to

Table 1. Mean and range of proportion of juvenile white-tailed deer in antlerless harvest ($\hat{p}_J$), Mann–Kendall statistic (S), and associated probability (P) of observing a value as extreme as S by Wildlife Management Unit (WMU), Pennsylvania, USA, 2004–2009.

WMU	Mean	Range	*S*	*P*
1A	0.46	0.44–0.48	3	0.720
1B	0.42	0.40–0.44	1	1.000
2A	0.39	0.35–0.43	−1	1.000
2C	0.44	0.41–0.49	3	0.720
2D	0.44	0.39–0.47	−7	0.272
2E	0.41	0.37–0.50	−1	1.000
2F	0.37	0.34–0.40	−7	0.272
2G	0.35	0.31–0.38	9	0.136
3A	0.37	0.33–0.42	3	0.720
3B	0.39	0.35–0.43	1	1.000
3C	0.36	0.31–0.39	−1	1.000
3D	0.34	0.32–0.36	−3	0.720
4A	0.37	0.34–0.41	−1	1.000
4B	0.42	0.38–0.44	−1	1.000
4C	0.42	0.41–0.44	−1	1.000
4D	0.37	0.31–0.42	−9	0.136
4E	0.45	0.43–0.46	3	0.720
5A	0.43	0.37–0.47	−11	0.056
5B	0.44	0.42–0.48	1	1.000

Table 2. Mean Pennsylvania modification to the sex–age–kill model population estimates for white-tailed deer, Mann–Kendall statistic (S), and associated probability (P) of observing a value as extreme as S, by Wildlife Management Unit (WMU), Pennsylvania, USA, 2004–2009.

WMU	Mean	*S*	*P*
1A	75,651	−1	1.000
1B	82,756	3	0.720
2A	82,671	−3	0.720
2C	133,019	−3	0.720
2D	108,453	−1	1.000
2E	50,896	−3	0.720
2F	81,519	−5	0.470
2G	80,242	−3	0.720
3A	43,423	−9	0.136
3B	63,411	−5	0.470
3C	79,744	1	1.000
3D	46,923	−11	0.056
4A	42,223	−7	0.272
4B	45,589	3	0.720
4C	47,322	−11	0.056
4D	55,434	−3	0.720
4E	59,201	−7	0.272
5A	30,742	−5	0.470
5B	121,650	−9	0.136

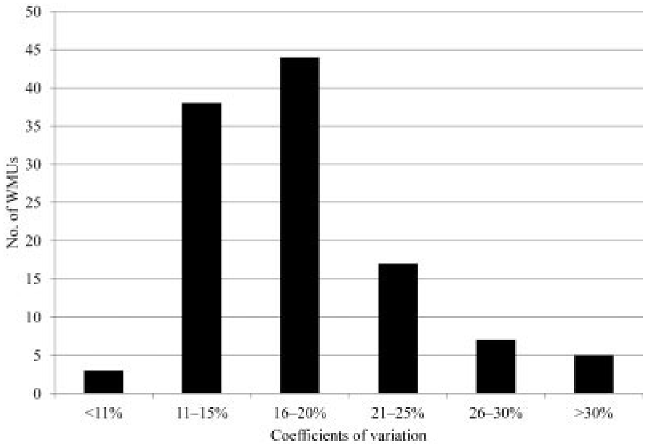

Figure 3. Distribution of coefficients of variation of Wildlife Management Unit (WMU) white-tailed deer population estimates for 6 yr, Pennsylvania, USA, 2004–2009.

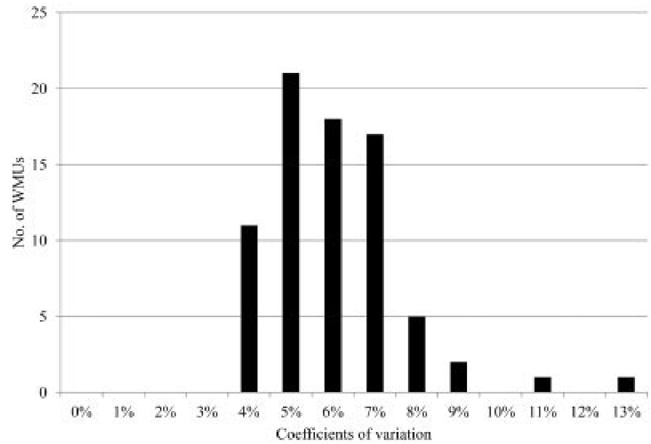

Figure 4. Distribution of coefficients of variation of Wildlife Management Unit estimates of white-tailed deer embryos per mature female for 6 yr, Pennsylvania, USA, 2004–2009.

interpret age ratios properly (Caughley 1974, McCullough 1994).

Use of a single objective value for all WMUs also ignores variation in deer population dynamics. In Pennsylvania, all WMU populations were stable and all but one WMU met embryo-per-mature female objectives, indicating healthy and sustainable deer populations by our definitions. However, the proportion of juveniles in the antlerless harvests varied from 0.34 to 0.46. As a result, there was no single value that would indicate a healthy and sustainable population. Establishing an objective based on a WMU-specific trend of proportion of juveniles in the antlerless harvest is more appropriate than a single value.

Many variables could explain why healthy and sustainable deer populations showed variation in proportion of juveniles in the antlerless harvest. In our simulation, the proportion of juveniles in the antlerless harvest accurately reflected the composition of our simulated population. However, variations in deer and hunter behavior may affect proportion of juveniles in the antlerless harvest (Coe et al. 1980, Roseberry and Woolf 1991). In addition, the growing popularity of Quality Deer Management with its emphasis on not shooting juveniles (Hamilton et al. 1995) can further affect representativeness of harvest age ratios.

Biological factors, including reproduction and survival of juveniles and mature females, may vary by WMU and affect proportion of juveniles in the antlerless harvest. In Pennsylvania and other areas, reproduction varies little across a range of habitats and population densities (Downing and Guynn 1985, this study). Mature females also experience high survival rates outside of the hunting seasons (Downing and Guynn 1985, Van Deelen et al. 1997, Ricca et al. 2002, Brinkman et al. 2004, Norton 2010). However, we have observed differences in fawn survival and predator impacts between parts of WMUs 2G and 4D in Pennsylvania (Vreeland et al. 2004). Consequently, proportion of juveniles in the antlerless harvest may provide an informative index to recruitment and potential predator impact.

Despite potential value of proportion of juveniles in the antlerless harvest as an index to recruitment and predator impacts, population trends should take precedence to support management actions. If the population trend is meeting objective despite changes in proportion of juveniles in the

Table 3. Sample sizes of mature female white-tailed deer collected and mean number of embryos per mature female of 3-yr pooled data sets by Wildlife Management Unit (WMU), Pennsylvania, USA, 2004–2009.

	2004–2006		2005–2007		2006–2008		2007–2009	
WMU	*N*	Mean	*N*	Mean	*N*	Mean	*N*	Mean
1A	57	1.58	77	1.52	81	1.49	113	1.65
1B	62	1.77	59	1.75	54	1.67	66	1.71
2A	66	1.55	86	1.45	77	1.38	92	1.48
2C	86	1.29	116	1.40	130	1.58	139	1.67
2D	44	1.75	87	1.60	100	1.65	110	1.67
2E	16	1.63	18	1.67	28	1.86	41	1.71
2F	48	1.42	66	1.41	82	1.56	111	1.60
2G	62	1.58	40	1.68	39	1.74	57	1.63
3A	36	1.50	28	1.61	23	1.78	41	1.68
3B	49	1.61	57	1.40	64	1.36	79	1.48
3C	33	1.45	35	1.57	31	1.55	69	1.42
3D	80	1.36	73	1.37	73	1.41	113	1.33
4A	79	1.58	96	1.56	97	1.47	111	1.55
4B	28	1.68	50	1.50	51	1.51	76	1.58
4C	19	1.58	45	1.42	53	1.43	60	1.50
4D	67	1.52	64	1.58	72	1.69	83	1.57
4E	30	1.73	34	1.71	50	1.82	68	1.66
5A	14	1.36	22	1.64	36	1.67	38	1.61
5B	38	1.47	55	1.58	59	1.69	64	1.78

Table 4. Results of simulation model showing antlerless harvest rates, fawn survival rates, and proportion of fawns in the prehunt antlerless population necessary to achieve a stable population of white-tailed deer, in Pennsylvania, USA. With given antlerless harvest rates, the populations declined when fawn survival was less than value in table.

Antlerless harvest rate	Fawn survival	Proportion of fawns in antlerless population
0.00	0.20	0.23
0.05	0.30	0.29
0.10	0.40	0.35
0.15	0.55	0.41
0.20	0.75	0.47
0.25	0.95	0.51

antlerless harvest, then no management action may be required. This is the case in Pennsylvania, where proportions of juveniles in the antlerless harvest range from 0.34 to 0.46, but population trends are stable and consistent with deer management objectives.

Although population trends may take precedence, including proportion of juveniles in the antlerless harvest as a management consideration has advantages. First, proportion of juveniles in the antlerless harvest can inform managers of possible causes if population declines are observed. Second, effective wildlife management must be based on sound science, but also must be communicated to, and understood by, the public. In this regard, proportion of juveniles in the antlerless harvest has an advantage over population trend information. Proportion of juveniles in the antlerless harvest is a simple count that is easier to explain than population estimates and models. Also, proportion of juveniles in the antlerless harvest comes directly from hunter experience and success in the field. As a result, public acceptance and understanding may be greater for simple counts than more complex population models.

The challenge for deer managers is to identify the correct management response when proportion of juveniles in the antlerless harvest changes. Unfortunately, managers may not have complete data on hunter behavior and the biological variables that influence proportion of juveniles in the antlerless harvest. Managers also may experience public pressure to implement predator controls or conduct field studies of juvenile survival, which may not be the most efficient use of resources. A step-by-step decision process that prioritizes management data and actions can assist managers in making the most effective recommendations.

We present an example of a decision chart to incorporate proportion of juveniles in the antlerless harvest into deer and predator management recommendations (Fig. 5). For simplicity and because the negative impact of predators is a motivating issue in Pennsylvania and other states, we began the decision chart with the question of whether the proportion of juveniles in the antlerless harvest is decreasing. If the proportion of juveniles in the antlerless harvest is decreasing, the next step must look at deer population trends in relation to population objectives. This ensures a management recommendation is based on corroborating information (i.e., population trend) and not solely on an index (i.e., proportion of juv in the antlerless harvest).

If the population is below objective; reproduction, mortality, or both may be causing the low population. White-tailed deer show a broad plateau in reproductive output across a range of population densities and environmental conditions (Downing and Guynn 1985, this study). In Pennsylvania and other areas, hunting causes a majority of the mortality in hunted populations (Nixon et al. 1991, Brinkman et al. 2004, Keenan 2010, Norton 2010) and can be directly affected by reducing antlerless hunting opportunities. As a result, reducing antlerless hunting opportunities would be the first management action taken to increase population abundance. Assessment of reproduction would follow at some time depending on whether the population responds to reduced

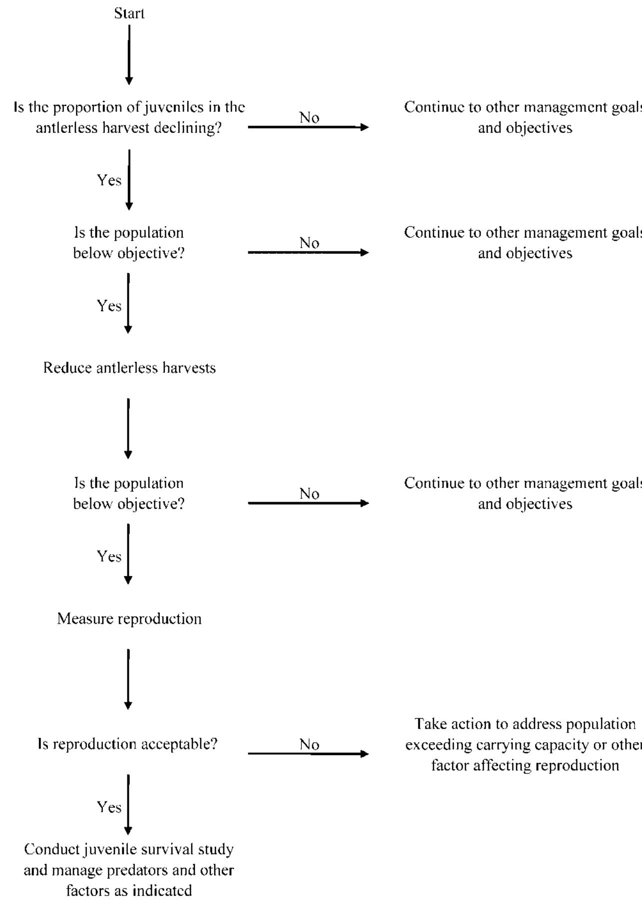

Figure 5. An example of a decision chart to guide management responses to changes in proportion of juvenile white-tailed deer in the antlerless harvest, Pennsylvania, USA.

harvest, significance of population declines, and available funding to collect reproductive data.

In our example, juvenile survival studies and predator management are considered at the end of the decision chart. Although predator management actions and juvenile deer survival studies are often desired by the public (Mulhollem 2010*c*), our example demonstrates a number of management considerations and actions that can be taken prior to addressing real or perceived predator impacts.

MANAGEMENT IMPLICATIONS

Proportion of juveniles in the antlerless harvest provides 1) an informative index when combined with population trend data (Caughley 1974, McCullough 1994, this study), and 2) simple count data that may be more understandable than population estimates generated from complicated models. If proportion of juveniles in the antlerless harvest is used to assess potential factors affecting deer population dynamics, monitoring trends provides more management-unit-specific information than does establishing a single objective value.

As predators gain more attention in the eastern United States (e.g., Kilgo et al. 2010) state agencies will continue to be questioned about the influence of predators on deer populations. Although predator management activities and juvenile survival studies are often desired by the public, our decision chart example indicated a number of deer management options exist before resorting to investing resources in predator management activities and juvenile survival studies.

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