Estimating Age and Antler Traits of Photographed Male White-tailed Deer

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Abstract: Antler measurements are used to set harvest restrictions for male white-tailed deer (*Odocoileus virginianus*) and to evaluate response to management. Remotely-triggered trail cameras are popular research and management tools, but have not been used to estimate antler size or age. We developed methods to estimate antler measurements and age of male deer ≥1 year old from photographs. We developed predictive equations for individual antler measurements using photographs of mounted deer heads, and evaluated five anatomical features for potential use as a known-sized scaling reference in field photos. Mean estimation error for individual antler characteristics of free-ranging deer ranged from 6.7% for tine length to 19.3% for length of non-typical points. Mean estimation error for gross Boone and Crockett antler score from a single photograph was ≤5.9%, and was improved by using multiple angles. To develop age-predicting models, we evaluated 64 morphometric ratios derived from photographed, captive, known-age males, retaining 12 ratios to develop multi-step models for pre- and post-breeding application. Accuracy of the multi-step models for assigning 1.5-, 2.5-, 3.5-, 4.5-, and ≥5.5-year-old age classes during pre-breeding was 75%, 86%, 40%, 0%, and 71%, respectively, and 88%, 71%, 53%, 14%, and 85%, respectively, during post-breeding. Accuracy of many age group combinations may be sufficient for management application. Remotely-triggered cameras paired with antler- and age-estimating predictive models would allow non-lethal collection of data from un-harvested deer with acceptable accuracy and less bias than hunter-harvested or visual observation samples.

Key words: aging, anatomical features, antler size, phenotypic measures, *Odocoileus virginianus*, remotely-triggered cameras, white-tailed deer.

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Accurate, cost-effective data collection from free-ranging wildlife can benefit researchers and managers. Many states that harvest cervids require or request reporting of phenotypic data for use in management or research. Antler measurements can be used as indicators of phenotypic quality (Vanpé et al. 2007), habitat quality (Strickland and Demarais 2000, 2008; Jones et al. 2010), or relative population density (Ashley et al. 1998, Keyser et al. 2006), and are of interest to many deer hunters. Nine of 16 state wildlife agencies in the southeastern United States collect data characterizing antler development of harvested white-tailed deer (*Odocoileus virginianus*) for use in setting harvest criteria and evaluating management effectiveness, including: main beam length, inside spread, and gross Boone and Crockett (B&C) score (C. Dacus, Mississippi Department of Wildlife, Fisheries and Parks, personal communication). In addition, 22 U.S. states used some form of antler-based harvest restrictions in 2011, with guidelines including antler spread, number of points, and main beam length (Adams et al. 2012). Such widespread use of antler-based harvest restrictions has created a need for an educational tool with potential to train hunters in visual estimation of antler characteristics (Strickland et al. 2001, Strickland and Demarais 2007).

Age distribution is an important component of deer management. Age structure typically is reconstructed using harvested animals, the sample of which is biased by widespread use of ant-

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ler-based harvest restrictions or selection by hunters (Coe et al. 1980, Ditchkoff et al. 2000, Strickland et al. 2001). Age of live deer is estimated visually by biologists and the general hunting public using subjective criteria but with limited accuracy (Gee et al. 2014). Age-specific development of body features such as chest girth, hind foot length, and total body length indicate that body measurements and ratios of body measurements may be useful in estimating age (Klinger et al. 1985). A quantitative live-animal age estimation technique would allow biologists and researchers to estimate age structure with greater confidence than current subjective techniques and without harvest-based biases.

Remotely-triggered cameras (RTCs) are widely used in wildlife management and research and are popular with the hunting public. Photographs from RTCs have been used to estimate density for a wide variety of terrestrial vertebrates (Rowcliffe et al. 2008, Rovero and Marshall 2009, Kays et al. 2011). In the United States, RTCs have been tested for estimating white-tailed deer density, sex ratio, and recruitment (Jacobson et al. 1997, McKinley et al. 2006, Roberts et al. 2006). Use of RTC photographs may provide less-biased, non-lethal samples of male population age structure and antler morphometrics for biologists and an educational opportunity for hunters if a relatively simple and accurate method was developed.

Methods to obtain morphometric data from photographs have been widely reported. Antler growth curves for Alaskan moose were derived from photographs taken at 7- to 10-day intervals (Van Ballenberghe 1982), suggesting that collection of phenotypic traits from photographs is feasible. Bergeron (2007) measured alpine ibex (*Capra ibex*) horns to within 3.9% of mean length using RTC photographs.

Our goal was to determine if male white-tailed deer antler measurements and age could be estimated accurately from photographs. We used photographs of mounted deer heads and morphological measurements of live and harvested deer to develop predictive models for estimating antler measurements. To develop predictive models for estimating age, we used photographs of known-age captive deer. We then validated the models on independent samples of live deer of known antler size or age.

Methods

Antler Measurement

Development. To obtain data for model training, we collected digital photographs of 150 deer heads from each of three orientations relative to the deer facing the camera: straight-on (0°), angled (45°), and side (90°). The training dataset included 126 mounted deer heads preserved by taxidermists (hereafter, mounted) that were entered into the Magnolia Records Program (*http://www.mdwfp.com/wildlife-hunting/deer-program/magnolia-records-program.aspx*) and 24 deer under sedation at the Mississippi State University Rusty Dawkins Memorial Deer Unit (MSU Deer Unit). For model validation, we photographed a separate sample of 50 mounted deer that were entered into the Magnolia Records Program. Within each photograph, we suspended a known-sized, spherical object (a ball with diameter = 44.45 or 57.15 mm) from the left antler to provide a scale feature within each photograph.

We calculated total score by summing measurements of main beam lengths, tine lengths, four main beam circumferences, and inside spread using guidelines outlined by Nesbitt et al. (2009). Our purpose was to characterize total antler size, so we made no deductions for asymmetry or non-typical points, and our total score is equivalent to the gross non-typical score (hereafter, gross score) in the Boone and Crockett scoring system (Nesbitt et al. 2009).

Three issues have to be addressed to accurately estimate antler size from a photograph. First, the photograph must be scaled to enable measurement of antler traits. Next, predictive equations must transform a 2-dimensional measurement from a photograph into a 3-dimensional estimate (e.g., equations must account for curvature of the antler which is lost in a 2-dimensional photo). Finally, separate predictive equations are needed for different angles because antler orientation relative to the camera affects the 3-dimensional estimation.

To scale the photographs, we loaded digital pictures of deer into ArcMap 9.2 (ESRI, Inc., Redlands, CA; hereafter, GIS) as a layer and scaled them relative to the known-sized, spherical object within each photograph. Antler trait measurements from scaled photographs were obtained using the GIS Measurement Tool, similar to Nesbitt et al. (2009), except circumference measurements were the diameter of the main beam in the four designated locations; main beam length was measured along the bottom of the antler beam; and, at 0° orientation the typical tine lengths were measured along either the outer or inner edge, depending on which was visible in the photograph. We estimated typical tines and circumferences hidden by other antler parts using the measurement from the equivalent feature on the visible antler ("mirror value"), because the typical components of antlers are often relatively symmetrical after 1 year of age (Demarais and Strickland 2011).

We used linear regression to develop 3-dimensional predictive equations for each antler trait at each orientation from the 2-dimensional GIS measurements using PROC REG in SAS 9.2 (SAS Institute, Cary). We tested accuracy of the predictive equations using the independent sample of 50 photographed, known-score, mounted antlers. We calculated error for each antler measurement at each orientation as the percent difference between estimated and measured 3-dimensional values.

Field Evaluation. We tested accuracy of the predictive equations using 37 live, free-moving deer with known antler measurements from the MSU Deer Unit (n = 30) and Oklahoma (n = 7). Oklahoma deer were sampled from the 1,214-ha Samuel Roberts Noble Foundation Wildlife Unit (NFWU) located in southern Oklahoma. A trained measurer used Nesbitt et al. (2009) guidelines to determine the value of each antler trait while the animal was sedated. We attempted to photograph deer at the same 3 orientations used for model development (0°, 45°, and 90°), but these views were approximate because of uncontrolled movements of live deer.

With live animals, anatomical features must be used as scale references because known-size objects are not available within the plane of the photographed deer. We sampled 5 anatomical features (eye-to-eye width, eyeball width, upper nasal planum width, lower nasal planum width, and ear width; Figures 1, 2) from 243 harvested or sedated deer from MSU Deer unit (n = 154, sedated), Noxubee National Wildlife Refuge (n = 49, harvested) in Noxubee County, Mississippi, and the NFWU in Oklahoma (n = 40, sedated; Little 2011). Because skeletal growth in deer is nearly complete by 2.5 years (Purdue 1983, Flinn 2010) and aging accuracy using tooth replacement and wear declines thereafter (Severinghaus 1949, Gee et al. 2002), we separated the samples into 1.5 and ≥2.5 year age classes for analysis. We compared anatomical features between age classes and location (Mississippi or Oklahoma) using a 2-way analysis of variance in PROC MIXED (SAS Institute, Cary, NC), accepting significance at $\alpha \leq 0.05$. We compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al. 2006). All scaling features were not visible from each of the 3 orientations, so we selected the available feature with the least variability among regions and age classes to scale measurements for the 37 free-ranging subjects.

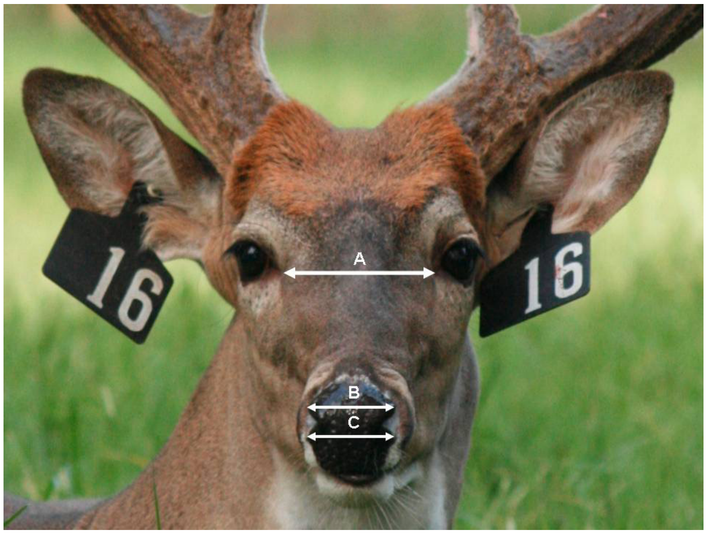

Figure 1. Anatomical measurements collected from hunter-harvested and captive white-tailed deer in Mississippi and Oklahoma, 2007–2008. Eye to eye width (A) was measured from the center of one pre-orbital gland to the center of the other pre-orbital gland. Upper nasal planum width (B) was measured perpendicular to the philtrum at the widest part of the black portion of the muzzle above the nostrils. Lower nasal planum width (C) was measured perpendicular to the philtrum at the widest point of the black portion of the muzzle below the nostrils. Photo Credit Emily Flinn.

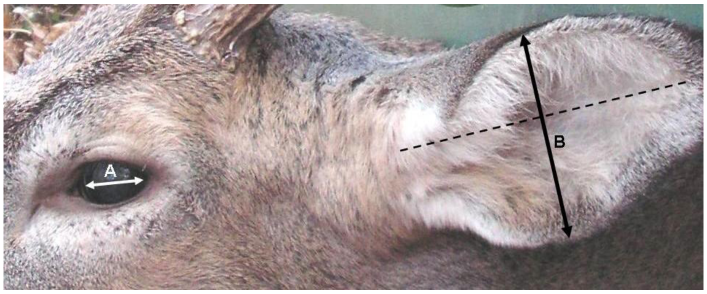

Figure 2. Measurements of eyeball width (A) and ear width (B) collected from hunter-harvested and captive white-tailed deer in Mississippi and Oklahoma, 2007–2008. We measured eyeball width as the diameter of the actual eyeball, not the entire socket. We measured ear width at the widest part of the ear perpendicular to the axis. Photo Credit Emily Flinn.

Age Estimation

Development. To determine if there was a definable progression of morphological characteristics associated with increasing age in male white-tailed deer, we photographed live, known-age adult males (≥1.5 years; $n = 145$) in the MSU Deer Unit. To account for changes in morphology associated with rut, we photographed subjects during September–October (pre-breeding) and late January–February (post-breeding). Unlike antler estimation, we did not include a scaling feature in these photographs because we intended to use morphological ratios rather than absolute measures.

Body mass typically is correlated with age in male cervids beyond the age of sexual maturity (Finstad and Prichard 2000, Strickland and Demarais 2000, Bender et al. 2003), so morphometric measures may have value as predictors of age. In addition, Klinger et al. (1985) reported hind foot length stabilized by 18 months, suggesting the possibility that morphometric ratios might be used to estimate age. We took eight direct measurements from the body, chest, stomach, legs, neck, and antlers to establish nine morphometrics (Figure 3). We calculated 64 morphometric ratios using combinations of morphometric features to capture changes in body proportions correlated with aging and compared them among ages 1.5, 2.5, 3.5, 4.5, and ≥5.5 years using PROC GLM (SAS Institute, Cary, NC). We eliminated 52 ratios that did not vary among age classes ($P > 0.10$), retaining 12 ratios for use in model development.

To most effectively separate age classes, we developed a multiple step procedure using a dichotomous key approach. We incorporated the 12 morphometric ratios into a stepwise logistic re-

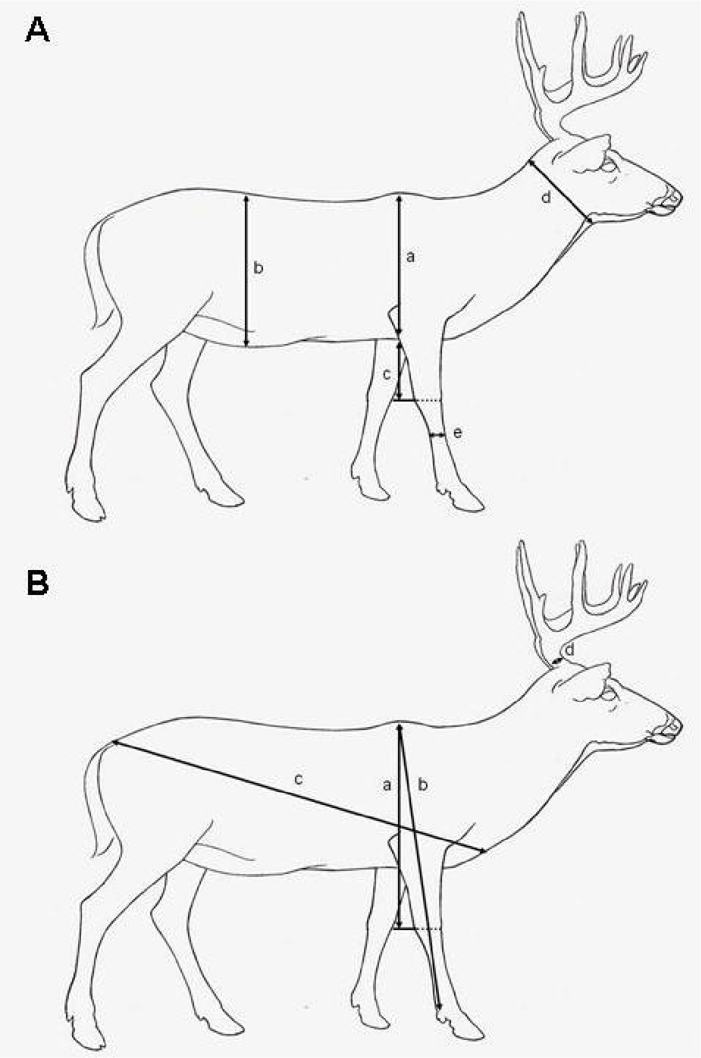

Figure 3. Schematic showing proper view and specific morphometric measurements used to calculate ratios for age class separation of live, male white-tailed deer from Louisiana, Mississippi, Oklahoma, and Texas, 2009–2010. A, chest depth (a), stomach depth (b), length of leg below the chest (c), neck width (d), and metacarpal width (e). B, leg measurement 1 (a), leg measurement 2 (b), body length (c), and basal circumference (d).

gression procedure in PROC LOGISTIC (SAS Institute, Cary, NC) to generate probability of a correct age class placement as a linear function of one of more explanatory variables (Karp 2000). We required $P \leq 0.10$ for a variable both to enter the model and to remain during subsequent steps. We diagnosed models for multicollinearity in PROC REG using the variance inflation factor and condition index (VIF), rejecting a model if any variable had $\text{VIF} > 4$ (Freund and Littell 2000, Allison 2012). We began by deriving models that best separated each age class (1.5, 2.5, 3.5, 4.5, or ≥5.5) from all other age classes. The age class with the greatest probability of correct assignment was then removed from the dataset and new models derived for the remaining age classes. This approach allowed us to refine the models and increase accuracy by deriving parameter estimates from a reduced subset of age classes. Next, we combined the best models from each analysis into a multi-step model, with each step using a separate set of morphometric ratios to calculate a probability that a subject was in a given age class versus all other remaining age classes. If the probability was <0.50, that age class was removed from further consideration, allowing subsequent steps to use models specific to the remaining ages. For example, we initially separated immature from mature bucks by separating 1.5-year-olds from ≥2.5-year-olds. Using a different model on the remaining animals, we next separated 2.5-year-olds from ≥3.5-year-olds, with no possibility that any of these deer could be labeled as 1.5-year-olds. We developed separate multi-step models for the pre-breeding and post-breeding periods.

Field Evaluation. We evaluated the resulting models on 106 wild, known-age deer from Mississippi, Louisiana, Texas, and Oklahoma. This data set included 72 males ($n = 30$ pre-breeding; $n = 42$ post-breeding) from enclosures located in the Western Gulf Coastal Plain physiographic region of Texas and Louisiana and Southeastern Plain physiographic region of Mississippi (The Nature Conservancy 2007). Enclosures ranged from 415 to 3,200 ha in size and were managed for high quality forage production using prescribed fire and food plots, and included year-round access to supplemental feeding (16% crude protein) *ad libitum*. The Oklahoma population included 34 post-breeding males from the NFWU (Webb et al. 2010). This enclosure was managed using prescribed fire and rotational grazing; supplemental feed and food plots were not available. To assess accuracy, we entered individual deer morphometric ratios into the derived logistic models using Microsoft Excel 2007 (Microsoft Inc., Redmond, Washington) to calculate probability of age class assignment.

Results

Antler Measurement

The 150 antler mounts used for developing the models represented a range of antler sizes with gross score mean of 328 cm and a range of 73–507 cm, and 60 sets included at least one non-typical tine. Using the photographs of mounted antlers, we generated 97 predictive equations to estimate four antler traits and gross B&C score at three antler orientations (i.e., 0°, 45°, 90°). Coefficient of determination (r^2) values ranged from 0.61 for inside spread at 45° to 0.97 for total length of non-typical points at 0° and 90°. The best models for estimation of inside spread ($r^2 = 0.94$) and total circumference ($r^2 = 0.88$) were from the 0° angle. The best model to estimate main beam length ($r^2 = 0.85$) was derived from the 90° angle, and a model from the 45° angle best estimated total tine length ($r^2 = 0.96$).

The validation data set of 50 mounted antlers used for testing the models had a gross score mean of 353 cm and a range of 274–431 cm. Accuracy of estimating individual antler measurements from mounted antlers varied by orientation (Table 1). Mean estimation error of inside spread was least (5.0%) at 0°. Main beam length, tine length, non-typical point length, and gross B&C score were more closely estimated from 45°, with 6.3%, 5.3%, 12.9%, and 3.2% mean error, respectively. Circumference was best estimated from 90°, with 4.9% mean error. From 90°, we were unable to estimate inside spread and so could not estimate B&C score using only this view. Using photographs from multiple angles resulted in gross B&C score estimation errors of 2.5% to 4.3%.

Of the five anatomical features measured, all varied between 1.5-year-old and ≥2.5-year-old deer, and 3 showed geographic differences. Eyeball width ($n = 243$) was 8% greater in older deer ($F_{1,239} = 10.13$, $P = 0.002$) and 13% larger in Oklahoma ($F_{1,239} = 69.01$, $P \leq 0.001$). Eye to eye width ($n = 191$) was 9% greater in older deer ($F_{1,187} = 39.71$, $P \leq 0.001$) and 9% larger in Oklahoma ($F_{1,187} = 39.35$, $P \leq 0.001$). Upper nasal planum width ($n = 153$) was 12% greater in older deer ($F_{1,149} = 81.05$, $P \leq 0.001$). Lower nasal planum width ($n = 191$) was 8% greater in older deer ($F_{1,187} = 15.23$, $P \leq 0.001$). Ear width ($n = 188$) exhibited a region × age class interaction ($F_{1,184} = 4.37$, $P = 0.038$) such that width for ≥2.5-year-old deer was 4% greater in Mississippi than in Oklahoma ($t_{184} = 2.51$, $P = 0.013$), and in Mississippi width was 3% greater in ≥2.5-year-olds than in yearlings ($t_{184} = -2.61$, $P = 0.010$).

Using region-specific ear width as the scaling feature provided the most accurate estimates of gross B&C score for the 37 live test animals at both 0° ($\bar{x} = 4.6$, SE = 0.8) and 45° ($\bar{x} = 5.9$, SE = 1.1). Eyeball width was the next most reliable scaling feature at 45° ($\bar{x} = 6.5$, SE = 0.9), but was not available at 0°. Eye to eye width, upper nasal planum, and lower nasal planum were less reliable ($\bar{x} > 8.1$), and were available only for the 0° orientation. Because ear width was sometimes unavailable in photographs from 90°, we used region-specific eyeball width when necessary to scale antler measurements from side-view photographs.

Antler measurement accuracy using live deer was less than that for mounted antlers (Table 1). Contrary to the results from mounted antlers, estimation error was least from 0° for all measurements except length of non-typical points, perhaps explained by loss of precision due to difficulty in obtaining exact 45° and 90° photographic views of live subjects. From 0°, mean estimation error for inside spread, main beam length, tine length, circumference, and gross B&C score were 7.0%, 8.1%, 6.7%, 7.3%, and 4.9%, respectively. Mean estimation error for length of non-typical points was least from 45° (10.8%). Using photographs from multiple angles resulted in gross B&C score estimation errors of 4.3% to 5.5%.

Table 1. Percentage error for estimates of antler characteristics using photographs from three orientations (0°, 45°, and 90°) of mounted and live[a] white-tailed deer ≥2.5 years of age from Mississippi, during 2007–2009.

Antler characteristic	Angle (°)	Mounted ($n = 50$)		Live ($n = 37$)	
		$\bar{x}$	SE	$\bar{x}$	SE
Inside spread	0	5.0	0.5	7.0	1.0
	45	7.8	0.8	9.7	1.7
Main beam length	0	7.3	0.6	8.1	1.1
	45	6.3	0.5	10.7	1.4
	90	6.4	0.5	15.6	2.2
Tine length	0	6.5	0.5	6.7	0.6
	45	5.3	0.5	9.5	0.8
	90	7.7	0.6	10.0	1.3
Circumference	0	5.2	0.4	7.3	0.7
	45	5.2	0.4	8.1	0.9
	90	4.9	0.4	9.1	1.1
Non-typical points[b]	0	17.7	2.3	19.3	5.7
	45	12.9	1.7	10.8	2.8
	90	13.5	2.3	15.0	5.9
Gross Boone & Crockett antler score[c]	0	4.6	0.5	4.9	0.8
	45	3.2	0.4	5.9	1.1
	0 & 45[d]	4.3	0.4	4.3	1.0
	0 & 90[d]	3.0	0.3	4.5	1.2
	45 & 90[e]	2.9	0.3	5.5	1.7
	0, 45, & 90[e]	2.5	0.3	4.9	1.3

a. Ear and/or eyeball width used for scaling.
b. $n = 12$.
c. Boone and Crockett antler score without deductions for non-typical points or asymmetry.
d. Live, $n = 20$
e. Live, $n = 15$

Age Estimation

Deer used to develop the model ranged from 1.5 to 12.5 years of age ($\bar{x} = 3.6$ yrs), and we grouped them into five age classes: 1.5 ($n = 31$), 2.5 ($n = 29$), 3.5 ($n = 28$), 4.5 ($n = 29$), and ≥5.5 ($n = 28$) years. Only two animals in the ≥5.5-year age class were ≥7.5 years.

Accuracy of the pre-breeding model was 75%, 86%, 40%, 0%, and 71% for ages 1.5, 2.5, 3.5, 4.5, and ≥5.5 years, respectively (Table 2). The greatest source of error was misclassification of 3.5- and 4.5-year-olds as ≥5.5-year-olds. Clustering two adjacent age classes improved overall accuracy except in the case of 3.5- and 4.5-year-olds (17%), where accuracy was reduced from the average of 3.5- and 4.5-year-olds considered separately ($\bar{x} = 20\%$). The multi-step model proceeded by first separating 1.5-year-olds using basal circumference:metacarpal width. Next, 2.5-year-olds were separated from remaining age classes using basal circumference:metacarpal width, neck width:length of the leg below the chest, leg measurement 2:chest depth, and metacarpal width:body length. Three-year-

Table 2. Matrix depicting percent accuracy (n) of multi-step models for estimating age (years) from photographs of wild, live white-tailed deer taken during pre-breeding (September–October; n = 30) and post-breeding (January–February; *n* = 76) from Mississippi, Louisiana, and Texas, 2009–2010. Yellow shading indicates underestimation, green indicates correct estimates, and red indicates overestimation.

	Actual age (Pre-breeding)				
Estimated age	**1.5**	**2.5**	**3.5**	**4.5**	**≥5.5**
1.5	75 (3)	0	0	0	0
2.5	25 (1)	86 (6)	0	14 (1)	0
3.5	0	14 (1)	40 (2)	0	14 (1)
4.5	0	0	0	0	14 (1)
≥5.5	0	0	60 (3)	86 (6)	71 (5)
Total *n*	4	7	5	7	7
	Actual age (Post-Breeding)				
Estimated age	**1.5 (*n* = 17)**	**2.5 (*n* = 17)**	**3.5 (*n* = 15)**	**4.5 (*n* = 14)**	**≥5.5 (*n* = 13)**
1.5	88 (15)	12 (2)	0	0	0
2.5	12 (2)	71 (12)	27 (4)	0	0
3.5	0	18 (3)	53 (8)	57 (8)	15 (2)
4.5	0	0	13 (2)	14 (2)	0
≥5.5	0	0	7 (1)	29 (4)	85 (11)
Total *n*	17	17	15	14	13

olds were then separated using neck width:leg measurement 2. The final step used basal circumference:metacarpal width, length of the leg below the chest:chest depth, chest depth:stomach depth, and metacarpal width:body length to separate 4.5- and ≥5.5-year-olds.

During the post-breeding period, age class accuracy of the multi-step model averaged 88%, 71%, 53%, 14%, and 85% for ages 1.5, 2.5, 3.5, 4.5, and ≥5.5 years, respectively (Table 2). Clustering two adjacent age classes improved overall accuracy in all cases. Contrary to pre-breeding assignments, post-breeding 3.5- and 4.5-year-olds were more often misclassified as 2.5- and 3.5-year-olds, than as 4.5- or ≥5.5-year-olds. Yearlings were separated first using basal circumference:metacarpal width. Separation of 2.5-year-olds involved basal circumference:metacarpal width, length of leg below the chest:body length, and metacarpal width:body length. Separation of 3.5-year-olds included using basal circumference:metacarpal width, length of leg below the chest:chest depth, chest depth:stomach depth, length of leg below the chest:body length, and metacarpal width:body length. The final step used basal circumference:metacarpal width and leg measurement 2:chest depth to separate 4.5- and ≥5.5-year-olds.

Discussion

The ability to visually estimate antler features and age is challenging when applied to free-ranging deer (Gee et al. 2014). Our results demonstrate that by combining software, digital photographs, and quantitative techniques it is feasible to accurately estimate age and antler size. This agrees with previous studies that indicate anatomical or phenotypic characters can be measured successfully using photographs and computer software (Bergeron 2007, Ditchkoff and deFreese 2010).

Remotely triggered cameras paired with antler score- and age-estimating software may provide opportunities to obtain information on population age structure and antler development from unbiased samples and thereby improve management recommendations. This technology allows non-lethal collection of valuable phenotypic data. Sample size is limited only by camera survey intensity and is independent of concern for harvest rate effects on population composition. RTCs are capable of generating large numbers of photographs, but only a small percentage would be at the correct angle and focus that would allow estimation of age or antler size. Current-generation RTCs offer a two- or three-photo burst option, which would greatly increase the chances of getting a usable photograph. Additionally, clear, high-resolution photographs are needed to accurately index and measure antler size.

The low error rate for gross B&C score estimates certainly indicates that antler score can be accurately gauged. Biologists considered 71%–80% and 81%–90% acceptable accuracy for quality deer management and trophy deer management, respectively, when estimating age of live deer (Gee et al. 2014). Accuracy for the most specific age class grouping (1.5, 2.5, 3.5, 4.5, or ≥5.5 years) did not reach either suggested level. However, grouping deer into 1.5, 2.5–3.5, or ≥4.5-year age classes exceeded the threshold for most deer management applications. In combination, these methods may provide unbiased estimates of male age structure and age-class specific estimates of antler development for deer populations.

Antler Measurement

Collection of antler data has been limited primarily to harvested animals. Although useful, harvest data may be biased due to hunter selectivity and mandatory antler restrictions (Coe et al. 1980, Ditchkoff et al. 2000, Strickland et al. 2001). Collection of unbiased, age-specific antler measurements would give biologists a more accurate picture of herd status, especially when coupled with RTC-collected data concerning population demographics. Number of antler points and antler basal circumference of yearling males have been reportedly correlated with density over a wide range of habitat qualities and densities (Kie et al. 1983, Keyser et al. 2006). Gross antler score represents a more complete measure of antler development and could be tested for its utility as a herd health indicator using camera surveys to estimate both population density and age-specific antler scores. Furthermore, antler development may itself be a management goal, and unbiased estimates would be valuable both for evaluating management effectiveness and communicating accurate results to stakeholders. In addition to being of value to game management, this technology potentially could be used to monitor body condition based on relative antler growth (Demarais and Strickland 2011). Using RTC technology and software could be especially important in monitoring condition of rare or elusive species, or of populations protected from harvest, such as the Florida Key deer (*O. v. clavium*).

Many deer herds are managed under the quality deer management paradigm, which seeks to increase male age structure by restricting harvest of younger males, often through antler-based selective harvest criteria (Miller and Marchinton 1995, Green and Stowe 2000). However, inefficiency may be introduced into such a system due to overlap in antler development among age classes (DeYoung 1990, Strickland et al. 2001). Antler-based selective harvest criteria are widely applied to white-tailed deer in the southern United States (Collier and Krementz 2006, Harper et al. 2012). Camera surveys using antler measurement and age-estimation software could provide biologists with unbiased data to judge the appropriate level of antler-based harvest restriction to balance protection of younger males and availability of harvestable older males.

Aging

Accuracy of our model to estimate age equaled that of widely used methods based on dental characteristics. Evaluations of the cementum annuli technique using known-age deer in the southern United States have yielded widely divergent conclusions, ranging from 16% to 71% accuracy (Cook and Hart 1979, Maffei et al. 1988, Jacobson and Reiner 1989), possibly because limited seasonal variation in this region prevents clear annuli from developing consistently (Cook and Hart 1979, Asmus and Weckerly 2011). Evaluations of the Severinghaus (1949) technique of tooth replacement and wear (TRW) have yielded equivocal results in both accuracy and bias (e.g., Cook and Hart 1979, Jacobson and Reiner 1989, Mitchell and Smith 1991), some of which may be attributable to a long-standing error in the technical manual used to train many biologists in this technique (Marchinton et al. 2003). Gee et al. (2002) tested the TRW technique with professional biologists using 88 jawbones or dental casts from known-age deer in Oklahoma and showed consistency in assigning deer to fawn, yearling, and adult (≥2.5 years) age classes only. Similarly, our complex model decreased in accuracy as deer matured, with particular difficulty accurately identifying 4.5-year-olds. Clustering 3.5-year-olds into a 2.5- to 3.5-year-old age class and 4.5-year-olds into a ≥4.5-year-old age class would reduce specificity but greatly increase accuracy (both for pre- and post-breeding deer). Clustering into these age groups provided accuracy similar to that of TRW (Gee et al. 2002). However, the tendency of our models to mis-assign 3.5- and 4.5-year-olds should be taken into account.

Aging on the hoof (AOTH) is a technique to visually estimate age of live deer using physical characteristics (Gee et al. 2014). Our post-breeding results can be compared to accuracy of ages estimated by 106 attendees of the 2009 Southeast Deer Study Group annual meeting that participated in an online test of AOTH using a set of 583 photographs of 70 wild, known-age males from Oklahoma taken after breeding season (Gee et al. 2014). All participants included in the analysis were professional deer biologists. Participants assigned age accurately to 62%, 43%, 25%, 30%, and 55% of 1.5-, 2.5-, 3.5-, 4.5-, and ≥5.5-year-olds, respectively. The objective measurements of our multi-step model averaged 19% greater accuracy across all age classes, with only 4.5-year-olds being less accurately assigned. Training observers with the multi-step model may yield improvements in AOTH estimates.

Development of morphometric ratios differentiated ages because body proportions change with ontogeny. Several non-technical publications have proposed physical characteristics similar to those we used to distinguish live, male age classes (Demarais et al. 1999, Richards and Brothers 2003). The most common body features proposed are stomach and chest girth and their relationship (Demarais et al. 1999, Richards and Brothers 2003, Hellickson et al. 2008); both the pre- and post-breeding models used chest depth:stomach depth to separate one age class. Because of the high degree of variability within age classes (Demarais and Strickland 2011), antler size is the most controversial morphometric used to age deer (DeYoung 1990, Hellickson et al. 2008). However, inclusion of basal circumference:metacarpal width in most model steps indicates that variation across ages outweighs the problem of within-age class variation in this case. Overall, metacarpal width was the most prevalent non-antler morphometric in the ratios, probably because it varied little with age and acted as a nearly fixed reference.

Age classes may be combined into various clusters for management purposes. For example, it may be desirable to forego harvesting males below a given age to increase male age structure. To monitor the effectiveness of such management, dividing age classes between 1.5 and ≥2.5 years or ≤2.5 and ≥3.5 years were supported at levels of >80% accuracy. Clearly, our most consistently accurate and potentially useful grouping during pre-breeding was of yearlings, 2.5- to 3.5-year-olds, and ≥4.5-year-olds, with 75%, 70%, and 86% correct assignment, respectively. The most reliable grouping during post-breeding was of 1.5- to 2.5-, 3.5- to 4.5-, and ≥5.5-year-olds, with 92%, 69%, and 85% correct assignment, respectively. Although still greater accuracy is certainly desirable, this method has the advantages of being as accurate as other available methods, of reducing or eliminating sampling bias, of being used on live subjects, and potentially including a greater number of subjects than data from harvested animals only.

Many of the deer used in developing and testing the aging methodology had access to supplemental feed or were from areas managed for high-quality forage. Range quality may affect body and antler growth (Klein 1964, Strickland and Demarais 2000, Jones et al. 2010), possibly altering age-specific morphological ratios. Likewise, morphology may be affected by subspecies, geographic range, climate, or density (Klein et al. 1987, Maffei et al. 1988, Lundmark 2008). The need we found for region-specific anatomical scaling features to accurately estimate antler measurements should warn against assuming that morphometric ratios will not vary among subspecies and across the broad range of deer. Although our method was useful under the conditions we developed and tested it, further testing should be done across a range of herd densities, geographic locations, and range conditions.

Management Implications

By working with landowners and hunters to establish monitoring programs, photographically derived data unbiased by harvest restrictions or hunter selection can be used to improve management prescriptions and more accurately inform stakeholders of deer herd status. Software based on this research (<http://buckscore.com/>) can be used to add male age structure and age-specific antler development to data already obtainable from camera surveys, such as herd density, sex ratio, and fawn recruitment. In addition, this software could help train users to better estimate antler characteristics in the field, potentially reducing accidental harvest of restricted animals and benefiting hunters in the 22 states that used antler-based harvest restrictions in 2011 for white-tailed deer (Adams et al. 2012). Use of deer at angles of orientation that differ from the studied 0, 45 and 90 degrees will add an unknown amount of error to antler size estimation. When used for either field or research purposes, users should be aware of the level of accuracy of the technique and the limitations that arise from bias associated with the technique itself or measurement error. Although our work was limited to male southern white-tailed deer, the success of these methods indicates the potential for developing similar applications for other regions, other cervid species, and for aging of females.

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