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Accuracy of estimating age and antler size of photographed deer

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ACCURACY OF ESTIMATING AGE AND ANTLER SIZE OF PHOTOGRAPHED DEER

By

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PHOTOGRAPHED DEER

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Objective and accurate techniques are needed to estimate age and antler size of live white-tailed deer (*Odocoileus virginianus*), because these parameters are essential to many white-tailed deer management strategies. I developed and evaluated accuracy of methods for estimating age and antler size from photographs of live, male white-tailed deer using Geographic Information Systems (GIS). I estimated size of photographed, known-score mounted antlers accurately using a fixed-scale object and photographed, live deer using anatomical features. I determined if a series of morphometric ratios could be used to predict age of deer from photographs using a dichotomous key procedure.

Mean percentage error for gross antler score was $< 6\%$ using a single photograph at 0° or 45°. The dichotomous key procedure effectively separated age classes of photographed, live white-tailed deer. When grouping deer into 1, 2, 3, 4, or ≥ 5 year age classes, the methodology respectively.

Key words: antler size, age, photographs, GIS

DEDICATION

I would like to dedicate this research to my parents, sister, extended family, and wife. To my parents, thank you for all the support and effort you have given me throughout my life. Mom, you always said that I could do whatever I set my mind to and you would do anything to give me that chance. Although we never had much, we always had Love to get us through the tough times. Dad, without you I would not be where I am today. I will always cherish the memories of our hunting and fishing trips. The time we have spent pursuing deer, turkey, grouse, and trout are some of the most influential moments of my wildlife career. They have made me a better biologist. Julie, I try to be the best role model I can. I want you to see that if you work hard, it will pay off in the end. To my extended family, the love and support over the years has been overwhelming. I will always remember all of the deer camps of years past, and the memories that will last a lifetime. Finally to my wife, Emily we have been through so much during our tenure in Mississippi and I could not imagine a better person to go through it with. You are my rock, there for me during hard times and supporting me all the way. For some reason, you chose me to spend your life with and I will never take that for granted. I will always love, support, and respect you.

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CHAPTER I

INTRODUCTION

Age and antler size of live white-tailed deer (*Odocoileus virginianus*) are estimated visually by wildlife professionals and the hunting public. Uncritical acceptance of techniques proposed in non-technical literature has obscured the questionable accuracy of many commonly used methods (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003). Even technical publications have presented live-age estimation techniques without stating accuracy (Dapson 1980). There is a need for the development and assessment of accurate, live-animal, age and antler size estimation techniques, because these parameters are essential to many white-tailed deer management strategies (Governo et al. 2006).

Researchers and managers require reliable, accurate, and cost-effective ways to collect data. Remotely-triggered cameras (RTCs) have been used successfully to estimate white-tailed deer density and sex ratio (Jacobson et al. 1997, McKinley et al. 2006, Roberts et al. 2006), movement (Newhouse 2004, Campbell et al. 2006), and resource selection (Atwood and Weeks 2003). Accurate age and antler size estimation from RTC pictures would provide age structure and antler data of value for management decisions. Collecting morphometric data from photographs is feasible; Bergeron (2007) obtained accurate estimates of alpine ibex (*Capra ibex*) horn growth from digital photographs.

My research sought to develop and evaluate the accuracy of methods to estimate antler size (Chapter II) and age (Chapter III) of live, male white-tailed deer from photographs. If I documented accuracy deemed sufficient by my peers, my second goal was to develop corresponding software that would allow researchers, managers and the interested public to estimate antler size of male white-tailed deer.

The first objective of Chapter II was to estimate the size of photographed, known-score antlers accurately using a fixed-scale object in the picture. Next, I developed a method to estimate antler size of photographed, live deer using anatomical features. For Chapter III, I determined if a series of morphometric ratios could be used to predict age of deer from photographs. I developed a dichotomous key procedure using a series of predictive models to assign photographed bucks accurately into age classes.

I developed two computer programs to estimate antler size of white-tailed deer from photographs. Free, online antler scoring software, available at www.buckscore.com, allows the upload of a single photograph to estimate inside spread, main beam length, and gross antler score. Commercial antler scoring software, licensed through Mississippi State University, uses multiple images to improve accuracy, monitor herd demographics, and manage photographs.

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CHAPTER II

ACCURACY OF ESTIMATING GROSS ANTLER SCORE USING PHOTOGRAPHS

Abstract

Widespread use of remotely-triggered, trail cameras produce photographs of male white-tailed deer (*Odocoileus virginianus*) with unknown antler size. Accurate estimation of antler dimensions would allow collection of research and management data from photographs. I developed methods and software to estimate selected antler measurements and gross antler score, similar to Boone and Crockett gross, non-typical score. I photographed 150 mounted antlers with known scores at three angles: straight-on (0°), angled (45°), and side (90°). I included a spherical object of known size in the picture for scale and measured the photographed antlers using Geographic Information Systems (GIS). Using the GIS and known antler values, I constructed predictive equations to obtain three-dimensional estimates from two-dimensional photographs. Using the known-size object for scale, I estimated gross antler scores of 50 known-score, mounted deer with 4.6% and 3.4% mean error at 0° and 45°, respectively. I sampled several anatomical features from harvested and sedated deer to use as known-size references for photographs of live deer. Using single photographs of 37 live deer and ear width as the scaling feature, I estimated gross antler score with 4.9% and 6.2% mean error at 0° and 45°, respectively. Using photographs of live deer from multiple angles and

ear width as the scaling feature, I estimated gross antler score with 4.3% mean error. I incorporated the predictive equations into an internet-based program (www.buckscore.com) to allow users to accurately estimate gross antler score using a single photograph.

Introduction

Accurate, cost-effective data collection from free-ranging wildlife benefits researchers and managers. Remotely-triggered cameras (RTCs) have been used successfully to estimate white-tailed deer density and sex ratio (Jacobson et al. 1997, McKinley et al. 2006, Roberts et al. 2006), and accurate antler size estimation would provide additional valuable data. Bergeron (2007) measured alpine ibex (*Capra ibex*) horns accurately (within 3.9% of mean length) using RTC photographs, suggesting the collection of antler morphometric data from photographs is feasible. Antler data collection currently is limited to harvested animals, with potential sample composition bias due to antler-based harvest restrictions and hunter selection (Coe et al. 1980). Additionally, the widespread use of antler-based harvest restrictions, such as minimum beam length, has created a need for an educational tool for hunters (Strickland et al. 2001, Strickland and Demarais 2007). Remotely-triggered camera photographs of bucks may provide less-biased, non-lethal samples of antler morphometrics for biologists and researchers and an educational opportunity for hunters.

Three issues must be addressed to accurately estimate antler size from a photograph. First, the photograph must be scaled to obtain meaningful measurements. Next, predictive equations must be constructed to transform a two-dimensional measurement from a photograph into a three-dimensional estimate. Finally, predictive equations are needed at different angles because antler orientation affects the three-dimensional estimation.

The first goal of my research was to evaluate if white-tailed deer antler size could be estimated accurately from photographs. I constructed predictive equations to obtain three-dimensional estimates from a two-dimensional photograph using measurements of mounted, known-score antlers with a known-size scale reference. I constructed equations applicable to photographs taken at three orientations to the camera. I determined accuracy of the predictive equations using a subsequent set of mounted, known-score antlers with a known-size scale reference in the photograph. I used the same predictive equations to evaluate accuracy on live deer using average anatomical features for scale. My second goal was to create free, online antler scoring software available for the general public at www.buckscore.com.

Methods

Development

I photographed 200 sets of antlers entered into the Magnolia Records Program (MRP), which is sponsored by the Mississippi Department of Wildlife, Fisheries and Parks and the Mississippi Wildlife Federation. A trained scorer used Boone and Crockett Club guidelines to determine the gross, non-typical score of each mounted set of antlers (Wright and Nesbitt 2003). I photographed each mounted antler set from 3 orientations relative to the deer looking at the camera; straight-on (0°), angled (45°), and side (90°). I photographed deer at close range with a Konica Minolta DImage Z20 digital camera (Konica Minolta Holding, Inc., Tokyo, Japan).

I established scale by geo-referencing a known-size, spherical object located in each photograph using ArcGIS 9.2. Geo-referencing relates something's existence in space to another object, and in this case, I related antlers of the deer to a known-size object in the photograph (ESRI, Inc. 2006). The known-size object was a ball with a diameter of either 44.45 or 57.15 mm.

I constructed predictive equations to transform two-dimensional measurements from photographs into three dimensional estimates. I measured 150 of the 200 mounted antlers in GIS using Boone and Crockett Club guidelines (Wright and Nesbitt 2003). I did not account for curvature and lack of depth perception in these initial measurements. I constructed a predictive equation for each three-dimensional measurement at each orientation using the two-dimensional estimate in PROC REG (SAS Institute, Cary, NC, USA). I hypothesized that each orientation would provide a unique view of an antler set and differing capability to transform the two-dimensional measurements into three-dimensional estimates of antler size. I estimated tines or circumferences hidden by other antler parts using the measurement from the equivalent feature on the other antler ("mirror value"), as antlers are relatively symmetrical after one year of age (Demarais and Strickland 2010).

I evaluated accuracy of the predictive equations on the remaining 50 photographed, known-score, mounted antlers. I calculated average accuracy for each antler measurement at each orientation. I determined which orientation provided the most accurate estimate of each major antler characteristic (inside spread, main beam length, total tine length, total beam circumferences, and total abnormal points) and gross antler score.

Program Development

To create a user-friendly program, I used a software developer to translate my methodology into Visual Basic 2008 Express Edition (Microsoft Inc., Redmond, WA, USA) code that would operate on the internet at www.buckscore.com. A user uploads a photograph of an antlered buck and selects the appropriate orientation and region of origin. The user then scales the photograph by identifying the extremities of one of several anatomical features. Region-specific average values for these attributes are accessed within the program. After the user measures each antler characteristic on the two-dimensional photograph, the value is transformed into a three-dimensional estimate using the predictive equations. A report is generated listing the estimated inside spread, main beam length, and gross antler score from a single photograph.

To increase accuracy, I had the developer create stand-alone software, called BuckScore, which will operate on a personal computer. BuckScore will allow the user to upload photographs of the same deer at up to three orientations. When using multiple photographs, the best available orientation to most accurately estimate each antler characteristic is pre-determined by the program.

Field Evaluation

I evaluated program accuracy for estimating antler characteristics of photographed, live, known-score deer from Mississippi and Oklahoma. A trained scorer used Boone and Crockett Club guidelines to determine the gross, non-typical score of each set of antlers (Wright and Nesbitt 2003). I photographed deer at each of the three orientations, but these views were approximate because of uncontrolled movements of live deer. I photographed deer from Mississippi with a Canon Rebel XTi digital camera (Canon Inc., Lake Success, NY, USA); whereas I obtained photographs of deer from Oklahoma taken by infrared-triggered DeerCams© (NonTypical Inc., Green Bay, WI, USA).

Anatomical features must be used as scale references because known-size objects are not available within photographs of live deer. I sampled 5 anatomical features (Fig. 2.1-2.2) from harvested and sedated deer in Mississippi and Oklahoma. I measured eye-to-eye width from the center of one pre-orbital gland to the center of the other pre-orbital gland. I measured eyeball width as the diameter of the actual eyeball, not the entire socket. I measured upper nostril width at the widest part of the black portion of the muzzle above the nares. I measured lower nostril width at the widest point of the black portion of the muzzle below the nares. I measured ear width at the widest part of the ear perpendicular to the axis.

I compared anatomical features among ages and between deer in MS and OK using a two-way analysis of variance in PROC GLM (SAS Institute, Cary, NC, USA). I knew the age for sedated deer and estimated age for hunter-harvested deer using tooth replacement and wear (Severinghaus 1949). I considered comparisons significant at alpha < 0.050.

Results

Development

I used photographs of 150 mounted antlers to construct predictive equations. Mean antler values included: gross antler score 329.9 cm (129 7/8 in), with a range of 73.3 to 507.4 cm (28 7/8 to 199 6/8 in), inside spread 40.6 cm (16 0/8 in), with a range of 9.2 to 62.9 cm (3 5/8 to 24 6/8 in), and main beam length 52.4 cm (20 5/8 in), with a range of 12.4 to 69.9 cm (4 7/8 to 27 4/8 in). Fifty-nine out of 150 mounted deer (39%) had one or more abnormal (non-typical) points.

I generated 97 predictive equations using the measurements from the photographed mounted antlers. All predictive equations required to estimate antler characteristics were significant statistically. Coefficient of determination (R^2) values varied from 0.97 for total length of abnormal points at 0° and 90° to 0.61 for inside spread at 45°. The 0° view best accounted for variation in inside spread (R^2=0.94). The 90° view best accounted for main beam length (R^2=0.85). The 45° view best accounted for total tine length variation (R^2=0.96). The 0° view best accounted for total circumference variation (R^2=0.88).

Accuracy of estimating three-dimensional antler measurements for mounted antlers varied by orientation (Table 2.1). For example, inside spread accuracy varied from 5.0% at 0° to 7.8% at 45°. Main beam length accuracy ranged from 6.3% at 45° to 7.3% at 0°.

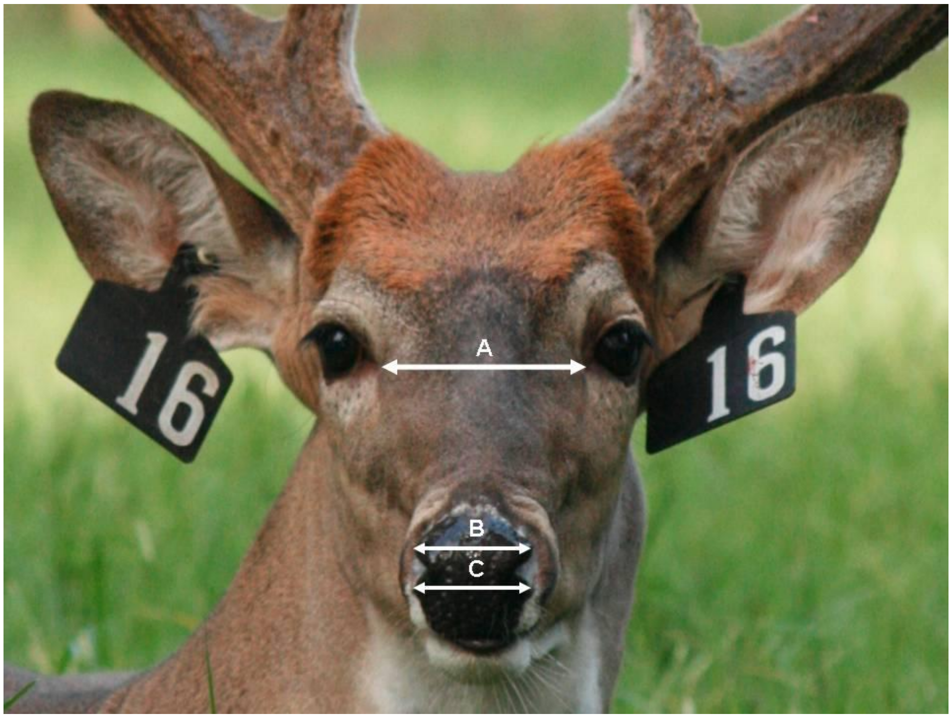

Figure 2.1 Three anatomical features, (A) eye-to-eye width, (B) upper nostril width and (C) lower nostril width, collected from hunter-harvested and captive white-tailed deer in Mississippi and Oklahoma, USA, 2007-2008.

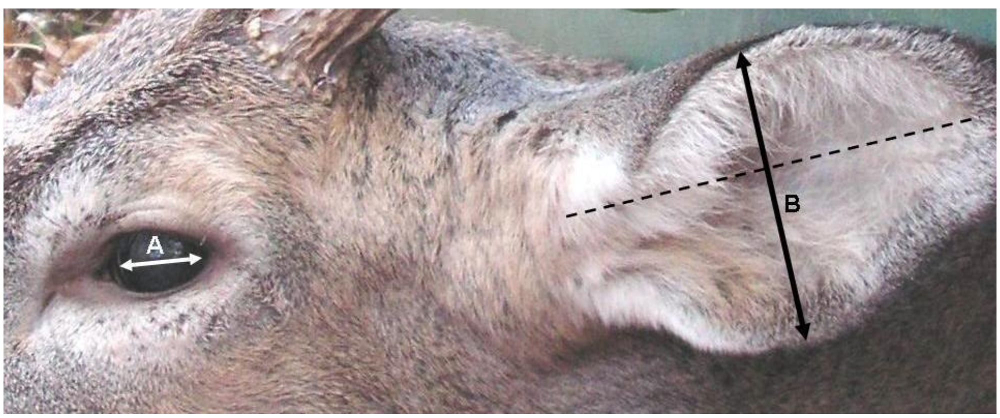

Figure 2.2 Two anatomical features, (A) eyeball width and (B) ear width, collected from hunter-harvested and captive white-tailed deer in Mississippi and Oklahoma, USA, 2007-2008.

Table 2.1 Percentage error for estimates of antler characteristics using a single photograph of mounted and live [1] white-tailed deer, $\geq 2\frac{1}{2}$ years of age, from Mississippi, USA, 2007-2009.

		Mounted (n=50)		Live (n=37)	
Antler Characteristic	Angle (°)	$\bar{x}$	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
Abnormal Points[2]	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 Antler Score	0	4.6	0.5	4.9	0.8
	45	3.2	0.4	5.9	1.1

[1] Scaled using ear width

[2] n=12

Table 2.2 Percentage error for gross antler score estimates using multiple photographs of mounted and live[1] white-tailed deer, ≥ 2 ½ years of age, from Mississippi, USA, 2007-2009.

	Mounted (n=50)		Live (n=20)	
Angle (°)	$\bar{x}$	SE	$\bar{x}$	SE
0 & 45	4.3	0.4	4.3	1.0
0 & 90	3.0	0.3	4.5	1.2
45 & 90[2]	2.9	0.3	5.5	1.7
0, 45, & 90[2]	2.5	0.3	4.9	1.3

[1] Ear and/or eyeball width used for scaling

[2] Live, n = 15

When using a single photograph, the 45° view generated the most accurate estimation of gross score for mounted antlers (3.2%), with loss of accuracy at 0° (Table 2.1). Gross antler score could not be calculated using a single photograph at 90° because I could not measure inside spread. Using two photographs and combining the best estimates from the 45° and 90° orientations improved gross antler score accuracy to 2.9% (Table 2.2). Using three photographs and combining the best estimates from each angle improved gross antler score accuracy to 2.5% (Table 2.2).

Field Evaluation

Five anatomical measurements collected from 243 adult (≥ 1.5 years old) male white-tailed deer from Mississippi (n=203) and Oklahoma (n=40) varied with age ($P<0.050$). In Mississippi, eyeball width was approximately 6% larger and upper nostril width was about 14% larger at ≥ 2 years than at 1 year ($P<0.001$). Eye-to-eye width and eyeball width were about 10% smaller in Mississippi than Oklahoma ($P<0.001$).

Accuracy of antler measurement estimates of live deer using a single photograph varied by angle and anatomical scaling feature (Tables 2.1-2.3). Using ear width as the scaling feature provided the most consistently accurate results (Table 2.3). Accuracy using ear width varied from 4.9% for gross score for the 0° view to 15.6% for main beam length at 90° (Tables 2.1-2.2). Using the second best anatomical feature, eyeball width, produced 6.0% mean error for gross antler score at 45° and 90°.

I successfully created user-friendly software in Visual Basic 2008 Express Edition (Microsoft Inc., Redmond, WA, USA). Users can upload digital photographs and estimate inside spread, main beam length, and a gross antler score, similar to Boone and Crockett non-typical gross score (Wright and Nesbitt 2003).

Discussion

Estimating gross antler score and specific antler characteristics from a photograph is feasible. The statistically-derived, predictive equations transformed two-dimensional measurements into accurate, three-dimensional estimates. Previous studies successfully

Table 2.3 Percentage error for gross antler score estimates using a single picture of live white-tailed deer (n=37), ≥ 2 ½ years of age, from Mississippi and Oklahoma, USA, 2007-2009.

Angle (°)	Anatomical Feature	$\bar{x}$	SE
0	Ear	4.6	0.8
	Eye to Eye	8.2	0.9
	Upper Nostril	12.0	1.3
	Lower Nostril	8.9	1.2
45	Ear	5.9	1.1
	Eyeball	6.5	0.9

measured bats and Alpine ibex using photographs. Bergeron (2007) estimated length of annuli on ibex horns within 2 mm of the hand-measured value on 93% of samples. Fixed-positioned lasers had to be visible on the horns at the time of the photograph, limiting the approach. Hirakawa and Maeda (2006) had varying accuracy when using the shadows of bats to calculate body size. This approach used the distance from the wingtip of a bat to the ground as a reference to calculate the distance of the bat to the camera. They concluded that the technique varied in accuracy, but, produced an unbiased size estimate (Hirakawa and Maeda 2006).

The wide range of antler sizes used to construct the predictive equations allows broad application of this software. However, accuracy may vary for antlers outside the 434 cm (170 7/8 in) range used in the development of the predictive equations.

There are several sources of error associated with estimating antler size from photographs. These sources include the variation in anatomical features, variation in antler orientation to the camera, number of photographed orientations used, photograph resolution, and user error. Accuracy of the estimates from mounted, known-score antlers involves the least amount of error (only user variation), and would be considered "best case" accuracy.

Anatomical features vary at two scales, individually and regionally. Average values of anatomical features must be used to scale a photograph, but the actual value for an individual photographed deer is unknown. The difference between the average and individual's anatomical feature values is a source of error in the estimate. White-tailed deer vary by geographic region (Gill 1956, Richie 1970, Strickland and Demarais 2000) and body size will likely affect size of anatomical features. Variation in eyeball and eye-to-eye width between Mississippi and Oklahoma indicates that values must be determined across the geographic range of white-tailed deer. To estimate antler size with greater accuracy, an additional 22 state and provincial agencies (Table 2.4) collected measurements to be used in free, online antler scoring software available at www.buckscore.com.

Accuracy of antler characteristic estimates varied by angle of orientation. I developed my predictive equations at specific angles to the camera to improve accuracy of the estimates. Increased error would be expected in photographs with deer that deviate from the designated orientations.

Table 2.4 Number of anatomical feature sets (n) measured from male white-tailed deer during 2009 in 24 states and Canadian provinces to be used for the free, online antler scoring software available at www.buckscore.com.

State/Province	n
Alabama	242
Alberta	35
Arkansas	51
Connecticut	29
Florida	38
Georgia	37
Illinois	63
Louisiana	23
Maine	38
Maryland	70
Michigan	118
Mississippi	208
Missouri	17
New Brunswick	17
New Hampshire	26
North Carolina	31

Table 2.4   Continued

State/Province	n
Oklahoma	40
Pennsylvania	46
Quebec	18
South Carolina	59
Tennessee	67
Texas	112
Vermont	11
West Virginia	104

The decreased accuracy of estimating gross antler score for live deer compared to mounted antlers with a fixed spherical object as a reference can be attributed to individual variation of anatomical features among deer and orientation of antlers in photographs. Similarly, Hirakawa and Maeda (2006) determined that the accuracy of estimates varied among photographs based on position of a bat relative to the camera. Choosing to use only photographs of live deer which were at the exact angle would have diminished the sample size substantially. This limitation could be minimized by using multiple photographs of the same deer at different orientations, which increased accuracy from

5.9% for one photograph to 4.3% for two photographs.

Photograph resolution affects ability of the user to take measurements. Greater resolution would allow more precise and potentially more accurate measurements. The anatomical feature used for scaling must be measured as accurately as possible; an unclear photograph will make identifying critical points of the feature difficult. Similar issues will occur when attempting to measure specific antler characteristics.

Lastly, there is variation associated with repeatability of measurements by an individual user and variation in ability of various users to take measurements. Starting and ending points for anatomical features and antler measurements are somewhat subjective. Additionally, a learning curve has been reported by users online. This study did not attempt to quantify user variation.

Inside spread and main beam length are two antler characteristics that are becoming widely used as selective harvest criteria (Strickland et al. 2001). Previously, ability to visually estimate antler size is considered an art more than a science. This program can provide two extremely useful tools for the avid deer enthusiast. The first is a hunter education tool to train the user's ability to recognize specific measurements. The second is to measure specific (known) individuals in the population prior to harvest. The accuracies generated by the program are acceptable for management and research. Certain orientations are better at producing an accurate estimate of a specific antler characteristic (e.g., inside spread at 0° compared to 45°). Although harvest decisions should not be based solely on the results of the program, it will guide the user in making appropriate harvest decisions.

My research suggests that estimating antler size from photographs is feasible and will be valuable to wildlife professionals and recreational hunters. Ability to collect data on un-harvested deer is an important advantage to wildlife managers and biologists. Estimating characteristics which are used commonly in selective harvest restrictions and difficult to estimate visually can help the general hunting public make better management decisions.

Management Implications

Wildlife professionals require reliable, cost-effective ways to collect useful data. Ability to use digital RTCs to passively collect accurate, antler size data is a valuable management tool. Using a camera survey (McKinley et al. 2006) and the methodology to estimate antler size, along with age (Chapter III), of all bucks can generate age-specific herd conditions for managers because antlers can reflect health and nutritional status (Kodric-Brown and Brown 1984, Kruuk et al. 2002).

This research provides wildlife agencies with an innovative tool to educate the hunting public on visually estimating specific antler characteristics. If used properly and repeatedly, the methods can hone a hunter’s skills at estimating antler size. The education of the hunting public could increase support for antler-based, harvest criteria in states looking to manage for older, male age classes. Although harvest decisions should not be made exclusively using this program, it will aid in making better management decisions.

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CHAPTER III

AGING LIVE MALE WHITE-TAILED DEER USING MORPHOMETRIC RATIOS

Abstract

Subjective methods for aging live, male, white-tailed deer based on physical characteristics are abundant in technical and non-technical literature, but their accuracy has not been evaluated. I used several quantitative measures of body features from 144 photographed, captive, known-aged bucks from Mississippi to develop age-predicting models. I validated the models using external testing of 106 wild, known-age deer. A series of models that assigned animals to increasingly more specific age categories proved more effective than a single model. Using the model series, I assigned wild deer to 1, 2, 3, 4, or ≥ 5 year age classes with 53% accuracy during September - October (pre-breeding period) and 67% during January - February (post-breeding period). More generalized groupings increased accuracy for wild deer; 77% during pre-breeding period placing deer into 1, 2, 3, or ≥ 4 years of age and 79% during post-breeding period placing deer into 1, 2, 3-4, or ≥ 5 years of age. These generalized groupings would provide valuable age composition data applicable to most white-tailed deer management scenarios.

Introduction

Age of live, male, white-tailed deer (*Odocoileus virginianus*) is visually estimated by researchers, biologists, and the general hunting public. Uncritical presentation of techniques in non-technical literature has obscured the un-quantified accuracy of these commonly used methods (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003). Even technical publications have used live-age estimation techniques without addressing accuracy (Dapson 1980). An accurate, live-animal, age estimation technique is needed because age distribution is an essential component of white-tailed deer management strategies based on population dynamics (Governo et al. 2006).

Accurate, cost-effective data collection from free-ranging wildlife benefits researchers and managers. Remotely-triggered cameras (RTCs) have been used successfully to estimate white-tailed deer density and sex ratio (Jacobson et al.1997, McKinley et al. 2006, Roberts et al. 2006), and accurate age estimation from these surveys would provide additional valuable data. Hirakawa and Maeda (2006) used RTCs to photograph and estimate size of bats, whereas Bergeron (2007) used them to estimate horn morphometrics of Alpine ibex (*Capra ibex*). Mott et al. (2010) concluded that using digital images to measure marbled salamanders (*Ambystoma opacum*) was significantly more accurate and faster than using calipers to obtain a hand-measured size estimate. Remotely-triggered camera photographs of bucks may provide less-biased, non-lethal samples of population age structure for biologists and researchers and an educational opportunity for hunters.

The goal of my research was to evaluate if live, male, white-tailed deer $\geq$ 1 year of age could be aged accurately from photographs. I calculated morphometric ratios by measuring physical characteristics of photographed captive, known-age deer. I constructed models to predict the probability of a deer being placed into an age class. To determine accuracy, I validated the models using sets of wild, known-age deer.

Methods

To determine if there was a definable progression of morphological characteristics associated with increasing age in male white-tailed deer, I photographed live, known-age, adults (≥ 1.5 years; n = 144) in research pens during September - October and late January - February. September - October and late January - February represented the pre- and post-breeding periods for the region, respectively (S. Demarais, Mississippi State University, personal communication). I photographed deer with a Canon Rebel XTi digital camera (Canon, Inc., Lake Success, NY, USA), and uploaded the pictures into ArcGIS 9.2 to measure morphological characteristics.

I measured morphological features that are routinely associated with aging live white-tailed deer (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003). The chest, stomach, legs, neck, and antlers generated 9 measurements (Fig. 3.1). I measured chest depth (planar view of chest girth) immediately behind the shoulder, and measured stomach depth (planar view of stomach girth) at the midpoint between the end of the rump and apex of the scapula. I measured leg measurement 1 from the proximal tip of the metacarpal to the apex of the scapula. I measured leg measurement 2 from the apex of the scapula to the proximal edge of the dew claw. I calculated length of leg below the chest

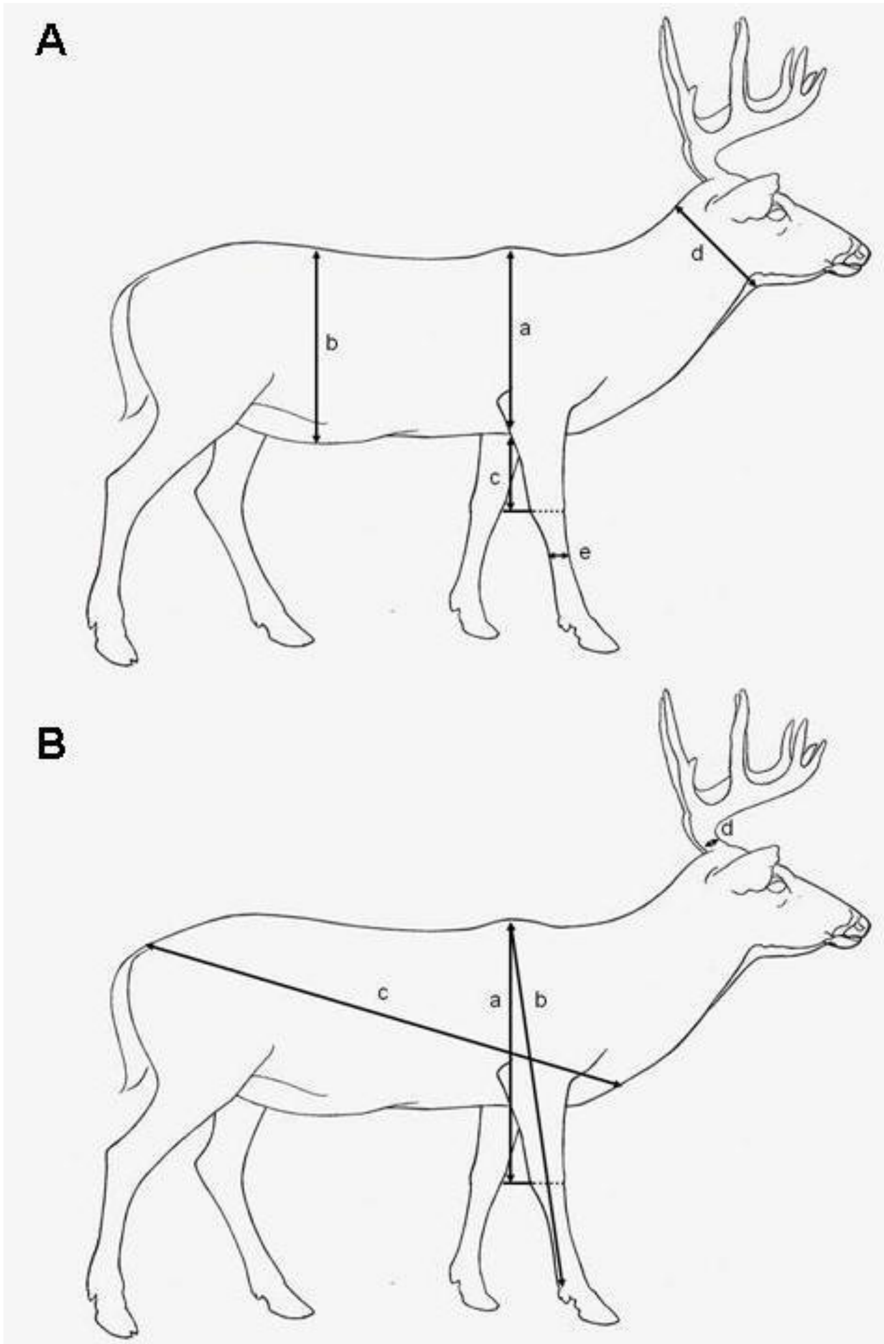

Figure 3.1 Schematic showing proper view and specific morphometric measurements used to calculate ratios for age class separation of live, male white-tailed deer from Mississippi, Louisiana, Texas, and Oklahoma, USA, 2009-2010. A, chest depth (a),stomach depth (b), length of leg below the chest (c), neck width (d), and metacarpal width (e). B, leg measurement 1 (a), leg measurement 2 (b), body length (c), and basal circumference (d).

as the difference between the chest depth and leg measurement 1. I measured neck width directly below the lower mandible with the deer looking straight ahead. I measured body length from the junction of the neck and brisket to the base of the tail. I measured basal circumference just above the burr of the antler. I measured metacarpal width at the most narrow point of the metacarpal bone.

I calculated morphometric ratios using combinations of morphometric features to capture the changes in body proportions associated with aging (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003). I evaluated 64 potential ratios for known-age, captive deer, ages 1, 2, 3, 4, and ≥ 5 years using PROC MEANS (SAS Institute, Cary, NC, USA). I eliminated ratios that did not vary among age classes, which resulted in 12 useable ratios.

I used a stepwise logistic regression procedure in PROC LOGISTIC (SAS Institute, Cary, NC, USA) to generate probability of a correct age class placement as a linear function of one of more explanatory variables (Karp 2000). The response variable was age class (1, 2, 3, 4, or ≥ 5 years). The explanatory variables were the 12 morphometric ratios. I developed single models using the parameter estimates and intercepts generated from the logistic regression procedure. I developed various single models by grouping different age classes. For example, the most specific age class grouping was 1, 2, 3, 4, or ≥ 5 years. The most general age grouping model placed deer into two age classes: 1 year or ≥ 2 years. I considered morphometric ratios significant at alpha < 0.100.

I evaluated the single models on a wild, known-age deer data set from Mississippi, Louisiana, and Texas. This data set included 72 males raised in enclosures, ranging from 415 to 3,200 ha in size. The enclosures were managed for high quality forage production using prescribed fire and food plots and deer had access to supplemental feeding (16% crude protein) ad libitum year-round. Enclosures were located in the Western Gulf Coastal Plain physiographic region of Texas and Louisiana and Southeastern Plain physiographic region of Mississippi (The Nature Conservancy 2007).

To test accuracy, I incorporated the model parameter estimates and individual deer morphometrics into a Microsoft Excel 2007 (Microsoft Inc., Redmond, WA, USA) spreadsheet to calculate probability of age class assignment. I assigned deer to the age class with greatest probability.

To more effectively separate age classes, I developed a multiple step procedure using a series of single models. This complex model followed a dichotomous key approach in which each step contained a best-fit single model. For example, I separated immature from mature bucks by separating 1 year-olds from ≥ 2 year-olds. Using a separate single model on the remaining animals, I separated 2 year-olds from ≥ 3 year-olds, with no possibility that any of these deer could be labeled as 1 year-olds.

I validated the set of complex models (pre- and post-breeding period) externally with two data sets of wild, known-aged deer; the Mississippi, Louisiana and Texas set and a set from Oklahoma. The Oklahoma population included 34 males from an enclosure in the Cross Timbers physiographic region of south-central Oklahoma (The Nature Conservancy 2007). This enclosure was managed using prescribed fire and rotational grazing and supplemental feed and food plots were not available.

I incorporated the model parameter estimates and individual deer morphometrics into a Microsoft Excel 2007 (Microsoft Inc., Redmond, WA, USA) spreadsheet to calculate probabilities of age class assignments. I assigned deer to the age class with the greatest probability and calculated overall and age-class accuracy of the complex models. The final age assignment included a level of confidence based on the cumulative probability for each of the steps in the complex model. I grouped deer based on management application and acceptable accuracy.

Results

The 144 deer used to create single models averaged 3.6 years of age, with a range from 1 (12-22 months) to 12 years. The sample sizes per age class were: 1 (n=31), 2 (n=29), 3 (n=28), 4 (n=29), and ≥ 5 (n=28). Only 2 of the 28 animals in the ≥ 5 year age class were 7 years or older.

I generated 26 single models for the pre- and post-breeding period (Tables 3.1-3.2). Overall model accuracy for wild deer was poor (Tables 3.1-3.2). Because of poor accuracy, I grouped classes uniquely to improve specific age class accuracy.

During pre-breeding period, the morphometric ratios used in the models and model accuracy varied by age class. Single models used a ratio with basal circumference and metacarpal width to separate wild, 1 year-olds with 75% accuracy. Single models used ratios with basal circumference and metacarpal width, neck width and length of the leg below the chest, leg measurement 2 and chest depth, and metacarpal width and body length to separate wild, 2 year-olds with 86% accuracy. Single models used a ratio with neck width and leg measurement 2 to separate wild, 3 year-olds with 40% accuracy.

Table 3.1 Pre-breeding period age class (years) accuracy (%) of single models for wild, live white-tailed deer from Mississippi, Louisiana, and Texas, USA, 2009-2010.

Age Groupings	Ratios[1]	R^2	Accuracy
1, 2, 3, 4, or ≥ 5	BC:MTC	0.75	33
	NW:LBC		
	MTC:BL		
1-2, 3, 4, or ≥ 5	BC:MTC	0.69	48
	NW:LBC		
1, 2-3, 4, or ≥ 5	BC:MTC	0.73	48
	NW:LBC		
	MTC:BL		
1, 2, 3-4, or ≥ 5	BC:MTC	0.76	39
	NW:LBC		
	MTC:BL		
1, 2, 3, or ≥ 4	BC:MTC	0.70	68
	NW:LBC		
	MTC:BL		
1-3, 4, or ≥ 5	BC:MTC	0.58	52
	NW:LBC		
	LM2:CD		
	MTC:BL		

Table 3.1 Continued.

Age Groupings	Ratios[1]	R^2	Accuracy
1-2, 3-4, or ≥ 5	BC:MTC	0.71	55
	NW:LBC		
1-2, 3, or ≥ 4	BC:MTC	0.63	71
	NW:LBC		
1, 2-3, or ≥ 4	BC:MTC	0.67	68
	NW:LM1		
	MTC:BL		
1-3 or ≥ 4	BC:MTC	0.50	74
	NW:LM2		
	MTC:BL		
1-2 or ≥ 3	BC:MTC	0.64	84
	NW:LBC		
1 or ≥ 2	BC:MTC	0.41	81
	NW:LBC		
	SD:CD		
	MTC:BL		
1-4 or ≥ 5	BC:MTC	0.43	58
	NW:LBC		
	MTC:BL		

[1] Morphometric feature code: BC-basal circumference, MTC-metacarpal width, BL – body length, LBC-length of leg below the chest, NW-neck width, CD-chest depth, SD-stomach depth, LM1-leg measurement 1, and LM2-leg measurement 2

Table 3.2 Post-breeding period age class (years) accuracy (%) of single models for wild, live white-tailed deer from Mississippi, Louisiana, and Texas, USA, 2009-2010.

Age Groupings	Ratios[1]	R^2	Accuracy
1, 2, 3, 4, or ≥ 5	BC:MTC	0.76	40
	LBC:CD		
	SD:CD		
	MTC:BL		
1-2, 3, 4, or ≥ 5	BC:MTC	0.68	49
	LBC:CD		
	SD:CD		
	MTC:BL		
	MTC:NW		
	LBC:BL		
1, 2-3, 4, or ≥ 5	BC:MTC	0.72	53
	LBC:BL		
	MTC:BL		
1, 2, 3-4, or ≥ 5	BC:MTC	0.75	53
	MTC:BL		
	LBC:BL		
	LBC:CD		
	SD:CD		

Table 3.2 Continued.

Age Groupings	Ratios[1]	R^2	Accuracy
1, 2, 3, or ≥ 4	BC:MTC	0.72	58
	MTC:BL		
	NW:LBC		
	SD:CD		
	CD:BL		
1-3, 4, or ≥ 5	BC:MTC	0.56	56
	MTC:BL		
	LBC:BL		
1-2, 3-4, or ≥ 5	BC:MTC	0.64	60
	LBC:CD		
	SD:CD		
	LBC:BL		
	MTC:BL		
1-2 or ≥ 3	BC:MTC	0.54	84
	SD:CD		
1 or ≥ 2	BC:MTC	0.54	94
1-4 or ≥ 5	BC:MTC	0.48	81
	MTC:BL		
	LBC:BL		

[1] Morphometric feature code: BC-basal circumference, MTC-metacarpal width, BL-body length, LBC-length of leg below the chest, NW-neck width, CD-chest depth, SD-stomach depth, LM1-leg measurement 1, and LM2-leg measurement 2

Single models were unable to correctly separate any wild, 4 year-old deer during the pre-breeding period. Single models used ratios with basal circumference and metacarpal width, length of the leg below the chest and chest depth, stomach depth and chest depth, and metacarpal width and body length to separate wild, ≥ 5 year-olds with 64% accuracy.

During post-breeding period, the morphometric ratios used in the models and model accuracy varied by age class. Single models used a ratio with basal circumference and metacarpal width to separate wild, 1 year-olds with an average accuracy of 88%. Single models used ratios with basal circumference and metacarpal width, length of leg below the chest and body length, and metacarpal width and body length to separate wild, 2 year-olds with an average accuracy of 71% using. Single models used ratios with basal circumference and metacarpal width, length of leg below the chest and chest depth, stomach depth and chest depth, length of leg below the chest and body length, and metacarpal width and body length to separate wild, 3 year-olds with an average accuracy of 53%. Single models accurately placed only an average of 13% of wild, 4 year-old deer during the post-breeding period. Single models used ratios with basal circumference and metacarpal width and leg measurement 2 and chest depth to separate wild, ≥ 5 year-olds with an average accuracy of 84%.

To improve accuracy for assignment of specific age classes, I constructed a complex model which used a series of unique single models. In the pre-breeding period, the complex model correctly assigned 53% of wild deer to the age class (1, 2, 3, 4, or ≥ 5 years). The complex model correctly assigned 77% of wild deer to 1, 2, 3, or ≥ 4 years. The complex model correctly assigned 80% of wild deer to 1, 2-3, or ≥ 4 years. Age class accuracy ranged from 0-91% for wild deer (Table 3.3). In the post-breeding period, the

Table 3.3 Age class (years) accuracy (%) of the complex model for wild, [1, 2] live white-tailed deer from Mississippi, Louisiana, Texas, and Oklahoma, USA, 2009-2010.

Age Grouping		Pre-breeding period Wild[1] (n=30)	Post-breeding period Wild[1] (n=42)	Post-breeding period Wild[2] (n=34)
1, 2, 3, 4, or ≥ 5		53	67	59
	1	75	100	75
	2	86	67	75
	3	40	56	50
	4	0	25	0
	≥ 5	71	86	83
1, 2, 3, or ≥ 4		77	72	62
	1	75	100	75
	2	86	67	75
	3	40	56	50
	≥ 4	86	73	50
1, 2, 3-4, or ≥ 5		53	79	74
	1	75	100	75
	2	86	67	75
	3-4	17	71	67
	≥ 5	71	86	83
1, 2-3, or ≥ 4		80	83	71
	1	75	100	75
	2-3	75	83	86
	≥ 4	86	73	50
1-2, 3-4, or ≥ 5		57	79	85
	1-2	91	83	100
	3-4	17	71	67
	≥ 5	71	86	83

[1] Wild, known-age deer from Mississippi, Louisiana, and Texas

[2] Wild, known-age deer from Oklahoma

complex model correctly assigned 67% of wild deer to age class (1, 2, 3, 4, or ≥ 5 years). The complex model correctly assigned 79% of wild deer to 1, 2, 3-4 or ≥ 5 years. The complex model correctly assigned 83% of wild deer to 1, 2-3, or ≥ 4. Age class accuracy ranged from 25-100% for wild deer (Table 3.3).

I evaluated the Oklahoma data set using the post-breeding period, complex model. The complex model correctly assigned 59% of the deer to 1, 2, 3, 4, or ≥ 5 years. When grouping 1, 2, 3-4, or ≥ 5 years, the complex model correctly assigned 74% of the bucks in the correct age class. The complex model correctly assigned 85% of the bucks to 1-2, 3-4, or ≥ 5 years. Age class accuracy ranged from 0-100% (Table 3.3).

Discussion

My study assigned photographed, live, male white-tailed deer to age class with accuracy and resolution acceptable for management and research applications. The morphometric ratios differentiated the changing body proportions associated with growth from yearling to maturity. Several non-technical publications (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003) proposed physical characteristics similar to those I used to distinguish live, male age classes. The most common body features are stomach and chest girth and their relationship to each other (Kroll 1996, Demarais et al. 1999, Richards and Brothers 2003). Although stomach depth to chest depth significantly influenced age prediction during the post-breeding period, occurring in nearly half of the single models, it occurred only once in the final complex model. Because of the high degree of variability within age classes (Demarais and Strickland 2010), antler size is the most controversial morphometric used to age deer (DeYoung 1990, Hellickson et al.

2008). In one of the few technical studies done on aging live deer, Hellickson et al. (2008) found antler size, specifically gross Boone and Crockett score, to be the most useful morphometric at predicting age. Similarly, I found basal circumference to be present in 100% of the single models indicating that antler size is important in predicting age of live white-tailed deer.

Minimal research has been conducted on aging live deer using morphometrics proposed in the non-technical literature (DeYoung 1998). My single models frequently used the stomach depth to chest depth ratio to separate age classes which concurred with results from Hellickson et al. (2008) conclusion that chest girth was an effective single body characteristic to distinguish specific age classes. Overall, metacarpal width was the most prevalent body morphometric in the ratios, probably because it varied little with age and acted as a fixed reference. Hellickson et al. (2008) indicated that chest girth, head length, and stomach girth were the most useful non-antler morphometrics to estimate age of males in southern Texas. However, Hellickson et al. (2008) did not use known-age deer, but rather used age estimates derived by tooth replacement and wear (Severinghaus 1949), which has significant accuracy issues (Gee et al. 2002), whereas my research was conducted with known-age animals. In addition, they collected data from physically restrained un-sedated deer, which could have affected the accuracy and repeatability of the measurements (Hellickson et al. 2008).

My results from the Oklahoma data set can be compared directly to accuracy of ages estimated by attendees of the 2008 and 2009 Southeast Deer Study Group annual meetings that participated in an online test using a larger set of photographs (K. Gee, The Samuel Roberts Noble Foundation, personal communication). Most participants at the meeting are professional deer biologists. Gee and Holman (2010) showed that the average biologist's accuracy for aging photographed, live white-tailed deer did not meet the minimum level suggested for management purposes at any specific age class grouping, including: 1, 2, 3, 4, or ≥ 5 years; 1, 2, 3-4, or ≥ 5 years; and 1-2, 3-4, or ≥ 5 years. Similar to Gee and Holman (2010), the 3 and 4 year-old classes were the most difficult to separate using the complex model. The average biologist was 18% less accurate than the model at placing deer into the 3-4 year age class. On average, biologists placed 51% of deer correctly into 1, 2, 3-4, or ≥ 5 years age grouping (Gee and Holman 2010), which was 23% less accurate than the complex model. In addition, the complex model was consistently more accurate in every age class than the professional biologists (Gee and Holman 2010). Therefore, the complex model can assign an age class to deer, during the post-breeding period, more accurately than the average professional biologist.

The complex models I developed should only be used to estimate age of deer within the specified demographics of this research. Although I used deer aged 1 to 12 years, most deer in the ≥ 5 year age class were 5 or 6 years. Older deer may begin to revert backward in physical development (Demarais et al. 1999, Richards and Brothers 2003), with unknown effects on accuracy. All deer used in the development and testing of the complex models were within the normal range of antler and body size for southern deer. Use of the methodology on deer bred for abnormally large antlers or for northern subspecies would result in unknown accuracy.

Season greatly affects condition of bucks (Sauer 1984, Richards and Brothers 2003). Body mass of mature deer varies seasonally (Demarais et al. 2000). Occurrence of the stomach depth to chest depth ratio was four times greater in the post-breeding period than the pre-breeding period suggesting that the stomach depth and chest depth vary disproportionately with season.

My research sought to age live, southern deer from photographs during the pre- and post-breeding period, deviating from these demographics will result in unknown accuracy. Use of two, wild, known-age deer data sets allowed me to evaluate accuracy with and without presence of supplemental feeding and food plots. Overall accuracy of the properties was similar regardless of presence of these intensive management techniques.

The morphometric models had consistent strength as evidenced by their large coefficient of determination, many of which exceeded 0.6. Other wildlife-related models have stated similar results, but most have failed to test the model outside of the training (development) set (Beutel et al. 1999). Beutel et al. (1999) stated that coefficient of determination values around 0.8 demonstrate model reliability. However, many technical biological publications have presented models with values less than 0.5 (e.g., Franklin et al. 1997, Pess et al. 2002).

Variation in habitat quality and climate may alter the relationship represented by ratios of morphometric features. The wild deer in this study occurred on well-managed habitats with quality nutritional intake and were considered to be in good body condition. Restricted habitat quality and nutritional availability may alter morphometric relationships and the accuracy of the methodology. In caribou (*Rangifer tarandus*), individuals deprived of nutrition remained in proportion to well-fed individuals of the same age class (Klein et al. 1987). Deer in the upper Midwest and Canada are much larger than those in the South (Demarais et al. 2000, Miller et al. 2003), although it has not been stated that they have different morphological proportions. Adaptations that may preclude consistent morphological relationships would reduce accuracy, such as the possibility that deer in climates with consistently deep snow may have adapted longer legs to facilitate winter travel (Telfer and Kelsall 1984). Additional regional evaluation with northern deer is needed.

Other sources of error include variation in posture and angle of orientation to the camera of the individual, photograph resolution, and user variation. A broadside view of a deer looking straight ahead is ideal and deviation from these conditions would likely result in increased error. Photograph resolution affects the ability of the user to take measurements. Greater resolution allows more precise measurements. Lastly, there is variation associated with the repeatability of measurements by an individual user and variation in the ability of various users to take measurements. This study did not attempt to quantify user variation.

A deer's proportions change with maturity (Scanes 2003) allowing for the separation of age classes using morphometrics. Some morphometric features may be better able to differentiate immature deer, but not older deer, or vice versa. Placing deer into an age class with a single model averaged the variation over all classes which reduced the accuracy for any single class. This likely resulted in the poor accuracy of the single models.

There are several morphometric-based techniques used to age white-tailed deer. The Severinghaus (1949) technique of tooth replacement and wear (TRW) has become the most widely used aging technique by wildlife professionals (Sauer 1984, Gee et al.

2002). Gee et al. (2002) evaluated the TRW technique (Severinghaus 1949) using 106 jawbones or dental casts from known-age deer in Oklahoma and showed consistency in assigning deer to only fawn, yearling, and adult age classes (Gee et al. 2002). Professional biologists correctly placed 85%, 73% and 43% of 1, 2, and 3-4 year age classes, respectively, using TRW (Gee et al. 2002), similar to the complex model accuracy of 88%, 77%, and 47% when averaging pre- and post-breeding period figures for 1, 2, and 3-4 year age classes, respectively. Using cementum annuli counts on known-age deer from Mississippi and Virginia, Mitchell and Smith (1991) correctly placed only 41% of the samples. Similarly, in Texas DeYoung (1989) correctly placed only 39% using the cementum annuli technique on extracted incisors from live captured deer. The complex model on average placed 60% of wild, known-age deer into the correct year class (1, 2, 3, 4, or ≥ 5 years).

Age composition data prior to the harvest could result in more accurate management decisions and recommendations. Aging by TRW is the most practical method for harvested animals, but may inaccurate, particularly for deer ≥ 3 years of age, and exhibit sample composition bias due to antler-based harvest restrictions and hunter selection (Coe et al. 1980, Gee et al. 2002). Additionally, tooth replacement and wear can vary based on nutrition level, soil type, vegetation grit, and biologist’s training (Ludwig 1967). Aging prior to the harvest is advantageous and simple. This is especially true because trail cameras used frequently by biologists and the general hunting public accumulate buck pictures during the pre- and post-breeding period. Using this less-biased, non-lethal sampling method may result in a more accurate overview of the herd’s age structure and subsequently lead to more precise management decisions.

Management Implications

Although little evaluation has been done, biologists and experienced hunters use morphometric characteristics and behavior as clues to age live deer (DeYoung 1998). The ability to consistently age deer accurately prior to harvest can assist in the development of an older male age structure within a population (Demarais et al. 1999, Strickland and Demarais 2007). This research will allow biologists and managers to collect age composition data that would otherwise remain unknown, which could increase the validity of resulting management recommendations. Although harvest decisions should not be made exclusively using this research, it can aid in making better management decisions.

Biologists considered 70% accuracy for management and 80% accuracy for research acceptable when aging live deer (Gee and Holman 2010). Accuracy for the most specific age class grouping (1, 2, 3, 4, or ≥ 5 years) did not reach this suggested level. However, for management purposes grouping deer into 1, 2, 3, or ≥ 4-year or 1, 2, 3-4, or ≥ 5-year age classes is acceptable and accuracy levels exceeded the threshold for management application. Biologists and managers can use this research to obtain acceptably accurate age composition data with less bias than harvest-based data.

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CHAPTER IV

SYNTHESIS AND RECOMMENDATIONS

Biologists and the general hunting public are increasingly interested in visually estimating age and antler size of white-tailed deer with the goal of managing for older age classes and protecting large-antlered young deer (Kroll 1996, DeYoung 1998, Demarais et al. 1999). However, Gee and Holman (2010) recently showed that biologists cannot accurately estimate age of live deer using their subjective visual evaluation. The ability to objectively age deer accurately prior to harvest can assist in the development of an older male age structure within a population (Demarais et al. 1999, Strickland and Demarais 2007) and will provide biologists a way to collect less-biased, non-lethal, accurate data on age and antler size.

This research will lead to the creation and commercialization of user-friendly, age and antler size estimating computer programs. There are two main uses of the programs. First, the programs will help educate the general public in estimating age, inside spread widths, main beam lengths, and gross antler scores. If used repeatedly, a hunter can hone their skills at estimating age and antler size. Second, the programs' ability to obtain age and antler data that would otherwise remain unknown through these methods increases the validity of resulting management recommendations.

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