AGE-SPECIFIC PHYSICAL CHARACTERISTICS, ACTIVITY, AND BEHAVIOR PATTERNS OF MALE WHITE-TAILED DEER IN SOUTHERN TEXAS

by

MICKEY WAYNE HELLICKSON

(Under the direction of KARL V. MILLER)

ABSTRACT

Knowledge of the age-specific physical characteristics, activity, and behavior patterns of white-tailed deer (*Odocoileus virginianus*) are required for making informed management decisions as the popularity of non-traditional management programs increase. Regression analyses indicated live mass of mature males can be predicted based on dressed mass. Live mass can be predicted for fawn and yearling females with models based on dressed mass, hoof length, shoulder height, and chest girth; whereas only dressed mass provided an accurate prediction for adult females.

Akaike information criterion indicated age of males can be best estimated by gross Boone and Crockett Club (BCC) score, inside spread, and basal circumference. Best 2- and 3-variable models included gross BCC score and number of points; and gross BCC score, number of points, and stomach girth. Gross BCC score, inside antler spread, and stomach girth for males, and live mass and chest girth for females, are likely the most useful criteria for visually estimating age.

Our data collection system accurately identified deer as active (90.2%) when relative pulse rates were >104% and as inactive (88.4%) when pulse rates were ≤104%. This same system was used to quantify relative activity rates of 35 males. Males were active an average of 42.6% (±2.1 SE) of the time monitored. Peak months were January and September-October, with lows during March and April-August. Males were most active during the evening crepuscular period except during rut when diurnal activity was highest. Highest seasonal activity occurred during prerut, with lowest activity during spring. Activity rates were highly variable, with some males >4 times as active as other males. Activity was highest for young and middle-aged males and lowest for mature and old males. Activity was unrelated to forage quantity and quality, precipitation, deer density, or antler and body size; but may be explained by social interactions, relative dominance and the varying ability among males to assimilate into bachelor groups.

We observed 111 male white-tailed deer responses to 4 antler rattling sequences. Loud rattling attracted 3 times as many males as quiet rattling. Highest response occurred during rut with lowest during prerut. Young, middle-aged, and mature males responded at highest rates during prerut, rut, and postrut, respectively.

INDEX WORDS: Activity, Age-specific, Antler characteristics, Behavior, Data collection unit, Diel pattern, Live age, Live mass, *Odocoileus virginianus*, Physical characteristics, Rattling, Southern Texas, White-tailed deer

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MICKEY WAYNE HELLICKSON

B.S., Iowa State University, 1988

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MICKEY WAYNE HELLICKSON

Approved:

Major Professor: Karl V. Miller

Committee: R. Larry Marchinton
Robert Warren
Steven Castleberry
John Carroll

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
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DEDICATION

This dissertation is dedicated to my family, especially my wife Genny, who endured weeks at a time home alone, while her husband was "in the field" conducting research, "at the office" writing the dissertation, or away taking classes. She chose to allow me to put my career first and for that I am eternally grateful. Dedication is also given to my parents Willis and Barb, and brothers Jason and Brad, in appreciation for their continuous support and encouragement. Special thanks are extended to my father who first inspired and encouraged my interest in the outdoors. He happily led me afield on weekends during the hunting season when he could have been home "sleeping in."

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PREFACE

The following dissertation is the result of 3 continuous years of field research on the physical characteristics, activity, and behavior patterns of male white-tailed deer in southern Texas. Specifically, I investigated differences in these patterns among various age classes of males. This research began with 2 related objectives: (1) to test for differences in activity and behavior patterns among different-aged males with different physical characteristics; and (2) if differences existed among age classes, to determine how changes occurred in individuals as they matured.

Phases I and II include the Introduction and Literature Review sections. Several predictive equations for estimating deer mass based on various body measurements were developed in Phase III. Results from this third phase allowed the proper separation of males into age groups based on physical characteristics. The usefulness of various antler and body measurements for visually estimating deer age in the field was evaluated in Phase IV. Results further assisted in separating males into appropriate age groups. Accuracy of the activity monitoring system was determined in Phase V. Age-specific annual, seasonal, monthly, and bi-hourly or hourly activity patterns of males were determined in Phase VI. Finally, age-specific behavior patterns of males in relation to antler rattling were examined in Phase VII.

As a result of this approach, the dissertation is organized into 7 distinct, but interrelated chapters. Each chapter is formatted for submission to a specific journal, and thus formats vary. The dissertation is separated into a general Introduction section, Literature Review section, 5 manuscript chapters, and a Summary section. Each section, except the Summary, is followed by its own literature cited section.

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CHAPTER 1

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) are one of the most economically important wildlife species in Texas (Teer and Forest 1968, Pope et al. 1984) and on managed forest lands in much of the U.S. (Lassiter 1985). Some landowners realize more profit from deer hunting leases than that generated from standard agricultural practices (Ramsey 1965, Pope et al. 1984, Payne et al. 1987). This recently discovered source of income has encouraged many landowners to implement management programs specifically for white-tailed deer.

QUALITY MANAGEMENT

A new approach to deer management is becoming established in the southeast (Wegner 1990:280-293, Schwalbach 1990, Hamilton et al. 1991, Marchinton et al. 1992, Miller and Marchinton 1995), northeast (Regan et al. 1995), and midwest (Kubisiak 1995, Ozoga et al. 1995). This innovative management concept, commonly referred to as "Quality Management," addresses problems of young age structures among males, unnatural and highly skewed adult sex ratios in favor of females, and overpopulation. Hamilton (1989:1) defined quality deer management as the use of restraint in harvesting males, along with an adequate antlerless harvest. He suggests that quality deer management involves the production of quality deer (i.e., males, females, and fawns), quality habitat, quality hunting, and quality hunters. A quality buck, defined by Kroll (1991:10), is a buck "that best realizes the potential of his age class, lives in a quality habitat, and is harvested through a quality hunting experience."

Largely because of early work by Brothers and Ray (1975), sport hunters are taking initiative to implement quality management techniques, especially in the Southeast

(Wegner 1990, Hamilton et al. 1995*a*). By 1990 in South Carolina alone, over 500 hunting clubs, controlling almost 500,000 ha, were participating in quality deer management (Schwalbach 1990).

Quality management emphasizes: (1) limiting harvest of young males (<3.5 years old) to balance age structure in the male segment of the population; (2) balancing adult sex ratios by shifting harvest away from immature males toward the productive, female segment of the population; and (3) maintaining the overall population at a level where individuals will be in excellent physical condition and highly productive. Because immature males are lightly harvested, more males are allowed to reach physical maturity, thereby increasing the number of quality males available for harvest.

TROPHY MANAGEMENT

A second, non-traditional approach to deer management also is gaining popularity, especially in Texas (Wooters 1997:11, 209), where an estimated 1,000,000 ha were under this management program by 1983 (Weishuhn 1983). Trophy management often has been confused with quality management (Van Brackle and McDonald 1995), especially prior to establishment of the Quality Deer Management Association. Trophy management often has been termed quality management (e.g., Brothers and Ray 1975, Weishuhn 1983) to avoid public dissatisfaction with the word "trophy" (A. Brothers, Zachary Ranches, personal communication).

These 2 management concepts share several approaches, but have different goals (Morris 1992:467, Van Brackle and McDonald 1995, Wooters 1997:7). Trophy management, like quality management, addresses problems of young age structures among males, skewed adult sex ratios, and overpopulation (McCullough 1979:239, Weishuhn 1983, Morris 1992, Wootters 1997:7). The primary difference between the 2 concepts is the age at which males are harvested (Morris 1992:467). Under quality management guidelines, males usually are not harvested until ≥3.5 years old (Hamilton et al. 1995*a*, Kroll and Jacobson 1995). Trophy management places emphasis on harvest of mature males (Morris 1992:13) ≥5.5 years old (Weishuhn 1983, Wooters 1997:13).

These 2 concepts are increasing in popularity for several reasons. Deer populations with young male age structures, skewed adult sex ratios, and high densities can have serious impacts. These populations negatively impact: (1) planted vegetation (Matschke et al. 1984*a*, Smith and Coggin 1984, Wywialowski 1996); (2) natural vegetation (Warren 1991, Prior 1994); (3) migratory birds (McShea and Rappole 1997) and (4) number of deer-vehicle collisions (Matschke et al. 1984*b*, Warren 1991, Conover et al. 1995). Also, populations with these characteristics may lead to increased disease outbreaks (Aquirre et al. 1995, Davidson and Doster 1997), dysfunctional social and biological systems (Guynn et al. 1988, Marchinton et al. 1988, Miller et al. 1995, Rutberg 1997), and genetic problems (Kroll 1991).

In deer populations with highly skewed adult sex ratios, 1.5-year-old males constitute the majority of male harvests. Annually in many southeastern (Whittington 1984), northeastern (Barber 1984, Mattfeld 1984, Shrauder 1984), and midwestern (Gladfelter 1984, Torgerson and Porath 1984) states, >70% of the male segment of the harvest is of males ≤1.5 years old. Many sportsmen may never have the opportunity to see a mature male because physical maturity is not reached until ≥5.5 years of age (Brothers and Ray 1975:83, Weishuhn 1983, Kroll 1991:213).

PROBLEM STATEMENT

Several factors are thought to hinder the implementation of quality and trophy management programs. First, minimum land size necessary to implement either of these programs is unknown. This is the most common question asked by landowners and hunters considering quality management (Hamilton et al. 1995*a*) and has been poorly addressed. Minimum land area sizes that have been suggested for quality management range from 32 ha (Kroll 1998) to >400 ha (Morris 1992:468). It is thought that for trophy management to be successful even more land area is required (Morris 1992:467).

Second, landowners and hunting club members are concerned with whether the older-aged males produced by quality and trophy management will remain on their land. The majority of land areas under private ownership in the southeast are relatively small and not enclosed by deer-proof fencing. If males move over large areas, neighboring hunters may harvest "their" quality or trophy deer. Little research has been conducted to determine if males increase their movements and home range areas as they mature. Some researchers have suggested that the most dominant mature males have the greatest movement patterns and largest home range areas (Brown 1971, 1974; Brown and Hirth 1979).

Third, older-aged males may be more difficult to harvest effectively. Statements of increased difficulty in harvesting older-aged males are prevalent in the popular (Morris 1992, Wooters 1997) and scientific (Hamilton et al. 1995*b*) literature. It is generally thought that older-aged males change their behavior as they mature (Morris 1992:473, Wooters 1997:50), although very little is known about the activity and behavior patterns of these older males. This information is important for successful implementation of quality and trophy deer management.

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CHAPTER 2

LITERATURE REVIEW

A significant amount of research has been conducted on the behavioral ecology of white-tailed deer. However, much of this research has focused on females. Few studies have investigated the behaviors of males, especially mature males. Researchers have found difficulty in capturing sufficient numbers of mature males for study because they are rare in most areas. Early studies were limited to direct observation (Michael 1966) and therefore biased because deer could not be observed at night, when hidden from view, or were sensitive to the presence of observers (Hansen et al. 1992). Early telemetry studies were limited because of short radio life (Jeter and Marchinton 1964, Brown 1971, Inglis et al. 1979). Recent research has been conducted with improved telemetry equipment (Hosey and Causey 1979, Pollock 1989, Beier and McCullough 1990, Whittaker 1990). However, sample sizes of mature males in these studies were small.

PHYSICAL CHARACTERISTICS

Physical characteristics of middle-aged and mature males are not well known because males $\geq$3.5 years old are rare in most free-ranging populations. Low numbers of older-aged males have led to difficulties in obtaining adequate sample sizes, although knowledge of these physical characteristics is important for developing predictive equations to provide simple, reliable estimates of body mass (Talbot and McCulloch 1965, Rideout and Worthen 1975). Predictive equations are useful in estimating body mass when handling time of live deer needs to be minimized (Weckerly et al. 1987). The only predictive equations developed for body mass in Texas white-tailed deer were obtained from a sample of females in the Edwards Plateau region (Osborn et al. 1995), thus no equations are available for white-tailed deer in southern Texas, or for males in Texas.

Previous researchers have examined relationships between body mass and chest girth for bison (*Bison bison*; Kelsall et al. 1978), Rocky Mountain elk (*Cervus elaphus nelsoni*; Millspaugh and Brundige 1996), mountain goat (*Oreamnos americanus*; Rideout and Worthen 1975), barren-ground caribou (*Rangifer tarandus groenlandicus*; McEwan and Wood 1966), black bear (*Ursus americanus*; Payne 1976), grizzly bear (*U. arctos*; Nagy et al. 1984), exotic deer (Osborn et al. 1995), and several east African ungulates (Talbot and McCulloch 1965) and domestic livestock (McCulloch and Talbot 1965). Regression equations relating body mass to chest girth have been developed for white-tailed deer in Virginia (Smart et al. 1973), Illinois (Roseberry and Klimstra 1970), South Carolina (Urbston et al. 1976), and Tennessee (Weckerly et al. 1987).

VISUAL CHARACTERISTICS

Limited research has been conducted to evaluate methods for visually estimating age of live deer in the field, although this information is becoming more important as deer hunters make the transition from hunter/consumer to hunter/manager (Kroll 1996) and as the popularity of quality and trophy management programs increase. For these programs to be efficient, middle-aged and mature males must be distinguished from young males in the field prior to harvest. Additional aging criteria would be useful for more accurately classifying deer sighted during helicopter and spotlight surveys because age composition data are important to management (Brothers and Ray 1975; Gilbert 1978; McCullough 1982*a*, 1993, 1994).

DeYoung et al. (1989) successfully classified 329 of 369 (89%) previously marked and aged male white-tailed deer sighted during 28 helicopter flights into 2 age groups ($\leq$3.5 or $\geq$4.5 years old) based on antler size and body musculature. They considered antler spread well beyond the tips of the ears, “heavy” appearance of antlers, or long tines as indicative of an older male. Older males also were denoted by “thick” necks and front shoulders, and a “blocky” appearance. Kroll and Jacobson (1995) outlined methods for visually separating males into 4 age classes (0.5, 1.5, 2.5, and $\geq$3.5 years) and Jacobson (1995) reported age relationships with antler size for penned white-tailed deer. Several additional characteristics have been described as useful in estimating deer age in the popular literature (Brothers and Ray 1975:70-71, Morris 1992:55-57, Kroll 1996, Wootters 1997:216).

In other cervid species antler weight was linearly related to estimated age in Colorado mule deer (*Odocoileus hemionus*; Anderson and Medin 1969). Antler weight, main beam length, and basal circumference were linearly related to age in New Mexico elk (*Cervus elaphus*; Wolfe 1982).

ACTIVITY MONITORING ACCURACY

Visual techniques have been used to quantify ungulate activity (Michael 1966, Brown 1971, Hirth 1973), but they are less effective during nocturnal periods and in areas of limited visibility. Observational data collected during spotlight counts allows nocturnal monitoring (Montgomery 1963, Braden 1978), but are biased because deer are not equally observable (McCullough 1982*b*). Track counts (Ockenfels and Bissonette 1982) have also been used. More recently, motion detection by automated cameras (Carthew and Slater 1991, Guynn et al. 1993) and radio transmitters allowed “hands off” monitoring and reduced human effects on ungulate behavior.

Signal-strength variation was the first method used to detect radio-transmittered animal movement (Cochran and Lord 1963, Marshall 1965), but signal strength is potentially affected by other factors. Activity has also been measured by distance traveled between sequential radio-locations (Marchinton 1964, 1968; Sparrowe and Springer 1970), but these measures provide no indication of activity other than estimated movement.

Transmitters equipped with reset (Garshelis et al. 1982) and tip-switch motion sensors allow researchers to discriminate activity based on signal amplitude (Georgii 1981, Georgii and Schroder 1983). Tip-switch transmitters combined with strip charts allow graphic print-outs of the pulse pattern (Beier and McCullough 1990). Variable-pulse collars that sampled instantaneous collar movement also have been used (Relyea et al. 1994). However, no method has yet allowed researchers to discriminate bedded, standing, grooming, feeding, walking, and running activities with high accuracy (>90%).

Sampling intervals of various lengths (0.5-10 minutes) have been used during previous studies (Kufeld et al. 1988, Skinner 1994). Beier and McCullough (1988) used a 5.25-min sampling interval to allow discrimination between bedded and standing deer. However, they recommended selecting the shortest sampling interval that would still allow for accurate separation of bedded and standing activities. Relyea et al. (1994) used a 1-min sampling interval because an average of 2.0 and 2.5 activities occurred during 3- and 5-min sampling intervals, respectively.

ACTIVITY

White-tailed deer are thought to be primarily crepuscular over most of their range (Michael 1970, Pledger 1975, Kammermeyer and Marchinton 1977, Beier and McCullough 1990). Lows in activity have been reported most often during early morning (0100-0500; Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981), midmorning (1000-1200; Pledger 1975, Skinner 1994), and late evening (2100-2400; Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981) hours.

Early studies reported that deer were most active during diurnal periods (Guyse 1978, Kammermeyer and Machinton 1977, Hosey 1980, Holzenbein and Schwede 1989). In areas where human disturbance was minimal, red deer (*Cervus elaphus*) and roe deer

(*Capreolus capreolus*) were equally likely to be active during any time of the day (Putnam 1988:58). However, more recent studies have reported either nocturnal peaks in activity (Kroll and Koerth 1996, Alexy et al. 2001), or the absence of any diel activity rhythm (Skinner 1994). Other studies have reported distinct crepuscular patterns during some seasons and a lack of any pattern (Hood 1971, Demarais et al. 1989), or a shift to a single peak (Beier and McCullough 1990) during other seasons. Minor activity peaks have been reported at midday and midnight (Michael 1970, Hood 1971).

Activity rates have also varied by region. In southern Texas, the monthly peak in activity occurred during January, while the low occurred during September (Michael 1970). In southern Michigan, greatest activity occurred during May and October, with lowest activity during January-February (Beier and McCullough 1990). Seasonal activity rates have also varied by region. Most studies on northern deer reported lowest seasonal activity during winter and highest during fall (Behrend 1966, Carbaugh et al. 1975, Beier and McCullough 1990).

Fall and winter activity rates have been further divided into different periods of the breeding season. Two studies reported that activity peaked during rut (Pledger 1975, Ivey and Causey 1981), while other studies have reported prerut (Holzenbein and Schwede 1989) and postrut (Hosey and Causey 1979, Hosey 1980, Skinner 1994) peaks.

Differences in activity rates have been reported among individual deer (Hosey 1980) and sexes (Beier and McCullough 1990), while another study found that activity rates were positively correlated to age (Pledger 1975). However, other studies have reported no age- or sex-related differences (Fritzen et al. 1995). One study reported that large-antlered males were more active than small-antlered males (Beier and McCullough 1990), while another study reported that differences in activity rates were due to changes in population density and were unrelated to changes in forage quantity or quality (Fritzen et al. 1995).

The percent of time deer were involved in individual activities has not been reported in most telemetric studies due to an inability to discriminate among activities. However in 1 observational study, Cohen et al. (1989) reported deer spent the majority of daylight hours grazing (73.2% of observations). Remaining activities included walking, standing, browsing, bedding, and running, which involved 16.6, 8.0, 1.3, 0.5, and 0.4% of observations, respectively.

In a New York study, the amount of time involved in each of 5 activities and corresponding heart rates were determined for 6 penned white-tailed deer (Moen 1978). Deer were classified as bedded, standing, walking, foraging, or running. Average annual heart rate (by min) and percentage of time involved in these activities were 72 and 60%, 86 and 10%, 102 and 7%, 90 and 23%, and 155 and 1%, respectively. Percent of time bedded peaked during July, while metabolism was estimated to be lowest in late January and highest in mid-August. Activity budgets of mature red deer stags changed dramatically through the breeding season. Proportion of time spent grazing decreasing from 44% during summer to less than 5% during rut, while time spent moving and standing inactive increased from 3 and 4 to 15 and 33%, respectively (Clutton-Brock et al. 1982:121-122). These researchers also reported that percent of time spent grazing, bedded, standing, moving, and running varied greatly among young (2-5 years old) stags (35.5, 44.2, 9.5, 6.8, and 0%, respectively) and mature ($\geq$6 years old) stags (4.0, <37.8, 33.1, 15.5, and 9.8%, respectively).

BEHAVIOR

Past studies of white-tailed deer behavior have examined (1) social behavior and organization (Thomas et al. 1965, Moore and Marchinton 1974, Hirth 1973, Marchinton and Atkeson 1985, Ozoga 1994, Miller et al. 1995); (2) reproductive behavior (Teer et al. 1965, Brown and Hirth 1979, Sawyer et al. 1982, Miller et al. 1987, Johansen et al. 1988, Sawyer et al. 1989); and (3) communication (Richardson 1981, Atkeson 1982, Atkeson et al. 1988, Miller and Marchinton 1994). Little research has focused on behavior during the breeding season. Male white-tailed deer establish a social hierarchy prior to the breeding season through a series of ritualized dominance displays and threats (Thomas et al. 1965, Brown 1971, Walther 1984). Sparring does not involve prior dominance displays or threats and lacks aggression (Goss 1983), but may be the principal method of establishing dominance rank among males (Brown and Hirth 1979). Small-antlered males ($\leq$8 antler points) spar more frequently than large-antlered males and most sparring occurs between males with similar-sized antlers (Michael 1966, Hirth 1973). Sparring begins in September and peaks in October, prior to rut (Brown 1971).

Aggressive fights differ from sparring and occur less frequently. Only 2-10% of confrontations between males were classified as aggressive fights (Michael 1966, Brown 1971, Hirth 1973). Aggressive fights typically follow a series of dominance displays and threats. In Grant's gazelle (*Gazella granti*), 78% of threats that were reciprocated resulted in fights (Walther 1984). Aggressive fights often result from a breakdown in the function of the hierarchal system due to a lack of recognition between males (Brown 1971). Most males have previously sparred with each other and established dominance allowing avoidance of aggressive fights. However, during rut males were more likely to enter new areas in search of females, increasing the likelihood of contact between unfamiliar males (Brown 1971). Most aggressive fights occur between larger-antlered males (Michael 1966, Brown 1971, Hirth 1973) and last $\leq$30 seconds (Marchinton and Miller 1994*b*).

Simulation of sparring or fighting is a common hunting technique used to attract males. The number and age of males that respond may provide wildlife managers with an indicator of physiological events related to the breeding season.

RESEARCH OBJECTIVES

The objectives of this investigation were to test for age-specific differences among activity and behavior patterns of males with different physical characteristics; and, if differences did occur among age classes, to determine how changes occurred in individual males as they matured. Radio-transmittered males were separated into 4 age classes: young (1.5-2.5 years old), middle-aged (3.5-4.5 years old), mature (5.5-6.5 years old), and old (7.5+ years old).

The objectives were evaluated by testing the following *a priori* hypotheses:

1. Ho: Seasonal and yearly activity rates are equivalent for individual males and age classes.
   Ha1: Males of all ages exhibit primarily crepuscular daily activity cycles
   Ha2: Seasonal activity levels are highest during rut and spring and lowest during summer and postrut for all age classes.
   Ha3: Mature males are more active than young, middle-aged, or old males during rut, with activity level increasing as individual males matured.
2. Ho: Behavior patterns remain equivalent during different periods of the breeding season and for different-aged males with respect to response to antler rattling.
   Ha1: Mature males exhibit the least response to antler rattling.
   Ha2: Different-aged males respond differently to antler rattling during different periods of the breeding season.

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CHAPTER 3

MASS ESTIMATION OF WHITE-TAILED DEER IN SOUTHERN TEXAS[1]

[1]Hellickson, M. W., K. V. Miller, C. A. DeYoung, R. L. Marchinton, S. W. Stedman, and R. E. Hall. To be submitted to the Proceedings of the Southeastern Association of Fish and Wildlife Agencies.

Abstract: Predictive equations based on various body measurements have provided managers with practical and reliable estimates of mass, but have not been reported for white-tailed deer (Odocoileus virginianus) in the Western Rio Grande Plains region of Texas, nor for male white-tailed deer in Texas. To address this need, we assessed relationships among live and dressed mass, chest girth, shoulder height, front hoof length and width, and gross Boone and Crockett Club (BCC) score. Regression analyses indicated live mass of mature (≥5.5 years old) males can be predicted based on dressed mass (R^2 = 0.883). Live mass for fawn and yearling females can be predicted with models based on dressed mass (R^2 = 0.962), front hoof length (R^2 = 0.898), shoulder height (R^2 = 0.822) and chest girth (R^2 = 0.772); while dressed mass (R^2 = 0.818) provided the best prediction of live mass for adult (≥2.5 years old) females. However, alternative variables other than dressed mass are needed for live-captured deer that are released. Multiple regression indicated that the best 2-variable models not including dressed mass were chest girth and shoulder height (R^2 = 0.575) for mature males and chest girth and hoof width (R^2 = 0.777) for females. Managers can use these sex- and age-class-specific equations to estimate the live mass of harvested or live-captured white-tailed deer in the Western Rio Grande Plains region of Texas.

INTRODUCTION

Knowledge of weights of wild animals is important to research and management (Talbot and McCulloch 1965). Previous research has determined that live mass is a useful predictor of fecundity in barren-ground caribou (Rangifer tarandus groenlandicus; Cameron and Ver Hoef 1994) and juvenile survival in bighorn sheep (Ovis canadensis; Festa-Bianchet et al. 1997).

Predictive equations based on chest girth or partial body mass have been used to provide simple, reliable estimates of live mass in several species of large mammals

(Talbot and McCulloch 1965, Rideout and Worthen 1975). The low cost and convenience of mass equations makes them practical for use when live mass is difficult to obtain in the field (Smart et al. 1973, Millspaugh and Brundige 1996), when budget constraints preclude the use of costly weighing equipment (Urbston et al. 1976), and when it is necessary to release live-captured deer as quickly as possible (Weckerly et al. 1987).

Previous studies have examined relationships between live mass and chest girth for bison (Bison bison; Kelsall et al. 1978), Rocky Mountain elk (Cervus elaphus canadensis; Millspaugh and Brundige 1996), mountain goat (Oreamnos americanus; Rideout and Worthen 1975), barren-ground caribou (McEwan and Wood 1966), black bear (Ursus americanus; Payne 1976), grizzly bear (U. arctos; Nagy et al. 1984), exotic deer in Texas (Osborn et al. 1995), several east African ungulates (Talbot and McCulloch 1965), and domestic livestock (McCulloch and Talbot 1965). All of these studies concluded that chest girth was sufficiently correlated to provide an accurate estimate of live mass.

Regression equations relating live mass to chest girth have been developed for white-tailed deer (Odocoileus virginianus) in Virginia (Smart et al. 1973), Illinois (Roseberry and Klimstra 1970), South Carolina (Urbston et al. 1976), and Tennessee (Weckerly et al. 1987). However, they have not been reported for deer in the Western Rio Grande Plains region of Texas. The only Texas study took place in the Edwards Plateau region and examined only females (Osborn et al. 1995).

Region-specific predictive equations for live mass of white-tailed deer are needed because variation in live mass has been found among areas as close as 250 km (Weckerly et al. 1987). These researchers concluded that use of regressions without regard to location and the conditions under which they were derived may not provide accurate results. Bandy et al. (1970) reported differences in growth rates within 4 races of black-tailed deer (Odocoileus hemionus columbianus) and McCulloch and Talbot (1965) reported that statistical relationships were only valid for mass estimations when applied to populations that did not differ significantly from the population in which the regressions were developed.

Mass estimation equations have not been reported for male white-tailed deer (O. v. texanus) in Texas, although this information would be valuable to landowners and managers who capture and transplant deer under the increasingly popular Texas Parks and Wildlife Department (TPWD) Trap, Transport, and Transplant permit program. Permit applications have increased during recent years and >100 permits were granted during 1996-97 (B. J. Richards, TPWD, pers. commun.). Mass estimation equations would also be valuable to researchers who capture and release white-tailed deer for research purposes. In addition, little research has been conducted to determine if variables other than dressed mass and chest girth provide adequate predictive equations for live mass.

Our objectives were to test a variety of body and antler measures for estimating live mass of white-tailed deer in the Western Rio Grande Plains region of Texas, and to develop predictive equations of live mass for each sex and age class. We thank the numerous individuals who assisted with data collections. Research was supported by the Rob and Bessie Welder Wildlife Foundation, Neva and Wesley West Foundation, Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, and the D. B. Warnell School of Forest Resources of The University of Georgia..

METHODS

The study was conducted on the 18,020-ha Faith Ranch in Dimmit and Webb counties of Texas. The ranch is located in the Western Rio Grande Plains region. Annual mean minimum and maximum temperatures were 15° and 29° C, respectively and annual mean precipitation was 54.6 cm. The gently rolling terrain was dominated by guajillo (Acacia berlandieri), blackbrush (A. rigidula), guayacan (Porlieria angustifolia), and honey mesquite (Prosopis glandulosa).

Sixty-five males ≥4.5 years old, 2 female fawns, 11 yearling females, and 74 females ≥2.5 years old were harvested during gun hunting seasons from 15 November-4 February 1993-97. All deer were aged using the tooth replacement and wear technique (Severinghaus 1949). Main beam length, antler circumferences, and tine lengths were measured on both antlers and combined with inside antler spread to obtain gross BCC scores according to guidelines provided by Nesbitt and Wright (1997). Chest girth was measured immediately behind the front shoulder. The tape was snugged to a moderate and uniform tightness for all circumference measurements. Shoulder height was measured from the apex of the shoulder to the tip of the front hoof. Live mass included body mass minus blood loss. Dressed mass included body mass after body cavity contents were removed. All mass measurements were to the nearest pound (0.45 kg) using a spring scale. A steel tape was used and all measurements were along body curves and to the nearest 0.32 cm (0.125 in).

Fifty of the females were harvested during 16 March-18 April 1994 under scientific permit (no. SPR-1090-310) from the TPWD. Measurements taken included live and dressed mass, chest girth, shoulder height, and front leg hoof length and width. Hoof lengths and widths were measured to the nearest 0.32 cm using a steel tape and all other measurements followed techniques previously described for males.

Statistical analyses were performed using a SAS statistical software package (SAS Inst., Inc. 1996). One and 2-way analysis of variance (ANOVA) using PROC GLM and Tukey's studentized range test (HSD) were used to test for significant differences among years, periods of the breeding season, and age for each sex. Breeding seasons based on reproductive data collected from 50 females during March-April 1994

(Ruthven et al. 1995) were prerut (15 Nov-7 Dec), when 6% of harvested females were successfully impregnated; rut (8 Dec-4 Jan), when 86% were impregnated; postrut (5 Jan-25 Jan), when 8% were impregnated; and non-rut (26 Jan-20 Apr), when no females were impregnated. Additional statistical analyses included least squares regression to develop equations describing the above relationships. Multiple regression analyses were used to develop predictive models for estimating mass using the above measures.

RESULTS

Males

Mass estimation analyses were limited to mature ($\geq$5.5 years old) males because only 4 males <5.5 years old were harvested and weighed. Live mass for mature males did not vary by breeding season (F = 1.40; 3, 39 df; P = 0.258), year (F = 0.47; 3, 39 df; P = 0.631), or age (F = 1.26; 7, 35 df; P = 0.303) and were combined in analyses. Least squares regression indicated the best variable for providing an estimate of live mass for mature males was dressed mass (R^2 = 0.883; P < 0.001; N = 42; Table 3.1). Chest girth (R^2 = 0.486, P < 0.001; N = 35), and shoulder height (R^2 = 0.397, P < 0.001; N = 35) provided moderate estimates, while gross BCC score and age provided poor estimates ($R^2 \leq$ 0.189; $P \geq$ 0.004; N = 42-44).

Multiple regression analyses indicated the best models for predicting live mass of mature males included dressed mass and shoulder height (R^2 = 0.897; $P \leq$ 0.291; N = 42) for a 2-variable predictive model and dressed mass, chest girth, and shoulder height (R^2 = 0.898; $P \leq$ 0.568; N = 42) for a 3-variable model. The best models not including dressed mass, were chest girth and shoulder height (R^2 = 0.575; $P \leq$ 0.019; N = 34) for a 2-variable model; chest girth, shoulder height, and age (R^2 = 0.609; $P \leq$ 0.131; N = 34) for a 3-variable model; and chest girth, shoulder height, gross BCC

Table 3.1. Linear regression equations involving dressed mass (kg) and various physical measures (cm) developed to estimate live mass (kg) for white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1993-97.

				Live mass			
Sex	Age	Season	N	0	R^2	SE	Equation
Male	5.5+	Fall-Winter	42	79.2	0.883	1.1	Y = 16.29 + 0.98(DM)[a]
			35		0.486		Y = -14.51 + 0.97(CH)
			35		0.397		Y = -31.29 + 1.18(SH)
Female	1.5-8.5+	Fall-Spring	80	50.0	0.892	0.8	Y = 1.85 + 1.26(DM)
			50		0.657		Y = -46.46 + 1.21(CH)
			50		0.550		Y = -12.95 + 15.80(HW)
Female	0.5-1.5	Fall-Spring	10	38.4	0.962	1.7	Y = 1.61 + 1.22(DM)
			10		0.898		Y = -22.33 + 8.73(HL)
			10		0.822		Y = -34.94 + 0.92(SH)

Table 3.1. Continued.

				Live mass			
Sex	Age	Season	N	0	R^2	SE	Equation
Female	2.5+	Fall-Spring	70	51.6	0.818	0.6	Y = 6.11 + 1.16(DM)
			40		0.460		Y = -24.71 + 0.95(CH)

[a]DM = dressed mass, CH = chest girth, SH = shoulder height, HW = front hoof width, and HL = front hoof length.

score, and age ($\underline{R}^2$ = 0.609; $\underline{P} \leq 0.930$; $\underline{N}$ = 32) for a 4-variable model (Table 3.2). These additional models were considered for purposes of estimating live mass of captured deer that were released.

Females

Live mass for females did not vary by breeding season (F $\leq$ 1.18; 3, 77 df; P $\geq$ 0.325) or year ($\underline{F}$ = 3.48; 4, 76 df; $\underline{P}$ = 0.066) and the breeding season x year interaction was not significant ($\underline{F}$ = 0.71; 1, 5 df; $\underline{P}$ = 0.402), so data were combined in analyses. Live mass did vary by age ($\underline{F}$ = 8.15; 7, 73 df; $\underline{P}$ < 0.001) with live mass of fawn and yearling females different from females $\geq$2.5-years-old ($\underline{F}$ = 57.7; 1, 4 df; $\underline{P}$ < 0.001). Tukey's studentized range test revealed that live mass of fawns was different from all other ages except yearlings, which were different from females $\geq$3.5 years old. No differences were found for females $\geq$3.5 years old. Therefore, females were separated into 2 age classes ($\leq$1.5 and $\geq$2.5).

Least squares regression indicated best variables for providing an estimate of live mass for females were dressed mass ($\underline{R}^2$ = 0.892; $\underline{P}$ < 0.001; $\underline{N}$ = 80), chest girth ($\underline{R}^2$ = 0.657; $\underline{P}$ < 0.001; $\underline{N}$ = 50), and hoof width ($\underline{R}^2$ = 0.550; $\underline{P}$ < 0.001; $\underline{N}$ = 50; Table 3.1). Hoof length, age, and shoulder height provided poor estimates ($\underline{R}^2 \leq 0.264$; $\underline{P} \geq 0.001$; $\underline{N}$ = 50-80). Best variables for females $\leq$1.5 years old were dressed mass ($\underline{R}^2$ = 0.962; $\underline{P}$ < 0.001; $\underline{N}$ = 10), hoof length ($\underline{R}^2$ = 0.898, $\underline{P}$ < 0.001; $\underline{N}$ = 10), shoulder height ($\underline{R}^2$ = 0.822, $\underline{P}$ < 0.001; $\underline{N}$ = 10), and chest girth ($\underline{R}^2$ = 0.772, $\underline{P}$ < 0.001; $\underline{N}$ = 10: Table 3.1). Best variables for females $\geq$2.5 years old were dressed mass ($\underline{R}^2$ = 0.818, $\underline{P}$ < 0.001; $\underline{N}$ = 70), and chest girth ($\underline{R}^2$ = 0.460, $\underline{P}$ < 0.001; $\underline{N}$ = 40; Table 3.1). Shoulder height, hoof length, and age provided poor estimates ($\underline{R}^2 \leq 0.219$; $\underline{P} \geq 0.003$; $\underline{N}$ = 40-70).

Multiple regression analyses indicated the best models for predicting live mass of females included dressed mass and hoof width ($\underline{R}^2$ = 0.944; $\underline{P}$ < 0.001; $\underline{N}$ = 50) for a 2-variable model; dressed mass, hoof width, and age ($\underline{R}^2$ = 0.951; $\underline{P}$ < 0.001; $\underline{N}$ 50) for a

Table 3.2. The best (highest $\underline{R}^2$ value) 2, 3, and 4-variable multiple regression models ($Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$) without inclusion of dressed mass for predicting live mass of male white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1993-97.

Dependent variable (Y)	Independent variables (X_i)	Coefficients (B_i)	$\underline{R}^2$	Coefficient SE	Coefficient $\underline{P}$-value	$\underline{N}$
Mass	Intercept	-50.7	0.575	21.5	0.025	34
	Chest girth	0.67		0.22	0.005	
	Shoulder height	0.69		0.28	0.019	
Mass	Intercept	-29.3	0.609	25.1	0.252	34
	Age	-1.02		0.66	0.131	
	Shoulder height	0.48		0.30	0.127	
	Chest girth	0.73		0.22	0.002	
Mass	Intercept	-30.0	0.609	26.7	0.270	32
	Chest girth	0.72		0.24	0.006	
	Shoulder height	0.48		0.31	0.136	
	Gross BCC score	0.01		0.07	0.930	
	Age	-1.00		0.71	0.172	

3-variable model; and dressed mass, hoof length and width, and age ($R^2 = 0.953$; $P < 0.001$; $N = 50$) for a 4-variable model. Best models not including dressed mass, included the variables chest girth and hoof width ($R^2 = 0.777$; $P < 0.001$; $N = 50$) for a 2-variable model; chest girth, age, and hoof width ($R^2 = 0.801$; $P \leq 0.023$; $N = 50$) for a 3-variable model; and hoof width, shoulder height, chest girth, and age ($R^2 = 0.809$; $P \leq 0.170$; $N = 50$) for a 4-variable model (Table 3.3).

Harvested males that had been previously captured (12-15 months earlier) by helicopter-drive net or net gun ($N = 20$), allowed the ability to test accuracy of chest girth and shoulder height measurements. Chest girth and shoulder height measurements increased an average of 2.5 and 1.6 cm, respectively. However, chest girth decreased for 25% of the sample and shoulder height decreased for 55% of the sample, indicating repeatability of measuring these indices may be poor. An additional 9 males were harvested or recaptured 24-30 months later. Chest girth and shoulder height increased an average of 3.3 and 1.7 cm for these males, but decreased for 22% of the sample for each measure.

DISCUSSION

Suitability of linear models for predicting live mass from dressed mass and chest girth for white-tailed deer in the Western Rio Grande Plains region of Texas agree with results reported for deer in the southeastern U.S. (Smart et al. 1973, Urbston et al. 1976, Weckerly et al. 1987) and for female deer in central Texas (Osborn et al. 1995) with R^2 values and standard errors similar to those previously reported. Our results also agree with Osborn et al. (1995) who found higher R^2 values for dressed mass when compared to estimates derived from chest girth.

Separate mass estimation equations were needed among age classes of females, but not among years and periods of the breeding season, contrary to previous results (Weckerly et al. 1987, Osborn et al. 1995) that indicated separate predictive equations

Table 3.3. The best (highest $\underline{R}^2$ value) 2-, 3-, and 4-variable multiple regression models ($Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$) without inclusion of dressed mass for predicting mass of female white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1994-97.

Dependent variable (Y)	Independent variables (X_i)	Coefficients (B_i)	$\underline{R}^2$	Coefficient SE	Coefficient $\underline{P}$-value	$\underline{N}$
Mass	Intercept	-118.30	0.777	18.20	<0.001	50
	Hoof width	49.83		9.95	<0.001	
	Chest girth	4.80		0.70	<0.001	
Mass	Intercept	-43.60	0.801	8.98	<0.001	50
	Hoof width	8.68		1.70	<0.001	
	Age	0.61		0.26	<0.001	
	Chest girth	0.70		0.14	0.023	
Mass	Intercept	-48.80	0.809	9.64	<0.001	50
	Hoof width	8.90		1.69	<0.001	
	Shoulder height	0.16		0.11	0.170	
	Chest girth	0.60		0.15	<0.001	
	Age	0.63		0.26	0.019	

were needed for each season. However, the year effect was nearly significant ($\underline{P}$ = 0.066) suggesting that caution should be used when combining data across years. Larger within-year sample sizes may have resulted in a significant year effect. Not enough data were available to determine if age class differences occurred for males.

Variables other than dressed mass found suitable for providing estimates of live mass were front hoof length, shoulder height, and chest girth for fawn and yearling females. No individual variables other than dressed mass were suitable for estimating live mass of mature males and adult females. However, chest girth combined with shoulder height increased accuracy of live mass estimates for mature males. These 2 variables combined with age further increased accuracy, but the addition of a fourth variable did not. Chest girth combined with hoof width increased accuracy for adult females. The addition of age as a third variable further increased accuracy.

No previous studies have examined the usefulness of front hoof length and width for predicting live mass even though Haugen and Speake (1958) found that hoof length was important for determining fawn age. More recently, Sams et al. (1996) reported that hoof growth provided the most reliable and accurate aging model for white-tailed deer fawns. Hoof length was the best variable, other than dressed mass, for predicting live mass of fawn and yearling females. Hoof width, when combined with chest girth, also provided the best 2-variable estimate of live mass for adult females. These results, combined with the ease with which these measures can be obtained, suggest that hoof width and length should be examined in other regions for their suitability in predicting live mass.

Measures of dressed mass provided the best estimate of live mass for mature males, fawn and yearling females, and adult females indicating that this measure should be used when possible. However, alternative measures are needed when measuring dressed mass is not possible (e.g., when it is necessary to release live-captured deer).

Our results indicate that measures of chest girth combined with shoulder height could be used to estimate live mass for mature males that are live-captured and released. Measures of hoof length for fawn and yearling females, and chest girth and hoof width for adult females, provided reliable estimates of live mass for these 2 age classes of females. These measures likely yield estimates of live mass of sufficient accuracy for monitoring population condition trends for management purposes, but were insufficient for estimating individual deer weights for research purposes.

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CHAPTER 4

PHYSICAL CHARACTERISTICS FOR AGE ESTIMATION OF WHITE-TAILED DEER IN SOUTHERN TEXAS[1]

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Abstract: Criteria for estimating age of live white-tailed deer (Odocoileus virginianus) in the field are becoming more important as the popularity of non-traditional deer management programs increase. We assessed gross Boone and Crockett Club (BCC) score, number of antler points, inside antler spread, main beam length, antler basal circumference, chest girth, stomach girth, shoulder height, head length, and interorbital width as predictors of age for ≤766 live-captured males; live and dressed mass for ≤65 harvested males and ≤140 harvested females; and front hoof length and width for 50 harvested females. Most antler measures differed for age classes 1.5, 2.5, 3.5, 4.5, and ≥5.5, while most body measures for males differed only for age classes 1.5 and ≥2.5. Individually, gross BCC score, inside antler spread, and basal circumference had lowest AIC_c scores. Models incorporating gross BCC score and number of antler points, or gross BCC score, number of antler points, and stomach girth had highest R^2 values. A combination of characteristics that include gross BCC and inside spread, and stomach girth relative to chest girth are likely to be most useful for visually estimating age of live male white-tailed deer. Percentage of each male age class protected by various criteria are provided. Live mass and chest girth appeared to have the most value for classifying females into 0.5, 1.5, and ≥2.5-year-old age classes. Additional research is needed to test appropriateness, precision, and accuracy of these characteristics in the field.

INTRODUCTION

Quantitative criteria for visually estimating age of live white-tailed deer in the field are becoming more important as deer hunters make the transition from hunter/consumer to hunter/manager (Kroll 1996) and as the popularity of non-traditional deer management programs increase. Quality management promotes restraint in the harvest of young males (Miller and Marchinton 1995), while trophy management promotes restraint in the harvest of both young and middle-aged males (McCullough

1979, Weishuhn 1983). Both programs also promote an adequate (i.e., increased) harvest of adult females. Thus, reliable characteristics are needed to identify young and middle-aged males and fawn and yearling females in the field prior to harvest.

The ability to accurately classify live deer while conducting aerial and ground-based surveys is also important in some areas for prescribing and evaluating harvest strategies (Brothers and Ray 1975), assessing herd population demographics (McCullough 1994), and providing information on recruitment and mortality rates (Gilbert 1978). During aerial surveys, observers routinely classify males into young, middle-aged, and mature age classes, while antlerless deer are classified as fawns or adults (DeYoung 1998).

Antler measures are increasingly used by state agencies at the county or statewide level to establish minimum harvest criteria for the male segment of the herd. However, criteria based on only 1-2 antler measures can have negative consequences (DeYoung 1990, Strickland et al. 2001). For example, if criteria are set too low, many young males will be subject to harvest, failing to maximize quality or trophy production. If criteria are established based on larger antler sizes, then some older-aged males with relatively small antlers will be protected.

A simulation model indicated that selective-harvest criteria designed to protect 1.5-year-old males from harvest resulted in reduced antler size for that cohort in subsequent years when harvest rates of unprotected males (i.e., large-antlered 1.5-year-old males) were high (Strickland et al. 2001). Antler size of 2.5- and 3.5-year-old males declined in 1 region of Mississippi after a statewide 4-point minimum harvest criterion was implemented because of regional differences in antler size of 1.5-year-old males (Strickland et al. 2001). Thus, not only do criteria need to be region specific, but knowledge regarding the approximate percentage of each age class that will be protected (and unprotected) for each criteria are also important.

Considering the increasing popularity of non-traditional management programs and the widespread dependence on classification surveys by state agencies and private entities to monitor and manage deer populations, criteria used to distinguish age classes are surprisingly absent from the literature. Kroll and Jacobson (1995) and Kroll (1996) described characteristics for estimating ages of both sexes, but did not provide data on their reliability. DeYoung et al. (1989) successfully classified 329 of 369 (89%) male white-tailed deer sighted during 28 helicopter flights. Sighted males, which were previously marked and aged by tooth replacement and wear (TRW), were placed into 2 age groups (≤3.5 or ≥4.5 years old) based on antler size and body musculature. They considered antler spread well beyond the tips of the ears, heavy appearance of the antlers, long tines, thick necks and front shoulders, and a blocky appearance as indicative of older-aged males.

Other researchers have compared antler size trends, but most reported considerable overlap among age classes, especially for males ≥3.5 years old (Roseberry and Klimstra 1975, McCullough 1982; DeYoung 1989a, 1990; DeYoung and Lukefahr 1995). Anderson and Medin (1969) found that antler weight was linearly related to estimated age in Colorado mule deer (Odocoileus hemionus hemionus). In elk (Cervus elaphus canadensis), Wolfe (1982) showed a linear relationship for main beam length, basal circumference, and antler weight for ages 2.5-10.5 years. Smith and McDonald (2002) measured precision and accuracy of classifying antlerless elk into calf, yearling, and adult age classes using head morphology characteristics.

Our objectives were to: determine the relationships of a variety of antler and body measures to the estimated ages of live white-tailed deer in southern Texas; develop predictive equations of age for each sex; and determine the percentage of each age class protected for each criteria. We thank the numerous individuals who assisted with data collections, especially D. A. Draeger and W. Colson. We also thank E. L. Marchinton and R. L. Bingham for reviewing the manuscript. Research was supported by the Rob and Bessie Welder Wildlife Foundation, Neva and Wesley West Foundation, Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, and the D. B. Warnell School of Forest Resources of The University of Georgia.

METHODS

The study was conducted on the 18,020-ha Faith Ranch in Dimmit and Webb counties, part of the Western Rio Grande Plains region of Texas. Annual mean minimum and maximum temperatures were 15° and 29° C, respectively and annual mean precipitation was 54.6 cm. The gently rolling terrain was dominated by guajillo (Acacia berlandieri), blackbrush (A. rigidula), guayacan (Porlieria angustifolia), and honey mesquite (Prosopis glandulosa).

We randomly captured (Leon et al. 1987) 766 free-ranging male deer during September-November 1985-97 using the helicopter drive-net (Beasom et al. 1980) or net gun (DeYoung 1988) techniques. Each male was placed into 1 of 8 age categories using tooth replacement and wear (TRW; Severinghaus 1949). We chose TRW, over the cementum annuli technique (Low and Cowan 1963), because TRW is less intrusive, less time consuming (DeYoung 1989b), and is the primary method used by managers and hunters (Brothers and Ray 1975, DeYoung 1998).

Each male was ear tagged and tattooed for identification. Main beam length, antler basal circumference, and tine lengths were measured on both antlers and combined with inside antler spread. Remaining antler circumferences were estimated to obtain gross BCC scores according to guidelines provided by Nesbitt and Wright (1997). Number of antler points ($\geq$2.54 cm) also was recorded.

During 1992-97 captures, chest girth and shoulder height were measured on 410 males. Fifty-two harvested males, including 8 not previously captured, were also measured. Chest girth was measured immediately behind the front shoulder. Shoulder height was measured from the apex of the shoulder to the tip of the front hoof. During 1995-97 captures, stomach girth ($\underline{N}$ = 196), head length ($\underline{N}$ = 246), and interorbital width ($\underline{N}$ = 245) were measured. Stomach girth was measured at the point half the distance between the distal portion of the front shoulder and the front of the thigh. Head length was measured from the highest point of the sagittal crest to the proximate point of the nose pad. Interorbital width was measured as the furthest point between the ridges above the eye orbits. A retractable steel tape was used and all measurements were along body curves and to the nearest 0.32 cm (0.125 in).

Live and/or dressed mass were measured on 65 males $\geq$4.5 years old, 3 fawn and 11 yearling females, and 75 females $\geq$2.5 years old harvested during hunting seasons from 15 November-4 February 1993-97. Live mass included body mass minus blood loss from the gunshot wound. Dressed mass was determined after body cavity contents were removed. All mass measurements were to the nearest pound (0.45 kg) using a spring scale. Measurements of an additional 50 females collected from 16 March-18 April 1994 under scientific permit (No. SPR-1090-310) from the Texas Parks and Wildlife Department included live mass, dressed mass, chest girth, shoulder height, and front hoof length and width.

Statistical analyses were performed using a SAS statistical software package (SAS Inst., Inc. 1996). One-way analysis of variance (ANOVA) using PROC GLM and Tukey's studentized range test (HSD) were used to test for significant differences among year, month of harvest, and age effects for each sex. Coefficients of variation were used to determine amount of variability within each measure. Spearman's correlation coefficients were determined between age and each of the 14 measures because assigned ages were ordinal. Akaike information criterion coefficients (AIC_c) were used to determine the best (lowest score) individual variables to use in regression models predicting age. Stepwise multiple regression was used to determine best (highest $\underline{R}^2$ value) 2-, 3-, and 4-variable combinations to use in additional models predicting age. Type III sum of squares were used in ANOVAs. Age was the dependent variable in all analyses (Dapson 1980) and statistical tests were considered significant at $\underline{P} < 0.05$.

RESULTS

Males

Mean age for the 766 captured males (range = 1.5-8.5 years) was 4.6 years (SE = 0.07). No yearly ($\underline{N}$ = 13) differences for captured males were found for mean age ($\underline{F}$ = 0.07; 12, 88 df; $\underline{P}$ = 1.000), any antler measure ($\underline{F} \leq 0.34$; 12, 88 df; $\underline{P} \geq 0.976$), or any body measure ($\underline{F} \leq 1.59$; 2, 14 and 5, 41 df; $\underline{P} \geq 0.228$). All antler measures except inside spread peaked at age 6.5 years, but did not differ after age 5.5 years (Figures 4.1-4.5). We therefore combined age classes 5.5, 6.5, 7.5, and 8.5 into 1 age class ($\geq$5.5) for further analyses due to non-linearity (Dapson 1980).

Most body measures peaked at age 7.5 years, but did not differ after age 1.5 years for stomach girth and interorbital width and after age 2.5 for remaining body measures (Figures 4.6-4.10). Body measures were therefore excluded for non-linearity reasons (Dapson 1980) from regression analyses that were used in combination with the Akaike information criterion.

Results of ANOVAs and Tukey's studentized range post hoc test indicated that age classes 1.5, 2.5, 3.5, 4.5, $\geq$5.5 differed for inside antler spread ($\underline{F}$ = 297.3; 4, 59 df; $\underline{P} < 0.001$), main beam length ($\underline{F}$ = 278.7; 4, 59 df; $\underline{P} < 0.001$), gross BCC score ($\underline{F}$ = 260.2; 4, 59 df; $\underline{P} < 0.001$) and basal circumference ($\underline{F}$ = 133.8; 4, 59 df; $\underline{P} < 0.001$). Age classes 1.5, 2.5, 3.5-4.5, and $\geq$5.5 differed for number of antler points ($\underline{F}$ = 169.3; 4, 59 df; $\underline{P} < 0.001$). Number of antler points for age classes 3.5 and 4.5 were not different from each other, but each differed from 1.5, 2.5, and $\geq$5.5 age classes. Age

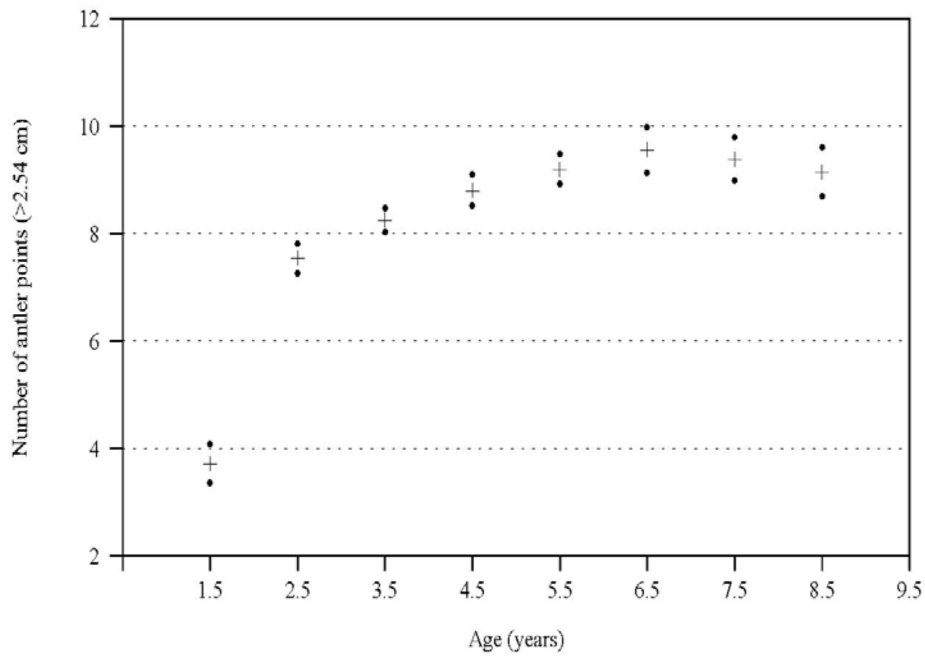

Figure 4.1. Relative means and ±95% confidence intervals for number of antler points (≥2.54 cm, N = 758) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97 (ages graphed as the independent variable for illustration purposes only).

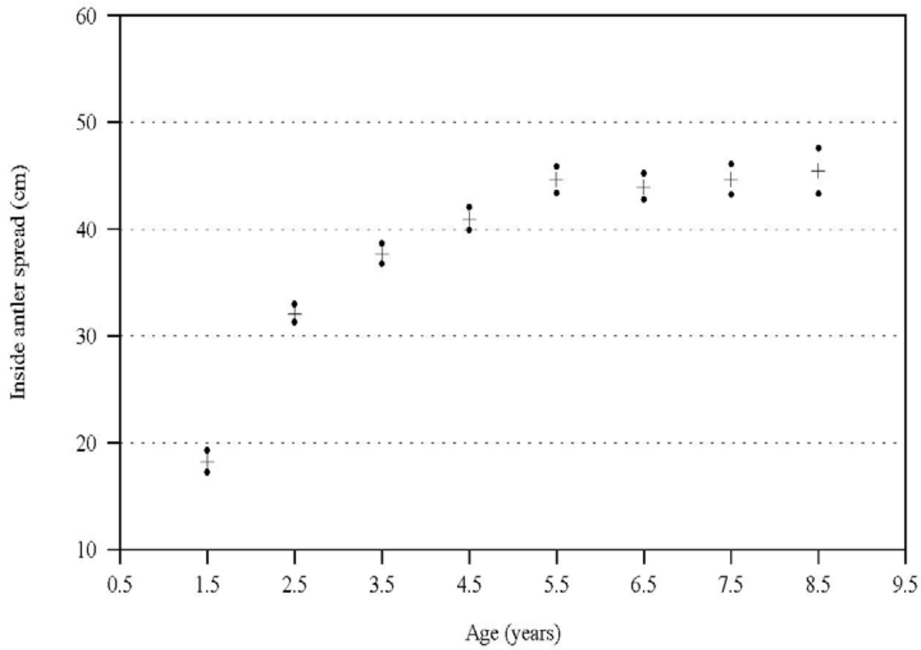

Figure 4.2. Relative means and ±95% confidence intervals for inside antler spread (N = 753) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97 (ages graphed as the independent variable for illustration purposes only).

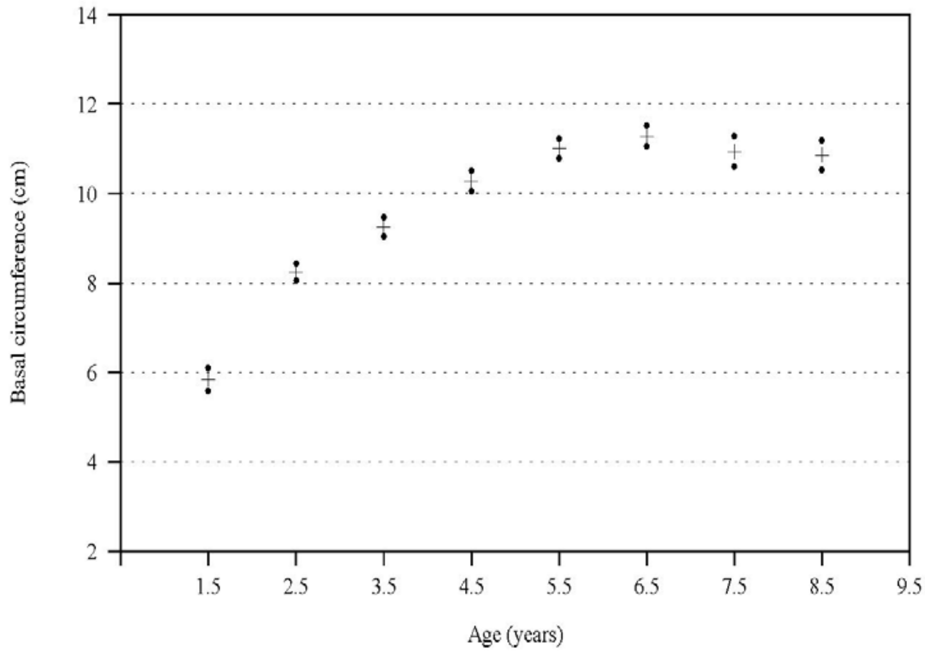

Figure 4.3. Relative means and ±95% confidence intervals for basal circumference (N = 759) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97 (ages graphed as the independent variable for illustration purposes only).

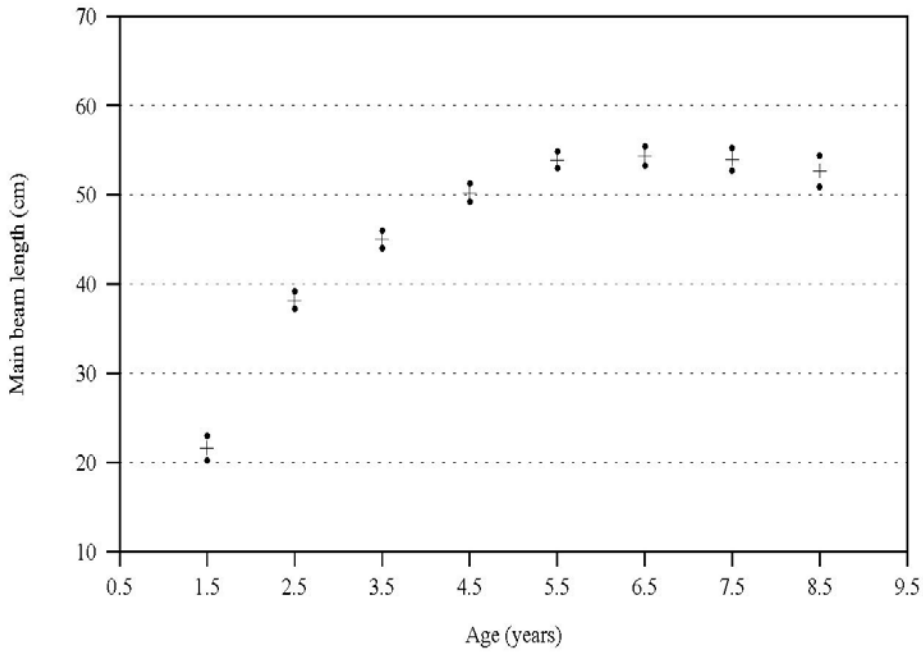

Figure 4.4. Relative means and ±95% confidence intervals for main beam length (N = 760) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97 (ages graphed as the independent variable for illustration purposes only).

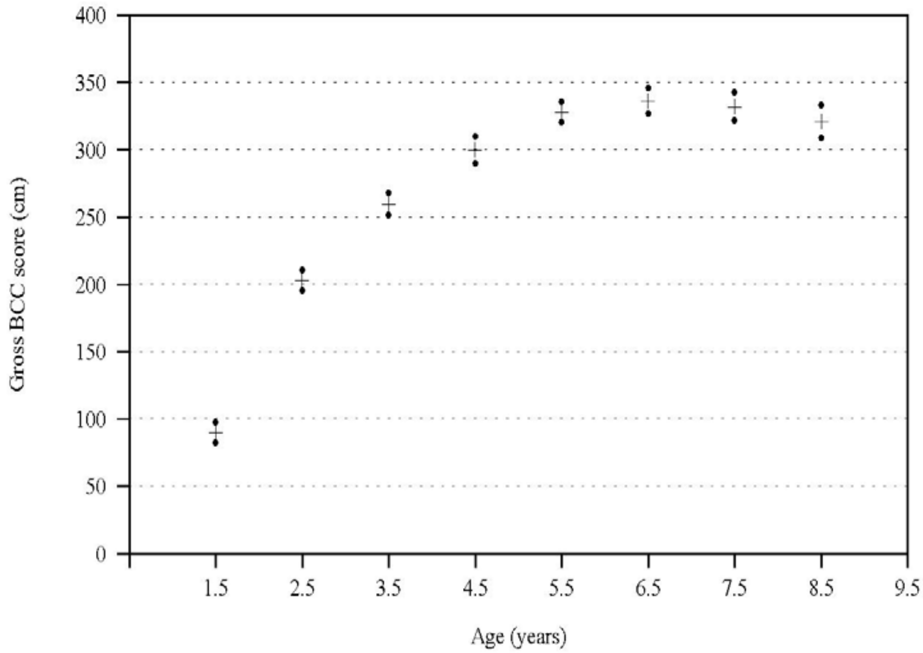

Figure 4.5. Relative means and ±95% confidence intervals for gross Boone and Crockett Club (BCC) score (N = 756) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97 (ages graphed as the independent variable for illustration purposes only).

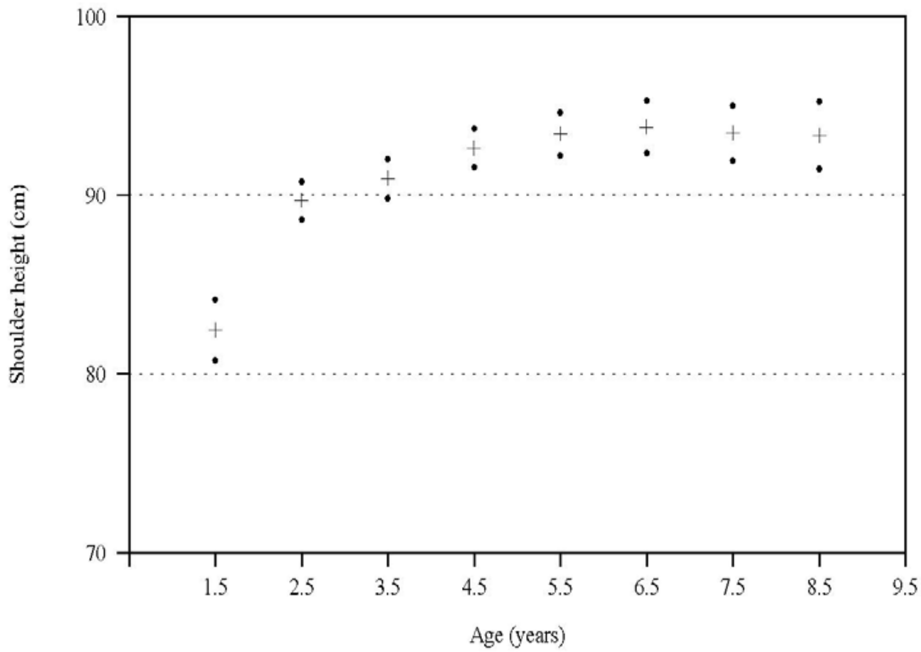

Figure 4.6. Relative means and ±95% confidence intervals for shoulder height (N = 410) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-97 (ages graphed as the independent variable for illustration purposes only).

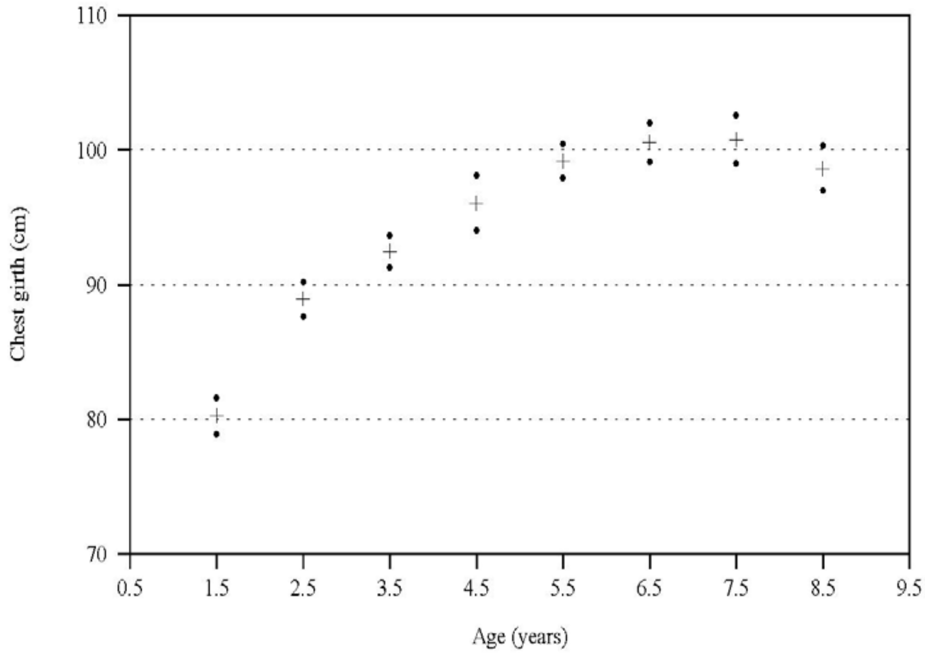

Figure 4.7. Relative means and ±95% confidence intervals for chest girth (N = 410) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-97 (ages graphed as the independent variable for illustration purposes only).

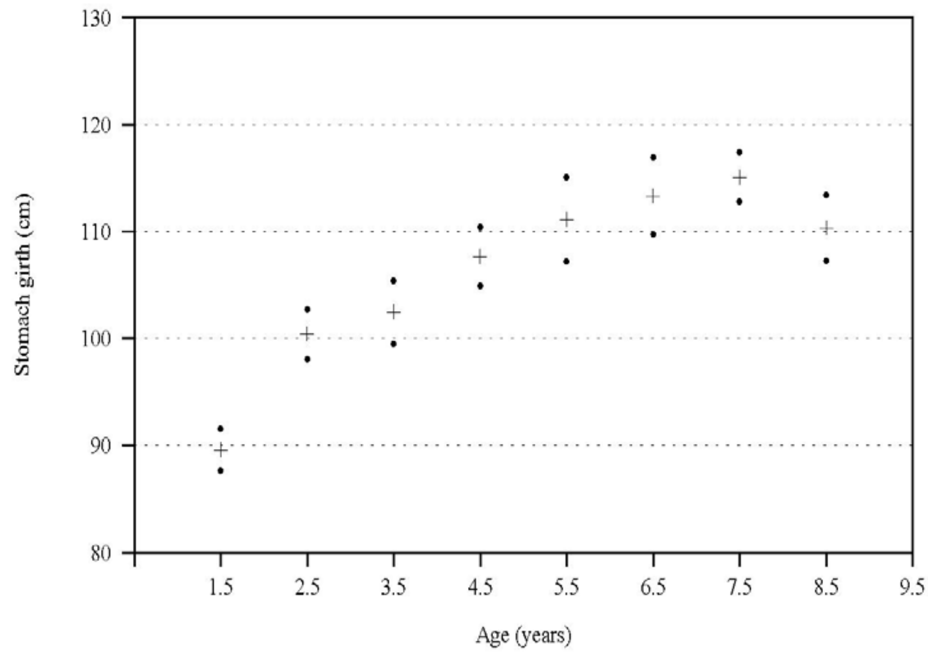

Figure 4.8. Relative means and ±95% confidence intervals for stomach girth (N = 196) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-97 (ages graphed as the independent variable for illustration purposes only).

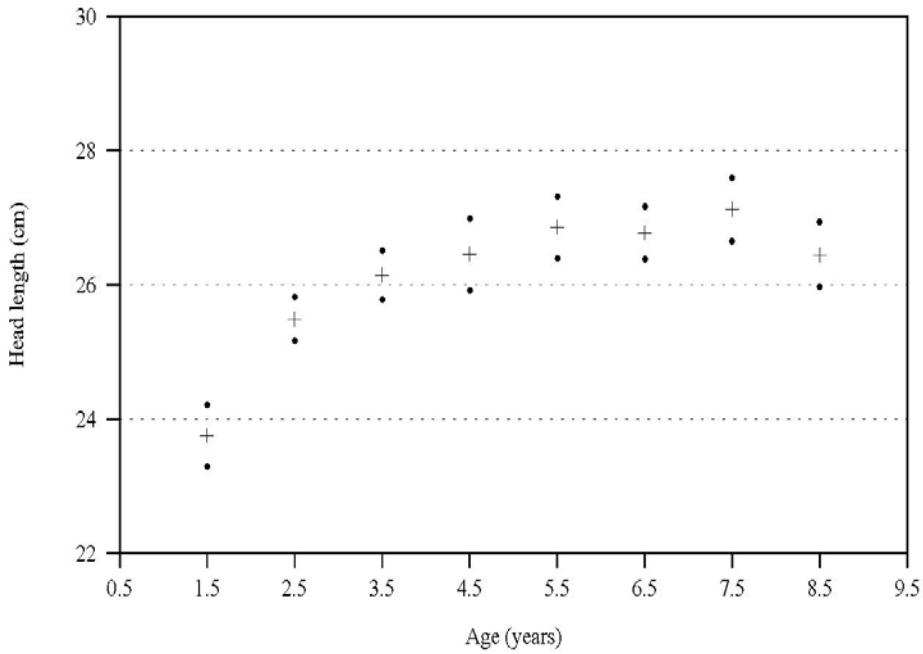

Figure 4.9. Relative means and ±95% confidence intervals for head length (N = 246) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-97 (ages graphed as the independent variable for illustration purposes only).

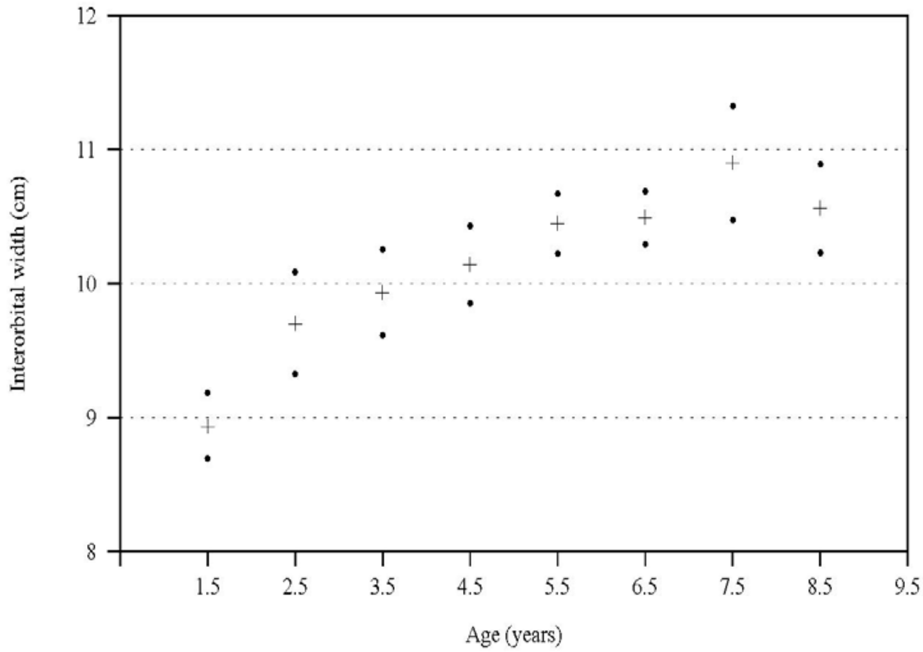

Figure 4.10. Relative means and ±95% confidence intervals for interorbital width (N = 245) by estimated age (Severinghaus 1949) for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-97 (ages graphed as the independent variable for illustration purposes only).

classes 1.5, 2.5, ≥3.5 differed for chest girth ($\underline{F}$ = 57.6; 4, 24 df; $\underline{P}$ < 0.001). Age classes 1.5 and ≥2.5 differed for head length ($\underline{F}$ = 31.3; 4, 9 df; $\underline{P}$ < 0.001) and shoulder height ($\underline{F}$ = 22.2; 4, 24 df; $\underline{P}$ < 0.001). Age classes 1.5 and ≥3.5 differed for stomach girth ($\underline{F}$ = 14.9; 4, 6 df; $\underline{P}$ = 0.003) and age classes 1.5 and ≥4.5 differed for interorbital width ($\underline{F}$ = 9.2; 4, 9 df; $\underline{P}$ = 0.003).

Least variable antler characteristics were basal circumference, main beam length, and inside spread (C.V. = 21.4, 25.6, and 26.5%, respectively). Gross BCC score and number of antler points (C.V. = 33.3 and 28.7%, respectively) were most variable. Least variable body characteristics were head length, shoulder height, and chest girth (C.V. = 5.7, 6.4, and 8.8%, respectively). Interorbital width and stomach girth (C.V. = 9.9%) were most variable.

Antler measures with highest correlations with age class were main beam length ($\underline{r}_s$ = 0.956; $\underline{P}$ < 0.001; $\underline{N}$ = 64), gross BCC score ($\underline{r}_s$ = 0.949; $\underline{P}$ < 0.001; $\underline{N}$ = 64), and inside antler spread ($\underline{r}_s$ = 0.948; $\underline{P}$ < 0.001; $\underline{N}$ = 64). Body measures with highest correlations were head length ($\underline{r}_s$ = 0.981; $\underline{P}$ < 0.001; $\underline{N}$ = 14), chest girth ($\underline{r}_s$ = 0.932; $\underline{P}$ < 0.001; $\underline{N}$ = 29), and stomach girth ($\underline{r}_s$ = 0.852; $\underline{P}$ < 0.001; $\underline{N}$ = 11). Live mass was negatively correlated with age for males ≥4.5 years old ($\underline{r}_s$ = -0.366; $\underline{P}$ = 0.017; $\underline{N}$ = 42). No relationship was found between age and dressed mass. The small sample size of males <4.5 years old ($\underline{n}$ = 2) precluded evaluating mass relationships for younger males.

Akaike information criterion indicated best antler size variables for providing an estimate of male age were gross BCC score (-86.9, N = 64), inside antler spread (-78.0, $\underline{N}$ = 64), and basal circumference (-75.7, N = 64). Stepwise regression analyses indicated the most significant variables for predicting age were gross BCC score and number of antler points for a 2-variable model ($\underline{R}^2$ = 0.943; 2, 8 df; $\underline{P}$ < 0.001); gross BCC score, number of antler points, and stomach girth for a 3-variable model ($\underline{R}^2$ = 0.966; 3, 7 df;

$\underline{P} < 0.001$); and gross BCC score, number of antler points, stomach girth, and head length for a 4-variable model ($\underline{R}^2 = 0.978$; 4, 6 df; $\underline{P} < 0.001$).

Individual criteria that resulted in the highest percentages of specific age classes of males being excluded from harvest included a minimum of 8 antler points for 1.5-year-old males (99% of age class protected); an inside spread minimum of 40.6 cm (16 in) for 2.5-year-old males (97% of age class protected); a main beam length minimum of 53.3 cm (21 in) for 3.5-year-old males (96% of age class protected); and an inside spread minimum of 48.3 cm (19 in) for 4.5-year-old males (96% of age class protected; Table 4.1). These same criteria would also protect varying percentages of mature males (Table 4.2).

Females

Mean age for the 140 females was 5.4 years (SE = 0.19). No yearly ($\underline{F} \leq 2.31$; 3, 28 df; $\underline{P} \geq 0.098$) or monthly ($\underline{F} \leq 1.51$; 5, 32 df; $\underline{P} \geq 0.238$) differences were found for live and dressed mass and no monthly differences were found for chest girth, shoulder height, and hoof length and width ($\underline{F} \leq 3.18$; 1, 14 df; $\underline{P} \geq 0.096$), so data were combined in the analyses. Body measures peaked at various ages, but were essentially unchanged after age 2.5 years (Figures 4.11-4.16). We therefore combined age classes 2.5-8.5 into 1 age class ($\geq$2.5) for further analyses due to non-linearity (Dapson 1980).

Analysis of variance and Tukey's studentized range post hoc tests indicated age classes 0.5, 1.5, and $\geq$2.5 differed for dressed mass ($\underline{F} = 45.7$; 2, 10 df; $\underline{P} < 0.001$), while age classes $\leq$1.5 and $\geq$2.5 differed for live mass ($\underline{F} = 19.7$; 2, 6 df; $\underline{P} = 0.002$). Age classes 0.5 and $\geq$1.5 differed for chest girth ($\underline{F} = 35.5$; 2, 3 df; $\underline{P} = 0.008$) and shoulder height ($\underline{F} = 13.0$; 2, 3 df; $\underline{P} = 0.033$), while age classes 0.5 and $\geq$2.5 differed for hoof length ($\underline{F} = 10.0$; 2, 3 df; $\underline{P} = 0.047$). No age-related differences were found for hoof width ($\underline{F} = 4.8$; 2, 3 df; $\underline{P} = 0.117$).

Table 4.1. Available criteria by age class for protecting young and middle-aged males from harvest during 1985-97 at the Faith Ranch, Dimmit and Webb counties, Texas.

Age class	Criteria	Percent of age class protected
1.5	Antler point minimum of 8	99
	Inside antler spread minimum of 25.4 cm (10 in)	99
	Main beam length minimum of 35.6 cm (14 in)	97
	Gross BCC[a] score minimum of 177.8 cm (70 in)	99
2.5	Inside antler spread minimum of 40.6 cm (16 in)	97
	Main beam length minimum of 45.7 cm (18 in)	94
	Gross BCC score minimum of 279.4 cm (110 in)	94
3.5	Inside spread minimum of 45.7 cm (18 in)	94
	Main beam length minimum of 53.3 cm (21 in)	96
	Gross BCC score minimum of 330.2 (130 in)	92
4.5	Inside spread minimum of 48.3 cm (19 in)	96
	Inside spread minimum of 45.7 cm (18 in)	88
	Main beam length minimum of 58.4 cm (23 in)	96
	Main beam length minimum of 55.9 cm (22 in)	90
	Gross BCC score minimum of 381.0 cm (150 in)	95
	Chest girth minimum of 101.6 cm (40 in)	93

[a]BCC = Boone and Crockett Club.

Table 4.2. Consequences (i.e., percentage of mature males inadvertently protected) of available criteria for protecting young and middle-aged males from harvest during 1985-97 at the Faith Ranch, Dimmit and Webb counties, Texas.

Age class	Criteria	Percent of age class protected
≥5.5	Antler point minimum of 10	54
	Antler point minimum of 9	39
	Antler point minimum of 8	8
	Inside spread minimum of 48.3 cm (19 in)	73
	Inside spread minimum of 45.7 cm (18 in)	50
	Inside spread minimum of 40.6 cm (16 in)	25
	Main beam length minimum of 58.4 cm (23 in)	78
	Main beam length minimum of 53.3 cm (21 in)	39
	Main beam length minimum of 50.8 cm (20 in)	23
	Gross BCC[a] score minimum of 381.0 cm (150 in)	85
	Gross BCC score minimum of 355.6 cm (140 in)	71
	Gross BCC score minimum of 330.2 cm (130 in)	48
	Gross BCC score minimum of 304.8 cm (120 in)	27
	Chest girth minimum of 101.6 cm (40 in)	67

[a]BCC = Boone and Crockett Club.

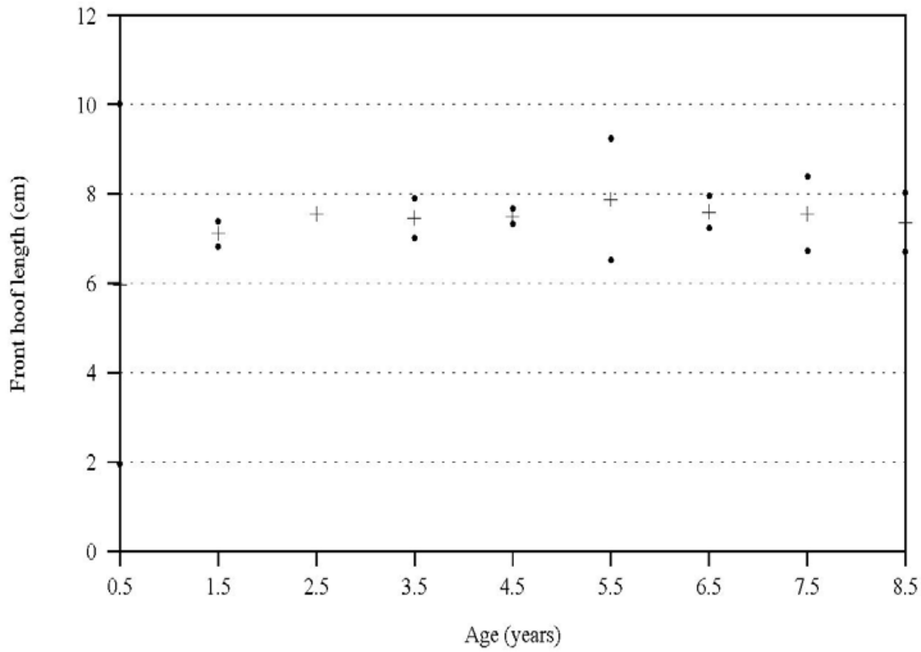

Figure 4.11. Relative means and ±95% confidence intervals for front hoof length (N = 50) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

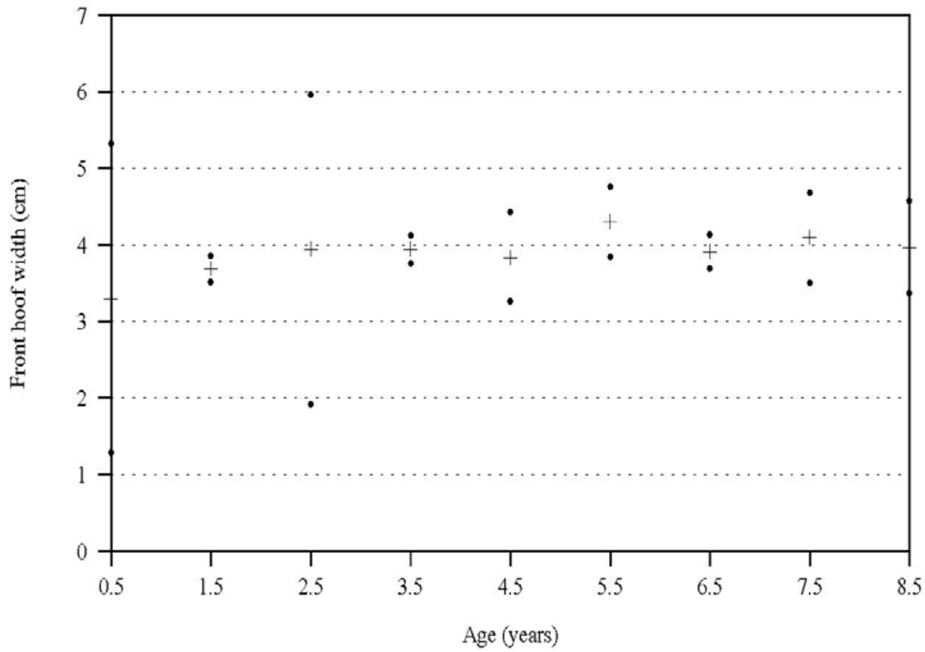

Figure 4.12. Relative means and ±95% confidence intervals for front hoof width (N = 50) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

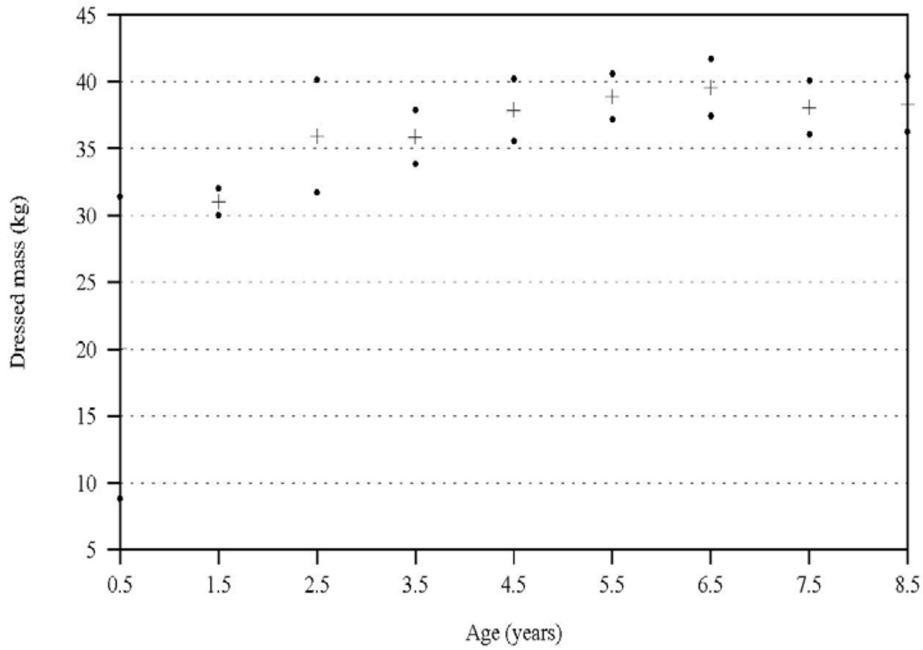

Figure 4.13. Relative means and ±95% confidence intervals for dressed mass (N = 140) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

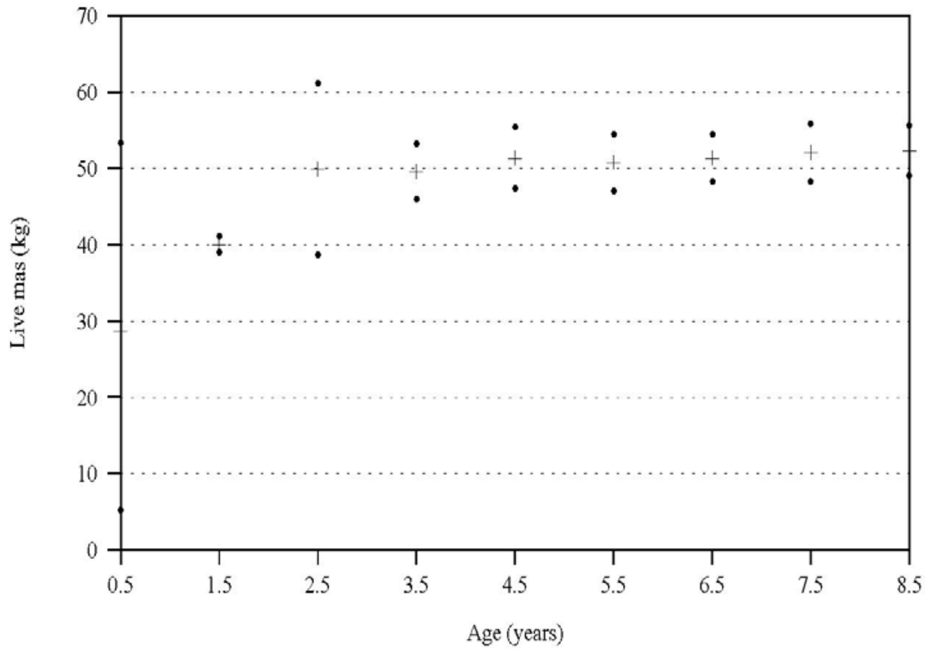

Figure 4.14. Relative means and ±95% confidence intervals for live mass (N = 81) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

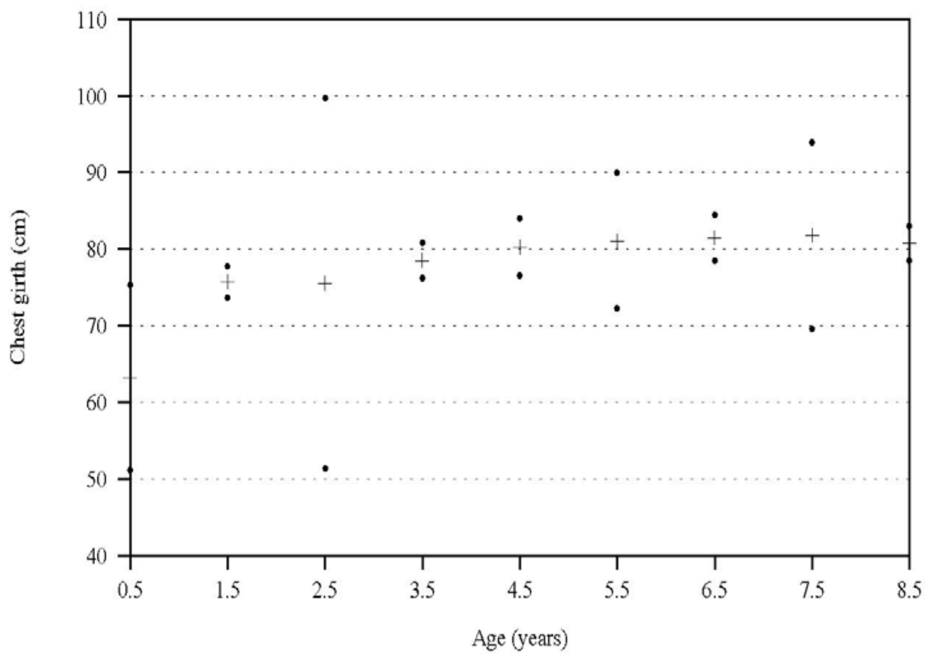

Figure 4.15. Relative means and ±95% confidence intervals for chest girth (N = 50) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

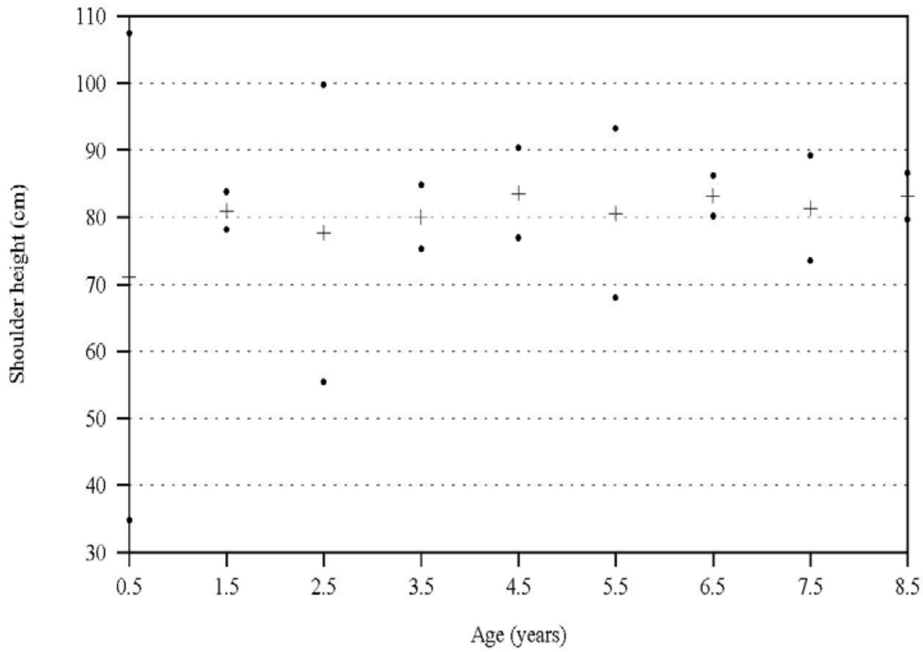

Figure 4.16. Relative means and ±95% confidence intervals for shoulder height (N = 50) by estimated age (Severinghaus 1949) for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas during 1994-97 (ages graphed as the independent variable for illustration purposes only).

Body measures with highest correlations were shoulder height ($\underline{r}_s$ = 0.956; $\underline{P}$ = 0.002; $\underline{N}$ = 6), chest girth ($\underline{r}_s$ = 0.956; $\underline{P}$ = 0.002; $\underline{N}$ = 6), and hoof length ($\underline{r}_s$ = 0.956; $\underline{P}$ = 0.003; $\underline{N}$ = 6). Akaike information criterion indicated best body size variables for providing an estimate of female age were dressed mass (-31.2, N = 13), live mass (-17.5, $\underline{N}$ = 9), and chest girth (-14.8, N = 6). Stepwise regression analyses indicated the most significant variables for predicting age were live mass and hoof width for a 2-variable model ($\underline{R}^2$ = 0.981; 2, 3 df; $\underline{P}$ = 0.003); live mass, chest girth, and hoof width for a 3-variable model ($\underline{R}^2$ = 0.995; 2, 3 df; $\underline{P}$ = 0.008); and dressed mass, chest girth, shoulder height, and hoof width for a 4-variable model ($\underline{R}^2$ = 0.999; 4, 1 df; $\underline{P}$ = 0.041). However, no models were significant for all coefficients.

DISCUSSION

An underlying assumption in our analyses was that estimated ages using TRW were accurate. Few deer were of known age, thus our results should be interpreted with caution (Dapson 1980). However, at present no other technique available for aging live southern deer is more accurate than TRW (Brokx 1972, Cook and Hart 1979, Hackett et al. 1979, DeYoung 1989b, Jacobson and Reiner 1989, McCullough 1996). In addition, harvested deer are aged almost exclusively using this method (Brothers and Ray 1975, Kroll 1991). Therefore, relating antler and body measures to estimated age using TRW likely provided results more useful to managers and hunters, who "verify" deer ages "in hand" using TRW.

Males

Our study suggests that gross BCC score, inside antler spread, basal circumference, and main beam length would likely be the most useful antler characteristics for estimating male age on the Faith Ranch, in southern Texas. Gross BCC score may be the best individual characteristic because remaining antler measures are all included in this characteristic. However, estimating gross BCC score accurately in the field may be difficult for most managers and hunters because much experience and knowledge of how the measures are obtained are required. Inside antler spread is likely easier to estimate in the field because tip-to-tip ear spread can be used for comparison. Inside antler spread was also the only measure found by Anderson and Medin (1969) that did not overlap in confidence limits. Rogers and Baker (1965) determined that main beam length and basal diameter were the 2 antler measures most related to antler volume, but each of these characteristics is likely more difficult to accurately estimate in the field than overall antler size and inside antler spread.

Antler characteristics provided the least overlap among age classes, were most correlated with age, and are likely easier to visually estimate from a distance than body characteristics because ear length and tip-to-tip ear spread can be used for comparison. Antler characteristics are also fixed within years, while most body characteristics change through the course of the breeding season with adult males losing an average of 27% of their body mass from prerut to postrut (Knowlton et al. 1979). Body measures were also not different for males ≥2.5 years old. However, large differences in sample sizes among antler and body measures may have contributed to these results.

Using antler size as the main criterion for harvest has potential pitfalls (DeYoung 1990) and may negatively impact antler size in subsequent years if harvest rates of unprotected males are high (Strickland et al. 2001). Therefore, the best available option is likely a combination of both antler and body characteristics.

Our results indicate that chest girth, head length, and stomach girth would likely be the most useful body characteristics for estimating male age. However, head length is likely difficult to accurately estimate in the field. Stomach girth relative to chest girth may be the best combination to use. Experience has indicated that mature males can often be identified in the field when stomach girth is visibly larger than chest girth (i.e., when the "bottom line" of the mid-section sags noticeably lower than the "bottom line" of the chest). The best combination of antler and body characteristics likely includes gross BCC score, inside spread, and stomach girth relative to chest girth for estimating male age in the field. Future research needs to test the precision and accuracy of using these 3 characteristics in the field.

Unlike most studies involving free-ranging deer, the age structure of the male segment of the deer herd in our study was well distributed through the age classes with >42% of randomly captured males $\geq$5.5 years old, allowing us to achieve sufficient sample sizes ($\underline{N}$ = 53-120) among these older age classes. This balanced age structure also allowed for a relatively large sample size of mature males in the harvest. However, restraint in the harvest of young and middle-aged males due to trophy management guidelines, resulted in insufficient sample sizes of males within these age classes. Because mass measures were limited to harvested mature males, a negative correlation resulted between age and live mass. It is doubtful a negative correlation would result if samples included young and middle-aged males.

Male Harvest Criteria

Our results indicate several criteria that may be useful for excluding certain age classes of males from harvest. Under quality management guidelines, harvest restrictions are often implemented to protect the 1.5- and 2.5-year-old age classes. A simple 8-point minimum would exclude 99% of males in the 1.5-year-old age class from harvest. It's doubtful a simpler criteria could be found for this age class. If the management goal also includes protecting the 2.5-year-old age class, we suggest an inside antler spread minimum of 40.6 cm (16 in). This criteria should also be fairly easy to estimate in the field because this measure is also the typical tip-to-tip ear spread for adult males on this same ranch (M. W. Hellickson, Univ. of Ga., unpub. data).

Under trophy management guidelines, harvest restrictions are often implemented to also protect the 3.5- and 4.5-year-old age classes from harvest. We recommend a gross BCC score minimum of 330.2 cm (130 in) for protecting the 3.5-year-old age class, although managers and hunters may prefer an inside spread minimum of 45.7 cm (18 in), which would exclude a similar percentage of this age class from harvest. A gross BCC score minimum of 381.0 cm (150 in) is recommended for protecting the 4.5-year-old age class.

Unfortunately, varying percentages of older-aged males would also be protected for each of these criteria. For example, a gross BCC score minimum of 381 cm (150 in) would also protect 85% of the ≥5.5-year-old age class from harvest. In areas where unprotected males are subjected to high harvest, we recommend that additional criteria be incorporated to allow for the harvest of older-aged males with small antlers. In our experience, stomach girth in relation to chest girth is helpful in identifying small-antlered mature males. This same criteria may also be useful to managers interested in culling small-antlered mature males from the population. However, the criteria needs to be field tested to determine it's accuracy and precision. Additional criteria are needed for identifying small-antlered middle-aged males.

Females

Characteristics for estimating age in females were limited because they lack antlers. In addition, females reach adult and peak body size sooner than males (Knowlton et al. 1979). As a result, it is likely only possible to separate females into 3 age classes (0.5, 1.5, and ≥2.5 years old) in the field. Our results indicated that live mass (i.e., body size) and chest girth would have the most value for classifying females into these age classes. Hoof length may be useful for estimating age of harvested females, but it likely has little value in estimating age in the field.

General body shape and appearance, although not easily quantifiable, when taken as a whole may also be most useful in estimating female ages (Kroll 1996). In addition, field observation allows the ability to note additional information such as pelage appearance, dominance interactions, and maternal-offspring behaviors that should enhance age class classification efficiency.

It is unlikely that our results are applicable to other regions, although DeYoung (1990) concluded that antler size differences due to genetic or nutritional factors did not appear important in his comparisons of 4 antler measures among males on 2 southern Texas ranches and males on the George Reserve (McCullough 1982) and the Crab Orchard National Wildlife Refuge (Roseberry and Klimstra 1975). However, other studies have reported geographic differences in antler measures for white-tailed deer (Severinghaus and Cheatum 1956; Kline 1965; Richie 1970; Strickland et al. 2000, 2001) and for moose (Alces alces; Saether and Haagenrud 1985).

We recommend that future research be conducted to test the appropriateness, precision, and accuracy of these characteristics in the field. Future research should also reevaluate live mass as a criteria in estimating male age because of the skewed age structure in our male harvest data. Additional characteristics, such as head length (Hamilton et al. 1995), rostral length, and interorbital width (Smith and McDonald 2002), should be evaluated for females. Finally, we suggest testing the training value of these potential classification tools during field trials of known-age deer, as also recommended by Smith and McDonald (2002).

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APPENDICES

Appendices A1-3

Antler and Body Characteristics for Males

Appendix A1. Antler characteristics by age for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1985-97.

	Gross BCC[a] score (cm)			Main beam length (cm)			Inside antler spread (cm)			Basal circumference (cm)			Number of antler points		
Age	0	SE	N	0	SE	N	0	SE	N	0	SE	N	0	SE	N
1.5	91.7A[b]	3.74	86	21.9A	0.69	89	18.5A	0.53	86	5.9A	0.13	89	3.8A	0.18	89
2.5	204.9B	3.82	123	38.5B	0.50	123	32.3B	0.42	122	8.3B	0.10	123	7.6B	0.14	122
3.5	261.3C	4.10	123	45.3C	0.50	123	37.9C	0.49	123	9.3C	0.11	123	8.3BC	0.11	123
4.5	301.5D	5.12	102	50.5D	0.53	102	41.2C	0.53	102	10.3D	0.12	102	8.9CD	0.15	102
5.5	330.0E	3.86	119	54.2E	0.46	120	44.9D	0.62	118	11.1E	0.11	120	9.2DE	0.14	119
6.5	338.3E	4.71	90	54.6E	0.53	90	44.2D	0.60	89	11.3E	0.12	90	9.6E	0.22	90
7.5	334.0E	5.20	60	54.3E	0.63	60	44.9D	0.70	60	11.0E	0.17	60	9.4DE	0.20	60
8.5+	322.9E	6.06	53	53.0DE	0.87	53	45.7D	1.07	53	10.9E	0.16	53	9.2DE	0.23	53
Total	268.3	3.25	756	45.9	0.43	760	38.2	0.37	753	9.7	0.08	759	8.2	0.09	758

[a]BCC = Boone and Crockett Club.
[b]T = Results of Tukey's post hoc tests. Different letters indicate significant differences in means at the $P < 0.05$ level.

Appendix A2. Body characteristics (cm) by age for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-96.

	Chest girth			Stomach girth			Shoulder height			Head length			Interorbital width		
Age	0	SE	N	0	SE	N	0	SE	N	0	SE	N	0	SE	N
1.5	80.4A[a]	0.7	46	89.8A	1.0	25	82.6A	0.8	46	23.8A	0.2	25	9.0A	0.1	25
2.5	89.1B	0.6	64	100.6AB	1.1	32	89.8B	0.5	63	25.5B	0.2	41	9.7AB	0.2	41
3.5	92.6BC	0.6	55	102.7B	1.4	21	91.1BC	0.6	55	26.2BC	0.2	34	9.9ABC	0.2	33
4.5	96.2CD	1.0	51	107.9BD	1.3	21	92.8BC	0.5	52	26.5BCD	0.2	33	10.2AC	0.1	33
5.5	99.4D	0.6	69	111.4BD	1.9	25	93.5BC	0.6	69	26.9CD	0.2	32	10.5BCD	0.1	32
6.5	100.7D	0.7	45	113.6CD	1.7	25	93.9BC	0.7	45	26.8CD	0.2	30	10.5BCD	0.1	30
7.5	100.9D	0.9	40	115.3CD	1.2	25	93.6C	0.8	40	27.2D	0.2	26	10.9D	0.2	26
8.5+	98.8D	0.8	40	110.6BD	1.5	22	93.5BC	0.9	40	26.5BCD	0.2	25	10.6CD	0.2	25
Total	94.6	0.4	410	106.3	0.8	196	91.4	0.3	410	26.2	0.1	246	10.1	0.1	245

[a]Results of Tukey's post hoc tests. Different letters indicate significant difference at the $P < 0.05$ level.

Appendix A3. Body characteristics (kg) by age for male white-tailed deer live-captured at the Faith Ranch, Dimmit and Webb counties, Texas during 1992-96.

	Live mass			Dressed mass		
Age	0	SE	N	0	SE	N
1.5	52.2[a]		1	37.9	3.9	2
2.5						
3.5						
4.5	79.4[a]		1	56.3	7.3	2
5.5	81.8	1.7	14	65.5	1.3	18
6.5	79.2	2.4	6	61.6	2.1	7
7.5	79.0	1.7	8	62.1	1.4	16
8.5+	75.9	2.3	14	60.4	1.7	20
Total	78.8	1.2	44	61.9	1.3	65

[a]Too few observations to calculate standard error (SE).

Appendices B1-3

Regression Models for Predicting Age

Appendix B1. Regression equations for antler and body characteristics with lowest Akaike information criterion (AIC_c) scores developed to estimate age for white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1985-97.

Sex	Age class	N	0	SE	AIC_c	Equation[a]
Male	1.5-5.5+	64	268.3	3.3	-86.9	Y = -0.218 + 0.016(GS)
		64	38.2	0.4	-78.0	Y = -1.393 + 0.140(IS)
		64	9.6	0.1	-75.7	Y = -2.686 + 0.687(BC)
		29	94.6	0.4	-34.8	Y = -13.563 + 0.187(CH)
		14	26.2	0.1	-11.5	Y = -27.188 + 1.190(HL)
		11	106.3	0.8	-9.0	Y = -13.630 + 0.168(SG)
Female	0.5-8.5+	50	79.1	0.7	21.2	Y = -19.00 + 0.30(CH)
		50	3.9	0.0	26.2	Y = -15.06 + 5.01(HW)

[a]Y = age, GS = gross BCC score (cm), IS = inside antler spread (cm), BC = basal circumference (cm), CH = chest girth (cm), HL = head length (cm), SG = stomach girth (cm), and HW = hoof width (cm).

Appendix B2. Best (highest $\underline{R}^2$ value) 2-, 3-, and 4-variable multiple regression models ($Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$) for predicting age of male white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1985-97.

Sex	Dependent variable (Y)	Independent variables (X_i)	Coefficients (B_i)	$\underline{R}^2$	SE	P-value	df
Male	Age	Intercept	1.084	0.943	0.51	0.065	2, 8
		Gross BCC[a] score	0.027		0.00	<0.001	
		No. antler points	-0.501		0.20	0.034	
	Age	Intercept	-4.442	0.966	2.57	0.128	3, 7
		Gross BCC score	0.022		0.00	0.002	
		No. antler points	-0.524		0.16	0.014	
		Stomach girth	0.066		0.03	0.066	

Appendix B2. Continued.

Sex	Dependent variable (Y)	Independent variables (X_i)	Coefficients (B_i)	$\underline{R}^2$	SE	P-value	df
Male	Age	Intercept	-15.590	0.978	6.38	0.050	4, 6
		Gross BCC score	0.019		0.00	0.004	
		No. antler points	-0.624		0.15	0.006	
		Stomach girth	0.058		0.03	0.072	
		Head length	0.524		0.28	0.112	

[a]BCC = Boone and Crockett Club.

Appendix B3. Best (highest $\underline{R}^2$ value) 2-, 3-, and 4-variable multiple regression models ($Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3$) for predicting age of female white-tailed deer at the Faith Ranch, Dimmit and Webb counties, Texas, 1985-97.

Sex	Dependent variable (Y)	Independent variables (X_i)	Coefficients (B_i)	$\underline{R}^2$	SE	P-value	df
Female	Age	Intercept	3.352	0.981	1.62	0.131	2, 3
		Live mass	0.143		0.02	0.009	
		Hoof width	-1.948		0.69	0.065	
	Age	Intercept	0.613	0.995	1.60	0.739	3, 2
		Live mass	0.104		0.02	0.046	
		Chest girth	0.038		0.02	0.151	
		Hoof width	-1.520		0.48	0.088	
	Age	Intercept	3.492	0.999	1.21	0.213	4, 1
		Dressed mass	0.172		0.02	0.073	
		Chest girth	0.044		0.01	0.129	
		Shoulder height	-0.061		0.01	0.117	
		Hoof width	-1.437		0.24	0.107	

Appendix C1-2

Body Characteristics for Females

Appendix C1. Body characteristics (cm) by age for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas, 1994-97.

	Chest girth			Shoulder height			Front hoof length			Front hoof width		
Age	0	SE	N	0	SE	N	0	SE	N	0	SE	N
0.5	63.5A[a]	1.0	2	71.4A	2.9	2	6.0A	0.3	2	3.3A	0.2	2
1.5	76.0AB	0.7	8	81.6A	1.0	8	7.2AB	0.1	8	3.7A	0.1	7
2.5	75.9AB	1.9	2	77.9A	1.8	2	7.6AB	0.0	2	4.0A	0.2	2
3.5	79.1AB	1.1	11	80.2A	2.4	11	7.3AB	0.1	11	4.0A	0.1	12
4.5	80.6AB	1.4	5	83.9A	2.4	5	7.6AB	0.1	5	3.9A	0.2	5
5.5	81.4B	2.1	3	81.0A	3.0	3	7.9B	0.3	3	4.3A	0.1	3
6.5	81.8B	1.3	10	81.8A	1.3	10	7.7B	0.2	10	3.9A	0.1	10
7.5	82.1B	3.8	4	81.7A	2.5	4	7.6AB	0.3	4	4.1A	0.2	4
8.5+	81.1B	0.8	5	83.5A	1.3	5	7.4AB	0.2	5	4.0A	0.2	5

Appendix C1. Continued.

	Chest girth			Shoulder height			Front hoof length			Front hoof width		
Age	0	SE	N	0	SE	N	0	SE	N	0	SE	N
Total	79.1	0.7	50	81.5A	0.8	50	7.4	0.1	50	3.9	0.0	50

[a]T = Results of Tukey's post hoc tests. Different letters indicate significant differences in means at the $P < 0.05$ level.

Appendix C2. Body characteristics (kg) by age for female white-tailed deer harvested at the Faith Ranch, Dimmit and Webb counties, Texas, 1994-97.

	Live mass			Dressed mass		
Age	0	SE	N	0	SE	N
0.5	29.0A[a]	2.7	2	20.3A	2.6	3
1.5	40.4AB	0.4	7	31.2B	0.4	10
2.5	50.2AB	3.5	4	36.1B	1.7	7
3.5	49.9AB	1.7	13	36.1B	1.0	23
4.5	51.7B	1.7	8	38.1B	1.1	18
5.5	51.1B	1.6	8	39.1B	0.8	17
6.5	51.7B	1.4	15	39.8B	1.0	20
7.5	52.4B	1.7	11	37.7B	1.1	19
8.5+	52.7B	1.5	13	38.5B	1.0	23
Total	50.0	0.8	81	37.2	0.5	140

[a]T = Results of Tukey's post hoc test. Different letters indicate significant differences in age class means at the $P < 0.05$ level.

CHAPTER 5

ACCURACY OF ACTIVITY MONITORING IN WHITE-TAILED DEER[1]

[1]Hellickson, M. W., K. V. Miller, R. L. Marchinton, and C. A. DeYoung. To be submitted to the Texas Journal of Science.

INTRODUCTION

Direct observations have been used to quantify ungulate activity (Michael 1966, Tibbs 1967, Brown 1971, Hirth 1973, Zagata 1972, Carbaugh et al. 1975), but their effectiveness is limited during nocturnal periods and in areas of limited visibility. Data collected with a photoelectric cell system (Harder 1969) and during spotlight counts allow nocturnal monitoring (Montgomery 1963, Progulske and Duerre 1964, Braden 1978), but are biased because deer are not equally observable (McCullough 1982) or behavior may be altered by the artificial light. Track counts (Ockenfels and Bissonette 1982) and deer seen per hunter hour (Curtis et al. 1972) also have been used. More recently, motion detection by automated cameras (Carthew and Slater 1991, Jacobson et al. 1997) and radio transmitters allowed "hands off" monitoring and reduced human effects on ungulate behavior.

Signal-strength variation was the first method used to detect radio-transmittered animal movement (Cochran and Lord 1963, Jackson et al. 1972, DeYoung 1979, Ivey and Causey 1981, Holzenbein and Schwede 1989), but signal strength is potentially affected by other factors. Activity also has been measured by distance traveled between sequential radio-locations (Marchinton 1968, Sparrowe and Springer 1970, Pledger 1975, Kammermeyer and Marchinton 1977, Evans 1992), but these measures provide no indication of activity other than estimated movement and may be biased because stationary animals are assumed to be inactive (Garshelis et al. 1982).

Transmitters equipped with heart rate sensors allow researchers to discriminate activities based on heart rate (Moen 1978). The addition of reset (Garshelis et al. 1982) and tip-switch motion sensors allow researchers to discriminate activity (head up or head down) based on signal amplitude (Georgii 1981, Green and Bear 1990, Hayes and Krausman 1993), but care must be taken to ensure tip switches are mounted correctly so they are activated only when the animal's head falls below the horizontal plane formed by its back (Skinner 1994). Tip-switch transmitters combined with strip charts allow graphic print-outs of the pulse pattern (Risenhoover 1986, Beier and McCullough, 1990, Kufeld et al. 1988, Hansen et al. 1992). Variable-pulse collars that sample instantaneous collar movement also have been used (Gillingham and Bunnell 1985, Relyea et al. 1994). However, no method has yet allowed researchers to discriminate bedded, standing, grooming, feeding, walking, and running activities with high accuracy (>90%).

Strip-chart activity monitoring systems provide abundant data, but evaluation is time consuming, subject to interpretation, and require manual data entry for analysis. In addition, identical strip-chart recorders may operate at different speeds, especially during periods of declining battery voltage (Gillingham and Parker 1992). Automated systems that quantify activity and store data in an electronic form (Howey et al. 1988) provide an advantage over strip-chart systems (Relyea et al. 1994, Skinner 1994). We used such a system, combined with variable-pulse transmitters, for monitoring activity of female white-tailed deer (*Odocoileus virginianus*). This new system used a field computer that counted number of pulse signals.

Sampling intervals of various lengths (0.5-10 minutes) have been used during previous studies (Kufeld et al. 1988, Skinner 1994). Beier and McCullough (1988) used a 5.25-minute sampling interval to allow discrimination between bedded and standing deer. They determined that the proportion of active traces misclassified as bedded increased as the sampling interval was shortened. However, their relatively long sampling interval required classifying the pulse-interval data into 5 additional categories and resulted in an overestimate of the amount of time spent active. They recommended selecting the shortest sampling interval that would still allow for accurate separation of bedded and standing activities. Relyea et al. (1994) used a 1-min sampling interval because an average of 2.0 and 2.5 activities occurred during 3- and 5-min sampling intervals, respectively. We chose a 1-min scan time *a priori* to reduce likelihood of multiple activities occurring during the sampling interval and to avoid overestimating the amount of time spent active.

The objectives were to test for differences in mean relative pulse rates among deer, transmitters, and 6 activities; determine accuracy of assigned activities based on relative pulse rates; and determine the relative pulse rate to be used to separate activities for future analysis of free-ranging white-tailed deer monitored with this same system.

METHODS

The study was conducted on the 18,020-ha Faith Ranch in Dimmit and Webb counties, part of the Western Rio Grande Plains region of Texas. Annual mean minimum and maximum temperatures were 15° and 29° C, respectively and annual mean precipitation was 54.6 cm. The gently rolling terrain was dominated by guajillo (*Acacia berlandieri*), blackbrush (*A. rigidula*), guayacan (*Porlieria angustifolia*), and honey mesquite (*Prosopis glandulosa*).

Three hand-raised female white-tailed deer (≥1.0 year old) were fitted with radio-transmitting collars containing variable-pulse activity sensors. The females were contained in a 1-ha pen with 10-12 additional females. Sensors used mercury switches that added pulses to the base pulse rate each time the collar tipped from side to side (Advanced Telemetry Systems, Isanti, Minn.). Sensors were oriented perpendicular to the long axis of the animal's body, contrasting with parallel orientation of tip switches. We attempted to fit each deer similarly with respect to collar tightness because loose-fitting collars allowed too much transmitter movement, while tight collars restricted movement, both of which biased sensitivity.

The data collection unit was computer-controlled and consisted of an omni-directional antenna (Telonics, Mesa, Ariz.) attached to a radio receiver and a small computer (DCCII; Advanced Telemetry Systems, Isanti, Minn.). The computer controlled radio-frequency scanning to monitor females for consecutive, 1-min intervals. The computer counted and stored number of radio signal pulses for each minute of monitoring (pulse rate) along with the date and time.

During August 1994, we visually observed transmittered females inside a 1-ha holding pen and noted specific activities while the telemetry receiver system operated nearby. We chose tame deer because: (1) observer visibility would never be limited by vegetation obstruction; (2) monitoring system could be viewed concurrently with deer observations to ensure synchronization of observations to pulse totals; (3) collars could be interchanged to measure transmitter variation; and (4) all activities could be observed for each deer to allow statistical analysis. This allowed us to determine the capability of discriminating specific activities, examine overlap among pulse ranges, and compare pulse rates of transmitters.

Observed activities were numbered and classified as bedded, standing, grooming, feeding, walking, or running. Bedded and standing deer were those that did not groom, feed, walk, or run during the 1-min interval. Any bedded deer involved in at least some grooming was categorized as grooming. Any standing deer involved in at least some feeding was categorized as feeding. A walking deer walked for at least part of the minute but did not run, and a running deer trotted or ran for at least part of the min.

A mean pulse rate was determined for each deer, transmitter, and activity and compared using ANOVAs with PROC MIXED (SAS Inst., Inc., 1996) and Tukey's studentized range test (HSD) was used to separate means. Spearman's correlation coefficients were determined between relative mean number of pulses and the 6 activities because numbered activities were ordinal. The value (relative pulse rate) for separating activities was determined using the method of Relyea et al. (1994).

RESULTS

We used 2,509 visual observations to calibrate pulse rates to behavioral activity. An average of 1.3 activities occurred during each 1-min scan. Pulse rates (no. of pulses/min) were converted to relative pulse rates (100 x pulse rate/base rate) based upon each transmitter's mean base rate (55.2-60.2 pulses/min). Four transmitters were interchanged among the 3 deer. However, data for 1 female were excluded from tests among transmitters and activities because of an inability to interchange transmitters.

A significant interaction occurred among activities and transmitters ($F = 3.04$; 15, 20 df; $P = 0.011$). The interaction occurred as a result of differences among at least 2 of the 4 transmitters within walking ($F = 3.92$; 3, 14.2 df; $P = 0.031$) and running ($F = 9.26$; 3, 14.2 df; $P = 0.001$). Tests among the 4 transmitters at these 2 activity levels were then conducted using Tukey's studentized range test. Mean relative pulse rates did not differ among transmitters for activities classified as walking ($P \geq 0.446$), although the mean relative pulse rate appeared higher for 1 transmitter (0 = 153.8%) when compared to remaining transmitters (0 = 104.0-107.1%; Fig. 5.1). The only difference in mean relative pulse rates among transmitters for observations classified as running occurred between transmitter 1328 (0 = 236.4%) and 290 (0 = 148.8%; $P = 0.008$; Fig. 5.1).

Highest relative pulse rates for bedded, standing, grooming, feeding, walking, and running activities were 132.9, 113.5, 257.1, 243.7, 260.4, and 331.5%, respectively (Table 5.1). Mean relative pulse rates for these activities were 99.8, 100.7, 116.2, 132.1, 132.0, and 178.9%, respectively. Activities were positively correlated with relative pulse rates ($r_s = 0.636$, $P < 0.001$).

Differences were found among $\geq$2 of the 6 activities for all 4 transmitters ($F \geq 3.33$; 5, 20 df; $P \leq 0.023$; Fig. 5.1). However, Tukey's studentized range test indicated no differences in mean relative pulse rates among activities for transmitter 290

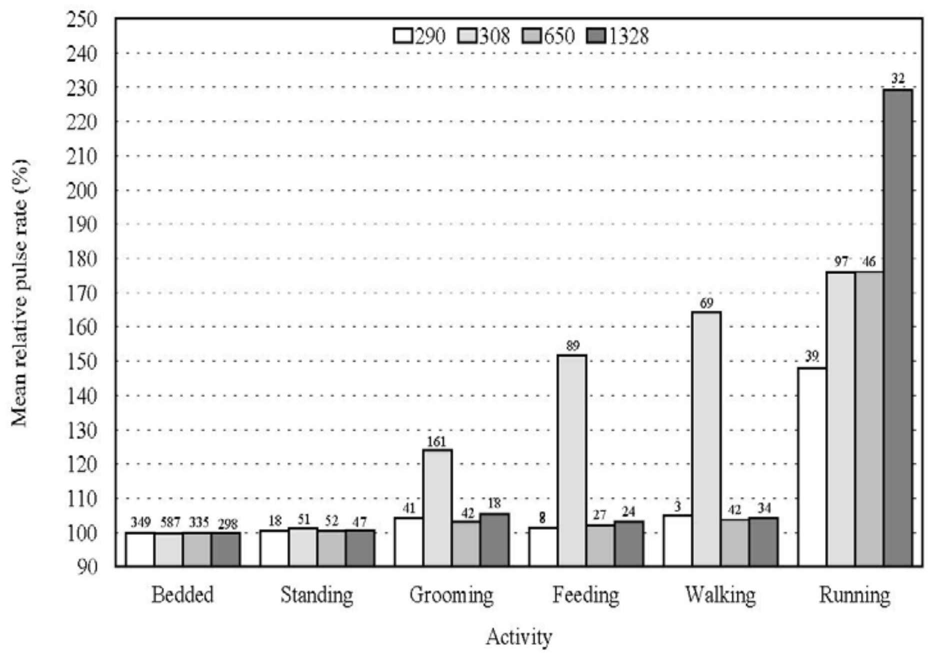

Fig. 5.1. Relative frequency of mean relative pulse rates (as percent of base rate) by transmitter (290, 308, 650, and 1328) for 6 activities (*n* = 3-587, SE = 17.4) of 2 tame, female white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors in Dimmit and Webb counties, Texas, August 1994. Data based on 2,509 1-min samples.

Table 5.1. Descriptive characteristics of relative pulse rates (as % of base rate) for 6 activities of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

			Relative pulse rates				Percent of 1-min scans ≤ the following relative pulse rates				
Activity	No. of 1-min obs	Percent of all activities	0	min	max	SE	100	101	102	103	104
Bedded	1,569	62.5	99.8	90.2	132.9	0.06	68.1	88.3	95.5	96.0	97.5
Standing	168	6.7	100.7	91.8	113.5	0.27	56.5	72.6	81.5	83.9	88.1
Grooming	262	10.4	116.2	95.2	257.1	1.66	14.5	21.0	28.6	33.2	39.3
Feeding	148	5.9	132.1	99.1	243.7	2.82	13.5	21.6	28.4	29.7	33.1
Walking	148	5.9	132.0	91.8	260.4	3.46	20.3	28.4	33.1	37.2	39.2
Running	214	8.5	178.9	96.8	331.5	3.80	2.8	2.8	3.3	4.7	4.7

($P \geq 0.236$, 20 df). The only differences found for remaining transmitters involved differences among the running activity and other activities for 6 of 12 comparisons ($P \leq 0.028$, 20 df).

Considerable overlap resulted among activities, especially among bedded and standing activities and grooming, feeding, and walking (Table 5.1, Fig. 5.2-5.7). Due to overlap, bedded and standing activities were combined and designated as "inactive." These 2 activities also involved the least amount of neck movement. The remaining activities (grooming, feeding, walking, and running), which all involved at least some neck movement, were combined and designated as "active." Mean relative pulse rates for inactive (n = 1,737) and active (n = 772) observations were 99.9 and 139.7%, respectively (Table 5.2), although overlap continued to occur (Fig. 5.8-5.9).

The interaction among transmitters and activities was not significant ($F = 3.05$; 3, 4 df; $P = 0.155$) after grouping activities into 2 categories. No differences were found among transmitters ($F = 2.98$; 3, 3 df; $P = 0.197$), while a highly significant difference was found between the 2 activity categories ($F = 67.7$; 1, 4 df; $P = 0.001$).

The accuracy of correctly identifying activities was plotted for a range of relative pulse totals (90-332%; Relyea et al. 1994). A single separation point resulted when relative pulse rates were rounded to the nearest 2 percent. The separation point, where the lines crossed indicating best accuracy for separating the 2 categories of activities, occurred at a relative pulse rate of 104% (Fig. 5.10). Greater than 96% of the inactive observations were at or below this separation point, while 71.5% of active observations were above this point. Combined, 88.4% of observations at or below the separation point were correctly identified as inactive, while 90.2% of observations above the separation point were correctly identified as active (Table 5.3).

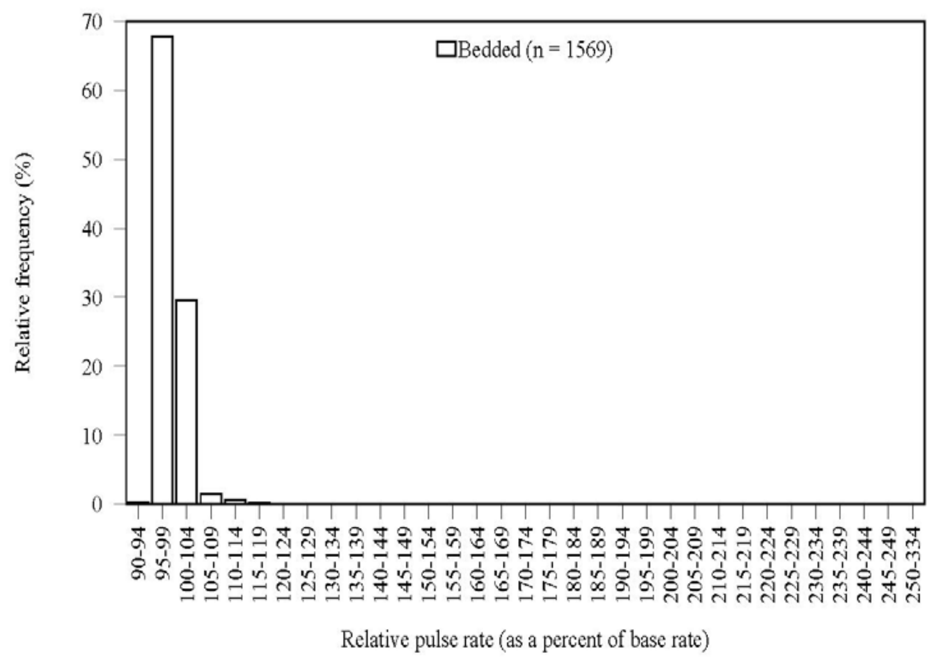

Fig. 5.2. Relative frequency of relative pulse rates (as % of base rate) for the bedded activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

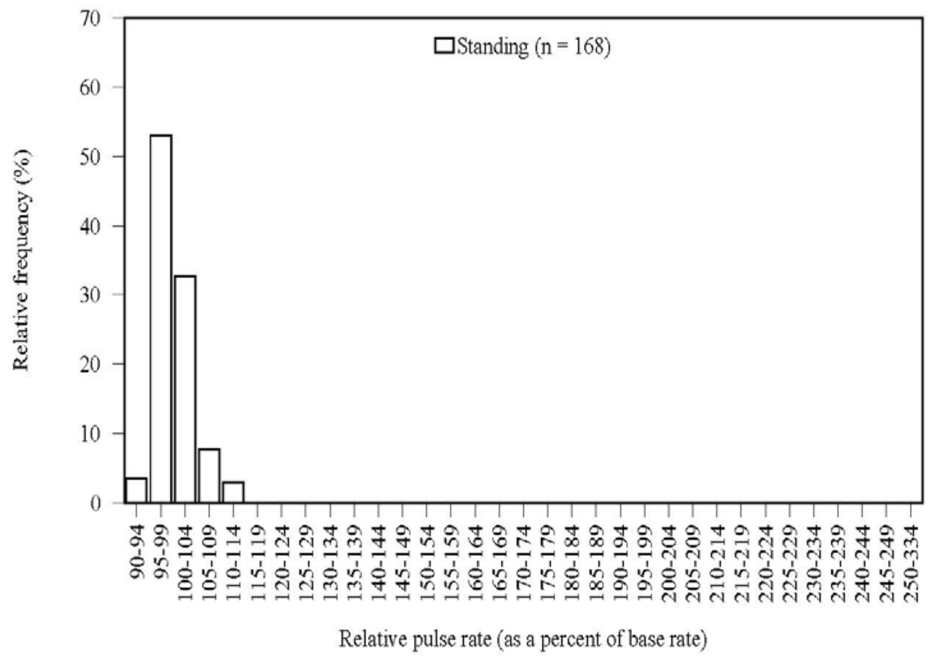

Fig. 5.3. Relative frequency of relative pulse rates (as % of base rate) for the standing activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

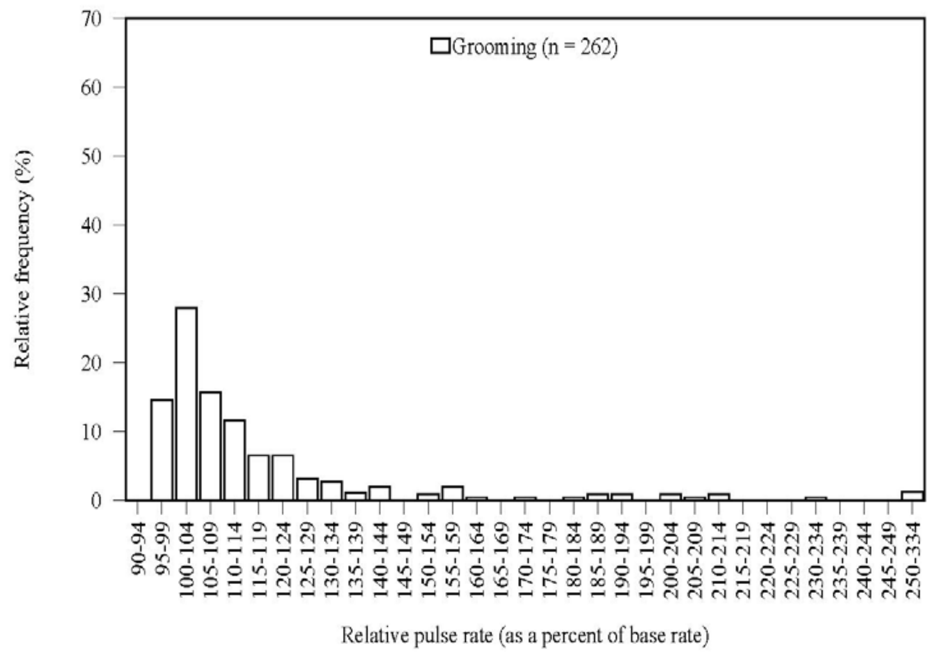

Fig. 5.4. Relative frequency of relative pulse rates (as % of base rate) for the grooming activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

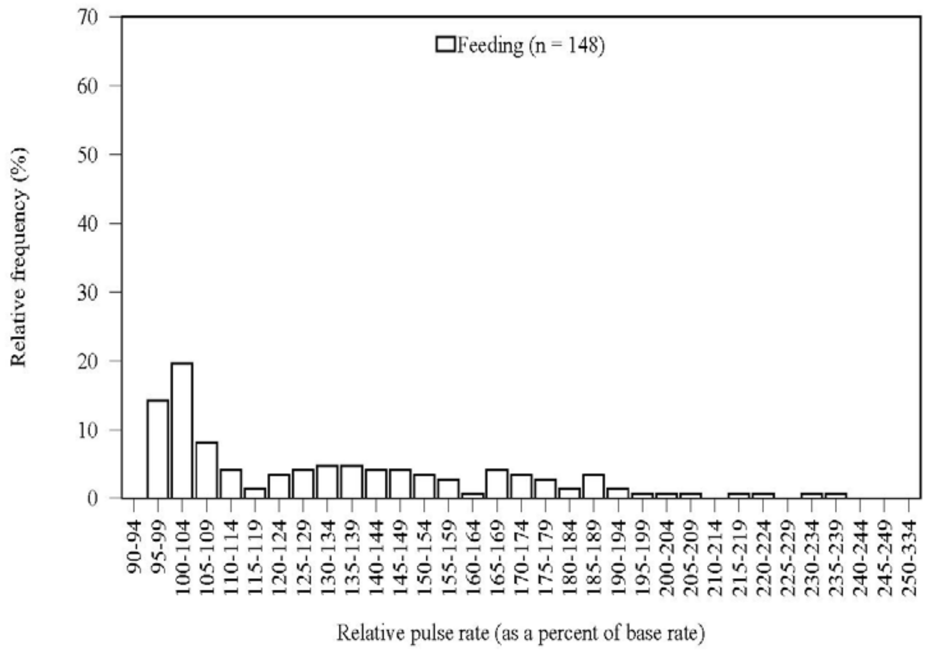

Fig. 5.5. Relative frequency of relative pulse rates (as % of base rate) for the feeding activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

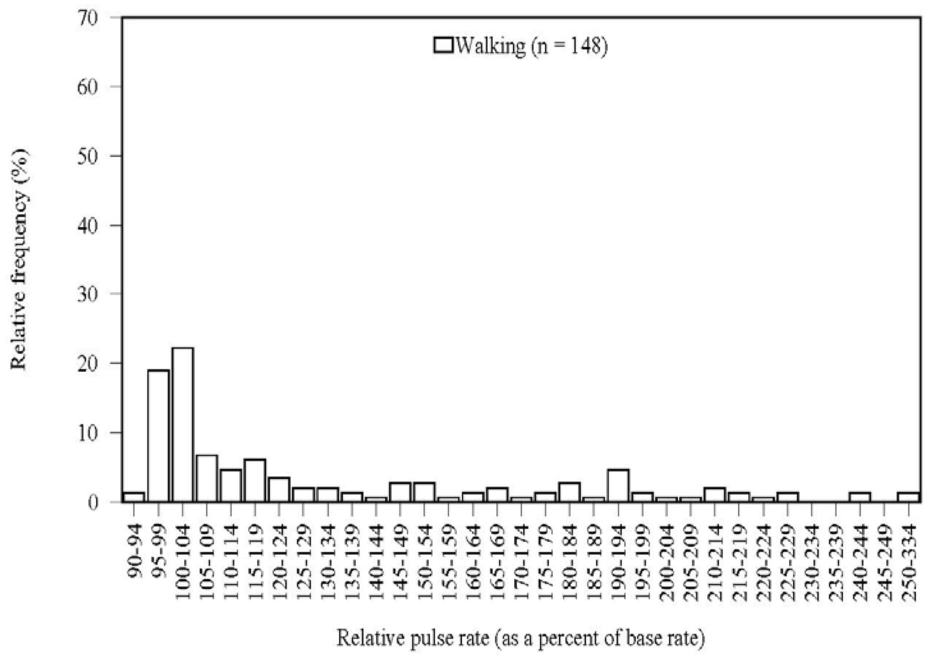

Fig. 5.6. Relative frequency of relative pulse rates (as % of base rate) for the walking activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

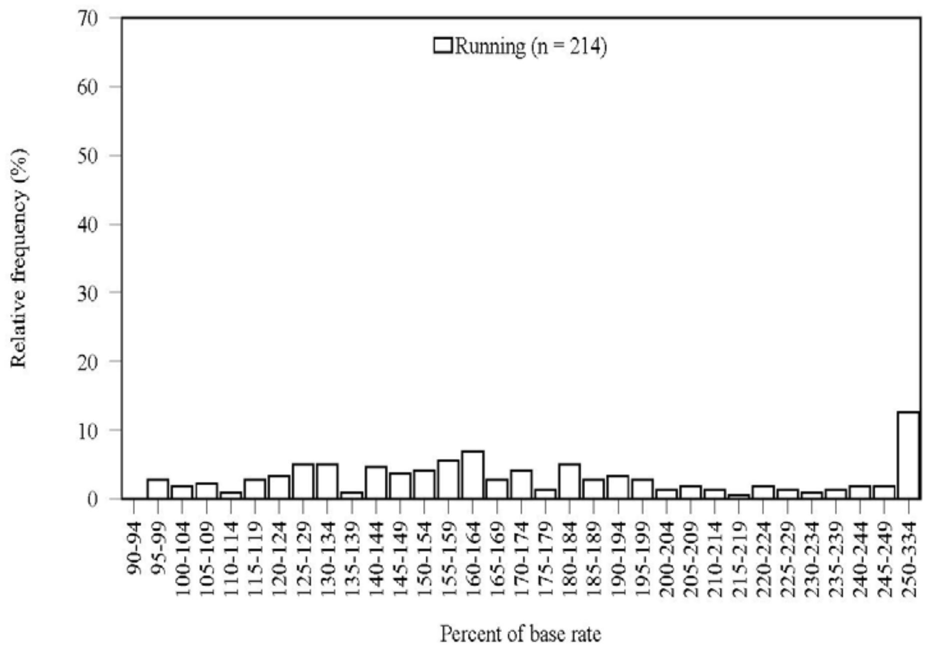

Fig. 5.7. Relative frequency of relative pulse rates (as % of base rate) for the running activity of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

Table 5.2. Descriptive characteristics of relative pulse rates (as % of base rate) for 2 categories of activities classified as inactive (bedded and standing activities) and active (grooming, feeding, walking, and running activities) using 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

			Relative pulse rates				Percent of 1-min scans ≤ the following relative pulse rates				
Activity	No. of 1-min obs	Percent of all activities	0	min	max	SE	100	101	102	103	104
Inactive	1,737	69.2	99.9	90.2	132.9	0.06	67.0	86.8	94.2	94.9	96.5
Active	772	30.8	139.7	91.8	331.5	1.73	12.2	17.5	22.4	25.4	28.5

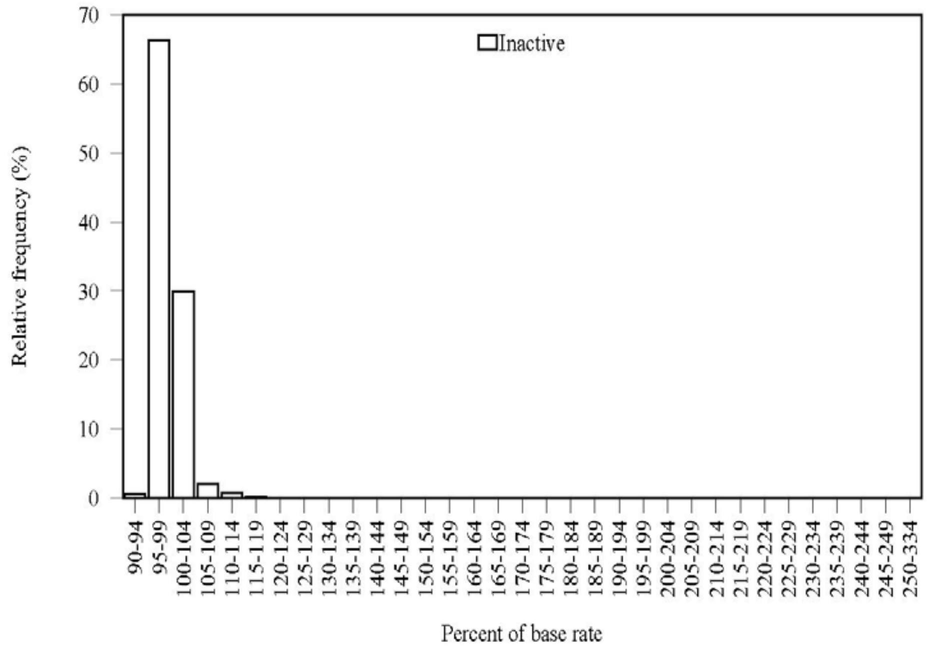

Fig. 5.8. Relative frequency of relative pulse rates (as % of base rate) for inactive (bedded and standing) activities of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

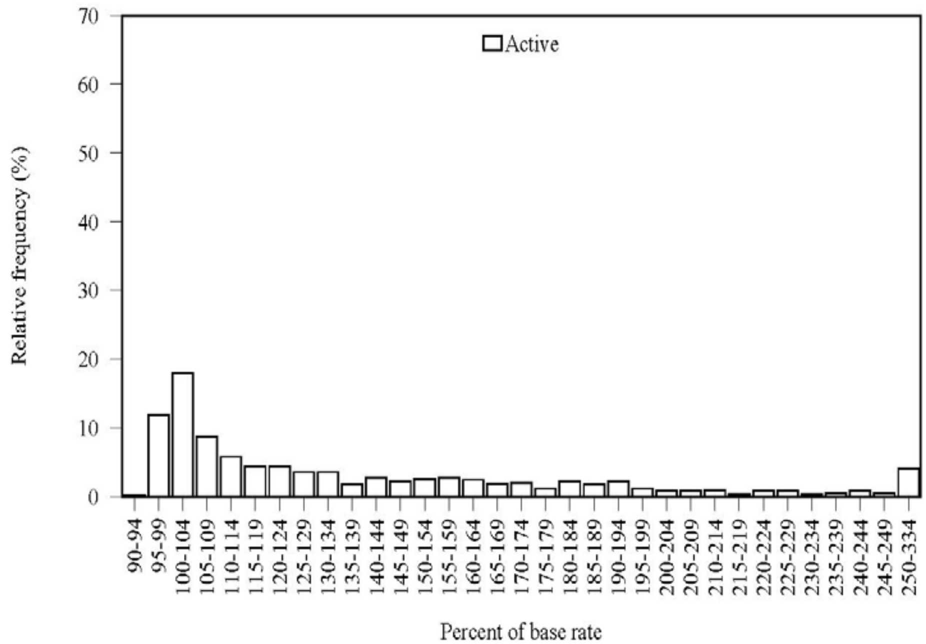

Fig. 5.9. Relative frequency of relative pulse rates (as % of base rate) for active (grooming, feeding, walking, running) activities of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994. Data based on 2,509 1-min samples.

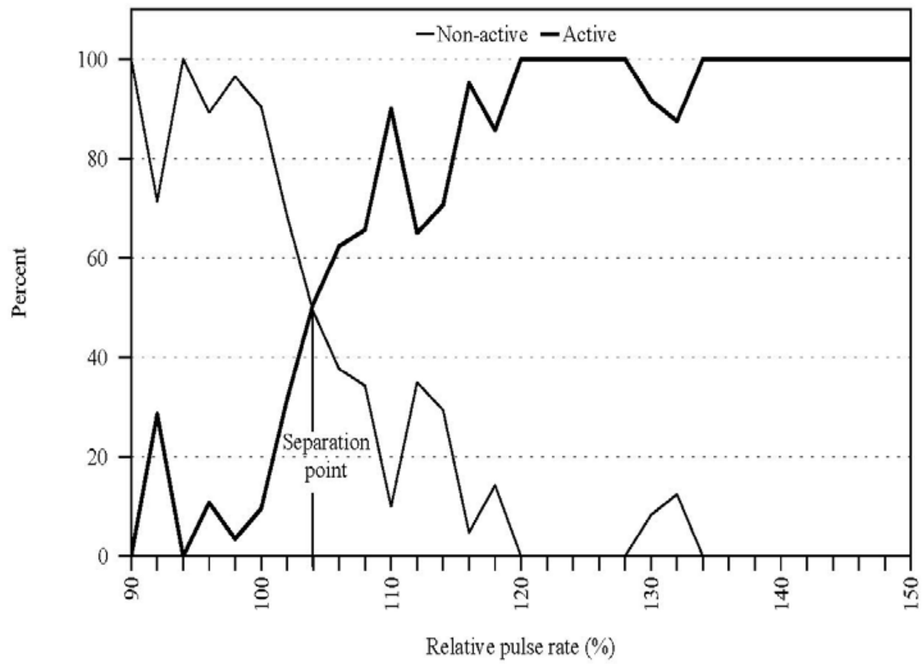

Fig.5.10. Accuracy of correctly identifying inactive and active activities against a range of relative pulse rates (as % of base rate) for 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors in Dimmit County, Texas, August 1994 (bedded and standing activities grouped as inactive, all other activities grouped as active; the inactive plots left of the separation point and active plots right of the separation point were correctly identified). Data based on 2,509 1-min samples.

Table 5.3. Accuracy of discriminating between inactive (bedded or standing) and active (grooming, feeding, walking, and running) activities of 3 tame, female white-tailed deer fitted with 4 radio-transmitting collars containing variable-pulse activity sensors and using a relative pulse rate (as % of base rate) separation point of 104% in Dimmit County, Texas, August 1994.

Relative pulse rate	Inactive obs	Active obs	Total
≤104%	1,677 (88.4%)[a]	220 (11.6%)	1,897
>104%	60 (9.8%)	557 (90.2%)[b]	612
Total	1,737	772	2,509

[a]Percent of observations correctly identified as inactive.

[b]Percent of observations correctly identified as active.

DISCUSSION

We were unable to correctly identify individual activities based on relative pulse rates because running was the only activity consistently different from other activities. However, a significant interaction occurred between transmitters and the running activity as a result of differences between mean relative pulse rates for transmitters 290 and 1328. It is unknown why the means differed, but varying sensitivity between transmitters was likely a factor. Differences in the amount of time spent running, or running level (i.e., trotting or running) within each 1-min observation may have been a factor as well. Mean differences also may have been due to differences in collar fit, even though attempts were made to fit all collars uniformly.

Our level of discrimination between specific activities was similar to results of previous studies. Misclassification arises because activity ranges along a continuum with specific activities overlapping in amount of head and neck movement. Thus, different activities can produce the same amount of relative collar movement. The ability to distinguish between bedded and standing has proven especially difficult in previous studies (Gillingham and Bunnell 1985, Beier and McCullough 1988).

In addition, bedded and standing deer are not always motionless and deer that are feeding and walking slowly commonly do not move their head and neck. Bedded and standing deer also may activate perpendicularly-oriented sensors when they look different directions. This right-to-left head movement is likely a minor problem with parallel-oriented sensors (Relyea et al. 1994). In contrast, feeding deer may keep their head down for several minutes with imperceptible head and neck movement from side to side or up and down. An alert deer walking slowly with its neck held horizontally also causes little collar movement. Gillingham and Bunnell's (1985) tip-switch collars transmitted an active signal 31% of the time when an animal was bedded because of grooming and slight movements. As in our study, Relyea et al. (1994) observed inactive pulse rates when deer were moving and active pulse rates when deer were stationary.

A further problem is that activities other than bedded are frequently of short duration. A deer may stand alert, feed, and walk several times within a min. Detection of each activity is difficult using scan times $\geq$1 min, but to group several activities together loses resolution and may bias results. Deer in our study averaged 1.3 activities per 1-min observation. A 30-sec scan time may be more appropriate for future white-tailed deer activity studies (Skinner 1994).

Jackson et al. (1972) recognized the problem of overlapping patterns of collar movement among different activities and grouped activities into broad categories. We chose to group bedded and standing activities together because of a high degree of overlap in relative pulse rates between these 2 activities. These 2 activities also involved the least amount of head and neck movement and were the most difficult to accurately separate by previous researchers (Gillingham and Bunnell 1985, Beier and McCullough 1988). The remaining 4 activities were grouped because they all involve at least some degree of head and neck movement. Running was included in this second category because mean relative pulse rates were not different from grooming, feeding, and walking activities for 6 of 12 Tukey's studentized range tests. In addition, running occurred very infrequently with study animals, unless they were harassed and forced to run by the observer.

Accuracy in our study improved after grouping the 6 activities into 2 categories. The separation point, at a relative pulse rate of 104%, allowed for the correct identification of 88.4% of observations as inactive and 90.2% of observations as active. Several other researchers have reported similar improvements in accuracy after grouping activities into broad categories. Thus, researchers may have to be content to group activities into broad categories rather than trying to identify specific behaviors.

CONCLUSIONS

Our system, using number of pulses per min, perpendicularly-oriented sensors, and 1-min scan times, accurately identified deer as active (90.2%) when relative pulse rates were >104% and as inactive (88.4%) when pulse rates were ≤104%. The additional time savings of instant computer analysis of incoming data in our system was very efficient. As suggested by Relyea et al. (1994), accuracy may be further improved by combining our monitoring system with parallel-oriented activity sensors to take advantage of apparent higher reliability of parallel sensors in discriminating active from inactive animals. Shorter scan times (e.g., 30 sec) may also improve accuracy.

ACKNOWLEDGMENTS

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APPENDIX

Appendix A1

Previous Activity Monitoring Studies

Appendix A1. Summary of previous activity monitoring studies indicating methods and accuracy of discriminating activities.

Study	Species	*n*	Transmitter type	Sensor orientation	Monitoring system	Scan time	Activities discriminated
Gillingham and Bunnell (1985)	Black-tailed deer (*Odocoileus hemionus columbianus*)	4	Tip-switch	Parallel	Strip-chart	1 min	Inactive vs. ">50% head-down"
Gillingham and Bunnell (1985)	Black-tailed deer	4	Variable-pulse	Perpendicular	Strip chart	1 min	None
Risenhoover (1986)	Moose (*Alces alces*)	1-7	Tip-switch	Parallel	Strip chart	Variable	Feeding vs. bedded
Beier and McCullough (1988)	White-tailed deer (*O. virginianus*)	13	Tip-switch	Parallel	Strip chart	5.25 min	Bedded vs. non-bedded
Kufeld et al. (1988)	Mule deer (*O. h. hemionus*)	4	Tip-switch	Parallel	Strip-chart	10 min	Feeding vs. "other"

Appendix A1. Continued.

Study	Species	*n*	Transmitter type	Sensor orientation	Monitoring system	Scan time	Activities discriminated
Hansen et al. (1992)	Dall's sheep (*Ovis dalli*)	1-5	Tip-switch	Parallel	Strip chart	1 min and 5 min	Inactive vs. active
Green and Bear (1990)	Rocky Mountain elk (*Cervus elaphus*)	?	Tip-switch	Parallel	Manual	Variable	Feeding, resting, moving
Hayes and Krausman (1993)	Desert mule deer (*O. h. crooki*)	5	Tip-switch	Parallel	Manual	Variable	Active vs. inactive (bedded or standing)
Relyea et al. (1994)	Desert mule deer	10	Variable-pulse	Perpendicular	Computer	1-5 min	None
Skinner (1994)	White-tailed deer	6	Tip-switch	Parallel	Computer	30 sec	Bedded vs. feeding

CHAPTER 6

AGE-SPECIFIC ACTIVITY RATES OF MALE WHITE-TAILED DEER IN SOUTHERN TEXAS[1]

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[1]Hellickson, M. W., K. V. Miller, R. L. Marchinton, and C. A. DeYoung. To be submitted to the Journal of Wildlife Management.

Abstract: Knowledge of the age-specific activity rates of male white-tailed deer (*Odocoileus virginianus*) is required for making informed management decisions as the popularity of non-traditional management programs increase. We combined radio-transmitting collars equipped with variable-pulse activity sensors with an automated telemetry system to quantify relative activity rates of 35 males in southern Texas during July 1993-October 1995. Males within 2.4-km of the data collection unit were monitored for 3 to 28 months. We categorized each of 470,443 1-min observations as inactive or active. Activity data were grouped into 2-hour intervals and divided into prerut, rut, postrut, spring, and summer periods and analyzed for age class and period effects. Males were active an average of 42.6% (±2.1 SE) of the time monitored. Seasonal and monthly diel activity patterns within years were variable. Activity levels were highest during January and September-October and lowest during March and April-August. Males were most active during the evening crepuscular period except during rut when diurnal activity was highest. Activity rates were highly variable, with some males >4 times as active as other males. Rates tended to decrease as individuals increased in age. Activity rates were highest for young and middle-aged males and lowest for mature and old males. Activity appeared to be unrelated to forage quantity and quality, precipitation, estimated density, or antler and body size. We suggest that changes in activity rates among individuals and age classes may be explained in part, by social interactions, relative dominance, and the varying ability among males to assimilate into bachelor groups.

INTRODUCTION

Extensive research has focused on the activity cycles of white-tailed deer due to their popularity with the hunting public, wide distribution, and economic importance (Teer and Forest 1968, Pope et al. 1984, Lassiter 1985). Some landowners realize more profit from deer hunting leases and the sale of commercial hunts than that generated from standard agricultural practices (Ramsey 1965, Pope et al. 1984, Payne et al. 1987). This source of income has encouraged many landowners to implement management programs specifically for white-tailed deer.

Landowner-driven deer management strategies designed to increase male age structure and balance sex ratios, such as Quality Deer Management (QDM), are becoming increasingly popular across the U.S. (Miller and Marchinton 1995). Most land areas in private ownership in the eastern U.S. are relatively small and not enclosed by deer-proof fencing. Many landowners and hunters are concerned how activity patterns of older-aged males may impact management effectiveness on their land. If activity rates increase as males mature, they may become more susceptible for harvest on adjoining properties. No research has been conducted to determine if activity rates change as males mature. In addition, little is known about the activity rates of mature males, although this information is critical for proper management.

White-tailed deer are primarily crepuscular in their daily activity patterns over most of their range (Michael 1970, Pledger 1975, Ozoga and Gysel 1972, Kammermeyer and Marchinton 1977, Ockenfels and Bissonette 1982, Herriges 1986, Beier and McCullough 1990). One study reported highest activity near sunrise (Marchinton 1968), while other studies have reported highest activity near sunset (Guyse 1978, Hosey 1980, Beier and McCullough 1990). However, 1 study found that the bimodal peak changed among seasons (Kammermeyer and Marchinton 1977). Low levels of activity occur during early morning (0100-0500; Marchinton 1968, Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981), midmorning (1000-1200; Marchinton 1968, Pledger 1975, Skinner 1994), and late evening (2100-2400; Hosey 1980, Ivey and Causey 1981) hours.

Early studies reported that deer were most active during diurnal periods (Guyse 1978, Kammermeyer and Machinton 1977, Hosey 1980, Holzenbein and

Schwede 1989). However, more recent studies have reported either nocturnal peaks in activity or the absence of any diel activity rhythm (Skinner 1994). Other studies have reported distinct crepuscular patterns during some seasons and a lack of any pattern (Hood 1971, Demarais et al. 1989), or a shift to a single peak (Beier and McCullough 1990) during other seasons. Naugle et al. (1997) reported that deer changed from a diurnal activity pattern to a crepuscular pattern between years. Minor activity peaks have been reported at midday and midnight (Michael 1970, Hood 1971, Herriges 1986, Inglis et al. 1986).

Activity rates have also varied by region. In southern Texas, the monthly peak in activity occurred during January, while the low occurred during September (Michael 1970). In southern Michigan, greatest activity occurred during May and October, with lowest activity during January-February (Beier and McCullough 1990). Most studies on northern deer reported lowest seasonal activity during winter and highest during fall (Behrend 1966, Carbaugh et al. 1975, Beier and McCullough 1990). However, deer activity was reported to be highest during winter in South Dakota (Sparrowe and Springer 1970). Activity rates were higher during fall than summer in Georgia (Kammermeyer and Marchinton 1977).

Fall and winter activity rates have been further divided into different periods of the breeding season. Two studies reported that activity peaked during rut (Pledger 1975, Ivey and Causey 1981), while other studies have reported prerut (Holzenbein and Schwede 1989) and postrut (Guyse 1978, Hosey and Causey 1979, Hosey 1980, Skinner 1994) peaks.

Differences in activity rates have been reported among individual deer (Hosey 1980) and sexes (Beier and McCullough 1990), while another study found that activity rates were positively correlated to age (Pledger 1975). However, other studies have reported no age- or sex-related differences (Fritzen et al. 1995). One study reported that large-antlered males were more active than small-antlered males (Beier and McCullough 1990), while another study reported that differences in activity rates were due to changes in population density and were unrelated to changes in forage quantity or quality (Fritzen et al. 1995).

Most previous telemetric studies on white-tailed deer activity have provided limited information because of (1) short transmitter battery life ($\leq$5 months; Marchinton 1968, Sparrowe and Springer 1970, Jackson et al. 1972) or study duration ($\leq$5 months; Hosey 1980, Ivey and Causey 1981, Skinner 1994, Naugle et al. 1997); (2) bias toward females (Hood 1971, Pledger 1975, Ivey and Causey 1981, Herriges 1986, Holzenbein and Schwede 1989, Naugle et al. 1997); (3) bias toward young deer (Jackson et al. 1972) or young males (Hosey 1980, Beier and McCullough 1990); (4) bias toward nocturnal observations (Fritzen et al. 1995); (5) small sample size (Kammermeyer and Marchinton 1977, Guyse 1978, Hosey 1980, Ockenfels and Bissonette 1984, Skinner 1994); (6) non-random capturing techniques; or (7) limited telemetric methodology (Demarais et al. 1989; Beier and McCullough 1990). In addition, most results are not applicable to southern Texas because of inherent environmental differences. No Texas studies have used the newer methodologies now available.

We quantified activity patterns of male white-tailed deer using radio-transmitting collars equipped with continuously variable motion sensors to record relative activity on a year-round basis. These radio transmitters allowed the ability to determine age-specific differences in activity levels among males on a monthly, seasonal, and annual basis. Our *a priori* hypotheses were as follows:

H_0: Monthly, seasonal, and annual activity levels will be equal for individual males and among different age classes.

H_{a1}: Males of all ages will exhibit a primarily crepuscular diel activity patterns.

H_{a2}: Seasonal activity levels will be highest during rut, with lows during spring and summer for all ages and age classes.

H_{a3}: Mature males will be significantly more active than other age classes during rut.

H_{a4}: Activity levels will increase in individual males as they mature.

METHODS

The study took place on the 18,020-ha Faith Ranch in Dimmit and Webb counties, Texas. Annual mean minimum and maximum temperatures were 15° and 29° C, respectively. Summer temperatures were high, often exceeding 38° C and winters were mild with temperatures rarely below freezing (Sanders and Gabriel 1985). Annual mean precipitation was 54.6 cm with the majority in May and September (Sanders and Gabriel 1985).

The gently rolling terrain was dominated by honey mesquite (*Prosopis glandulosa*), guajillo (*Acacia berlandieri*), blackbrush acacia (*A. rigidula*), prickly pear cactus (*Opuntia lindheimeri*), and tasajillo cactus (*O. leptocaulis*). Additional shrub species included twisted acacia (*A. schaffneri*), guayacan (*Guaiacum angustifolium*), lotebush (*Zizyphus obtusifolia*), kidneywood (*Eysenhardtia augustifolia*), spiny hackberry (*Celtis pallida*), and whitebrush (*Aloysia gratissima*). Dominant grasses included red grama (*Bouteloua trifida*), pink pappus (*Pappophorum bicolor*), threeawn grasses (*Aristida* spp.), and bufflegrass (*Cenchrus ciliarus*) and common forbs included western ragweed (*Ambrosia cumanensis*), goldenweed (*Isocoma* spp.), bundleflowers (*Desmanthus* spp.), crotons (*Croton* spp.), bladderpods (*Lesquerella* spp.), and plantain (*Plantago* spp.).

Animal Capture.–Free-ranging male (≥1.5 years old) white-tailed deer were randomly captured (Leon et al. 1987) during October 1992-94 using the helicopter drive-net (Beasom et al. 1980) or net gun (DeYoung 1988) techniques. All males were aged by the same observer to reduce bias and placed into 1 of 8 age categories according to tooth replacement and wear (TRW; Severinghaus 1949). Tooth replacement and wear was chosen over the cementum annuli technique (Low and Cowan 1963) because TRW is less intrusive and less time consuming (DeYoung 1989).

Main beam length, antler basal circumference, and tine lengths were measured on both antlers and combined with inside antler spread. Remaining antler circumferences were estimated to obtain gross Boone and Crockett Club (BCC) scores according to guidelines provided by Nesbitt and Wright (1997). Number of antler points (≥2.54 cm) was also recorded. Chest girth was measured immediately behind the shoulder. A retractable steel tape was used and all measures were to the nearest 0.32 cm (0.125 in).

Males were fitted with frequency-specific (150-151 Mhz) radio transmitters containing variable-pulse activity sensors (Advanced Telemetry Systems [ATS], Isanti, Minn.) attached to leather collars. Sensors used mercury switches that added pulses to the base pulse rate of the transmitter each time the collar tipped from side to side, linearly increasing as collar movement increased (R. Huempfner, ATS, personal communication). Sensors were oriented perpendicular to the long axis of the animal's body, contrasting with parallel orientation of tip-switches. Attempts were made to fit each male similarly with respect to collar tightness because loose-fitting collars allowed too much transmitter movement, while tight collars restricted movement, both of which biased sensitivity.

Data Collection Unit.–The data collection unit was computer controlled and consisted of a 3-m omni-directional antenna (RA-6B; Telonics, Mesa, Ariz.) attached to a 6.1-m utility pole and connected to a scanning receiver (RSU2000; ATS, Isanti, Minn.) and a small computer data logger (DCCII; ATS, Isanti, Minn.). The receiver and data logger were enclosed in a weather-resistant container. A 12-volt battery connected to 2 solar panels powered the unit.

The computer scanned radio frequencies to monitor individual males for 15-sec intervals. If a signal was received during the 15-sec interval, the computer locked onto that frequency for one min, recording the number of pulses produced during the 1-min scan time. A 1-min scan time was chosen *a priori* to reduce likelihood of multiple activities occurring during the sampling interval (Relyea et al. 1994) and to avoid overestimating time spent active (Beier and McCullough 1988). Year, Julian day, time (24-hr system), radio frequency, and pulse total were then stored in the data logger, while the unit switched to the next frequency pre-programmed into the frequency table of the scanning receiver.

Transmitter frequencies were set by the manufacturer before shipment. However, this frequency was not always the frequency best received by the data collection unit. Proper frequencies were determined by periodically programming additional frequencies into the frequency table. Frequencies with the fewest observations were determined when data were offloaded. These frequencies were then deleted from the frequency table.

Range of the data collection unit was tested prior to placement in the 4,366-ha study area using reference transmitters placed at varying distances from the unit. Proper placement within the study area was determined by sampling from the points of highest elevation using a hand-held scanning receiver (TR2, Telonics, Mesa, Ariz.) and 4-element yagi antenna (ATS, Isanti, Minn.). The unit was then moved to an elevated ridge near the center of the study area where the highest number of transmittered males were received by the hand-held unit. Unit reception rate, accuracy, and range were re-tested after placement in the study area.

Data Coding.–The 24-hour cycle was divided into 4 periods that included a morning crepuscular period (0600-0759), a diurnal period (0800-1759), an evening crepuscular period (1800-1959), and a nocturnal (2000-0559) period. Seasons were established based on conception dates estimated by fetus measurements (Hamilton et al. 1985) from 50 females collected on the study area during March-April 1994 (Ruthven et al. 1995). Timing of velvet and antler shedding and nutrition and temperature peaks were also considered in establishment of seasons. Seasons were delineated as: prerut (1 Oct-31 Nov), when the majority of bucks had shed their velvet but before most breeding occurred; rut (1 Dec-10 Jan), when 94% of collected females were impregnated; postrut (11 Jan-31 Mar), after most breeding occurred but before antlers were shed; spring (1 Apr-31 May), when nutritional conditions were likely highest; and summer (1 Jun-30 Sep), when temperatures were highest and most of antlerogenesis occurred.

Age classes were established *a priori* based on accuracy levels associated with the TRW aging technique (DeYoung 1989). Males were grouped into the following age classes based on estimated age at the time of first capture: young males, which included males estimated to be 1.5-2.5 years old (accuracy of placing males into the 1.5-year-old category should have been 100% due to the timing of the captures); middle-aged males, which included males estimated to be 3.5-4.5 years old; mature males, which included males estimated to be 5.5-6.5 years old; and old males, which included males ≥7.5 years old. Aging bias was likely highest within the middle and mature age classes (M. W. Hellickson, University of Georgia, unpublished data). Male ages were increased by 1 on 1 July of each successive year.

This standardized birth date was chosen based on an average 200-day gestation (Harwell and Barron 1975) and a 21 December conception mean (Ruthven et al. 1995).

Forage quantity (amount of live biomass) and a subset of forage quality (forb biomass) were measured during October 1994-November 1995 on a portion of the study area by Draeger (1996) and Hall (1997). Vegetation was sampled at $\geq$80 sites during each season using a 0.25-m^2 rectangular frame (Gysel and Lyon 1980). Clippings included all grasses and forbs rooted within the rectangular frame. In addition, green leaves, mast, and non-lignified stem tips from shrubs were clipped to a height of 1.5 m, the approximate reach of a feeding deer. Clipped vegetation was sorted into browse, grasses, and forbs, with grasses and forbs further divided into live and dead components. Vegetation was dried at 50E C for 3-5 days. Sorted vegetation was weighed to the nearest 0.1 g. Live biomass included the combined grass, forb, and browse estimates. Precipitation was measured after each precipitation event at 2 gauges within the study area. Precipitation amounts were combined between the 2 gauges to calculate an average precipitation amount for the study area for the months of August 1993-May 1995.

Deer density estimates for the study area were determined by partial-coverage helicopter surveys conducted during October-November of each year. Survey methods followed Beasom (1979), DeYoung (1985), and Beasom et al. (1986). Density estimates (R. E. Hall, Jr., Faith Ranch, personal communication) were compared to the prerut weighted mean activity rates for all males combined to evaluate relationships among density and activity rates for the years 1993-95.

Data Analyses.--Pulse rates (no. of pulses/min) for each 1-min observation were converted to relative pulse rate percentages (100 x pulse total/mean base rate) based on the mean base rates of each transmitter (58.5-62.2 pulses/min; Table 2). An earlier study (Hellickson 2002) with tame deer using the same data collection unit indicated that inactive (bedded or standing) and active (grooming, feeding, walking, and running) observations could be accurately (88.4 and 90.2% accuracy, respectively) separated using a separation point of 104% of each transmitter's base rate. Observations of standing deer were combined with bedded observations due to high overlap in activity rates and a lack of collar movement within these 2 behaviors (Hellickson 2002). This same criteria was used to classify activity level in this study. All relative pulse rates ≤104% were classified as inactive, while those >104% were classified as active.

An activity rate (% of time active; 100 x no. of active obs/total no. of obs) was the dependent variable with males as the experimental unit in all analyses. Males were not assumed to be independent because several males were sampled across years, seasons, and age classes. Activity rates were calculated for each male by 1-hour intervals (e.g., 0000-0059) for descriptions of diel activity patterns. Whenever sample sizes were insufficient ($n < 11$ males), or when analyzing all other activity patterns, a 2-hour interval (e.g., 0000-0159) was used. Only intervals with ≥2 observations were included in the data set to reduce effects caused by differences in sample size and to simplify analyses (Beier and McCullough 1990). A weighted mean activity rate (100 x total no. of all active obs combined/total no. of obs) expressed as a percentage was used (versus a simple average of individual activity rates) whenever observations were grouped into intervals ≥2 hours to further reduce effects of varying sample sizes.

Pearson's product moment correlation coefficients were used to express relationships among (1) reception rate, accuracy, and bias relative to transmitter distance from the unit; (2) estimates of forage quantity and quality by season and weighted mean activity rates for all males combined during the same seasons;

(3) monthly precipitation and weighted mean activity rates for all males combined during the same months; (4) estimated deer density and weighted mean activity rates for all males combined during prerut; and (5) number of antler points ≥2.54 cm, gross BCC score, and chest girth relative to the weighted mean activity rate by individual and grouped by age. Weighted mean activity rates by diel period and season were compared within years using weighted 1-way ANOVAs and Tukey's studentized range test (HSD) in PROC GLM (SAS Inst., Inc., 1996). Weighted mean activity rates for each age class were compared across years using these same procedures. Weighted ANOVAs were chosen because number of observations for each male varied. Repeated measures analyses were performed with 1-way ANOVAs using PROC MIXED (SAS Inst., Inc., 1996) to test for differences among years for 20 males that were monitored at ≥2 ages. Tests for daily and monthly differences in weighted mean activity rates were avoided because of independence questions. Spearman's correlation coefficients were used to test for relationships among activity rates and age classes. All treatments were considered significantly different at $P < 0.05$, although tests with $0.05 < P < 0.10$ are discussed.

RESULTS

Forty-three males were captured during 1992-94 and fitted with radio-transmitting collars containing variable-pulse activity sensors. Four males died of non-hunting-related causes prior to monitoring. An additional 4 males were censored because their home range areas exceeded the range of the data collection unit. Another 4 males were censored 4-8 months after monitoring began due to shifts in home range areas that exceeded the range of the unit. Sufficient data were collected on 35 males to compute activity rates (Table 6.1). Monitoring period ranged from 3-28 months (0 = 15.2 months). Number of 2-hour observations for each male

Table 6.1. Base rate[a], year of birth[b], duration of radiotelemetry, number of 2-hour observations, and activity rates (%)[c] for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

			1993	1994	1995		
Male no.	Base rate	Birth yr	JASOND	JFMAMJJASOND	JFMAMJJASO	*n*	Activity rate
180	60.3	1990	SOND	JFMAMJJASOND	JFMAMJJA	2,742	57.8
290	60.2	1986	ASOND	JF		1,070	19.2
291	60.2	1987		OND	JFMAMJJASO	1,126	42.5
309	59.9	1990	JASOND	JFM		1,584	35.1
310	59.9	1992		OND	JFMAMJJASO	1,119	24.2
443	60.2	1991	ND	JFM		974	33.1
444	60.2	1989		OND	JFMAMJJASO	1,682	35.5
511	58.7	1986	ND	JFMAMJJASOND	JFMAMJJASO	5,679	57.1
602	60.0	1991	JASOND	JFMAMJJASOND	JFMAMJJA	3,297	25.6

Table 6.1. Continued.

Male no.	Base rate	Birth yr	1993 JASOND	1994 JFMAMJJASOND	1995 JFMAMJJASO	*n*	Activity rate
651	58.5	1988	JASOND	J		1,143	38.8
652	58.5	1993		OND	JFMAMJJA	734	25.9
790	59.9	1985	OND	JFMAMJJASOND		4,012	23.2
862	59.8	1989	ND	JFM		362	62.3
863	59.8	1988		OND		356	39.2
924	60.3	1989	JASOND	JFMAMJJASOND	JFMAMJJ	1,114	84.4
1262	59.7	1987	JASOND	JFMAMJJASOND	JFM	3,456	34.6
1281	62.2	1990	ND	JFMAMJJASOND	J	4,198	21.3
1301	58.3	1990	ND	JFMAMJJASOND	JFMAMJJASO	5,069	30.6
1330	60.1	1987	JASOND	JF		105	50.5
1331	60.1	1987		ND	JFMAMJJASO	457	39.6

Table 6.1. Continued.

Male no.	Base rate	Birth yr	1993 JASOND	1994 JFMAMJJASOND	1995 JFMAMJJASO	*n*	Activity rate
1380	60.1	1990	ASOND	JFM		1,181	70.6
1381	60.1	1989		OND	J	540	25.1
1422	60.1	1987	SOND			324	87.4
1423	60.1	1992		OND	JFMAMJJASO	1,475	44.4
1463	60.9	1989	SOND	JFMAMJJASOND	JFMAMJJASO	4,949	57.6
1482	60.8	1987	SOND	JFMAMJJASOND	JFMAMJJASO	2,122	71.5
1541	59.5	1991	ND	JFMAMJJASOND	JFMAMJJASO	5,775	36.4
1560	60.2	1989	JAS			239	62.1
1561	60.2	1985	ND	JFM		1,469	47.0
1680	61.2	1988	JASOND	JFMAMJJASOND	JFMAMJJASO	4,140	65.9
1722	61.2	1991	JASOND	JFMAMJJASOND	JFMAMJJASO	6,607	70.1

Table 6.1. Continued.

			1993	1994	1995		
Male no.	Base rate	Birth yr	JASOND	JFMAMJJASOND	JFMAMJJASO	*n*	Activity rate
1800	61.3	1987	JASOND	JFMAMJJASOND	JFMAMJJASO	3,793	42.6
1857	60.2	1986		OND	JFMAMJJASO	1,204	18.7
1880	60.9	1989	JASOND	JFMAMJJASOND		3,513	59.5
1941	61.9	1988	ND	JFMAMJJASOND	JFMAMJJASO	5,781	24.8

[a]Base rate was the average number of pulses recorded for the transmitter when stationary.

[b]Year of birth based on estimated age at time of first capture using the tooth replacement and wear aging technique (Severinghaus 1949). All males aged by one observer to reduce bias.

[c]Activity rate was the percent of time active (no. active obs/total no. obs x 100).

ranged from 105-6,607 (0 = 2,383 2-hr obs), while estimated age at time of capture varied from 1.5-8.5 years (0 = 4.5 years).

Monitoring of activity took place during July 1993-October 1995. The computer data logger received and stored data at an average rate of 1,200 observations (i.e., 1-min scans) per day. An average of 6.3 observations occurred per 2-hour interval for each male. Observations were deleted when pulse totals were outside the expected range (57-185 pulses/min) determined when accuracy of the unit was tested with enclosed, tame deer (Hellickson 2002). Most erroneous observations were caused by males that were on the periphery of the range of the unit.

Reception rate, accuracy, and range of the data collection unit were tested after the unit was moved to the study area with reference transmitters placed at 7 areas 0.0-4.1 km from the unit. Transmitter reception rate varied from 0.5-66.6 observations per day and was negatively correlated to distance from the unit ($r_p = -0.890$, $P = 0.018$), while accuracy (% of pulse totals within the "inactive" range [$\geq$57 pulses/min, but $\leq$104% of the transmitter's base rate]) varied from 0.0-100.0% and also was negatively correlated to distance from the unit ($r_p = -0.969$, $P < 0.001$). Males were censored when home range areas exceeded 2.4 km from the unit. This distance was chosen based on range tests with reference transmitters placed 2.4 and 3.4 km from the unit.

Bias (% of obs outside the expected range) varied from 0.0-81.3% and was positively correlated to distance from the unit ($r_p = 0.972$, $P < 0.001$). However, relatively few observations occurred at distances where bias was highest because reception rate decreased as distance from the unit increased. Bias was also negatively correlated to reception rate (n/day; $r_p = -0.864$, $P = 0.014$). Additional age- and season-related bias may have occurred from improperly fitted collars or because collars were not expandable.

Diel Patterns

Males could best be described as diurnal in their diel activity patterns, although small peaks in activity occurred shortly after sunrise and at sunset (*n* = 78-81; SE = 2.0-2.9; Fig. 6.1). Activity was highest at 1800-1859 and 0700-0859 and lowest at 0500-0559 and 2200-2259. Males exhibited a diurnal activity pattern without the small peaks at sunrise and sunset during the 5 months sampled in 1993. The pattern for 1994 was similar to the pattern for all 3 years combined. A crepuscular pattern occurred during the 10 months sampled in 1995.

Season.--During prerut 1993, the bi-hourly activity pattern was diurnal (*n* = 24-25; SE = 3.8-5.1; Fig. 6.2). Prerut activity during 1994 was relatively uniform across the 24-hour period except for slight peaks near sunrise and sunset (*n* = 22-25, SE = 3.0-5.1). Prerut activity during 1995 was mostly nocturnal with peaks at 0400-0559 and 2200-2359 (*n* = 4-7, SE = 7.9-28.9). However, sample sizes were low.

The hourly activity pattern during the rut for 1993 (including 1-10 Jan 1994) was diurnal with a peak at 1200-1259 (*n* = 22-24; SE = 4.3-5.4; Fig. 6.3). A crepuscular pattern occurred during 1994 (including 1-10 Jan 1995), with a morning peak at 0800-0859 (*n* = 21-25, SE = 3.2-6.2). A crepuscular pattern in hourly activity occurred during the postrut in 1994 (*n* = 23-24, SE = 3.5-5.7) and 1995 (*n* = 18-21; SE = 2.9-5.6; Fig. 6.4). A similar crepuscular pattern in hourly activity occurred during spring 1994 (*n* = 16, SE = 3.5-7.2) and 1995 (*n* = 15-19; SE = 3.3-7.1; Fig. 6.5). The bi-hourly activity pattern for summer was diurnal during 1993 (*n* = 8-14, SE = 3.7-8.3) and crepuscular during 1994 (*n* = 16, SE = 3.0-6.1) and 1995 (*n* = 14-19; SE = 4.6-8.0; Fig. 6.6). However, the evening peak in activity was higher than the morning peak during 1994 and occurred later during 1995.

Month.–During January 1994, male activity was diurnal (*n* = 23-24; SE = 4.3-6.2) with hourly peaks 2-3 times higher than January 1995 (*n* = 16-21, 2300-2359; Fig. 6.7).

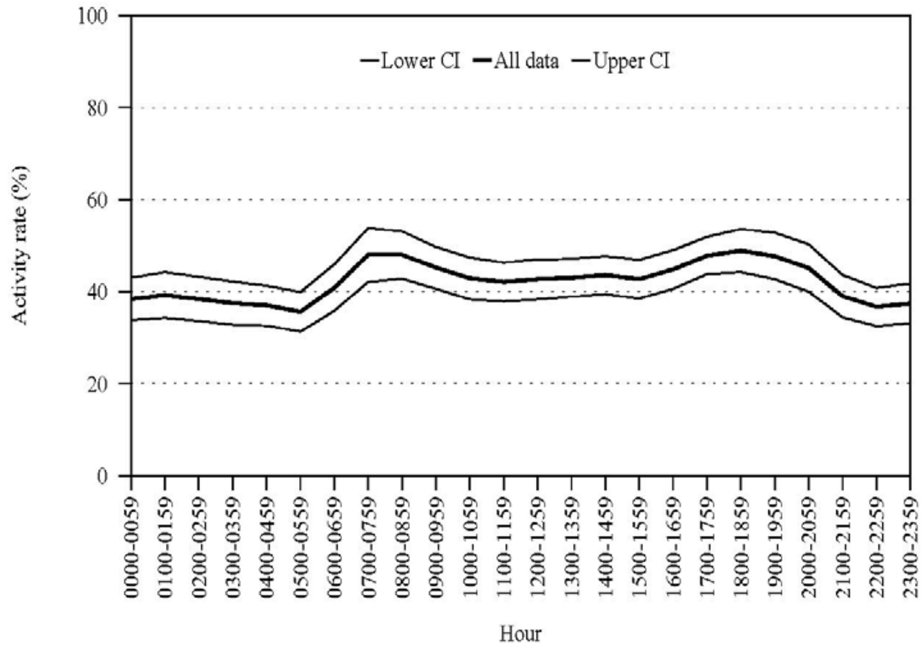

Figure 6.1. Hourly activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 78-81; SE = 2.0-2.9) with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

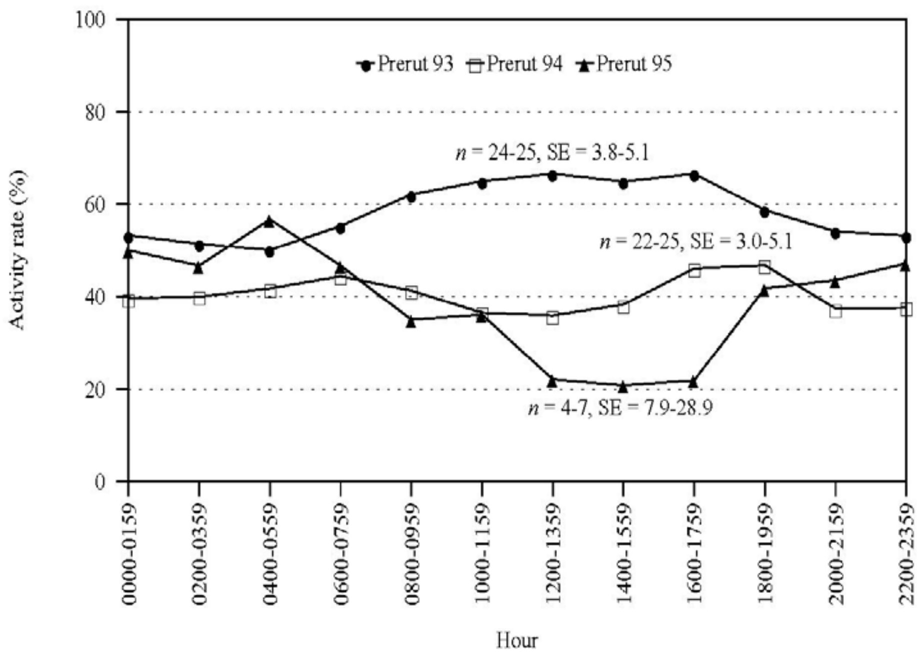

Figure 6.2. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during prerut (1 Oct-31 Nov) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

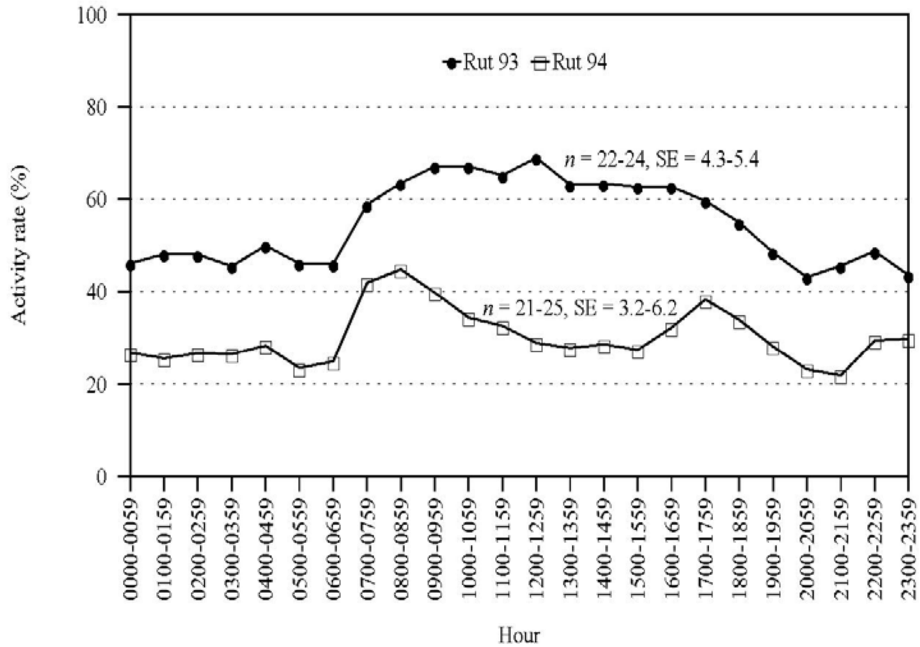

Figure 6.3. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during rut (1 Dec-10 Jan) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

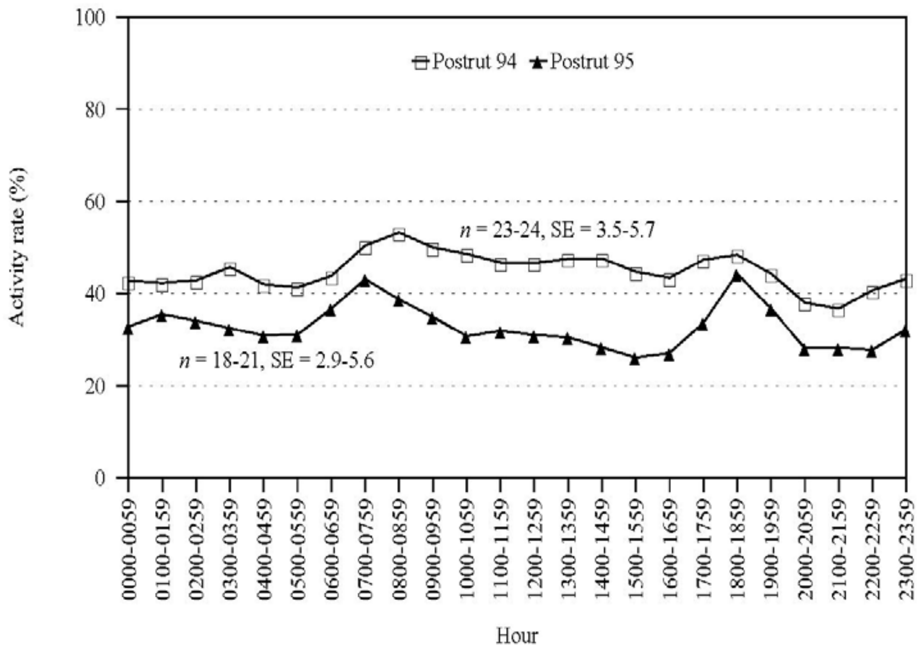

Figure 6.4. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during postrut (11 Jan-31 Mar) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

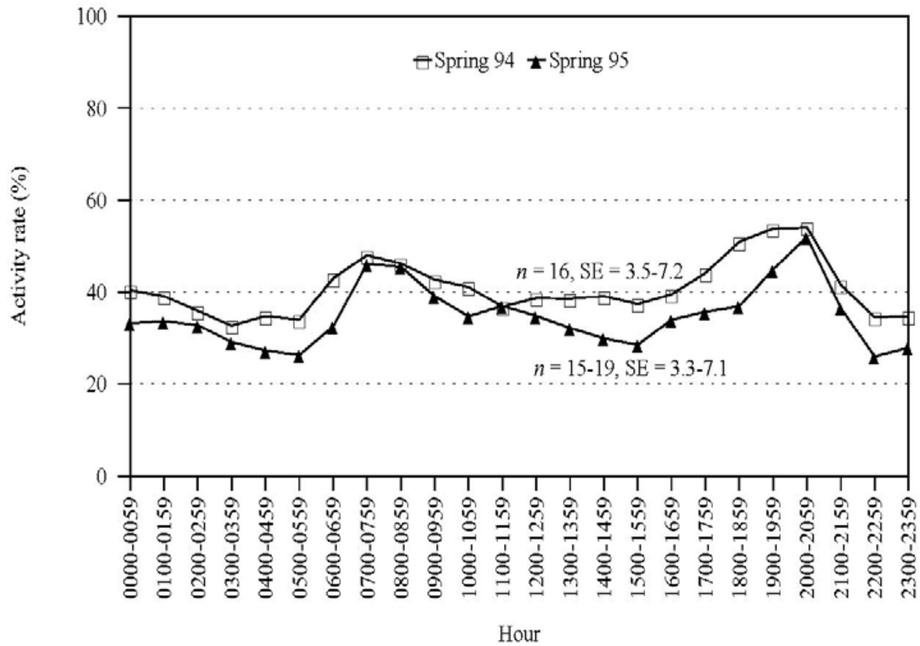

Figure 6.5. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during spring (1 Apr-31 May) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

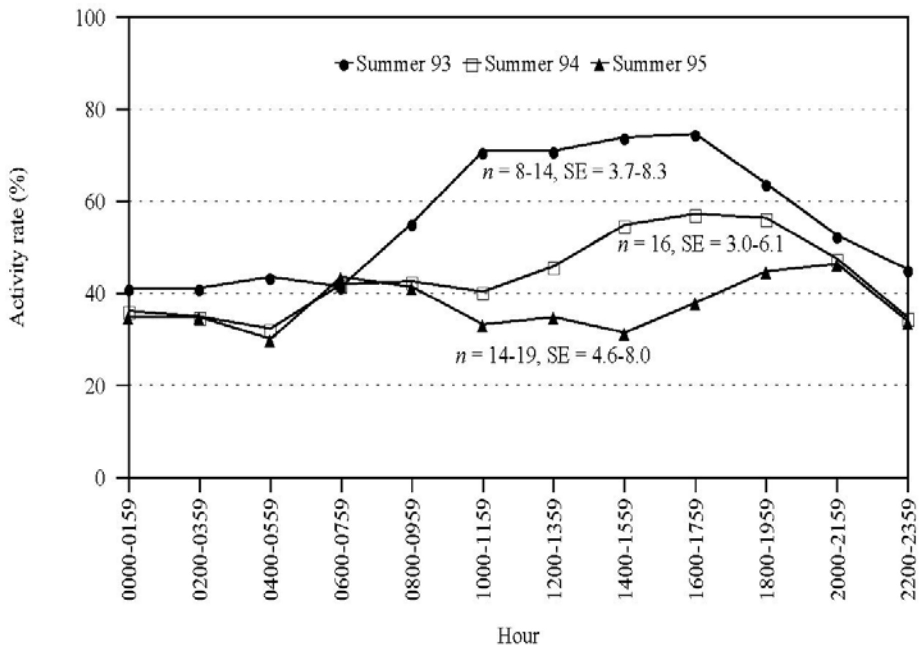

Figure 6.6. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during summer (1 Jun-30 Sep) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

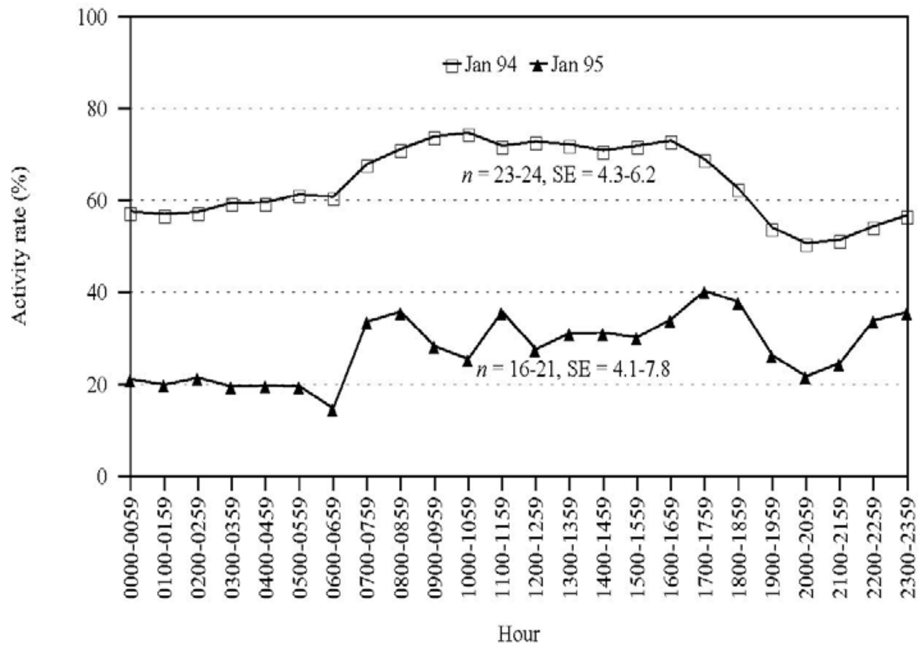

Figure 6.7. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during January for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

The hourly activity pattern was more similar between years during February with peaks near sunrise and sunset for both 1994 (*n* = 21-22, SE = 4.7-6.6) and 1995 (*n* = 17-19, SE = 3.9-6.0), but diurnal activity was lower during 1995 resulting in a more distinct crepuscular pattern for this month and year (Fig. 6.8). Hourly activity patterns were similar between years during March, but slightly higher for each hour in 1994 (*n* = 18-21, SE = 3.9-7.1) than in 1995 (*n* = 16-20; SE = 2.5-6.7; Fig. 6.9). Distinct crepuscular peaks in activity occurred during March of both years. This same pattern occurred during April 1994 (*n* = 14-16, SE = 4.1-8.7) and 1995 (*n* = 15-19; SE = 2.8-7.3; Fig. 6.10).

A crepuscular pattern in hourly activity occurred during May 1994 (*n* = 14-16, SE = 3.7-6.5) and 1995 (*n* = 12-18, SE = 3.9-8.0), but activity was higher near sunset (Fig. 6.11). Three additional peaks in activity occurred (0100-0159, 1100-1159, and 1700-1759) during 1995. Bi-hourly activity peaked at 1400-1559 and remained relatively high into the evening hours during June 1994 (*n* = 13-16; SE = 3.5-7.0; Fig. 6.12). However, a different pattern occurred during June 1995 (*n* = 7-11, SE = 6.1-13.6) with 4 peaks (0200-0359, 0800-0959, 1200-1359, and 2200-2359). A crepuscular pattern in hourly activity occurred during July 1994 (*n* = 12-16, SE = 3.9-8.3) and 1995 (*n* = 11-17, SE = 4.7-8.7), but the peak near sunset occurred later in 1995 (Fig. 6.13).

Different patterns in bi-hourly activity occurred among years during August-October. A distinct diurnal pattern occurred during August 1993, with diurnal activity as much as 2-times higher than nocturnal activity (*n* = 3-7; SE = 3.2-18.2; Fig. 6.14). A single, afternoon peak occurred during 1994 (*n* = 15-16, SE = 3.1-7.4) and a less distinct crepuscular pattern, with a morning peak occurred during 1995 (*n* = 10-16, SE = 4.3-8.6). A small, early morning (0400-0559) peak, followed by a higher midday-early evening (1100-1959) peak occurred in bi-hourly activity during September 1993 (*n* = 8-13; SE = 4.3-13.3; Fig. 6.15). A single, afternoon peak in activity occurred

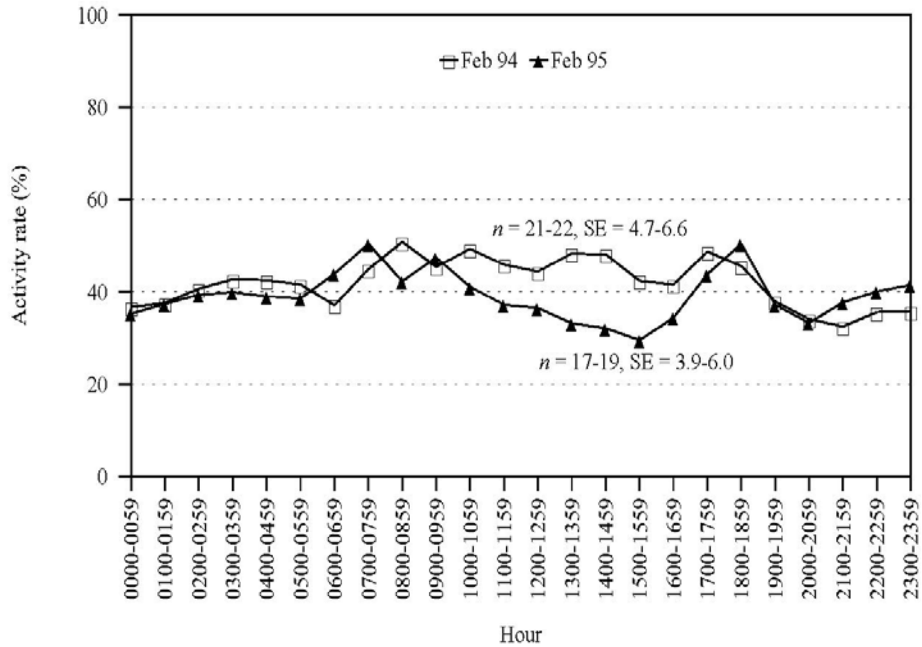

Figure 6.8. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during February for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

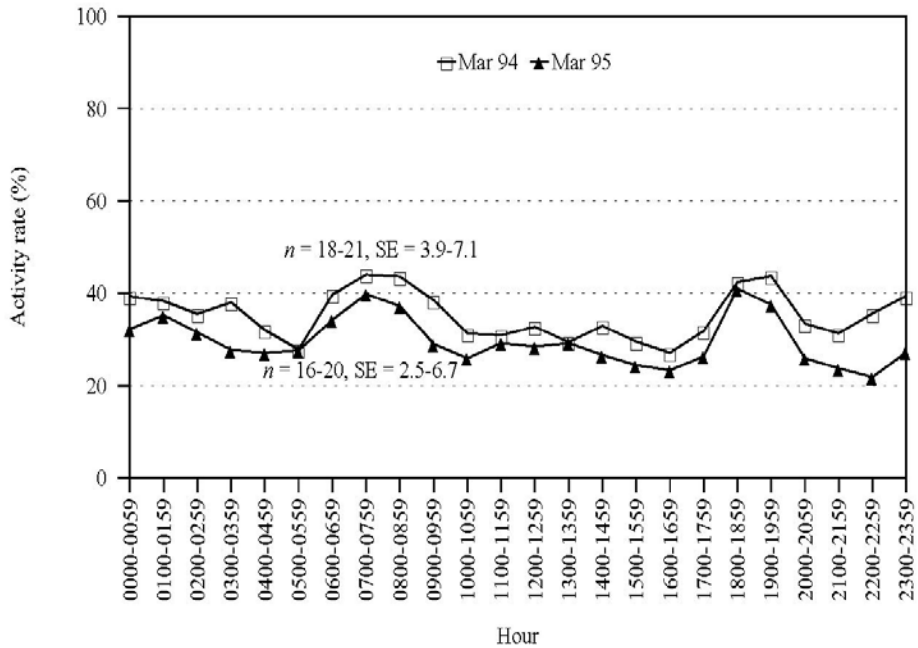

Figure 6.9. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during March for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

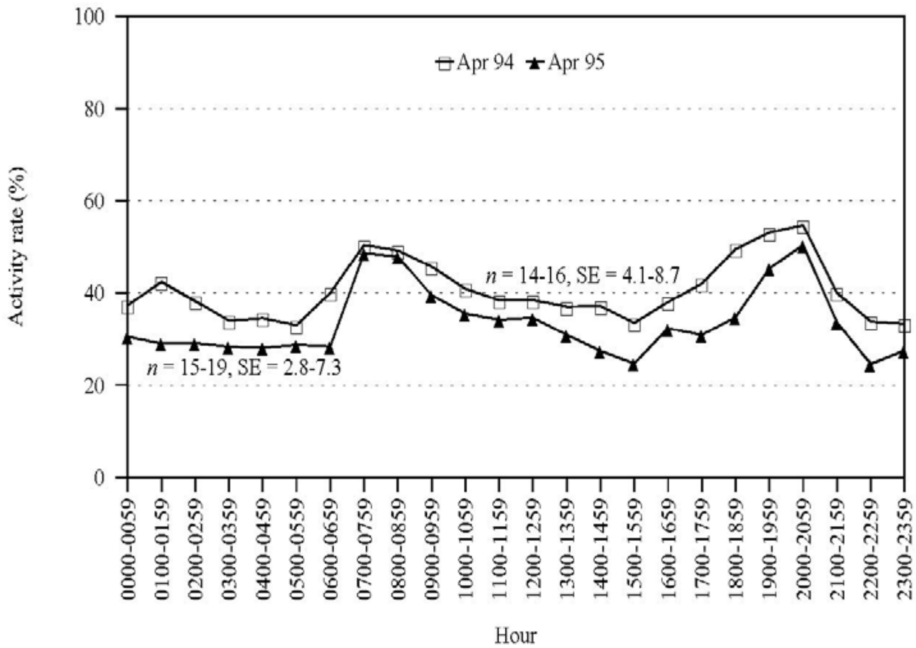

Figure 6.10. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during April for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

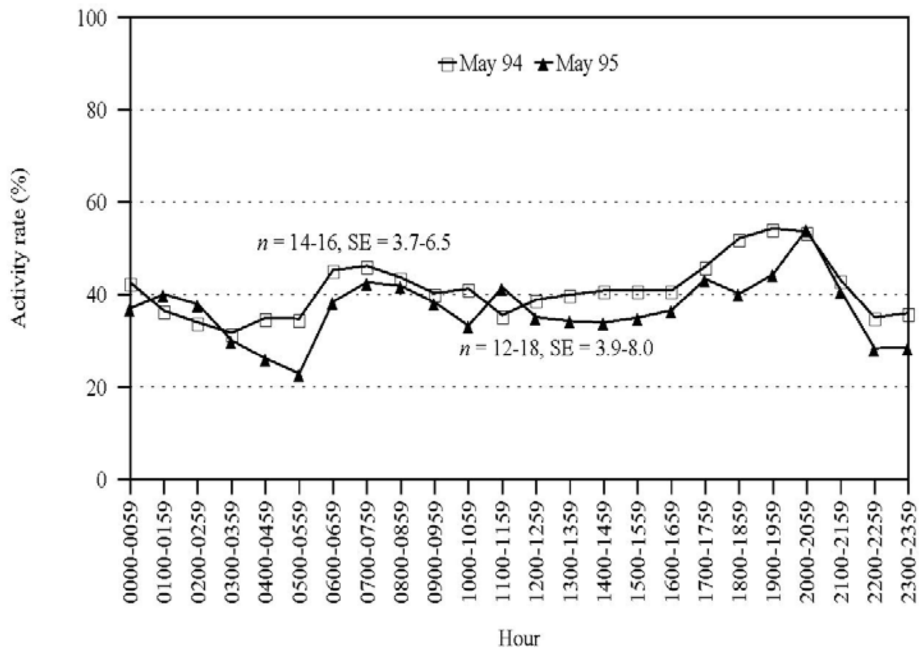

Figure 6.11. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during May for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

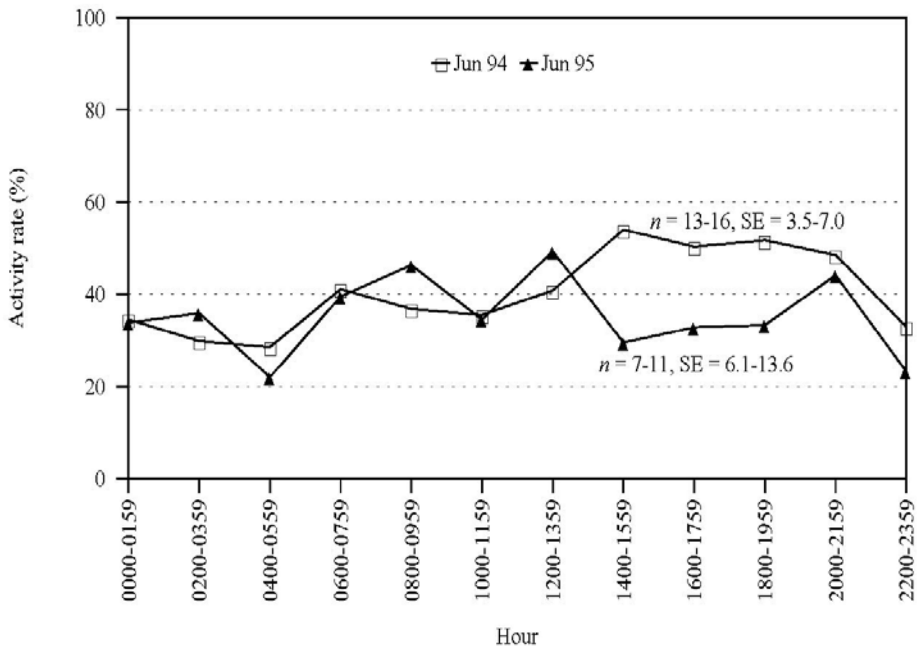

Figure 6.12. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during June for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

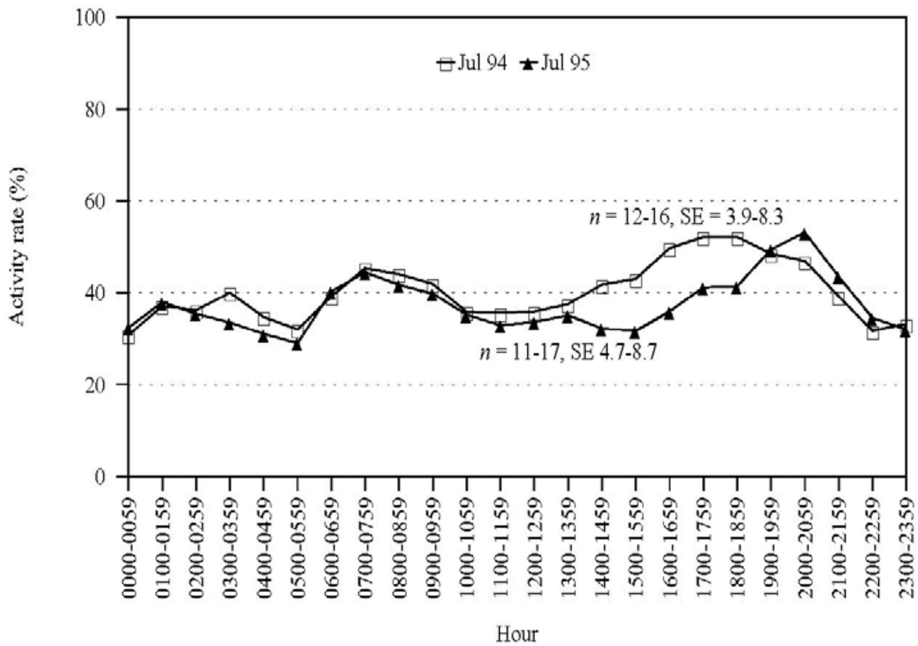

Figure 6.13. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during July for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

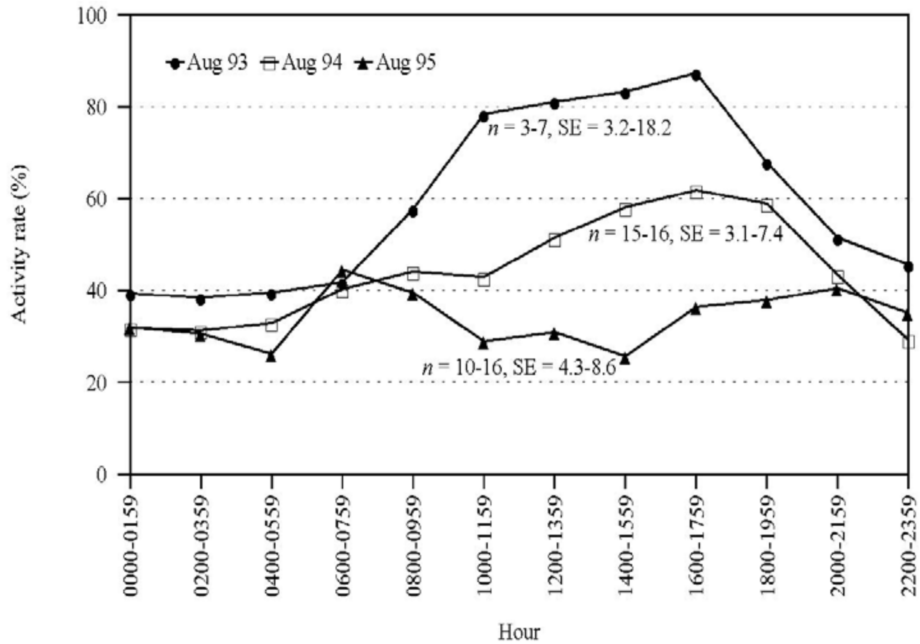

Figure 6.14. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during August for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

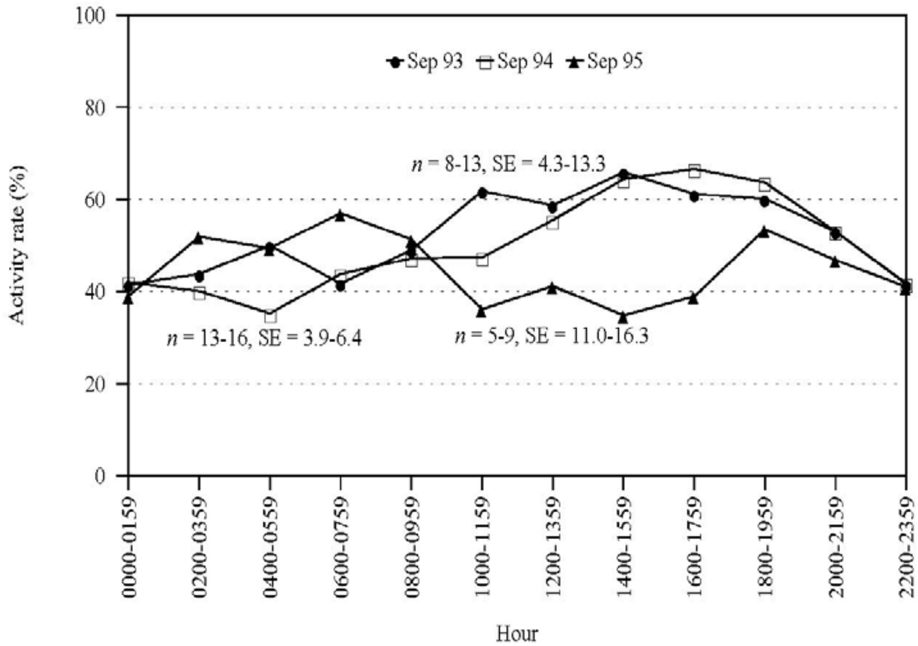

Figure 6.15. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during September for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

during 1994 (n = 13-16, SE = 3.9-6.4) and a less distinct crepuscular pattern, with a morning peak in activity, occurred during 1995 (n = 5-9, SE = 11.0-16.3).

A single, afternoon peak in activity occurred during October 1993 (n = 13-19; SE = 4.7-6.5; Fig. 6.16). A less distinct crepuscular pattern with an afternoon peak in activity occurred during 1994 (n = 12-20, SE = 3.9-7.8). A crepuscular pattern with a morning peak in activity occurred during 1995 (n = 4-7, SE = 7.9-28.9). However, peaks in activity were further apart and the afternoon low in activity was less than half the morning peak. During November 1993, male activity was diurnal (n = 20-23, SE = 4.4-6.5) with hourly rates nearly twice as high as occurred during 1994 (n = 16-21, SE 4.1-7.8) when the pattern was crepuscular (Fig. 6.17). This same pattern occurred during December 1993 (n = 20-23, SE = 4.4-5.6) and 1994 (n = 20-24; SE = 3.4-6.3; Fig. 6.18). Smaller peaks in hourly activity occurred around midnight during most months.

The bi-hourly activity pattern for all years combined was crepuscular for all age classes (Fig. 6.19). Activity peaked near sunset for the middle-aged (n = 15, SE = 4.3-6.3), mature (n = 14-16, SE = 4.1-5.1), and old (n = 6-8, SE = 3.3-11.0) age classes, while activity peaked near sunrise for young (n = 7, SE = 6.7-10.2) males. Lows in bi-hourly activity occurred at 0400-0559 for young, middle-aged, and old males and at 0200-0359 for mature males.

Activity Rates

Males were active an average of 42.6% (n = 81, SE = 2.1) of the time they were monitored (10.3 hours/day). Activity rates for all males combined by year were 54.8 (n = 26, SE = 3.8), 43.2 (n = 33, SE = 3.2), and 34.7% (n = 22, SE = 3.9) for the years 1993-95, respectively. However, activity data during 1993 included only July-December and during 1995 only January-October.

Diel Period.–Activity rates were analyzed within seasons due to a significant diel period x season interaction ($F_{12, 541}$ = 2.36, P = 0.006). Prerut activity rates peaked

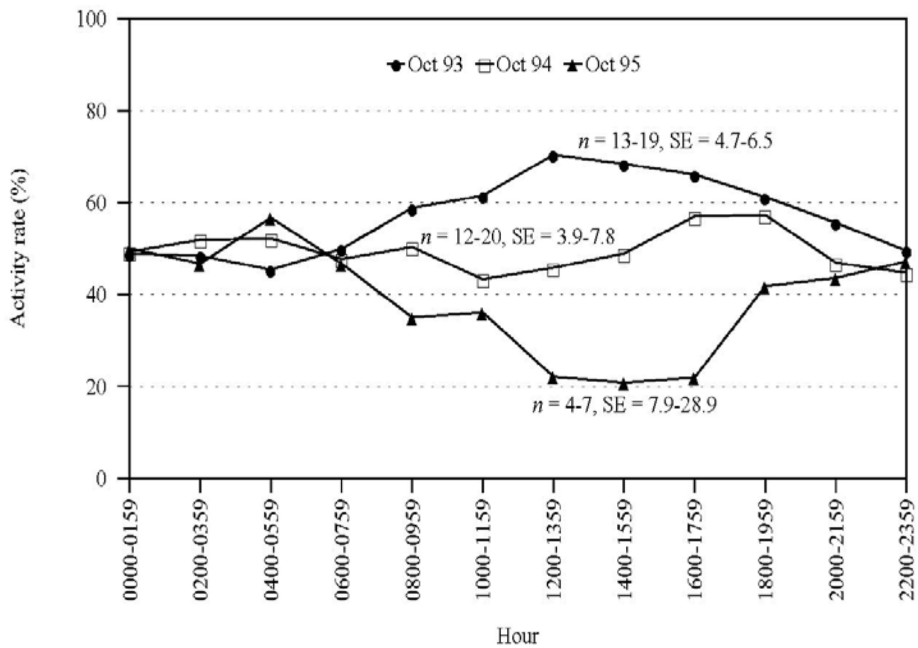

Figure 6.16. Bi-hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during October for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

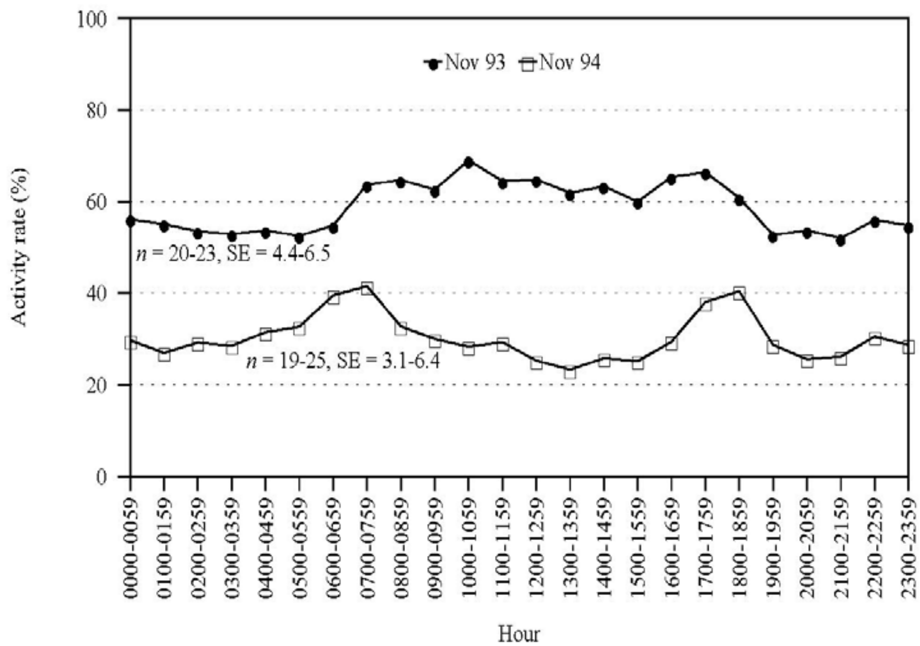

Figure 6.17. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during November for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

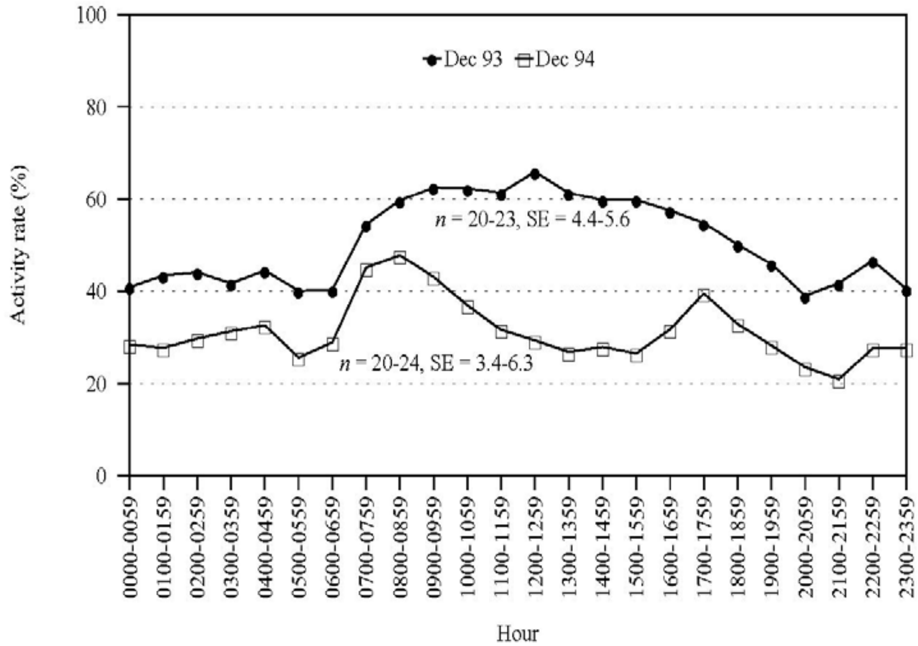

Figure 6.18. Hourly activity rates (% of time active, 100 x no. of active obs/total obs x 100) during December for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

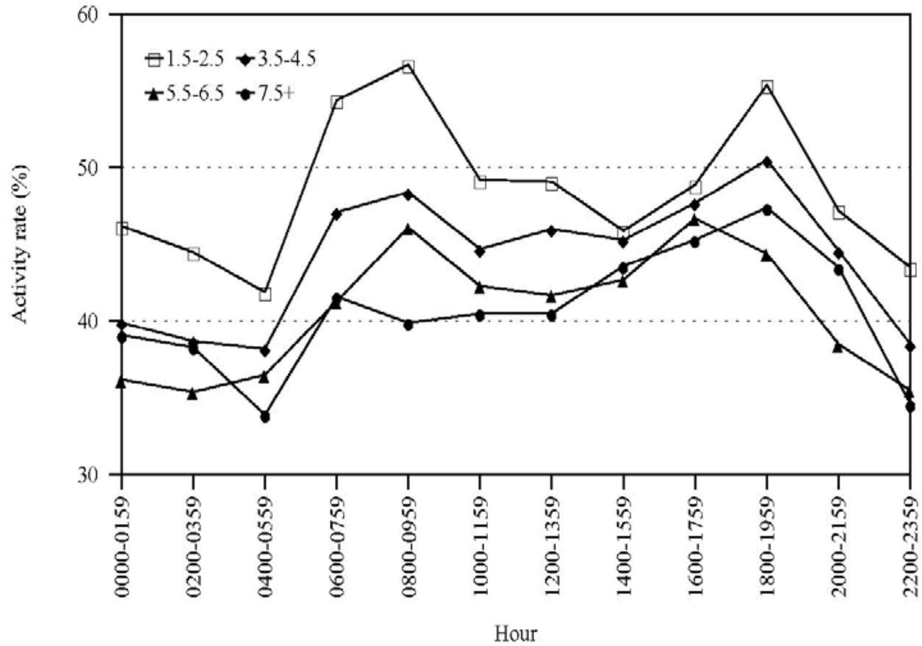

Figure 6.19. Bi-hourly activity rates (% of time active; 100 x no. of active obs/total obs; n = 2-17; SE = 2.2-16.3) by age class (yr) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

during the evening crepuscular period (51.7%) and reached a low during the diurnal (43.8%) and nocturnal (43.8%) periods, but differences were not significant ($P \geq 0.851$; $n = 33$-34; SE = 3.2-4.5; Fig. 6.20). During rut, the diurnal activity rate (48.7%) was significantly higher than the nocturnal rate (36.1%; $P < 0.001$; $n = 33$-34; SE = 3.5), but no differences were found between other periods ($P \geq 0.934$; $n = 33$, SE = 3.5-3.7). Postrut activity rates peaked during the evening crepuscular period (43.7%) and reached a low during the nocturnal period (36.1%), but differences were not significant ($P \geq 0.794$; $n = 30$-31; SE = 3.1-4.5).

Spring activity rates were significantly higher during the evening crepuscular period (45.5%) when compared to the nocturnal period (33.5%; $P = 0.018$; $n = 23$; SE = 4.0-4.1), but no differences among other periods were significant ($P \geq 0.317$; $n = 23$; SE = 3.5-5.4). Summer activity rates were significantly higher during the evening crepuscular period (50.5%) when compared to the nocturnal (34.9%; $P < 0.001$; $n = 28$-29, SE = 3.9-4.0) and diurnal (41.2%; $P < 0.001$; $n = 28$; SE = 3.1-4.0) periods. Diurnal activity rates were also significantly higher than nocturnal rates ($P = 0.038$). No additional differences among periods occurred ($P \geq 0.308$).

Season.–Activity rates for all males combined across years were highest during prerut and then declined each season thereafter, reaching a low point during spring ($n = 35$-79, SE = 2.4-3.2). However, rates were analyzed within years due to a significant season x year interaction ($F_{5,\ 195} = 4.75$; $P < 0.001$; Fig. 6.21). During 1993, seasonal activity rates peaked during prerut (56.5%) and reached a low during rut (53.3%), but seasonal differences were not significant ($P \geq 0.125$; $n = 15$-25; SE = 3.9-4.2).

Activity rates during postrut (41.9%; $P = 0.021$; $n = 24$-25; SE = 4.0-4.2) and summer (41.1%; $P = 0.047$; $n = 16$-25, SE = 4.0-4.4) 1994 were significantly higher than rates during rut (29.1%) of this same year. No additional differences occurred

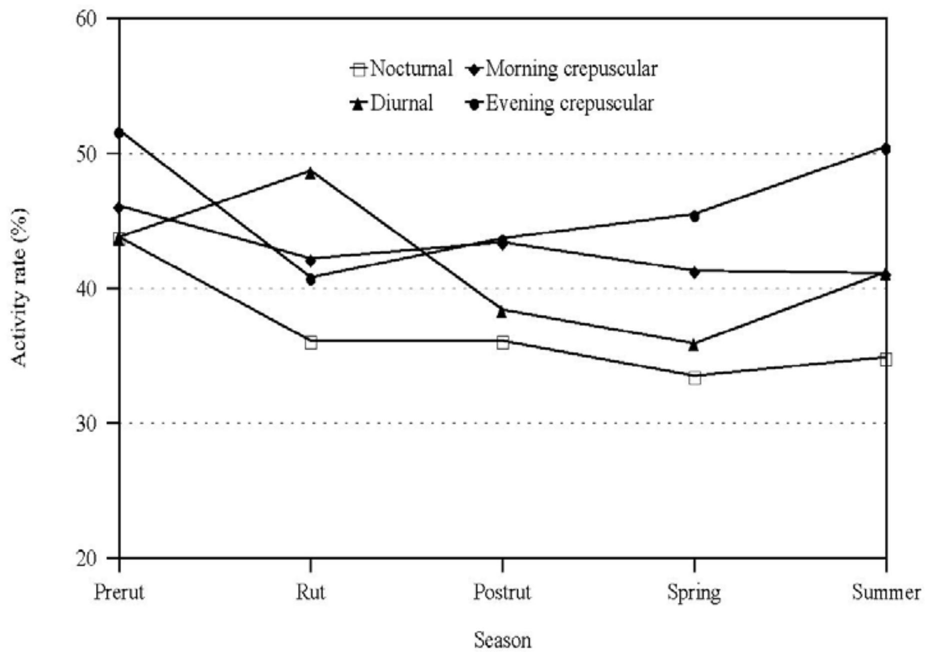

Figure 6.20. Diel period (morning crepuscular period = 0600-0759; diurnal period = 0800-1759; evening crepuscular period = 1800-1959; and nocturnal period = 2000-0559) activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 23-34; SE = 3.1-5.4) by season (prerut = 1 Oct-31 Nov; rut = 1 Dec-10 Jan; postrut = 11 Jan-31 Mar; spring = 1 Apr-31 May; and summer = 1 Jun-30 Sep) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

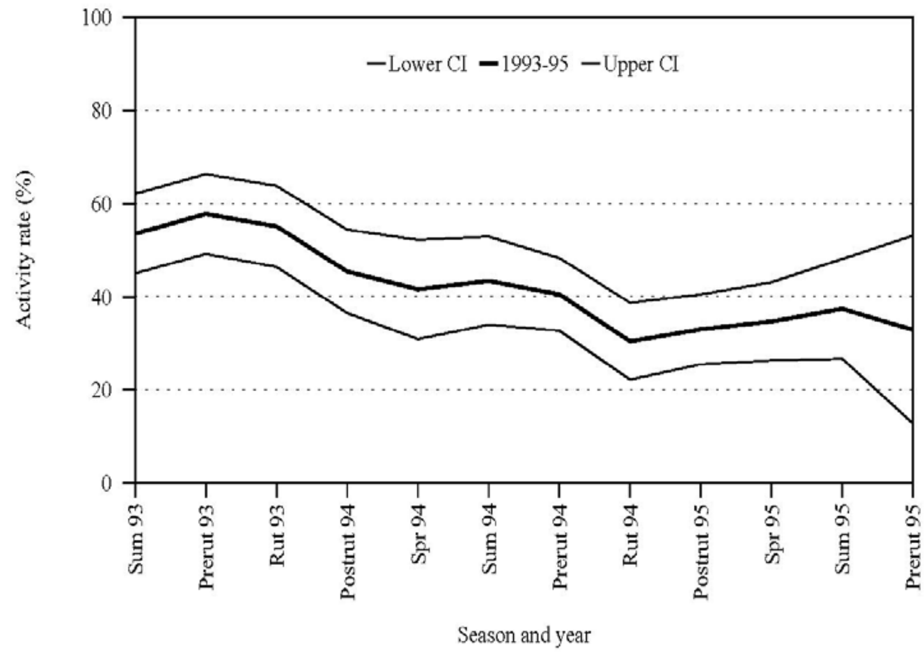

Figure 6.21. Seasonal (prerut = 1 Oct-31 Nov; rut = 1 Dec-10 Jan; postrut = 11 Jan-31 Mar; spring = 1 Apr-31 May; and summer = 1 Jun-30 Sep) activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 11-25; SE = 3.6-9.1) by year with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

among seasons during 1994 ($P \geq 0.146$, SE = 3.7-5.0). Seasonal activity rates peaked during summer (35.0%) and reached a low during postrut (31.0%), but seasonal differences during 1995 were not significant ($P \geq 0.921$; n = 11-21; SE = 3.6-8.2).

Month.--The monthly activity pattern for all males combined across years indicated a peak in activity during January, a low in activity during March, with activity remaining relatively low during April-August. A second, smaller peak in activity occurred during September-October (n = 29-51, SE = 2.9-4.1).

Monthly peaks in activity varied among age classes. Young males exhibited a peak in activity during September and a low in activity during March. Activity for middle-aged males peaked during October and reached a low during March. Activity for mature males peaked during January and reached a low during July, while activity for old males also peaked during January, but reached a low during February. Monthly activity rates were not statistically tested however, due to concerns regarding independence.

Individual And Age Class.–Activity rates were highly variable among individuals, with some males >4 times as active as other males (range = 18.7-87.4%; CV = 46.7%; n = 35; SE = 0.9-15.4; Table 6.1). The magnitude in variability was more apparent when activity rates were converted to hours. The least active male (1857; n = 1,204 2-hr obs during 13 months) was active an average of only 4.5 hours per day. The most active male (1422; n = 324 2-hr obs during 4 months) was active an average of 21.0 hours per day.

Sufficient sample sizes ($\geq$100 obs.) allowed for comparisons of activity rates among years for 20 males (Table 6.2). Activity rates were similar among years for most ages ($F_{1, 2\text{-}4} \leq 7.63$, $P \geq 0.110$). However, activity rates decreased for males from age 4.5 to 5.5 ($F_{1,2} = 63.45$, $P = 0.015$) and the difference in rates for males from age 6.5 to 7.5 tended toward significance ($F_{1,4} = 6.70$, $P = 0.061$). In addition, rates decreased for 18 of

Table 6.2. Activity rates (% of time active; 100 x no. of active obs/total obs; SE = 0.2-15.4) at different ages and results of repeated measures analyses to test for differences among years for 20 male white-tailed deer (≥100 obs/male) fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

	Estimated age[a]								Repeated measures analyses			
Male no.	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Comparison	*F*	*P*	df
602	21.4	31.9							2.5-3.5	0.73	0.454	1, 3
1423	46.2	37.6										
1541	45.4	31.4	30.5						3.5-4.5	2.52	0.187	1, 4
1722	73.2	67.2	68.3									
180		58.4	56.1									
1281		24.2	17.5									
1301		45.6	28.2	9.9					4.5-5.5	63.45	0.015	1, 2
1463			63.9	50.1	43.6				5.5-6.5	0.25	0.649	1, 3
1880			63.3	51.2								
444				32.8	48.9							

Table 6.2. Continued.

	Estimated age[a]								Repeated measures analyses			
Male no.	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Comparison	*F*	*P*	df
1680				70.9	60.7	52.2			6.5-7.5	6.70	0.061	1, 4
1941				33.6	20.9	13.3						
1262					34.5	34.6						
1482					76.7	55.3						
1800					50.2	22.6						
291						41.4	51.3		7.5-8.5	0.16	0.730	1, 2
511						53.9	58.9	61.1	8.5-9.5	7.63	0.110	1, 2
1331						41.3	32.9					
790							20.2	28.0				
1857							17.9	21.7				

[a]Age estimated at time of first capture based on the tooth replacement and wear technique (Severinghaus 1949). All males aged by 1 observer to reduce bias.

27 comparisons, indicating that activity tended to decrease within individual males as they increased in age.

High variability in activity rates also occurred among males within the same age class. The range in average number of hours active per day for young males varied from 5.1 hours for male 602 to 17.6 hours for male 1722. Middle-aged males varied from 4.2 hours for male 1281 to 16.9 hours for male 1380. Mature males varied from 2.4 hours for male 1301 to 21.0 hours for male 1422, a nearly 9-fold difference. Old males varied from 3.2 hours for male 1941 to 19.5 hours for male 1800.

Activity rates by age class were combined across years due to a non-significant age class x year interaction ($F_{6, 49} = 0.97$; $P = 0.453$; Fig. 6.22). A significant difference among activity rates occurred after combining rates across years ($F_{3, 12} = 7.53$, $P = 0.004$). Tukey's studentized range test indicated that activity rates for young males (46.5%; $n = 7$; SE = 8.2) were significantly higher than activity rates for mature and old males (35.1-38.5%; $P \leq 0.009$; $n = 12$-16; SE = 4.2-5.2). Activity rates for middle-aged males (41.0%; $n = 15$; SE = 4.9) were also significantly higher than activity rates for mature and old males ($P \leq 0.014$). No other significant differences occurred among age-related activity rates across years ($P \geq 0.116$).

Seasonal age-class-related activity rates were combined across years due to a non-significant age class x season interaction ($F_{12, 149} = 1.17$, $P = 0.308$; Fig. 6.23). A significant difference among activity rates within seasons occurred after combining rates across years ($F_{3, 12} = 18.60$, $P < 0.001$). Tukey's studentized range test indicated that activity rates for young (59.2%; $n = 7$; SE = 8.2) and middle-aged (52.0%; $n = 14$; SE = 5.3) males were significantly higher than rates for mature and old males (42.3-46.7%; $P \leq 0.010$; $n = 12$-15; SE = 5.0-6.0) during prerut. During rut, young males (58.2%; $n = 7$; SE = 8.8) were more active than mature and old males (37.8-42.7%; $P \leq 0.001$; $n = 10$-14; SE = 4.9-7.3), while middle-aged males (45.0%; $n = 12$; SE = 6.9)

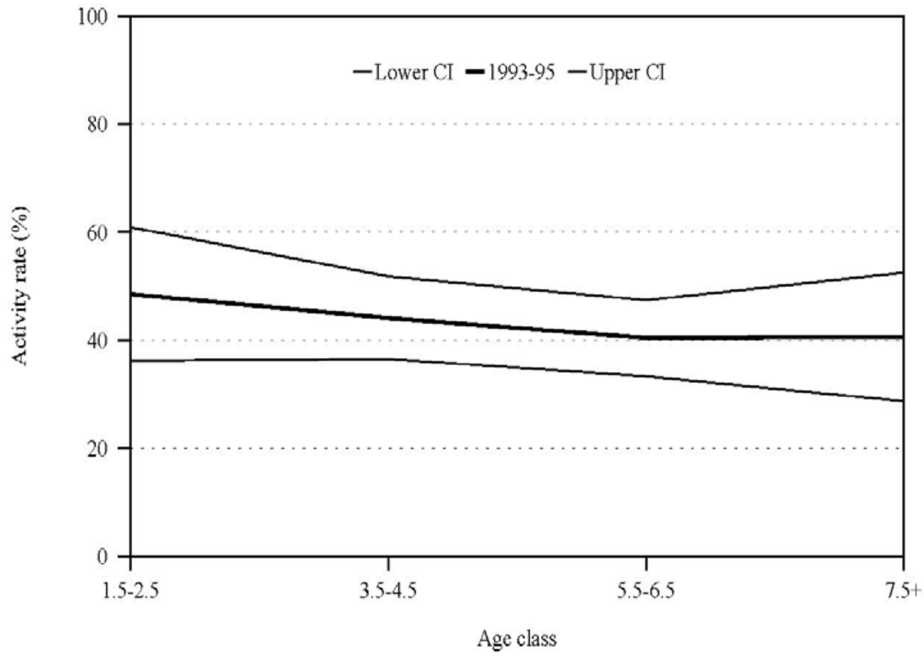

Figure 6.22. Activity rates (% of time active; 100 x no. of active obs/total obs; n = 12-30; SE = 3.4-5.7) by age class (yr) with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

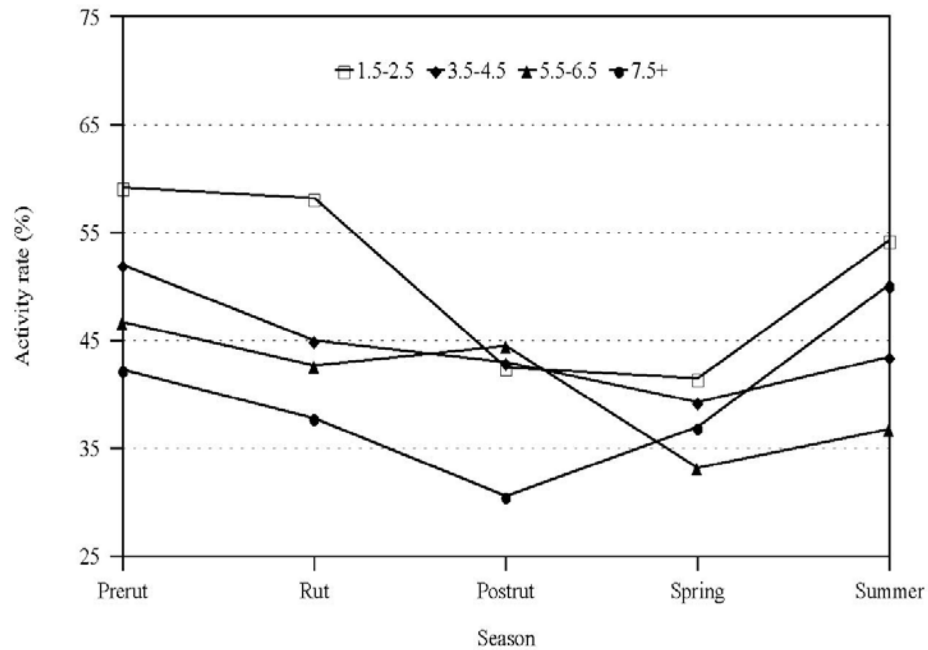

Figure 6.23. Activity rates (% of time active; 100 x no. of active obs/total obs; n = 12-30; SE = 3.4-5.7) by age class (yr) within seasons (prerut = 1 Oct-31 Nov; rut = 1 Dec-10 Jan; postrut = 11 Jan-31 Mar; spring = 1 Apr-31 May; and summer = 1 Jun-30 Sep) with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

were more active than old males ($P < 0.001$). During postrut, mature males (44.5%; $P = 0.024$; $n = 10$; SE = 6.1) were more active than old males (30.6%; $n = 10$; SE = 5.1). No other differences among age classes were significant during postrut ($P \geq 0.310$). During spring, activity rates for young males (41.5%; $n = 6$; SE = 8.9) were higher than rates for mature and old males (33.2-37.0%; $P \leq 0.015$; $n = 7$-8; SE = 5.0-7.6), while middle-aged males (39.3%; $n = 9$; SE = 6.6) were also more active than mature males ($P = 0.026$). During summer, activity rates for young males (54.3%; $n = 5$; SE = 8.8) were higher than rates for mature males (36.8%; $P = 0.043$; $n = 13$; SE = 5.2). No other differences among age classes were significant during summer ($P \geq 0.601$).

The correlation among weighted mean activity rates and age class was negative but not significant ($r_s = -0.800$; $P = 0.200$, $n = 4$). No relationship was found among weighted mean activity rates and indices of forage quantity ($r_p = 0.448$; $P = 0.372$; $n = 6$) and quality ($r_p = 0.583$, $P = 0.224$, $n = 6$); monthly precipitation ($r_p = 0.109$; $P = 0.629$; $n = 22$), cumulative precipitation beginning 1 month previous ($r_p = 0.184$; $P = 0.412$; $n = 22$), cumulative precipitation beginning 2 months previous ($r_p = 0.172$; $P = 0.445$; $n = 22$); prerut density estimates ($r_p = -0.925$; $P \geq 0.248$, $n = 3$); number of antler points ($r_p \leq -0.529$; $P \geq 0.116$, $n = 5$-10); gross BCC score ($r_p \leq -0.560$; $P \geq 0.191$, $n = 5$-10); and chest girth ($r_p \leq -0.415$; $P \geq 0.413$, $n = 5$-10).

DISCUSSION

Diel Patterns

Most previous studies have reported crepuscular diel activity patterns for white-tailed deer (Michael 1970, Kammermeyer and Marchinton 1977, Beier and McCullough 1990). The pattern in this study was best described as diurnal, although small crepuscular peaks occurred. A diurnal activity pattern was also reported by Guyse (1978), Hosey (1980), Holzenbein and Schwede (1989), and Naugle et al. (1997).

Minor peaks in activity occurred near midnight during most periods. Michael (1970), Hood (1971), and Herriges (1986) also reported minor peaks at midnight. Lows in activity occurred at 0500-0559, 1500-1559, and 2200-2259. Only the low in activity during late evening has previously been reported (Kammermeyer and Marchinton 1977, Hosey 1980, Ivey and Causey 1981).

Although overall diel activity was diurnal, a crepuscular pattern occurred during 7 of 12 seasons monitored. Patterns were diurnal for the 3 seasons monitored during 1993. A single, afternoon peak in activity occurred during summer 1994, while males were primarily nocturnal during prerut 1995. Changes in diel activity patterns among seasons were discovered during 2 other Texas studies that reported crepuscular patterns during some seasons and a lack of any pattern during other seasons (Hood 1971, Demarais et al. 1989). Michael (1970) found deer in southern Texas were active 82% of daylight hours during winter but only 45% of daylight hours during summer. Studies in other states have also reported changes in diel patterns among seasons (Beier and McCullough 1990) and years (Naugle et al. 1997). The bimodal peak in activity during the 7 seasons with a crepuscular pattern varied, with the peak occurring near sunset during 5 seasons and near sunrise during 2 seasons. One other study reported a change in bimodal peaks among seasons (Kammermeyer and Marchinton 1977).

Monthly activity rates peaked during January and September-October. Michael (1970) also reported a January peak in activity for deer in the Gulf Coast Prairie region of southeast Texas. However, he reported the monthly low in activity occurred during September. A study in southern Michigan reported peaks during May and October and lows during January-February (Beier and McCullough 1990).

The September-October peak in activity corresponded with the seasonal peak in activity during prerut. The January peak in activity was the result of increased activity during this month for males monitored during 1994 because activity was lowest for this same month during 1995.

Activity Rates

Males were active an average of 43% of the time monitored. Skinner (1994:42) reported that males in northwestern Louisiana were active an average of 70% of the time monitored. However, his study involved only 4 males monitored during the prerut, rut, and postrut seasons of 1 year. Activity rates for all males combined tended to decrease each year of the study. This apparent decrease in activity may have been an artifact of the different monitoring periods for each year. However, a general decreasing trend occurred in seasonal activity rates as well.

Diel Period.–Males tended to be most active during the evening crepuscular period for all seasons monitored except rut, when males were most active during the diurnal period. A seasonal shift from peaks in activity during crepuscular periods to a peak during the diurnal period was reported by Beier and McCullough (1990:20), who found crepuscular peaks in activity during spring-fall. During winter however, they reported that deer were most active during the diurnal period. Hood (1971:128) reported similar results for deer in southern Texas. He found a crepuscular seasonal activity pattern during summer that shifted to a diurnal peak in activity during winter. Demarais et al. (1989) reported that the distinct crepuscular pattern exhibited during spring-prerut was not apparent during rut and postrut.

Beier and McCullough (1990:32) suggested that the shift to a diurnal peak in activity during winter was due to a need to reduce foraging activity to conserve energy. They proposed that deer reduced morning activity because this was the coldest part of the day. Mean monthly temperatures for my study area were lowest during December-February (Stevens and Arriaga 1985), months that corresponded to the rut and postrut seasons. It is unlikely that colder temperatures caused the shift in activity during rut because this same pattern was not observed during postrut when temperatures were similarly cold.

Naugle et al. (1997) reported that deer exhibited diurnal activity patterns before and during hunting seasons in 1992, while crepuscular patterns were observed for these same seasons in 1993. They suggested that a lack of escape cover during 1993, due to a flood, caused the shift in activity patterns. It is doubtful that changes in the amount of escape cover caused the seasonal shift in activity patterns in this study because escape cover remained consistent among seasons.

The shift to a diurnal peak in activity during rut may have been related to breeding behavior because 94% of conceptions occurred during this season. Thus, the increase in male activity rates during daylight hours may have been related to mate searching and mate selection. Females that are nearing estrus initially flee from approaching males, a fixed action pattern termed courtship flight (Brown and Hirth 1979). Males may be more successful in maintaining contact with females when these chases, which may last >4 hours, occur during daylight hours. Additional female behaviors and visual cues that indicate reproductive status, such as spot-urination, rub-urination, and the solid stance (Brown and Hirth 1979) may also be more visible to males during daylight hours. Continued visual contact is also likely important in the maintenance of pair bonds during the tending phase.

Activity rates tended to be lowest during the nocturnal period for all seasons monitored. Kroll and Koerth (1996:140-143) suggested that intensive hunting pressure has resulted in increased nocturnal activity and an increased flight distance in white-tailed deer. Lowered activity rates during the nocturnal period across all seasons may have been the result of the light hunting pressure that occurred on the study area (≤1 male harvested/1,287 ha/yr; R. E. Hall, Jr., Faith Ranch, personal communication). In areas where hunting pressure is light or non-existent (e.g., refuges), deer tend to be more active during diurnal periods and less active during nocturnal periods (Kammermeyer and Marchinton 1977, Guyse 1978, Suring and Vohs 1979, Hosey 1980, Inglis et al. 1986, Holzenbein and Schwede 1989, Naugle et al. 1997).

Season.--The seasonal peak in activity for all data combined occurred during prerut. One other study reported a prerut peak in activity (Holzenbein and Schwede 1989). However, most studies have reported peaks during rut (Pledger 1975, Ivey and Causey 1981) or postrut (Guyse 1978, Hosey and Causey 1979, Hosey 1980). A significant seasonal difference in male activity rates was reported by Skinner (1994:41) who found that percent of time active increased from 59% during prerut, to 69% during rut, and then peaked at 81% during postrut.

Beier and McCullough (1990:30-31) explained changes in seasonal activity based on changes in foraging time relative to changing metabolic and energy demands. They suggested that decreased activity during winter was based on a general decrease in deer metabolic rates at a time when stored energy reserves were high. Increased activity during spring was explained by increased metabolic demands due to early antler growth. Decreased activity during June-July was explained by increases in forage quantity and quality even though energy demands for antlerogenesis were high. Increased activity during fall was explained by decreased forage quality and high metabolic demands.

Indices of seasonal forage quantity and a subset of forage quality were not related to activity rates in this study. In addition, precipitation, which was found to be correlated to an estimate of deer carrying capacity (Hellickson 1991, Strickland 1998), was not related to activity. The lack of any relationship indicates that it was unlikely changes in forage quantity, quality, or precipitation explained changes in activity rates.

Previous research has indicated that the most stressful seasons for white-tailed deer in southern Texas were summer (Varner et al. 1977, Meyer et al. 1984, Hellickson 1991) and winter (Draeger 1996, Hall 1997, Strickland 1998). Activity rates would be expected to increase during these seasons if rates were influenced by changes in foraging time and metabolic and energy needs as suggested by Beier and McCullough (1990). Activity rates were relatively high during postrut and summer 1994 and summer 1995. However, activity reached a low point during rut in both 1993 and 1994, while activity during 1995 was lowest during postrut.

Fritzen et al. (1995) reported deer activity rates in Florida were significantly higher within a high density population when compared to a low density population. They concluded that population density alone affected activity rates as a result of increased social interactions among deer within the high density population. They further concluded that activity rates were not influenced by forage quantity and quality because measures of these 2 variables were highest within the high density population. No relationship was found in this study among activity rates and prerut density estimates, indicating that changes in activity rates were not the result of changes in density.

We propose that the increase in activity during prerut resulted from an increase in the number and intensity of social interactions caused by changing dominance hierarchies. Brown (1971:26) reported that antler fights, the highest form of antagonistic encounters between males, peaked during prerut, when hierarchical organization was expanded. Hirth (1973:143) reported that interaction rates among adult males on the Welder Wildlife Foundation refuge peaked during November and then gradually declined reaching a low point during July.

The unexpected decrease in activity during rut may have been a result of the prior establishment of dominance hierarchies among males during prerut. Brown (1971) found that dominant-subordinate relationships established during prerut carried over to the breeding season after bachelor groups of males disbanded. Body and antler sizes alone, may have served as visual rank indicators to reduce aggressive interactions among males during rut (Brown and Hirth 1979). The fact that bachelor groups disbanded prior to rut likely resulted in lowered activity rates as well because dominant-submissive interactions among males within bachelor groups were no longer occurring.

Reduced activity rates during rut may have also been related to the formation of pair bonds between males and females. A pair bond is formed after the courtship-flight phase ends and females first permit physical contact from the male (Brown and Hirth 1979). These tending pairs then isolate themselves from other deer. Hirth (1973:171) reported that tending males "spent most of their time standing behind the doe while she grazed" and that males did little feeding. Holzenbein and Schwede (1989) reported that activity rates for females decreased as the breeding season progressed and that activity was low during the time when tending bonds were formed.

Increased diurnal activity during rut may explain the perception hunters have that males increase activity during this season. Males became more active during daylight hours increasing the likelihood of being observed by hunters, even though overall activity rates during rut declined from prerut.

Individual.--Activity rates were highly variable among individuals. Previous studies have also indicated high variability in activity rates. Skinner (1994:40) reported 3-day activity rates for all males combined varied from 15-90% when monitored over a 120-day period during prerut-postrut. Beier and McCullough (1990) reported daily activity rates for all deer combined varied from 21-82% and that monthly rates varied from 37-68%. Although these reports indicate high variability on a daily or monthly scale, activity rates for males in our study were highly variable across the entire time frame (3-28 months) males were monitored.

The high variability in activity rates may have been related to variable dominance rank and a varying ability among males to assimilate into bachelor groups. Males associate in bachelor groups outside of the breeding season, with prevalence toward grouping with other males strongest during February-October (Brown 1971:106). It is likely that activity rates were influenced by dominance hierarchies within bachelor groups because males spend the majority of their time associating with other males. Brown (1971) observed several bachelor groups to determine dominance hierarchies within groups based on results of dominant-submissive interactions. He reported that bachelor groups typically consisted of 2-3 core males and 1-4 less dominant males termed "floaters" because they periodically left and rejoined the group.

Least active males in this study may have been more dominant on a relative basis and therefore more successful at assimilating into stable bachelor groups. Males that were more active may have been subordinates that had difficulty assimilating into bachelor groups and were therefore forced to travel back and forth among different bachelor groups.

Previous studies have suggested a correlation among dominance rank and number of antler points, antler size, and body size (Brown 1971, Hirth 1973). Although relative dominance was not measured during this study, number of antler points, gross BCC scores, and a measure of body size (chest girth) were measured when each male was initially captured, allowing for comparisons among these 3 variables and weighted mean activity rates for these same individuals within each age class. Although 18 of 21 correlation coefficients were negative, none were significant ($P \geq 0.116$) suggesting that either these variables did not adequately reflect dominance rank, or that activity rates were only weakly related to dominance.

Activity tended to decrease within individual males as they increased in age. This trend toward decreasing activity as males increased in age was confounded however, because an annual and seasonal trend toward decreased activity rates also occurred. Pledger (1975) found that activity rates were positively correlated to age. Beier and McCullough (1990) reported that large-antlered males (≥8 antler points) had higher activity rates than small-antlered males (<8 antler points) during May-December. They suggested that activity rates were higher for larger-antlered males because the peak in antler growth occurred during May-June and prerut mass gain occurred during July-September. However, another study reported no age-related differences in activity rates (Fritzen et al. 1995).

If activity rates were related to dominance and the ability to assimilate into bachelor groups as we suggest, then activity rates would be expected to decrease in individual males as they increased in age because dominance rank is age related where male age structures are balanced (Brown 1971). Older-aged males likely became less active as a result of improved dominance rank and a decrease in dominant-submissive interactions.

Age Class.--The high variability in activity rates among similar-aged males casts further doubt on the theory that activity rates were related to changes in forage quantity and quality and metabolic and energy needs. It is unlikely these variables could have varied among individuals to the degree necessary to cause up to a 9-fold difference in activity rates.

Activity rates were highest for young and middle-aged males and lowest for mature and old males when data for all years were combined. These 2 age classes tended to be most active within individual seasons as well, with the exception of postrut, when mature males were most active. High activity rates for young males may have resulted from their attempts to associate with bachelor groups of more dominant males. Brown (1971:99) termed males within this age class “subdominant floaters” because they were in their first year of separation from the family group and as a result, associated with a variety of bachelor groups. He found that associations were transitory and that males within this age class wandered over a considerable area with home ranges among the largest measured for all deer.

Middle-aged males may have been more active for this same reason. The male age structure on the study area was unusually balanced, with ≥40% of randomly captured males estimated to be ≥5.5 years old. Middle-aged males may have encountered difficulty assimilating into bachelor groups as well, as a result of the prevalence of older-aged males in the population.

Mature and old-aged males were likely less active as a result of their relatively high dominance rank and stable positions within bachelor groups. Brown (1971:208) termed males within these age classes “core members.” He reported that they had relatively small, stable home ranges and that aggression within these core groups was low in frequency and low in intensity because of their strong bonds.

Increased foraging time relative to higher metabolic and energy needs may have resulted in increased activity rates for young and middle-aged males as well. Body measurements of captured males indicated that bone (i.e., shoulder height) and body (i.e., chest and stomach girth) growth did not stop until males reached the mature age class (Hellickson 2002). Age class biases associated with collar fit may have also been a factor in the differences in activity rates observed among age classes.

MANAGEMENT IMPLICATIONS

The effective range of the data collection unit was approximately 2.4 km. Accuracy was highest when transmittered males were within this range. Therefore, during future studies animals within this range should be targeted for transmitter attachment. We also recommend that future studies incorporate a shorter monitoring period to reduce the number of erroneous observations stored by the data collection unit. We further recommend the use of an omni-directional antenna in place of the multiplexor antenna array.

The diel pattern was variable and frequently changed among different seasons and months, emphasizing the importance of long-term studies that measure activity across years. Visual census techniques used during the prerut and postrut seasons should be conducted during the evening crepuscular period to take advantage of the diel period when males were most active. The nocturnal period should be avoided because males were least active during this period for all seasons monitored. However, a diurnal peak in activity during rut indicated that visual census techniques would be most appropriate during this season when conducted during daylight hours. If visual census techniques are used to estimate male age ratios, our results indicate that ratios may be biased toward young and middle-aged males because males within these age classes were more active than males within the mature and old age classes.

The seasonal peak in activity occurred during prerut. It is likely that males would be most susceptible to harvest during this time, indicating that hunting seasons should include the prerut period if the objective is to increase male harvest, or exclude the prerut period if the objective is to decrease male harvest. Males may be more susceptible to harvest during rut as well due to increased diurnal activity. Landowners and managers interested in QDM and trophy management should be aware that (1) activity rates for middle-aged and mature males were highest during prerut; (2) young and middle-aged males were more active than mature and old males and were therefore more susceptible to harvest; and (3) activity rates were highly variable among individual males.

A lack of consistent patterns in activity rates made it difficult to relate activity to causative factors and small sample sizes limited results of correlation analyses. However, trends in activity rates for individual males and by age class agreed best with the social interaction theory proposed by Fritzen et al. (1995) when modified by the male behavior patterns observed by Brown (1971). It is likely that changes in foraging times relative to changes in metabolic and energy needs also influenced activity rates, although evidence of these relationships were lacking. We propose that a large portion of the changes in activity rates among individuals and age classes can be explained by relative dominance and the varying ability of different males to assimilate into bachelor groups. The behavioral characterizations relative to age and dominance rank introduced by Brown (1971) corresponded well to changes in activity rates observed in this study.

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APPENDICES

Appendix A1

Previous Deer Activity Studies

Appendix A1. Published studies examining activity rates of white-tailed deer using telemetric methods, including principal investigators, location, monitoring length and method, *n*, sex, and age.

Study	Location	Monitoring length	Monitoring method	*n*	Sex[a]	Age[b]
Marchinton 1968	5 areas in	≤4 months	Change in amplitude	9	2 M	2 Y
	3 states		and straight-line movements		7 F	1 F, 6 A
Sparrowe and	Southeast	≤2 months	Straight-line movements	3	1 M	1 Y
Springer 1970	S.D.				2 F	2 Y
Hood 1971	Southeast	≤6 months	Change in amplitude	20	3 M	1 F, 1 Y, 1 A
	Tex.		and straight-line movements		17 F	3 Y, 14 A
Jackson et al. 1972	Southeast	≤2 months	Change in amplitude	27	15 M	15 F
	Tex.				12 F	12 F
Pledger 1975	Southeast	≤14 months	Straight-line movements	6	1 M	1 F
	Ark.				5 F	5 A
Kammermeyer and	Northwest	≤7 months	Straight-line movements	7	5 M	Unknown
Marchinton 1977	Ga.				2 F	Unknown

Appendix A1. Continued.

Study	Location	Monitoring length	Monitoring method	n	Sex[a]	Age[b]
Guyse 1978	Southwest Ala.	≤7 months	Change in amplitude	8	8 M 0 F	8 A
Hosey 1980	Southwest Ala.	≤5 months	Change in amplitude	11	11 M 0 F	2 F, 3 Y, 6 A
Ivey and Causey 1981	Southwest Ala.	≤5 months	Change in amplitude and straight-line movements	10	0 M 10 F	10 A
Ockenfels and Bissonette 1984	North-central Okla.	Unknown	Straight-line movements	5	Unk	Unknown
Herriges 1986	East-central Mont.	≤10 months	Change in amplitude and straight-line movements	51	9 M 42 F	3 Y, 6 A 4 F, 9 Y, 29 A
Demarais et al. 1989	Southwest Tex.	Unknown	Straight-line movements	24	24 M 0 F	24 A
Holzenbein and Schwede 1989	Northern Va.	≤11 months	Change in amplitude	8	0 M 8 F	8 A

Appendix A1. Continued.

Study	Location	Monitoring length	Monitoring method	*n*	Sex[a]	Age[b]
Beier and	Southeast	≤38 months	Change in signal using tip-switch	21	13 M	4 Y, 9 A
McCullough 1990	Mich.		transmitters and strip-chart recorders			8 F1 F, 2 Y, 5 A
Skinner 1994	Northwest	≤4 months	Change in signal using tip-switch	10	4 M	Unknown
	La.		transmitters and data logger		6 F	Unknown
Fritzen et al. 1995	Northern	≤36 months	Change in signal using	58	14 M	2 F, 6 Y, 6 A
	Fla.		motion-sensitive transmitters		44 F	15 Y, 29 A
Naugle et al. 1997	Northeast	≤5 months	Change in signal using tip-switch	21	0 M	
	S.D.		transmitters		21 F	2 Y, 19 A

[a]Sex - Unk = unknown (sex not reported); M = male; F = female.

[b]Age - estimated at the time of transmitter attachment; F = fawn (0-11 months); Y = yearling (12-23 months); A = adult (≥2 years).

Appendices B1-2

Data Collection Unit

Appendix B1. Data collection unit.

Monitoring of activity took place during November 1992-October 1995. However, data collected prior to 28 July 1993 were excluded from the analyses because of recurring problems with downloading data stored in the computer data logger. Additional problems occurred with the multiplexor antenna array (4 4-element, directional, yagi antennas connected to the utility pole at cardinal directions; ATS, Isanti, Minn.) that resulted in infrequent data collection and poor reception. The multiplexor antenna array was replaced with an omni-directional antenna on 28 July 1993. Additional electrical problems occurred with the data collection unit during June 1995 that resulted in lowered sample sizes for this month.

The computer data logger received and stored data at an average rate of 1,200 observations (i.e., 1-min scans) per day. This collection rate required that the logger be disconnected and returned to research headquarters every 18-20 days (an average of 5.6% of the logger's memory capacity was used daily), where the data could be downloaded to a desktop computer. During the downloading process, data were printed, viewed to determine if any inconsistencies occurred, and stored on computer diskettes. Adjustments to the frequency table (e.g., deletion of frequencies due to mortality or lack of reception) were made prior to reconnecting the unit. The frequency of downloading (n = 46) resulted in gaps of 1-2 days in the data every 15-25 days. Additional gaps in data occurred when the 12-volt, scanning receiver, or data logger batteries lost power.

An average of 6.3 observations occurred per 2-hour interval for each male. A total of 635,873 observations was recorded by the computer data logger after 27 July 1993. Of these data, 165,430 (26.0%) observations were deleted because pulse totals were outside the expected range (57-185 pulses/min) determined when accuracy of the unit was tested with enclosed, tame deer (Hellickson 2002). The majority of erroneous observations (*n* = 130,821; 79.1%) were <57 pulses per min. Only 34,609 (20.9%) observations were >185 pulses per min.

A hand-held scanning receiver, 4-element yagi antenna, and stereo headphones were used concurrently with the data collection system to determine why pulse totals outside of the expected range occurred. Most of the erroneous observations were caused by males that were on the periphery of the range of the unit. Transmitters attached to males at the periphery produced faint signals that resulted in erroneous observations (<57 pulses/min) when only a portion of the pulses produced by the transmitter were received by the unit. Observations >185 pulses per min occurred when interference (i.e., static) was falsely interpreted by the data logger as a pulse.

Reception rate, accuracy, and range of the data collection unit were tested after the unit was moved to the study area with reference transmitters placed at 7 areas 0.0-4.1 km from the unit. An additional transmitter (1562) served as a reference when the male was found dead on 29 September 1994. This male was captured, photographed, and fitted with the transmitting collar on 30 October 1993. When found, the hardened antlers measured during the capture were still attached to the skull indicating that the male had died before 31 March because the majority of males have shed their antlers prior to this date. The location where the transmitter was found was mapped and the observations collected on this male from 1 April-28 September 1994 were added to the test data set.

Transmitter reception rate varied from 0.5-66.6 observations per day and was negatively correlated to distance from the unit (r_p = -0.890, P = 0.018). Accuracy (% of pulse totals within the "inactive" range [$\geq$57 pulses/min, but $\leq$104% of the transmitter's base rate]) varied from 0.0-100.0% and also was negatively correlated to distance from the unit (r_p = -0.969, P < 0.001). Factors known to affect reception include terrain, weather, power lines, and vegetation (White and Garrott 1990). The most likely factor in our study was terrain because this factor was the most variable among transmitter locations.

Reception range of the data collection unit decreased as distance from the unit increased, with very few observations recorded at distances ≥3.4 km. Males were censored when home range areas exceeded 2.4 km from the unit. This distance was chosen based on range tests with reference transmitters placed 2.4 (transmitter 512) and 3.4 (transmitter 1304) km from the unit, respectively. An average of 35.8 observations per day was recorded for transmitter 512, versus only 0.5 for transmitter 1304. In addition, 40.9% of observations for transmitter 512 were within the expected range, versus only 9.1% for transmitter 1304.

Transmitters containing variable-pulse activity sensors were placed on males captured during 1992 without regard to the distance between the capture site and the data collection unit resulting in the censorship of 4 males because their home range areas exceeded the range of the unit. Transmitters were purposely placed on males randomly captured nearest the data collection unit during 1993-94 captures to reduce the likelihood of males exceeding the range of the unit.

A shorter monitoring length (e.g., 5-10 sec) likely would have resulted in fewer erroneous observations. The lower and upper ranges of acceptable pulse totals can also be programmed into the computer data logger so that observations exceeding this range are not stored in the unit. Skinner (1994) programmed a range of 45-90 pulses per min into the computer data logger used in his study. However, pulse totals >180 occurred when transmitters were attached to enclosed female white-tailed deer that were especially active (Hellickson 2002).

Appendix B2. Accuracy (% of obs within expected range) and reception rate (*n*/day) of a data collection unit programmed to record pulses from 8 variable-pulse, activity-sensing reference transmitters that were stationary at beacon locations during 1993-94 on the Faith Ranch, Dimmit and Webb counties, Texas.

		1-min pulse totals and relative pulse rate (%)[a]										
	Distance	<57		≥57 and ≤104%		>104% and ≤185		>185				
Radio frequency	from unit (km)	*n*	%	*n*	%	*n*	%	*n*	%	Total	Days	*n*/day[b]
1302	0.0	0	0.0	68	100.0	0	0.0	0	0.0	68	<1	
1424	1.2	1	0.1	1,149	90.8	100	7.9	15	1.2	1,265	19	66.6
1303	1.9	374	18.2	1,317	64.0	359	17.4	8	0.4	2,058	103	20.0
1562[c]	2.0	24	0.2	9,761	63.0	5,154	33.3	558	3.6	15,497	181	
512	2.4	947	36.3	1,068	40.9	597	22.9	0	0.0	2,612	73	35.8
1304	3.4	34	77.3	4	9.1	6	13.6	0	0.0	44	89	0.5

Appendix B2. Continued.

Radio frequency	Distance from unit (km)	1-min pulse totals and relative pulse rate (%)[a] <57 *n*	%	≥57 and ≤104% *n*	%	>104% and ≤185 *n*	%	>185 *n*	%	Total	Days	*n*/day[b]
1942	3.5	16	100.0	0	0.0	0	0.0	0	0.0	16	19	0.8
1542	4.1	101	83.5	3	2.5	13	10.7	4	3.3	121	73	1.7

[a]Relative pulse rate (100 x pulse total/mean base rate) of 104% used as a separation point between inactive (≤104%) and active (>104%) observations.

[b]Reception rate was not calculated for 1302 and 1562 because monitoring times programmed into data collection unit differed.

[c]1562 was attached to a male that died >181 days before collar was retrieved.

Appendices C1-3

Source and Direction of Bias

Appendix C1. Source and direction of bias.

Potential sources of bias relative to the number of pulses received and stored by the data collection unit included distance from the unit and signal interference. Bias associated with misclassifying inactive observations as active was examined with the placement of reference transmitters. These transmitters were stationary and therefore should have been received by the unit as inactive (≥57 pulses/min, but ≤104% of the transmitters base rate). Bias (% of obs outside the expected range) varied from 0.0-81.3% and was positively correlated to distance from the unit ($r_p = 0.972$, $P < 0.001$). As a result, bias toward misclassifying males as active when they are actually inactive, increases as their distance from the unit increases. This bias was minimized however, because number of observations decreased as distance from the unit increased. Therefore, relatively few observations occurred at distances where bias was highest.

Additional evidence of a relationship between bias and distance from the unit was discovered when 4 frequencies from free-ranging males wearing mortality-sensing transmitters were programmed into the frequency table. These males were each monitored for 87 days. Bias (% of obs outside expected range) relative to reception rate (*n*/day) varied from 50.4-86.3% and was negatively correlated to reception rate ($r_p = -0.864$, $P = 0.014$). Transmitters may have also varied in their sensitivity to movement (Hellickson 2002).

Bias in activity rates may have occurred due to improperly fitted collars, or because leather collars were not expandable, even though attempts were made to fit all collars similarly. During 1992-94 captures, 58 additional males were collared with mortality-sensing transmitters (ATS, Isanti, Minn.) and tracked concurrently with males in this study (M. W. Hellickson, University of Georgia, unpublished data). At least 1 of these additional males likely died as a result of a loose mortality-sensing collar (when found, part of his front leg was stuck through the collar). The mortality-sensing collars on 2 additional males were known to have slipped (1 male was later observed alive and the second male was later harvested) and collar slippage was suspected for 3 additional males.

Biases associated with collar attachment were likely the result of seasonal changes in male neck circumference that occurred as a result of physiological changes. Male neck circumference increased during prerut, reached a peak during rut, and then declined during postrut. All males were captured and fitted with collars during late October each year. At the time of capture, neck circumferences were enlarged, but not yet at their peak. Bias associated with collar fit during prerut should have been minor due to the timing of the captures. However, during rut, activity rates were likely biased toward misclassifying active males as inactive because collar movement was likely restricted as neck circumference reached its peak. Activity rates likely were biased toward misclassifying inactive males as active during postrut through summer because neck circumferences had decreased below prerut levels.

In addition to the seasonal trend in bias, an age-related trend also likely occurred related to collar fit. The greatest seasonal changes in neck circumference occurred within the middle-age and mature age classes. A more moderate seasonal change occurred in young males. Therefore, bias toward misclassifying males was likely highest in the middle-age and mature age classes and lowest in the young age class. Collar movement up the neck as circumferences increased and back down the neck as circumferences decreased, likely minimized effects of changing neck circumference.

Additional bias toward classifying inactive males as active may have occurred whenever males died of non-hunting-related causes during the time frame they were monitored. The transmitters used in this study lacked mortality sensors. Therefore, the precise time of death was often difficult to determine. Whenever a male was found dead and the remains indicated that death had not occurred within the last 24 hours, location bearings were mapped to determine when the male was last located a significant distance from the site of mortality. Previous activity data also were examined to determine when the male was last received as active. The date of mortality was then estimated and all activity data collected after this date were deleted.

The use of motion-sensitive transmitters requires that care be used when attaching collars to insure uniform fit. Ideally, collars should have the capability of expanding and contracting as neck circumference changes. The addition of mortality sensors would be helpful for determining a more accurate time of death.

Appendix C2. Bias (% of obs outside expected range) associated with distance from a data collection unit programmed to record pulses from 7 variable-pulse, activity-sensing reference transmitters that were stationary at beacon locations during 1993-94 on the Faith Ranch, Dimmit and Webb counties, Texas.

		1-min pulse totals and relative pulse rate (%)[a]			
	Distance	≥57 and ≤104%		>104% and ≤185	
Radio frequency	from unit (km)	*n*	%	*n*	%
1302	0.0	68	100.0	0	0.0
1424	1.2	1,149	92.0	100	8.0
1303	1.9	1,317	78.6	359	21.4
1562	2.0	9,761	65.4	5,154	34.6
512	2.4	1,068	64.1	597	35.9
1304	3.4	4	40.0	6	60.0
1542	4.1	3	18.8	13	81.3

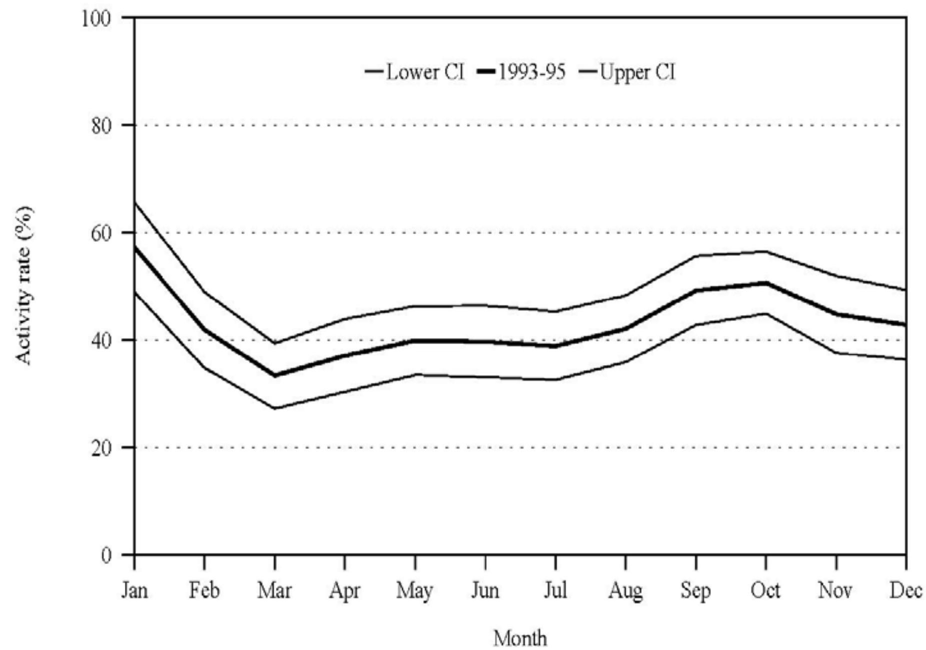
[a]Relative pulse rate (100 x pulse total/mean base rate) of 104% used as a separation point between inactive (≤104%) and active (>104%) observations.

Appendix C3. Bias (% of obs outside expected range of 50-65 pulses/min) associated with reception rate (*n*/day) for a data collection unit programmed to record pulses from 4 mortality-sensing transmitters attached to free-ranging males during 1993 on the Faith Ranch, Dimmit and Webb counties, Texas.

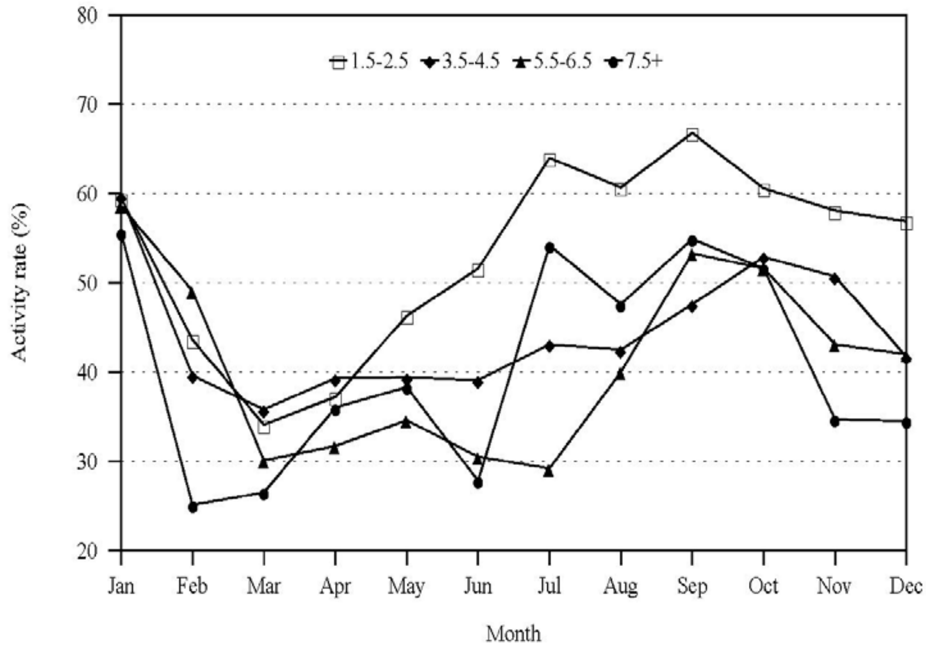
	1-min pulse totals						
	<50		50-65		>65		
Radio frequency	*n*	%	*n*	%	*n*	%	*n*/day
1277	737	49.9	733	49.6	8	0.5	17.0
763	215	62.5	128	37.2	1	0.3	4.0
1069	189	76.2	57	23.0	2	0.8	2.9
1120	125	85.6	20	13.7	1	0.7	1.7

Appendices D1-2

Monthly Trends in Activity Rates



Appendix D1. Monthly activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 29-51; SE = 2.9-4.1) with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.



Appendix D2. Monthly activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 2-17; SE = 2.2-16.3) by age class with all data pooled for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

Appendices E1-4

Correlations among Weighted Mean Activity Rates and

Forage Quantity and Quality, Precipitation, Estimated Density, and

Antler and Body Characteristics

Appendix E1. Pearson's product moment correlation coefficients among seasonal weighted mean activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 11-25; SE = 3.6-9.1) and seasonal indices of forage quantity (amount of live biomass; kg/ha) and quality (forb biomass; kg/ha) obtained from Hall (1997:17) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during prerut 1994-prerut 1995 on the Faith Ranch, Dimmit and Webb counties, Texas.

Season	Activity rate	Forage quantity	*r*	*P*	Forage quality	*r*	*P*
Prerut 1994	40.5	1,181	0.448	0.372	175	0.583	0.224
Rut 1994	30.4	662			100		
Postrut 1995	33.0	584			32		
Spring 1995	34.7	645			54		
Summer 1995	37.4	1,268			187		
Prerut 1995	32.9	1,471			151		

Appendix E2. Pearson's product moment correlation coefficients among monthly weighted mean activity rates (% of time active; 100 x no. of active obs/total obs; *n* = 7-25; SE = 3.8-5.5) for all males combined and precipitation (cm) measured during the same month, cumulative precipitation beginning 1 month previous, and cumulative precipitation beginning 2 months previous for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during Aug 1993-May 1995 on the Faith Ranch, Dimmit and Webb counties, Texas.

Month and yr	Activity rate	Precipitation		
		Same mo	1 mo previous	2 mo previous
Aug 1993	55.2	0.15	2.15	3.75
Sep	51.0	2.20	2.35	4.35
Oct	55.7	0.95	3.15	3.30
Nov	59.2	0.35	1.30	3.50
Dec	51.2	1.25	1.60	2.55
Jan 1994	63.8	1.35	2.60	2.95
Feb	42.5	0.40	1.75	3.00
Mar	35.9	1.15	1.55	2.90
Apr	41.3	0.50	1.65	2.05
May	41.8	4.45	4.95	6.10
Jun	40.0	2.05	6.50	7.00
Jul	40.5	0.80	2.85	7.30
Aug	43.5	1.15	1.95	4.00
Sep 1994	49.6	2.05	3.20	4.00

Appendix E2. Continued.

Month and yr	Activity rate	Precipitation		
		Same mo	1 mo previous	2 mo previous
Oct	49.6	1.50	3.55	4.70
Nov	31.0	0.85	2.35	4.40
Dec	31.4	0.75	1.60	3.10
Jan 1995	27.9	0.00	0.75	1.60
Feb	39.9	0.00	0.00	0.75
Mar	29.7	1.18	1.18	1.18
Apr	33.3	1.05	2.23	2.23
May	36.8	0.70	1.75	2.93
r		0.109	0.184	0.172
P		0.629	0.412	0.445

Appendix E3. Pearson's product moment correlation coefficients among weighted mean activity rates (% of time active; 100 x no. of active obs/total obs) for all males combined during prerut and estimated deer densities (deer/km^2; R. E. Hall, Jr. Faith ranch, personal communication) determined by partial-coverage helicopter surveys conducted during the same season for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

Yr	Prerut activity rate	Estimated deer density	*r*	*P*
1993	57.8	5.03	-0.925	0.248
1994	40.5	6.14		
1995	32.9	8.18		

Appendix E4. Pearson's product moment correlation coefficients among weighted mean activity rates (% of time active; 100 x no. of active obs/total obs) for individual males combined by age (yr; Severinghaus 1949) and number of antler points ≥2.54 cm, an antler size index (gross Boone and Crockett Club score), and chest girth (cm) for 35 male white-tailed deer fitted with radio-transmitting collars containing variable-pulse activity sensors during 1993-95 on the Faith Ranch, Dimmit and Webb counties, Texas.

Estimated age		Antler points	Antler size	Chest girth	*n*
2.5	*r* =	-0.403	-0.560	-0.079	7
	P =	0.370	0.191	0.867	
3.5	*r* =	-0.529	-0.284	0.208	10
	P =	0.116	0.427	0.565	
4.5	*r* =	-0.241	-0.079	0.106	10
	P =	0.503	0.828	0.771	
5.5	*r* =	0.095	-0.157	-0.113	9
	P =	0.808	0.687	0.772	
6.5	*r* =	-0.030	-0.016	0.270	5
	P =	0.962	0.980	0.661	
7.5	*r* =	-0.449	-0.087	0.429	9
	P =	0.226	0.823	0.249	
8.5	*r* =	-0.454	-0.448	-0.415	6
	P =	0.366	0.373	0.413	

CHAPTER 7

BEHAVIORAL RESPONSES OF MALE WHITE-TAILED DEER TO ANTLER RATTLING[1]

[1]Hellickson, M. W., K. V. Miller, R. L. Marchinton, C. A. DeYoung, and R. E. Hall. To be submitted to the Proceedings of the Southeastern Association of Fish and Wildlife Agencies.

Abstract: We observed 111 male white-tailed deer (Odocoileus virginianus) responses to 4 antler rattling sequences performed 171 times during 1992-95. Thirty-three additional sessions were performed within 200 m of 18 radio-transmittered males during 1994-96. The 4 sequences, short and quiet (N = 43), short and loud (N = 45), long and quiet (N = 43), and long and loud (N = 40), were determined by rattling duration and volume. Sequences were randomly chosen and performed near 17 observation towers to test which attracted the highest number of males. Loud rattling attracted nearly 3 times as many males as quiet rattling, but duration of rattling did not differ. Overall, highest response rate was during rut and lowest during prerut. Most responses occurred during the first 10-min rattling segment. Males estimated to be young (1.5 to 2.5 years old) responded in the highest rates during prerut. Middle-aged males (3.5-4.5) responded at highest rates during rut, while mature males (≥5.5) responded at highest rates during postrut. Highest response rates occurred during morning. Lower response rates of mature males during rut is likely because they were engaged in courtship of females. Males apparently did not learn to avoid rattling. Antler rattling may be used as an indicator of physiological events related to the breeding season because peaks in male responses occur simultaneously with peaks in conception dates.

INTRODUCTION

Male white-tailed deer establish a social hierarchy prior to the breeding season through a series of ritualized dominance displays and threats (Thomas et al. 1965, Brown 1971, Walther 1984). Two types of antler contact have been described. Sparring does not involve prior dominance displays or threats and lacks aggression (Goss 1983), but may be the principal method of establishing dominance rank among males (Brown and Hirth 1979). Two males walk to each other and slowly begin pushing until 1 dominates

(Michael 1966). Small-antlered males ($\leq$8 antler points) spar more frequently than large-antlered males and most sparring occurs between males with similar-sized antlers (Michael 1966, Hirth 1973). Sparring begins in September and peaks in October, prior to rut (Brown 1971). Hirth (1973) reported sparring peaks in September and again in late December and January after rut. A similar pattern occurs in other cervids (Bubenik 1968, Barrette 1977, Geist 1981).

Aggressive fights differ from sparring and occur less frequently. Only 2-10% of confrontations among males were classified as aggressive fights (Michael 1966, Brown 1971, Hirth 1973). Aggressive fights typically follow a series of dominance displays and threats. In Grant's gazelle (*Gazella granti*) 78% of threats that were reciprocated resulted in fights (Walther 1984). Aggressive fights result from a breakdown in the function of the hierarchal system due to a lack of recognition between males (Brown 1971). Most males have previously sparred with each other and established dominance allowing avoidance of aggressive fights. However, during rut, males were more likely to enter new areas in search of females, increasing the likelihood of contact between strange males (Brown 1971). Most aggressive fights occur between larger-antlered (older) males in a contest over females and occur during rut (Michael 1966, Brown 1971, Hirth 1973).

Simulation of sparring or fighting is a common hunting technique used to attract males. The number and age of males that respond may provide wildlife managers with an indicator of physiological events related to the breeding season. I measured the age-specific response rates of males to 4 antler rattling sequences during 3 periods of the breeding season from 1992-95 to determine which sequence attracted the highest number of males.

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METHODS

Experiment 1

The initial phase of the study took place at the 3,157-ha Welder Wildlife Refuge located in San Patricio County, Texas. Woody vegetation was predominately honey mesquite (Prosopis glandulosa) with black brush (Acacia acacia), huisache (A. smallii), twisted acacia (A. tortuosa), and agarito (Berberis trifoliolata) in mottes of chaparral (Drawe et al. 1978). The refuge was chosen because of the high deer population, balanced sex and age ratios (Blankenship et al. 1994) and because 17 10-m observation towers located throughout the refuge provided excellent visibility.

We determined male response rates to 4 rattling sequences. Sequences were 30 minutes in length and began with either 1 (short) or 3 (long) min of rattling followed by 7 or 9 min of silence. This pattern was then repeated during the next 2 10-min segments. Short and quiet (SQ) sequences included 1 min of low volume rattling followed by 9 min of silence. During quiet sequences elbows were kept against the body to avoid loud antler clashes to simulate 2 males sparring. Short and loud (SL) sequences were similar to SQ except volume was increased by clashing antlers as hard as possible. In addition, nearby branches were broken, bark rubbed, and the ground scraped to simulate aggressive fighting. Long and quiet (LQ) sequences included 3 min of low volume rattling followed by 7 min of silence. Long and loud (LL) sequences were similar to LQ except volume was increased.

We conducted rattling sequences in random order at randomly chosen towers. One person performed the rattling upwind of the observer from a clump of brush nearest the tower. The second person observed deer responding and first recorded activity with a video camcorder and then on a data sheet. Overt movements toward the tower by males that became alert after rattling had begun were classified as responses.

Rattling sessions were performed during prerut, rut, and postrut. These periods were determined on the Welder Wildlife Refuge based on reproductive data collected from 943 females during 1961-92 (Blankenship et al. 1994). All rut rattling sessions were conducted within 1 week of mean conception dates. Prerut and postrut were then arbitrarily set as the 1-month periods 15-45 days before and after mean conception date. Prerutting activity on the Welder Refuge has been reported to last 4-6 weeks preceding rut (Brown and Hirth 1979).

Ages of responding males were estimated by the observer and reviewed on videotape according to DeYoung and Lukefahr (1995), DeYoung et al. (1989), and Kroll (1996). Observers were first trained in estimating age by viewing video of known-age male white-tailed deer. Direction where each male was first sighted was recorded and wind speed and direction estimated.

Experiment 2

The second portion of the study was conducted on the Faith Ranch, Dimmit and Webb counties, Texas. The ranch is located in the Western Rio Grande Plain region. The gently rolling terrain is dominated by guajillo (Acacia berlandieri), blackbrush acacia (A. rigidula), guayacan (Porlieria angustifolia), and honey mesquite (Gould 1969). Breeding season periods were determined from reproductive data measured on 50 females collected during 1994 (Ruthven et al. 1995). Mean conception date was 24 December.

We had previously attached activity-sensing radio transmitters (Advanced Telemetry Systems, Inc., Isanti, Minn.) to 48 males throughout the study area as part of a second study. Males were captured using the helicopter drive-net (Beasom et al. 1980) and net gun (DeYoung 1988) techniques, photographed, and aged using tooth wear and replacement (Severinghaus 1949). Activity-sensing transmitters allowed the ability to discern activity (inactive or active) based on pulse rate (Fritzen et al. 1995, Naugle et al. 1997). Observers practiced estimating age of free-ranging ear-tagged males ($\underline{N}$ = 486) on the Faith Ranch study area. Estimates were compared to ages indicated by tooth wear and development when males were originally captured.

Eighteen of the 48 males were then located using hand-held telemetry. Error, estimated using test transmitters, was ±3.9° during each season. Males were chosen based on their proximity to a road and were cautiously approached from downwind to a distance estimated to be within 175-200 m if time constraints allowed. The LL rattling sequence was performed and the male's response monitored with telemetry equipment. If the pulse rate from the signal indicated it became active, and if the signal became stronger, the male was classified as having responded. Visual observations of target males and other males were recorded. Radio-equipped males were then relocated $\geq$30 minutes after completing the session to measure escape distance and direction.

Statistical analyses were performed using a SAS statistical software package (SAS Inst., Inc., 1996). Pearson's product moment correlation coefficients were used to test for relationships among male response rates and various weather parameters. One-way analysis of variance (ANOVA) and Tukey's studentized range test (HSD) were used to test for significant differences among variances and mean male response rates by rattling sequence, period of breeding season (Blankenship et al. 1994, Ruthven et al. 1995), estimated age class (1.5-2.5, 3.5-4.5, 5.5+), time of day, wind speed, temperature, and tower site.

RESULTS

Experiment 1

During 1992-95, 171 antler rattling sessions were performed and 111 males responded (Table 7.1). Forty-eight males (43%) were sighted by the person at ground level. Overall male response rates were not different among years ($\underline{F}$ = 0.31; 3, 167 df; $\underline{P}$ = 0.815) and were combined in further analyses. Greatest male response rates ($\underline{F}$ = 12.55; 1, 167 df; $\underline{P}$ < 0.001) were to the 2 sequences incorporating high volume levels (SL and LL). Response rates did not differ among rattling lengths ($\underline{F}$ = 0.03; 1, 167 df; $\underline{P}$ = 0.853). During prerut, no individual rattling sequence attracted significantly more males, although loud volume sequences combined had highest response rates ($\underline{F}$ = 3.80; 1, 55 df; $\underline{P}$ = 0.056). During rut, the SL had the highest response rate ($\underline{F}$ = 7.83; 1, 56 df; $\underline{P}$ = 0.007), as did the loud volume sequences combined ($\underline{F}$ = 13.94; 1, 56 df; $\underline{P}$ < 0.001). During postrut no differences were found between sequences ($\underline{F}$ = 0.15; 3, 48 df; $\underline{P}$ = 0.932). When combining time periods, the SL sequence had the highest response rate ($\underline{F}$ = 5.46; 1, 167 df; $\underline{P}$ = 0.021) and the SQ sequence lowest ($\underline{F}$ = 6.33; 1, 167 df; $\underline{P}$ = 0.013).

Male response rates were highest during morning sessions for all sequences except LL, which had highest rates during afternoon (Table 7.1). Male response rates for all sequences combined were higher during morning than midday ($\underline{F}$ = 4.05; 1, 168 df; $\underline{P}$ = 0.046), but not different ($\underline{F}$ = 1.86; 1, 168 df; $\underline{P}$ = 0.174) from afternoon. Afternoon response rates were highest for loud volume sequences. No differences were found when response rates were grouped by hour ($\underline{F}$ = 0.99; 11, 159 df; $\underline{P}$ = 0.456).

Response rates during rut peak were higher than responses during prerut ($\underline{F}$ = 14.28; 1, 168 df; $\underline{P}$ = 0.0002) and postrut ($\underline{F}$ = 6.10; 1, 168 df; $\underline{P}$ = 0.015), but prerut responses did not differ ($\underline{F}$ = 1.40; 1, 168 df; $\underline{P}$ = 0.239) from postrut (Table 7.1). The rut

Table 7.1. Response rates of male white-tailed deer to 4 antler rattling sequences by period of the breeding season and time of day during 1992-95 at the Welder Wildlife Refuge, San Patricio County, Texas (sample sizes in parentheses).

		Period of breeding season			Time of day			No. of males responding
Seq[a]	N	Prerut	Rut	Postrut	0730-1030	1030-1330	1330-1630	(resp. rate)
SQ	43	0.13 (15)	0.29 (14)	0.43 (14)	0.50 (14)	0.36 (11)	0.06 (18)	12 (0.28)
SL	45	0.38 (16)	1.94 (16)	0.62 (13)	1.61 (19)	0.45 (11)	0.73 (15)	45 (1.00)
LQ	43	0.13 (15)	0.50 (16)	0.67 (12)	0.50 (16)	0.43 (14)	0.23 (13)	18 (0.42)
LL	40	0.57 (14)	1.50 (14)	0.58 (12)	1.00 (16)	0.27 (11)	1.38 (13)	36 (0.90)
Total	171	0.30 (60)	1.07 (60)	0.57 (51)	0.92 (65)	0.38 (47)	0.56 (59)	111 (0.65)

Seq[a] = rattling sequence abbreviations stand for short and quiet (SQ), short and loud (SL), long and quiet (LQ), and long and loud (LL).

had the highest rates with ≥1 male response per session. During prerut, young males responded at highest rates and males in the middle-age class the lowest (Table 7.2). During rut, middle-aged males responded in the highest rates and mature males the lowest. During postrut, middle-aged and mature males responded equally. When combining data, the highest response rates occurred with middle-age males. Mature males exhibited lowest response rates.

Male response rates were higher during the initial 10-minute segment of rattling during loud sequences (Table 7.3). During quiet sequences, highest response rates occurred during the second segment. When combining sequences, highest male response rates occurred following the initial segment, but differences among segments were not significant (F = 0.74; 2, 9 df; P = 0.503).

Male response rates were highest during rattling sessions performed when wind speed was lowest (0-8 km/hr) and decreased as wind speed increased, but differences were not significant (F = 2.05; 3, 167 df; P = 0.109). Sixty-seven (60%) of 111 males were first sighted downwind of the observer, but differences in response by wind direction were not significant (F = 0.71; 7, 163 df; P = 0.661). Response rates did not vary with cloud cover (F = 0.29; 4, 166 df; P = 0.882), or temperature (F = 1.32; 10, 160 df; P = 0.223). Male response rates by tower site varied from 25-92% (C.V. = 43.3%) and number of deer sighted from each tower varied from 12-166, but differences were not significant (F = 1.05; 20, 150 df; P = 0.413).

Experiment 2

During 1994-96, 33 rattling sessions were performed near 18 (1.5-9.5 years old, $\bar{x}$ = 6.2) transmitter-equipped males (Table 7.4). Overall male response rates were not different among years (F = 1.36; 2, 30 df; P = 0.271) and were combined in further analyses. Response rates tended to be lower (F = 3.20; 1, 30 df; P = 0.083) during prerut than during rut and postrut. Response rates were not different between morning, midday,

Table 7.2. Response rates of male white-tailed deer to antler rattling by estimated age class and period of the breeding season during 1992-95 at the Welder Wildlife Refuge, San Patricio County, Texas (number of males responding in parentheses).

Period of breeding season	N	Estimated age class			Total
		1.5-2.5	3.5-4.5	5.5+	
Prerut	60	0.39 (7)	0.28 (5)	0.33 (6)	0.30 (18)
Rut	60	0.33 (21)	0.48 (31)	0.19 (12)	1.07 (64)
Postrut	51	0.31 (9)	0.34 (10)	0.34 (10)	0.57 (29)
Total	171	0.33 (37)	0.41 (46)	0.25 (28)	0.65 (111)

Table 7.3. Response rates (number in parentheses) of male white-tailed deer to different antler rattling sequences by time segment and volume during 1992-95 at the Welder Wildlife Refuge, San Patricio County, Texas.

	Rattling sequence[a]						
Time segment[b]	SQ	SL	LQ	LL	SQ+LQ	SL+LL	Combined
1	0.56 (5)	0.38 (17)	0.28 (5)	0.62 (16)	0.37 (10)	0.46 (33)	0.44 (43)
2	0.11 (1)	0.40 (18)	0.56 (10)	0.15 (4)	0.41 (11)	0.31 (22)	0.34 (33)
3	0.33 (3)	0.22 (10)	0.17 (3)	0.23 (6)	0.22 (6)	0.23 (16)	0.22 (22)
N	43	45	43	40	86	85	171

[a]Abbreviations stand for short and quiet (SQ), short and loud (SL), long and quiet (LQ), and long and loud (LL) sequences.

[b]Time segment of response for 13 males not recorded.

Table 7.4. Response rates of radio-transmittered male white-tailed deer (N =18) to antler rattling sessions performed within 200 m during different periods of the breeding season and time of day during 1994-96 at the Faith Ranch, Dimmit and Webb counties, Texas (no. of sessions performed in parentheses).

Period of breeding season	N	Time of day 0730-1030	1030-1330	1330-1630	Total
Prerut	5	0.0 (0)	0.50 (2)	0.33 (3)	0.40
Rut	14	1.00 (5)	0.67 (3)	0.67 (6)	0.79
Postrut	14	0.75 (4)	0.75 (4)	0.83 (6)	0.79
Total	33	0.89 (9)	0.67 (9)	0.67 (15)	0.73

and afternoon sessions (F = 0.78; 2, 30 df; P = 0.468). Response rates by male age were not different (F = 1.35; 7, 25 df; P = 0.269), but mean age (0 = 5.8 years old, N = 24) of responding males was younger than mean age (0 = 7.4 years old, N = 9) of males that did not respond (T = -2.21; 8, 23 df; P = 0.035) and response rates of males in the oldest age class (7.5+ years old) tended to be lower than response rates of males in the other 3 age classes (F = 3.83; 1, 31 df; P = 0.060).

Eleven males were rattled to on ≥2 occasions (Table 7.5). In 13 of 14 instances, males responded to rattling during successive sessions. Four of these males had not responded during the first session. One male responded on all 4 occasions that a rattling session was performed nearby. Distances moved ≥30 minutes after rattling were highest during postrut (0 = 564 m) and lowest during prerut (0 = 328 m).

DISCUSSION

Volume of rattling was more important than duration. Seventy-three percent of male responses were to a loud sequence. The only exception occurred during post-rut when response rates were nearly equal among SL, LQ, and LL sequences. Increased response to loud rattling was at least partially due to the greater distances it could be heard. However, males also responded quicker to loud sequences and appeared more aggressive. Males may have become accustomed to sounds of low volume rattling, because of the high frequency of sparring during prerut and postrut (Brown 1971, Hirth 1973), reducing their likelihood of response. Also, aggressive fights usually are observed during rut (Brown 1971, Hirth 1973) and are associated with a female nearing estrus (Michael 1966).

Responses were greatest during rut and lowest during prerut in both experiments. Goss (1983) related aggressive fighting in cervids to the seasonal surge in testosterone concentration during rut. He suggested that prerut and postrut peaks in sparring

Table 7.5. Estimated age and response (Y = yes, N = no) of 11 radio-transmittered male white-tailed deer to successive antler rattling sessions performed during 1994-96 at the Faith Ranch, Dimmit and Webb counties, Texas.

Male no.	Estimated age	Rattling session 1	2	3	4
180	4.5	Y	Y		
602	4.5	N	Y		
1540	4.5	N	Y	Y	
1721	4.5	Y	Y		
1300	5.5	Y	Y		
1462	5.5	N	Y		
924	6.5	Y	Y		
1940	6.5	Y	Y	Y	Y
1326	7.5	Y	Y		
980	9.5	N	N		
1561	9.5	N	Y		

coincided with intermediate levels of testosterone. Previous research has verified the rising production of testosterone during rut (West and Nordan 1976). Fewer responses during prerut and postrut also may be related to the tendency for males to travel in bachelor groups at these times (Brown 1971). During prerut, typically only 1 male from a bachelor group responded to the rattling. These males appeared older and may have been dominants. Physically- and behaviorally-mature males can suppress reproductive performance of younger males (Miller et al. 1995). During rut, bachelor groups had disbanded (Brown 1971) and males were seen traveling alone throughout the refuge. Single males observed from towers usually responded to the rattling. This high response rate may have occurred because dominant males were not in the immediate area to discourage subordinates.

Caution should be used in interpreting age class relationships because ages were estimated visually at the Welder Refuge study site. The majority of males that responded during rut peak were identified as young and middle-aged. Low response from mature males likely was because most were actively engaged in chasing or tending females. Hirth (1973) did not observe any males with <8 antler points tending females during 26 observations. He classified 95% of these males as large antlered with ≥8 points. A significant difference was found in response rates by age class at the Faith Ranch study area, with older males less likely to respond to rattling. However, the age structure of the sample was highly skewed toward older-age males (0 = 6.2 years) and males ≤3.5-years-old (N = 2) were under represented.

During postrut, most young and middle-aged males observed on the refuge had returned to traveling in bachelor groups (Brown 1971). Mature males were typically still engaged in chasing and scent checking females (Brown and Hirth 1979). These single, mature males represented the majority of responses during postrut. According to

Blankenship et al. (1994) 75% of females on the refuge are successfully bred during November.

Significantly higher numbers of males responded to morning and afternoon rattling when compared to midday. However, Michael (1966) reported no differences in number of sparring matches observed by hour-of-day. We found no relationships between response rates and temperature, but Michael (1966) observed more matches during below-average temperatures. More male responses occurred when wind speeds were lowest. As wind speeds increased, sound travel likely decreased. Michael (1966) reported a trend toward an increase in sparring during high winds and aggressive fights during low winds. Most males that responded to our rattling were first sighted downwind from the tower, indicating males used the wind to determine what (or who) was producing the rattling sound. Males observed prior to segment 1 typically circled from their initial position to a position downwind as they approached.

Male responses varied greatly by tower site. However, response rates did not appear to be correlated with number of deer, male or female, in the area of the tower. Visibility was not measured but also varied by tower. This variation may explain the lack of significant correlations between number of deer sighted and rattling response. When rattling sessions were repeatedly performed to the same radio-transmittered males during successive sessions on the Faith Ranch study area, response rates increased indicating that males did not learn to avoid rattling.

Male response rates to antler rattling may be used as an index to physiological events related to the breeding season and to verify dates for the rut peak. Although this technique may be more time consuming than harvesting pregnant female deer for necropsy, it may provide a non-lethal alternative.

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SUMMARY

As a result of this 3-year study investigating the age-specific physical characteristics, activity, and behavior patterns of male white-tailed deer in southern Texas, the following conclusions can be made:

(1) Regression analyses indicated live mass of mature ($\geq$5.5 years old) males can be predicted with a model based on dressed mass.

(2) Fawn and yearling live mass can be predicted with models based on dressed mass, hoof length, shoulder height, and chest girth.

(3) Dressed mass provided an accurate prediction of live mass for adult females.

(4) The best 2-variable model for estimating live mass of mature males that did not include dressed mass, involved chest girth and shoulder height.

(5) The best 2-variable model for estimating live mass of adult females that did not include dressed mass, involved chest girth and hoof width.

(6) Wildlife managers can use these sex- and age-class-specific equations to accurately estimate live mass of harvested or live-captured white-tailed deer in the Western Rio Grande Plains region of Texas.

(7) Gross Boone and Crockett Club (BCC) score, inside antler spread, and basal circumference had lowest Akaike information criterion scores.

(8) Models incorporating gross BCC score and number of antler points, or gross BCC score, number of antler points, and stomach girth had highest $\underline{R}^2$ values.

(9) A combination of characteristics that include gross BCC score and inside antler spread, and stomach girth relative to chest girth are likely to be most uesful for visually estimating age of live male white-tailed deer.

(10) Live mass and chest girth appeared to have the most value for classifying females into 0.5, 1.5, and $\geq$2.5-year-old age classes.

(11) Our system, using number of pulses per min, perpendicularly-oriented sensors, and 1-min scan times, accurately identified deer as active (90.2%) when relative pulse rates were >104% and inactive (88.4%) when pulse rates ≤104%.

(12) The diel activity pattern for male white-tailed deer in southern Texas was diurnal, although small crepuscular peaks occurred.

(13) Males were active an average of 42.6% (±2.1 SE) of the time monitored.

(14) Seasonal and monthly diel activity patterns were highly variable.

(15) Males were most active during the evening crepuscular period except during rut when diurnal activity was highest.

(16) Activity rates were highly variable, with some males >4 times as active as other males.

(17) Activity rates tended to decrease as individuals increased in age.

(18) Activity rates were highest for young and middle-aged males and lowest for mature and old males.

(19) Activity appeared to be unrelated to forage quantity and quality, precipitation, estimated density, or antler and body size.

(20) We suggest that changes in activity rates among individuals and age classes may be explained in part, by social interactions, relative dominance, and the varying ability among males to assimilate into bachelor groups.

(21) Loud rattling attracted nearly 3 times as many males as quiet rattling but length of rattling was not significant.

(22) Highest response rate was during rut and lowest during prerut.

(23) Males estimated to be young (1.5 to 2.5 years old) responded in the highest rates during prerut. Middle-aged (3.5-4.5) responded at highest rates during rut, while mature males (5.5+) responded at highest rates during postrut.

(24) Lower response rates of mature males during rut is likely because they were engaged in courtship of females.

VITA

Name: Mickey Wayne Hellickson

Date of birth: 04 May 1965

Place of birth: Fort Dodge, Iowa

Wife: Genny G. Hellickson

Parents: Willis W. and Barb J. Hellickson

Educational background:

B.S., Fisheries and Wildlife Biology, Iowa State University, 1988

M.S., Range and Wildlife Management, Texas A&I University, 1991

Ph.D., Wildlife Biology, The University of Georgia

Work experience: Park Aide, Humboldt County Conservation Commission, Humboldt, Iowa, 1985 (Park maintenance).

Wildlife Aide, Clear Lake Wildlife Research Unit, Iowa Department of Natural Resources, Clear Lake, Iowa, 1986 (Assisted with research on predator use and waterfowl nesting success in response to nesting cover management).

Wildlife Aide, Big Sioux Wildlife Management Unit, Iowa Department of Natural Resources, Spirit Lake, Iowa, 1987 (Assisted with maintenance of state wildlife management areas).

Laboratory Technician, Department of Botany, Iowa State University, Ames, Iowa, 1987-88 (Assisted with research on carbon and nitrogen dynamics in streams and wetlands).

Wildlife Research Assistant, CKWRI, Texas A&I University, Kingsville, Texas, 1989-90 (Completed research on effects of increased harvest on south Texas deer populations, effects of intensive coyote control on post-rut mortality of male deer, and winter fawn mortality).

Wildlife Research Assistant, CKWRI, Texas A&I University, Kingsville, Texas, 1990-91 (Completed field research and thesis on predicting carrying capacity based on estimates of digestible energy and biomass).

Wildlife Research Assistant, D.B. Warnell School of Forest Resources, The University of Georgia, Athens, Georgia, 1992-97 (Completed field research and dissertation on age-specific physical characteristics, activity, movement, and behavior patterns of male white-tailed deer in southern Texas).

Editor and Staff Writer, Trophy Magazine, Laredo, Texas, 1995-96 (Edited popular articles on white-tailed deer submitted to the magazine for publication and wrote editorial and 1-2 feature articles per issue).

Wildlife Research Scientist, CKWRI, Texas A&M University-Kingsville, Kingsville, Texas, 1998-present (Assisted with the completion of a Wildlife Monograph summarizing nearly 20 years of deer population ecology research in southern Texas and initiated the South Texas Buck Capture Project).

Staff Writer, Journal of the Texas Trophy Hunters magazine, San Antonio, Texas, 1999-present (Responsible for writing 1 feature article on white-tailed deer management and behavior per bi-monthly issue).

Chief Wildlife Biologist, King Ranch, Inc., Kingsville, Texas, 1999-present (Responsible for wildlife management program, with emphasis on deer and quail, on 825,000-acre privately owned ranch in southern Texas).