ECOLOGY OF FALLOW DEER (*DAMA DAMA* L.) ON LITTLE SAINT SIMONS ISLAND, GEORGIA

by

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(Under the Direction of Karl V. Miller)

ABSTRACT

During the 1920s, several exotic deer species were introduced to Little Saint Simons Island (LSSI), Georgia, an approximately 4,340-ha, privately owned barrier island. Currently, the only exotic cervid inhabiting the island is the fallow deer (*Dama dama*). The economic value of fallow deer hunting, along with concerns over altered ecological communities, have triggered the need for research on this population and its potential ecological impacts. From 2003-2006, I examined the population's demographics, health, food habits, and spatial ecology. Antler and body measurements of fallow deer on LSSI were smaller than those from other populations. Density estimates ranged from 36.4-62.4 deer/km^2, and the sex ratio was estimated at 1.1 bucks to 1 doe. No clinical signs of disease were noted, parasite burdens were low, and overall the population was in good health. Parasite species were similar to those found in white-tailed deer (*Odocoileus virginianus*) with the exception of two abomasal nematodes. Fallow deer foraged on a wide variety of food items, preferring grasses and mast of *Quercus* spp. Data from deer instrumented with global positioning system (GPS) collars indicated that adult female home ranges averaged 130.3 ± 0.45 ha. Male home ranges were more variable, ranging from 56.9 to 354.8 ha. Deer avoided salt marsh habitats, but among the other habitats represented on LSSI, no general patterns in preference were observed. Fallow deer have adapted well to the barrier island ecosystem and competitive advantages apparently have helped to exclude native white-tailed deer. However, the population likely has exceeded carrying capacity for LSSI and a reduction in herd size may be warranted.

INDEX WORDS: barrier island, competition, *Dama dama*, disease, exotic, fallow deer, food habits, GPS, habitat, insular, parasites, population, spatial ecology

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, STUDY AREA, OBJECTIVES, AND THESIS FORMAT

INTRODUCTION

Little St. Simons Island is an approximately 4,340 ha undeveloped barrier island on the coast of Georgia. It was purchased in 1908 by the Eagle Pencil Company from the descendents of Major Pierce Butler, and ownership was passed to Philip Berolzheimer in 1913 (McIntyre, 2001). During the 1920s, Philip Berolzheimer introduced several species of domestic animals such as cattle for ranching, as well as exotic species of deer and wildfowl for recreational hunting. Fallow deer (*Dama dama*), roe deer *(Capreolus capreolus)*, a single sambar deer (*Cervis unicolor niger*), Barasingha (*Cervus duvauceli*), sika deer *(Cervus nippon nippon)*, and elk/red deer *(Cervus elaphus)* were all brought to the island (Rochester, 1994). The status of native white-tailed deer (*Odocoileus virginianus*) at the time of these introductions is unknown, but they populate neighboring islands such as St. Simons, Sea Island as well as the mainland. Sightings of white-tailed deer on LSSI have been rare, and none were observed from 2002-2006. The fallow deer is the only introduced species remaining, and it is currently thriving on the island.

The number of fallow deer that were originally stocked on LSSI is unknown, however records indicate that 6 individuals, 4 male and 2 female, were purchased from the Bronx Zoo in New York and shipped to the caretaker of LSSI in 1923 (Johnson, pers. comm.). With few predators and little competition for resources, the fallow deer population grew to over 1,000 animals (Mierau, GADNR, unpub. data) in the early 1980s. Since then a private hunting club was created and is used to control deer population growth and produce income for the management and upkeep of LSSI. The island is presently under private ownership and is used for owner recreation and a small, commercially operated tourism business.

Exotic wildlife introductions and managing existing exotic populations has become a controversial conservation topic (Bolen and Robinson, 1995). Wildlife biologists and land managers have become increasingly concerned about exotic deer populations and their potential negative impacts on native species and local ecosystems (NPS, 2006; Demaris et al., 1990; Davidson et al., 1985). Concerns over these introductions include disease transmission, habitat degradation or modification, and competition over resources, particularly food (Bolen and Robinson, 1995).

Little St. Simons Island presents a unique research opportunity in that it is a coastal barrier island supporting a wild population of exotic fallow deer. The population has completely displaced native white-tailed deer. Little is known about the ecology of the fallow deer on LSSI and their impact on the barrier island ecosystem. This study was undertaken to provide descriptive data on population characteristics, herd health, food habits, spatial use, and habitat selection of this exotic, insular population of fallow deer.

LITERATURE REVIEW

Population Characteristics

The fallow deer is one of the most recognizable and widely distributed Old World deer species. Chapman and Chapman (1975) provide a detailed examination of the natural history of fallow deer. They are medium-sized deer with male body weights averaging 62.5 kg in their native range in Europe and the Middle East. Females are smaller and average 37 kg. Fallow deer antlers have characteristic palmation in adult males with wide, flat "palms" occurring at the top of the antlers. Historic domestication attempts are believed to have caused the wide variety of pelage coloration in fallow deer. Four color phases exist: black (sometimes referred to as chocolate), common, menil and white. Two subspecies of fallow deer currently are recognized, *Dama dama dama* and *Dama dama mesopotamia*. The latter has limited distribution in the Middle East, and is listed as endangered (IUCN, Gland, Switzerland). The more widespread and abundant European fallow deer is found throughout Europe. Successful introductions of fallow deer have occurred in Asia, Africa, South America, Australia, New Zealand, and North America. In the United States, fallow deer have been introduced in 9 states. The population at Land Between the Lakes, Kentucky has declined to approximately 20-30 animals (E. Raikes, pers. comm.), while there is uncertainty about the populations in Alabama (D. Nelson, per. Comm.) and Nebraska (B. Trendle, pers. comm.). Recently, eradication efforts have been undertaken to eliminate fallow deer in California (N. Gates, pers. comm.). Thriving populations exist in Texas (Osborn, 1990) and Georgia.

Fallow deer population density is highly variable and dependent on range conditions, location, hunting pressure, introduction time, etc. Fallow deer densities of 10-20 deer/km^2 have been reported from England (Putnam, 1986) and New Zealand (Nugent, 1994). Population density in some parts of Point Reyes National Seashore, California ranged as high as 81 deer/km^2 (NPS, 2006).

Fallow deer exhibit plasticity in breeding systems, including the use of leks by males (Thirgood et al., 1999). This mating system, unique among cervids, involves adult male deer defending aggregations of small clustered territories which are visited by females primarily to mate (Thirgood, et al., 1999). Lek breeding has been observed in fallow deer populations in Texas (Hirth, 1997) and California (Fellers and Osbourn, 2007). Mating occurs in the fall in the Northern Hemisphere, and males go through a pronounced rut (Chapman and Chapman, 1975). Females normally carry one fawn, with twins being rare (Chapman and Chapman, 1975).

Gestation length is reported to be 229 days (Chapman and Chapman, 1975) and 234 days (Asher, 1986). Weight at birth of neonates is approximately 4.5 kg (Chapman and Chapman, 1975).

Disease and Health

Disease and health parameters of fallow deer have been documented in many parts of the species' range. Chapman and Chapman (1975) provided a thorough examination of diseases and parasites of fallow deer in England. Other studies have investigated introduced fallow deer populations in the United States, and the disease relationships with sympatric animals. Doster and Friend (1971) first reported the nematode *Spiculopteragia asymmetrica* in North America from fallow deer on Little St. Simons Island. This nematode was subsequently identified in fallow deer from Kentucky (Davidson et al., 1985). Descriptions of abomasal parasites of fallow deer have been documented in New Zealand (Andrews, 1973) and Europe (Ambrosi et al., 1993; Santin-Duran et al., 2004). A relationship between abomasal parasite burdens and population health has not been developed for fallow deer, such has been developed for white-tailed deer (Eve and Kellogg, 1977).

Results from investigations of other exotic deer populations in the southeastern United States suggest that exotics have superior health ratings than sympatric white-tailed deer (Davidson and Crow, 1983; Davidson et al., 1987). Parasites common to native white-tailed deer such as ticks and nematodes often parasitize sympatric exotic deer, though their impact to the exotics is unknown (Corn et al., 1990; Davidson et al., 1985). Exotic ungulates in the U.S., including fallow deer, have low seroprevalence to bovine viral diarrhea and *Leptospira* sp. (Corn et al., 1990; Riemann et al., 1979). Positive seroprevalence results to bluetongue and epizootic hemorrhagic disease were greater than 33% in fallow deer from California (Riemann et al., 1979) and Texas (Corn et al., 1990). Fallow deer in Europe and the United States also have shown evidence of exposure to *Mycobacterium avium* (Feldhamer et al., 1988).

Mineral requirements or toxicity of fallow deer has received little research attention. Puls (1994) provides a detailed list of mineral concentrations from >300 fallow deer. Copper is an essential element for farmed deer and concentrations less than 7 ppm in the liver can cause osteochondrosis (Jones, 1994). Liver copper concentrations of fallow deer from enclosures in Poland were 31.0±21.9 ppm (Vengust and Vengust, 2004), similar to those reported by Puls (1994).

Food Habits

Fallow deer food habits have been researched extensively throughout their native and introduced range. Rumen contents and feeding observations of fallow deer in the New Forest of England indicate that grasses are used predominantly in the spring and summer. Their diet shifts to mast such as acorns in the fall and to brambles, ivy and conifers during winter (Jackson 1977). Fallow deer diets from Poland (Borkowski and Obidzinski, 2003) and Spain (Garcia-Gonzalez and Cuartas, 1992) also indicated a preference for graminoids. However, in Italy, Bruno and Apollonio (1991) described fallow deer as browsers, selecting tree and shrub species in the fall and spring. Fallow deer introduced to the Blue Mountains of New Zealand showed a marked preference for mid-story browse species (Nugent, 1990). They also consume large quantities of leaf fall, along with secondary use of lichens, fungi, and exotic grasses.

Studies of fallow deer diets in North America have produced dissimilar results. Fallow deer on the Kerr Wildlife Management Area in Texas preferred browse (54% of diet), but also consumed significant amounts of grass (Mungall and Sheffield, 1994). However, in a California study, grass provided 90% of fallow deer food intake (Connolly, 1981). This plasticity has allowed fallow deer to adapt to a wide variety of habitats, often competing with native species for available food.

Dietary overlap and competition between fallow deer and other ungulates have been documented in North America (Demaris et al., 1990; Elliott and Barrett, 1985). Rumen characteristics may provide fallow deer with an advantage in food utilization species (Prins and Geelen, 1971; Dehority et al., 1999), allowing fallow deer to impact native vegetation or out-compete native species (Veblen et al., 1989; NPS, 2006).

Fallow deer food habits on barrier islands in the southeastern United States are largely unknown, although the diets of other deer species have been examined in similar habitats. White-tailed deer food habits on Blackbeard Island (Osborne et al., 1992) and Cumberland Island (Warren et al., 1990) in Georgia indicate a preference for browse in the fall and winter and heavy reliance on acorns when available. These studies also have suggested that white-tailed deer population dynamics on barrier islands are closely associated with acorn production. Exotic sambar deer (*Cervus unicolor*) introduced to St. Vincent Island, Florida utilized browse more than other forage classes year-round (Shea et al., 1990). On Assateague National Seashore in Maryland, sika deer were considered primarily grazers during fall, spring and summer and browsers during winter (Kochenberger, 1982). Important plants consumed by the sika deer included wax myrtle (*Myrica cerifera*), cordgrass (*Spartina patens*) and greenbrier (*Smilax* spp.).

Spatial Ecology and Habitat Use

The home range development, habitat selection, and movement ecology of insular populations of exotic deer in the United States have been little studied. Using radio telemetry, Shea et al. (1990) examined the spatial ecology of introduced sambar deer on St. Vincent Island, Florida. They report that male sambar had larger and more variable home ranges than females, and that sambar preferred freshwater swamp habitats. In Maryland, researchers are currently studying aspects of sika deer spatial ecology on Assateague Island (S. Christensen, pers. comm.).

Similarly, fallow deer spatial ecology and habitat use have been little investigated across their native and introduced range. In Kentucky, introduced fallow deer preferred open, grassy habitats or areas planted in a crop (Terpening and Hawkins, 1970). Studies of fallow deer movement ecology in Italy (Davini et al., 2004) and New Zealand (Nugent, 1994) demonstrate seasonal variation in home range size, and that the use of leks during the rut by male deer influences home range development. Males had larger home ranges than females, but considerable variation was noted among radio-collared animals (Nugent, 1994). Fallow deer in the New Forest of England used deciduous woodlands in fall and spring, and more open habitats in winter and summer (Parfitt, 1985; Thirgood, 1995).

STUDY AREA

This study was conducted on Little Saint Simons Island in Glynn County, Georgia. Little Saint Simons Island (LSSI) is a privately owned, 4,340-ha, coastal barrier island located approximately 21 km northeast of Brunswick, Georgia. It is bordered by the Atlantic Ocean to the east, the Altamaha River to the north, and the Hampton River to the south and west with no land bridge. Most of LSSI lies east of Saint Simons Island, but a narrow hook of salt marsh wraps around the northern end of Saint Simons Island.

Little St. Simons Island is typical of other undeveloped barrier islands in the South Atlantic/Carolinian biogeographic classification (McIntyre, 2001). Of the total area, 3,189 ha are comprised of tidally influenced salt marshes. Low salt marshes are flooded daily and vegetation is predominantly smooth cordgrass (*Spartina alternaflora*), saltmeadow cordgrass (*S. patens*) and needle rush (*Juncus roemerianus*). High salt marshes are flooded less frequently and are comprised of salt grass (*Distichlis spicata*), glasswort (*Salicornia* spp.), saltwort (*Batis maritima*), sea oxeye (*Borrichia frutescens*), and marsh elder (*Iva frutescens*). The remaining 1,151 ha consists of uplands and freshwater habitats. Uplands are composed of parallel remnant dune ridges with varying successional communities in a north to south orientation. Primary dune ridges contain low species richness due to exposure to salt spray and other harsh conditions. Sea oats (*Uniola paniculata*), beach pennywort (*Hydrocotyle bonariensis*), seaside croton (*Croton punctatus*) and beach elder (*Iva imbricata*) are common in this community. Interdune swales, protected backslopes, and secondary dunes contain grass and herbaceous plants such as muhly grass (*Muhlenbergia filipes*), dogfennel (*Eupatorium capillifolium*) and flat topped goldenrod (*Euthamia tenuifolia*) on the higher and drier sites. Areas of lower relief contain a shrub dominated community of wax myrtle (*Myrica cerifera*) and groundsel bush (*Baccharis halimifolia*) along with various herbaceous plants and grasses in openings and wetter areas. Backdune regions on the southern portion of LSSI are dominated by southern red cedar (*Juniperus silicicola*), yaupon holly (*Ilex vomitoria*), buckthorn (*Bumelia tenax*), toothache tree (*Xanthoxylum clava-herculis*), Carolina laurel cherry (*Prunus carolinina*) and live oak (*Quercus virginiana*).

Forested areas in the northern part of LSSI are predomiantly mature live oak, southern red cedar, southern magnolia (*Magnolia grandiflora*) and laurel oak (*Q. laurifolia*), along with minor amounts of red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*) and pignut hickory (*Carya glabra*). Understory vegetation includes saw palmetto (*Serenoa repens*), cabbage palmetto (*Sabal palmetto*), red bay (*Persea borbonia*), American beautyberry

(*Callicarpa americana*), and sparkleberry (*Vaccinium arboretum*). Forests in the central portions of the island are a mix of oak and pine forest along with depressional wetlands composed of red maple, giant sugarcane plumegrass (*Erianthus giganteus*), and a variety of herbaceous plants. Slash pine (*Pinus elliottii*) dominates the southern forested parts of the island. Understory vegetation is more abundant in this forest type and includes wax myrtle, saw palmetto, cabbage palmetto, and yaupon holly. Sloughs are freshwater wetlands in the maritime forests and contain wetland plants such as cattail (*Typha* spp.), pickerelweed (*Pontederia cordata*), rushes (*Juncus* spp.) and swamp rosemallow (*Hibiscus grandiflorus*). Floral diversity is low on LSSI compared to nearby larger barrier islands and the mainland, likely due to its small size, poor soils (Rigdon and Green, 1980), isolation from the mainland, and topographic limitations.

Elevations range from sea level to 9 m, although most upland habitats are <3 m above sea level. Sea breezes moderate the climate on LSSI providing cooler summers and warmer winters than the mainland (McIntyre, 2001). Mean temperatures for January and July are 11.9ºC and 28.1ºC respectfully. Mean annual rainfall is 132.4 cm (cirrus.dnr.state.sc.us). Severe droughts and floods are common. Flooding occurs mainly from tropical storm systems and high spring tides.

Little St. Simons Island was formed during the Holocene era in the last 5,000 years. Its unique geographic location at the mouth of the Altamaha River has resulted in consistent accretion since its formation. Accretion up to 1 meter/year eastward has been recorded since the mid-nineteenth century (McIntyre, 2001). Most soils on LSSI were derived from quartz deposited during its formation and have an acidic pH level of 5.0-5.5 (McIntyre, 2001).

The island is undeveloped other than a small cluster of buildings comprising the Lodge on Little St. Simons Island tourism operation. The Lodge operations are located in a 4.4-ha compound along a tidal creek. There are 35 km of unpaved dirt and limestone roads located on LSSI. Management goals for the island are to preserve the natural state of the island, maintain private ownership, and create economic self-sufficiency from the tourist program (McIntyre, 2001). There has been little habitat manipulation since cattle operations were removed in the 1980s, and the island remains in relatively pristine habitat. The island is rich in cultural and natural resources and has significant conservation value.

Fallow deer are the only large, free-ranging mammal on LSSI. Predators such as bobcats (*Lynx rufus*), foxes (*Vulpes vulpes* and *Urocyon cineroargenteus*), and coyotes (*Canis latrans*) do not occur on LSSI. The only potential predator of fallow deer is the American alligator (*Alligator mississippensis*). Competition for mast resources includes gray squirrels (*Sciurus carolinensis*) and raccoons (*Procyon lotor*).

OBJECTIVES

The goal of this study was to describe the ecology of introduced fallow deer on LSSI in an effort to understand their ecological influence on the barrier island ecosystem. This research was designed to provide baseline biological data to assist with management decisions. Specific objectives for the study were to:

1. Document LSSI fallow deer characteristics including body weights, antler characteristics, pelage proportions, reproductive behavior and biology and to estimate population density, sex ratio and recruitment,

2. Evaluate population health including disease parameters, parasite burdens and toxicology, and to document potential impacts to human health or native species,
3. Identify specific foods eaten by fallow deer and determine their importance to the diet , and
4. Examine and describe seasonal and spatial home range development and habitat use.

THESIS FORMAT

This thesis is presented in manuscript format. Chapter 1 includes an introduction, study area description, objectives and thesis format. Chapters 2-5 are separate manuscripts that will be submitted for publication in peer-reviewed scientific journals. Chapter 2 focuses on the physical characteristics, population density, and reproductive cycles of the insular fallow deer. Chapter 3 investigates disease prevalence, parasitic fauna and burdens, and some toxicology parameters of the herd. Chapter 4 describes food habits from rumen and fecal sample examination. Chapter 5 examines spatial use and habitat selection. Chapter 6 is a summary and conclusions chapter providing a review of findings and the management implications of the results.

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CHAPTER 2

POPULATION CHARACTERISTICS OF AN INSULAR FALLOW DEER (*DAMA DAMA* L.) POPULATION ON LITTLE ST. SIMONS ISLAND, GEORGIA, U.S.A. [1]

[1] Morse, B. W. and K. V. Miller. To be submitted to the *European Journal of Wildlife Research*

***Abstract*:** We describe population characteristics including body weight, antler measurements, pelage, population density, and reproduction of an introduced population of fallow deer (*Dama dama* L.) on Little Saint Simons Island, Georgia, USA. Between 2002 and 2006, we obtained data from 181 hunter-harvested deer. Adult males (n=45) averaged 48.8 kg ± 2.6 kg SE and females (n=34) averaged 35.7 kg ± 1.4 kg SE. Based on seasonal spotlight surveys sex ratios averaged 1.2:1 bucks to does, and recruitment estimated at 0.5 fawns per doe. Herd density was estimated at 47.3 deer/km^2. Lek behavior was common and peak rut occurred in early to middle October. Fallow deer on LSSI demonstrated low body weights and antler measurements, high population density, and depressed reproduction. Based on these characteristics, a reduction in deer density is warranted.

***Keywords*:** body weights, conception, density, DISTANCE, reproduction, rut

INTRODUCTION

Due to widespread introductions, fallow deer *(Dama dama)* are one of the most widely distributed cervids (Chapman and Chapman 1975). In the United States, fallow deer have been released in 9 states (Chapman and Chapman 1975), although few wild populations remain. Where wild populations occur, concern exists over potential impacts on native deer species and local ecosystems (Davidson et al. 1985; Keiper 1985; Jackley 1991; NPS 2006). For example, recently the National Park Service has called for the eradication of exotic fallow deer and axis deer (*Axis axis*) from Point Reyes National Seashore, California (NPS 2006). This decision stemmed from declines in native black-tailed deer (*Odocoileus hemionus columbianus*) and tule elk (*Cervus elaphus nannodes*) populations due to resource competition with the exotics, as well as overall habitat degradation.

During the 1920s, European fallow deer (*Dama dama dama*), a single sambar deer (*C. unicolor niger*), barasingha (*C. duvauceli*), and red deer *(C. elaphus elaphus)* were released on Little St. Simons Island (LSSI), a barrier island off the coast of Georgia, USA (Rochester 1994). Only fallow deer remain and are currently thriving on the island. The number of fallow deer stocked on the island is unknown, although records indicate 4 male and 2 female deer were purchased from the Bronx Zoo in New York and shipped to LSSI in 1923 (S. Johnson, pers. comm.). Fallow deer on LSSI exhibit all four pelage varieties (black, common, menil, and white) described for this species (Chapman and Chapman, 1975). A regulated hunting program is the primary cause of mortality in this population.

Although LSSI is within the native range of white-tailed deer (*Odocoileus virginianus*), the historical status of this species is unknown. Recent sightings of white-tailed deer on LSSI have been rare, and none have been observed since 2002. However, white-tailed deer are present on all the surrounding barrier islands as well as the adjacent mainland. Apparently fallow deer have displaced native white-tailed deer on LSSI. Because little is known about the ecology of fallow deer on LSSI and their potential impact on the island ecosystem, our objectives were to document population demographics to provide scientific information to assist in the management of this species.

STUDY AREA

Little Saint Simons Island is a 4,340-ha, coastal barrier island in Glynn County, Georgia (ca. 31° 16′ N, 81° 18′ W). The island has no land linkage and is bounded by large water bodies; the Atlantic Ocean to the east, Altamaha River to the north and the Hampton River to the south and west.

Vegetation communities change on an east-west gradient and are predominantly controlled by saltwater influences. Tidally influenced salt marshes dominated by smooth cordgrass (*Spartina alternaflora*) in lower marshes and saltgrass (*Distichlis spicata*) in higher marshes comprise the majority of LSSI (3,189 ha). Upland habitats include primary and secondary dune systems, maritime shrub communities comprising a mosaic of open grassland, shrub/scrub, and wet meadows and depressions, mixed pine-oak-palmetto forest and mature maritime forest. Freshwater habitats are limited to a few permanent ponds and ephemeral sloughs. Floral diversity is low compared to the mainland due to its small size, poor soils (Rigdon and Green 1980), isolation from the mainland, and topographic limitations. Sandy soils on LSSI are acidic with pH levels below 5.5.

Elevation ranges from sea level to 9 m with most upland habitats <3 m above sea level. Marine influences provide a mild climate. Mean temperatures for January and July are 11.9ºC and 28.1ºC, respectively, and mean annual rainfall is 132.4 cm.

Little St. Simons Island is privately owned and undeveloped with the exception of a 4.4-ha compound used in tourism operations. There are 35 km of unpaved roads on LSSI and there has been little habitat manipulation since cattle operations were removed in the 1980s. Fallow deer are the only ungulate currently on LSSI. Large or medium-sized mammalian predators are absent; the only potential predator of fallow deer is the American alligator (*Alligator mississippensis*).

MATERIALS AND METHODS

Biological Data

We recorded biological data from hunter-harvested fallow deer 2002-2006. Hunts occurred approximately every 2-3 weeks from mid-November through February as well as October 2004 and March 2006. Hunters were assigned specific zones throughout LSSI and could select does or bucks. Bucks <2 years of age were not allowed to be harvested, and only one buck <4 years old was allotted per hunter (n=12). Hunters brought harvested deer to a central processing station where live weight and eviscerated weights were recorded. The left mandible was removed from each animal and age was estimated using the tooth wear and eruption technique (Severinghaus 1949), as modified for fallow deer (Murphy 1994). We compared age estimates derived by the toothwear and eruption technique with cementum annuli counts by selecting 20 mandibles from deer of varying ages. An incisor was removed from each mandible and sent to Matson's Laboratory (Milltown, Montana, USA) for aging. Ages were estimated using cementum annuli models from mule deer/black-tailed deer (Gary Matson, pers. comm.).

Antler measurements recorded from adult male deer (≥2 years) included beam length, greatest inside spread, total number of antler points, and beam circumference at 1 cm above the brow tines. We defined beam length as the mean of the outside length from both antlers measured from coronet to tip. All measurements were recorded from deer with fully mineralized antlers.

Hunter-harvested does were examined for the presence and sex of a fetus. All fetuses collected from 2004-2006 were frozen for later analyses. Fetuses were later thawed and weighed using a digital platform scale. We assumed a gestation length of 231 days. This is the mean of gestation lengths reported by Chapman and Chapman (1975) and Asher (1986). To calculate fetal age we assumed a birth weight of 4,500g (Chapman and Chapman 1975) and used the relationship between gestational age and the cubic root of fetal weight (Suzuki et al. 1996). Conception dates were estimated by back-dating the age of fetuses from the date of kill. Parturition dates were then estimated by adding 231 days to the estimated conception date. Male reproductive behavior was recorded by direct observations over a 3-year period. We recorded all observations of rut behavior including stage of antler maturity, lek use, signpost activity, vocalizations, and morphological changes.

We combined harvest data from 2002-2006 for analysis. We report data as mean live weight for males and females, antler beam length, inside spread, and beam circumference along with standard errors and range. We also estimated the proportion of each pelage color in the population.

Population Density

We used bi-monthly nocturnal spotlight counts to assess population density, sex ratios and pelage color variability from September 2004 to March 2006. We selected 5 survey routes to represent the variety of habitats on the island. Route length ranged from 2.4 km to 4.3 km and totaled 15.0 km. During each survey, routes were spotlighted in random sequence each night over a 4-night period. Counts began approximately 30 minutes after sunset (Astronomical Applications Department, U. S. Naval Observatory, Washington, D.C.) and were conducted from the bed of a truck with a minimum crew of driver, spotter, and recorder. At least one crew member was experienced in sexing and estimating age for LSSI fallow deer and was present at every spotlight count. For all sightings we recorded route number, time, weather, sex, antler characteristic (spike, stick, and quality), pelage color and perpendicular distance from the vehicle. We determined sex and antler characteristics using Leica Trinovid optics (Leica, Inc., Solms, Germany) with 8x42 magnification, and measured the perpendicular distance to the animal(s) by laser rangefinder. All animals observed in clusters were assigned a unique cluster ID and were considered as one observation. We assumed all requirements of line transect distance sampling were met (Buckland et al. 2001). Due to the variety of pelage colors and unique antler characteristics, individual deer were easily recognized, which reduced the risk of double counting. We assumed that density estimates obtained from the selected routes would be representative of all available habitats on LSSI.

We grouped monthly counts by season based on environmental and floral conditions. Winter consisted of January - March; Spring from April - June; Summer from July - September and Fall from October - December. We truncated distances at 250 m and estimated density using program DISTANCE version 5.0 (Thomas et al. 2006). We obtained density estimates over six sampling seasons and for each route over all seasons. Data from summer 2005 violated the assumption of distance sampling that animals are not attracted to the transect line, and was therefore ignored as a seasonal density. We calculated an overall density by averaging all seasonal densities excluding summer 2005, and averaging densities from the routes. The best fitting model for each estimate was chosen using Akaike's Information Criterion (AIC) (Akaike 1973). We determined total available area by subtracting areas classified as low marsh, and other areas that deer were not observed from the total area of LSSI. Density estimates were calculated using 1,554 ha as available habitat. Proportions of each coat color were calculated from spotlight survey observations and compared to the results of harvest data.

Observation Data

During the 2003-2006 hunting seasons, hunters were requested to record data during each hunting period including date, time of hunt, hours hunted, zone location, number of bucks observed by antler categories (spike, stick/other, and quality), antlerless deer (adult or fawn), deer of unknown sex, and other observations. We summarized these observations each year to estimate sex ratio and recruitment. We recorded behavioral observations opportunistically from March 2004-March 2006. These observations were summarized to infer biological events including fallow deer antler cycles, fawning, rutting behavior, food habits, mortality and predation, health, and other behavior. Procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (Permit # A2005-10150-0).

RESULTS

Fallow deer harvest was relatively constant over the 4-year period, ranging from 48-53 animals (23-28 female and 24-28 male) annually. Rainfall was consistent throughout the period

(93 - 112 cm annually), but below the long-term (59 year) annual average of 124.9 cm. We recorded morphological data from 181 individuals comprising 90 males and 91 females. According to the tooth wear and replacement technique, the estimated median age of harvested males was 3.5 and females 2.5 (Figure 2.1). Age estimates determined by tooth wear and eruption were validated against 39 samples estimated using the cementum annuli technique. Of the 39 samples, 14 (39%) were aged correctly using tooth wear and eruption. Of those incorrectly aged (25), 20 (80%) were under-aged and 11 (44%) were within one year error. Estimated ages were most dissimilar between the two techniques for individuals >5.5 years of age.

Adult male body weights were more variable than adult female weights (Table 2.1). Both sexes appeared to reach maximum body size at approximately 3.5 years of age. Eviscerated weights were 63.5% of the total body weight of female and 64.8% of male deer.

The earliest observation of a male with cast antlers was 6 April. By 11 May, all bucks observed had cast their antlers, and many had initiated new antler growth. The first observation of velvet shed was a yearling (1-2 years of age) on 30 July. No older males were observed with cleaned antlers until 6 August and by 25 August all males observed had shed velvet. All bucks 1.5 years of age observed on LSSI carried spike antlers. All antler measurements increased with increased age of the males through 5.5+ years of age. Beam length and spread were highly variable within age class (Table 2.2).

Approximately one-half (52%) of the animals observed were the black color variety, 22% common color, 16% white and 10% were menil. We did not observe any differences in proportions of pelage color varieties of 196 deer harvested between 2002 and 2006, and 419 deer observed during spotlight counts (χ^2 =3.92, df=3, *P*>0.05). Pelage varieties between males and females from harvest data did not differ (χ^2 =0.94, df=3, *P*>0.05).

We conducted 12 spotlight surveys over 48 nights across six seasons resulting in 304 observations of deer. Observations from all subsets of seasons and routes contained sufficient observations (k > 20) to estimate variance (Buckland et al. 2001). Estimates of fallow deer densities did not differ significantly among routes or seasons (*P*>0.05). Estimated density ranged from a low of 19.8 deer/km^2 in fall 2005 to 69.7 deer/km^2 in spring 2005 (Table 2.3). Pooled data across all seasons resulted in an estimated density of 47.3 deer/km^2.

We observed 139 adult males and 119 adult females during spotlight surveys providing a sex ratio of 1.2 to 1. Data obtained from hunter observations indicate a male to female sex ratio of 1.1:1 in 2003 (n=931 observations), 1.1:1 in 2004 (n=1,508 observations), and 1.5:1 in 2005 (n=1,101 observations).

We recovered 27 fetuses from harvested does during 2003-2006. All detectible pregnant does carried a single fetus and were ≥ 1.5 years old. Estimated conception dates ranged from 25 September to 7 January. Of the 27 fetuses measured, 18 were conceived in October with an estimated peak around 9 October. Harvest records from 2003-2006 indicate that 50% of does had bred by mid-January and 90% by mid-March. Of twenty-five 1.5 year-old does harvested from 2003-2006, only three carried an identifiable fetus, and all three had conceived after 29 November. Harvest data indicated a fetus:doe ratio of 0.41 and a 1.0:1.0 fetal sex ratio. However, reproductive rates likely are underrepresented in the harvest data because the hunting season overlapped with breeding on LSSI and all pregnant does may not have had a detectible (≥30 days) fetus at time of kill. Hunter observation data (n=1,592 doe and fawn observations) and spotlight surveys (n=182 does and fawns) indicated a fawn:doe ratio of 0.38, and 0.60, respectively.

Rut-associated vocalizations were made primarily by mature, dominant bucks at leks and were heard from 20 September 2004 to 25 October 2004 with a peak before 18 October 2004. During 2005, vocalizations were not heard until 11 October. Estimated fawning dates indicate that 21 of the fetuses would have been born between 14 May and 8 June, although estimated birth dates occurred as late as 26 August. Observational records indicate that fawns were first observed on 6 June in 2004, 26 May in 2005 and 4 June in 2006.

DISCUSSION

Little data are available describing techniques for estimating the age of fallow deer. Although we combined ages >5.5 years of age as estimated by the modified tooth wear and replacement technique (Murphy 1994), age estimates of a subset of animals as determined by cementum annuli suggest that many animals are surviving until 10-11 years of age. Further, the tooth wear and replacement technique tended to underestimate deer age as compared to counts of cementum annuli. Therefore, because 56% of the harvest from 2002-2006 were estimated at 3.5 years and older, counting cementum annuli will likely provide more accurate age estimates of LSSI fallow deer.

Male fallow deer on LSSI had smaller body size and antler characteristics than populations in Tasmania (Murphy 2001), England and Germany (Chapman and Chapman 1975), and California (N. Gates pers. comm.). However, doe body weights were similar to fallow herds in Texas, California, and England (D. Osborn pers comm; N. Gates pers. comm.; Chapman and Chapman 1975). Insular populations of white-tailed deer similarly tend to be of smaller stature than most mainland populations (Brisbin and Lenarz 1984; Osborne et al. 1992), likely due to lower habitat quality and food deficiencies (Miller 1988; Osborne et al. 1992). Soil types on LSSI influence vegetation quality and provide poor resources for large herbivores like deer (Rigdon and Green 1980). High deer densities may also account for the depressed body weights of LSSI fallow deer.

Nutrient deficiencies can also depress antler growth (French et al. 1956). Antler size of LSSI fallow deer varied greatly within age classes and may reflect social status and food quality intake of individual deer. Antler characteristics are similar to those reported for fallow deer in the arid Edward Plateau region of Texas (D. Osborn pers comm), but are smaller than other fallow deer populations (Murphy 2001; Palotas and Pataky 1993; Chapman and Chapman 1975).

Historical domestication attempts have been proposed as the reason for the wide variety of pelage colors in fallow deer. It is unclear whether the original, natural pelage was the common color (Mungall and Sheffield 1994), or the black phase (Chapman and Chapman 1975). Pelage colors of the original fallow deer released on LSSI are unknown. However, because our results indicate that >50% of the LSSI population is of the black variety, the original stock likely was majority black.

The breeding season of fallow deer on LSSI was highly seasonal. Peak conception (~9 October) coincided with vocalizations in 2004. The duration and peak of male vocalizations is related to the first estrus in does of farmed fallow deer (Asher 1986). The first vocalizations in 2005 were not heard until mid-October. Several tropical storm systems flooded much of LSSI in late September into October 2005 with 44.7 cm of rain (cirrus.dnr.state.sc.us). This event and consequent mosquito hatching may have impacted rutting behavior in males and disrupted lek visitation by females. Although several mating strategies have been documented from fallow deer (Thirgood et al. 1999), lekking was the only observed behavior on LSSI. Most leks were in the forested parts of the island, with several leks used multiple years. Aggression between males on lek sites can be frequent and often fatal (Clutton-Brock et al. 1988; Thirgood et al. 1999).

Conception and parturition dates on LSSI are similar to other populations in the northern hemisphere (Braza et al. 1988; Howery et al. 1989; Moore et al. 1995; Hirth 1997). Conception dates also are similar to white-tailed deer conception dates on nearby Blackbeard (Osborne et al. 1992) and Cumberland Island (Miller 1988). The first calculated parturition estimate from fetal data was 14 May, 12 days before the first fawn observation.

Density estimates calculated from the spotlight surveys did not differ significantly among seasons or routes. However, this lack of significance likely is due to high variability both among seasons and within seasons of different years. Habitats available to fallow deer on LSSI are dominated by evergreen vegetation and differences in visibility between seasons were not expected. Some biases exist using spotlight counts to estimate population densities (McCullough 1982; Fafarman and DeYoung 1986; Winchcombe and Ostfeld 2001). However, this technique proved to be the most-effective method for estimating fallow deer population size on LSSI. Although estimates within season tended to be highly variable, the variability around our density (47.3 deer/km^2) based on pooled data suggests a more precise estimate. This high deer density on poor habitat reflects similar situations with white-tailed deer on neighboring barrier islands where vegetation is abundant, predators and other sources of mortality are limited, and emigration does not exist. Given the differences between fallow deer and white-tailed deer it is likely that fallow deer on barrier islands can achieve even higher densities. Population reduction and maintenance are now practiced on many of these islands to suppress white-tailed deer numbers and associated damage.

The introduced population of fallow deer on LSSI exists to the exclusion of native white-tailed deer. Current population density is high compared to neighboring barrier islands white-tailed deer populations. Population statistics suggest that growth is slow and recruitment is restricted. High densities, coupled with low body weights and antler characteristics suggest that the herd has exceeded carrying capacity, and may be impacting the islands vegetative communities. Between 2002 and 2006, annual hunter harvest approximated 7% of the island population. This level appears inadequate to regulate population growth at the current density. Increased harvest levels to reduce population density are warranted.

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Table 2.1 Live weights (kg) of hunter-harvested fallow deer on Little St. Simons Island, Georgia 2002-2006

	Live Weight (does)			Live Weight (bucks)		
Age Class	***n***	**Mean**	**SE**	***n***	**Mean**	**SE**
0.5	11	18.2	0.74	8	21.8	1.96
1.5	15	27.7	0.75	6	33.0	1.17
2.5	5	32.0	1.67	7	43.1	2.70
3.5	10	35.7	1.72	11	48.3	1.50
4.5	7	36.7	1.25	9	48.3	2.77
5.5+	12	38.4	1.36	18	55.5	2.04

Table 2.2. Antler measurements (cm) of hunter-harvested adult male fallow deer by age class on Little St. Simons Island, Georgia 2002-2006

		Spread			**Circumference**			**Length**		
Age Class	***n***	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**
2.5	9	33.0	29.5-40.6	1.21	5.7	4.9-7.6	0.27	28.9	21.3-41.9	2.21
3.5	19	40.0	28.2-50.8	1.40	6.8	5.1-8.9	0.21	39.1	27.3-55.9	1.59
4.5	13	44.6	27.9-67.9	2.66	7.45	5.7-9.5	0.28	43.9	29.7-57.2	2.10
5.5+	29	51.6	30.5-64.8	1.18	8.4	5.7-10.2	0.17	52.4	33.7-64.1	1.35

Table 2.3. Population density statistics for fallow deer on Little St. Simons Island, Georgia based on spotlight surveys by season 2005-2006

Season	# Obs.	Model	AIC	Deer/sq. km	Lower	Upper	CV
Fall 2004	64	hazsimp	577.55	60.85	40.00	92.63	0.21
Winter 2005	28	negcos	260.96	36.09	21.85	60.25	0.25
Spring 2005	80	hazcos	728.13	69.67	30.98	156.49	0.33
Summer 2005*							
Fall 2005	25	negcos	244.19	19.85	5.61	70.28	0.56
Winter 2006	65	hazcos	667.53	50.93	31.58	82.11	0.24
Pooled	304	halfcos	2847.32	47.32	35.59	62.76	0.14
Season Mean				47.48	27.60	87.42	

* Included in pooled data, but excluded as an individual seasonal analysis

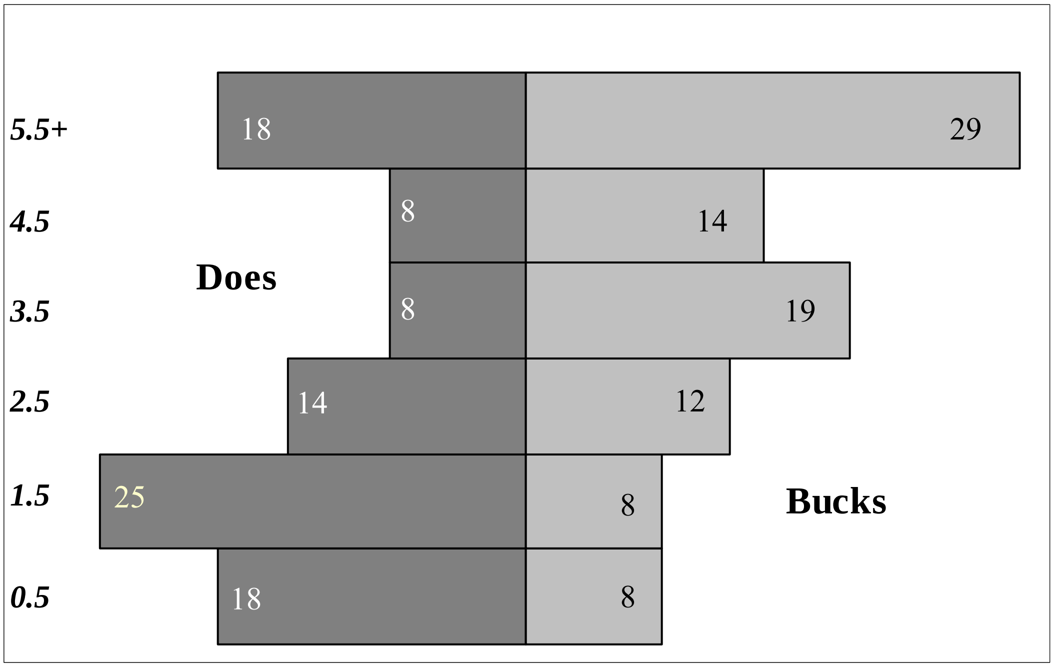

Figure 2.1. Age structure of hunter-harvested fallow deer on Little St. Simons Island, Georgia 2002-2006.

CHAPTER 3

POPULATION HEALTH OF FALLOW DEER (*DAMA DAMA* L.) ON LITTLE ST. SIMONS ISLAND, GEORGIA, U.S.A. [1]

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[1]Morse, B.W., D. L. Miller, K. V. Miller, and C. A. Baldwin. To be submitted to the *Journal of Wildlife Diseases*.

***Abstract*:** Fallow deer (*Dama dama*) were introduced to Little St. Simons Island, Georgia in the 1920s and thrive at high population densities to the exclusion of white-tailed deer (*Odocoileus virginianus*). The presence of introduced pathogens and parasites as a result of introduction is currently unknown, as is the impact of native disease to the exotic fallow deer. Hunter-killed fallow deer from 2003-2005 were necropsied and surveyed for evidence of infectious disease, parasitic agents and toxicological parameters. Fallow deer were positive for antibodies to bovine virus diarrhea I and II, bluetongue virus, and bovine adenovirus. Twenty species of bacteria were isolated from the internal organs and 14 species of parasites were recovered, including one abomasal nematode, *Spiculopteragia asymmetrica*, which is not known to occur in native North American ungulates. Concentrations of liver and copper were low, while lead, zinc and iron were considered within normal levels. No clinical signs of disease were noted, and the overall health of the insular fallow deer was considered good.

***Key words*:** bacteria, barrier island, disease, exotic, fallow deer, parasite, ungulate

INTRODUCTION

Populations of exotic ungulates have been established outside of their native range in many parts of the world (Chapman and Chapman, 1975; Feldhamer et al., 1988) before current regulations banned their transport and release (e.g., GADNR, 2004). Concern exists regarding the potential detrimental impacts of these introductions on the health of livestock (e.g., cattle) and native wildlife species, as well as, on the resource availability for native species. These concerns are magnified by reports that suggest exotics may be more resistant to some diseases than native species, thus conferring a competitive advantage over native species (Davidson and Crow, 1983; Davidson et al., 1985; Flynn et al., 1990).

The European subspecies of fallow deer (*Dama dama dama*) is a widely distributed member of the Cervidae, with worldwide introductions including the United States (Chapman and Chapman, 1975). Fallow deer have been successfully established in Kentucky, California, Texas, and Georgia (Chapman and Chapman, 1975). Fallow deer were introduced to Little St. Simons Island (LSSI), Georgia in 1927 as a shipment of 6 individuals (4 male, 2 female) from the Bronx Zoo in New York (Bronx Zoo files, unpublished). Between 1919 and 1924, attempts to introduce sambar deer (*Cervus unicolor* niger), Barasingha deer (*Cervus duvauceli*) and red deer (*Cervus elaphus*) to LSSI were unsuccessful (Bronx Zoo files, unpublished). The extent to which the fallow deer interacted with these other species before their extirpation is unknown. Similarly, the population status of the native white-tailed deer (*Odocoileus virginianus*) on LSSI at the time of the fallow deer introduction is unknown. However, since that time, there have been only anecdotal records of white-tailed deer sightings on the island, with none reported from 2002-2006. Additionally, fallow deer have coexisted for varying lengths of time with cattle, goats or feral horses on LSSI between 1927 and 1996.

Health surveys have been conducted for introduced fallow deer populations in Kentucky (Davidson et al., 1985), California (Riemann et al., 1979) and Texas (Corn et al., 1990). In general, these surveys have reported that fallow deer are susceptible to exposure from parasites and diseases of native deer in North America, but were not impacted by these diseases. Corn et al. (1990) revealed high seropositive results in fallow deer for blue tongue disease (BT) (59%) and epizootic hemorrhagic disease (EHD) (64%) in Texas. *Amblyomma americanum* was the most commonly found (85%) ectoparasite in the Texas survey. Serum neutralization also revealed BT in California fallow deer (Riemann et al., 1979) and BT and EHD in fallow deer from Kentucky (Davidson et al., 1985). Nine parasites including the non-native nematode *Spiculopteragia assymetrica* parasitized fallow deer in Kentucky, but without noticeable pathogenic impacts. However, Davidson et al. (1985) relate lesions present in all 5 fallow deer sampled to previous infections of *Parelaphstrongylus tenuis.* Because the LSSI fallow herd represents an insular population that have historically co-existed with other domestic and exotic ungulates, we examined hunter-harvested fallow deer from 2003-2006 to evaluate the health status of this population.

STUDY AREA

Little St. Simons Island is a privately owned undeveloped coastal barrier island located in Glynn County, Georgia, U.S.A. (ca. 31° 16’ N, 81° 17’ W). The island is comprised of approximately 1730 ha of upland habitats (maritime forest, oak/pine forest, shrub/scrub) and approximately 3470 ha of salt marshes. It is surrounded by water with no land linkage. Elevations range from sea level to 9 m; however, most of the island is less than 3 m above mean sea level. Fallow deer are the only large feral mammal on LSSI, and population size is currently estimated at 500-700 animals. Mammalian predators of deer such as bobcats (*Lynx rufus*), foxes (*Vulpes vulpes* and *Urocyon cinereoargenteus*) and coyotes (*Canis latrans*) are absent. The only potential predator of fallow deer is the American alligator (*Alligator mississippianis*). The island does not support populations of white-tailed deer or feral pigs (*Sus scrofa*), thus eliminating significant competition for food resources.

MATERIALS AND METHODS

Sample Collection

Hunter-killed fallow deer (n=68) were sampled from LSSI during 2 hunting seasons 2003-2004 (Year 1, n=28) and 2004-2005 (Year 2, n=40). The island was divided into hunting zones and hunters distributed themselves throughout the island. Six separate hunts lasting 3 to 5 days each occurred at approximately 2-3-week intervals between November and March. Hunters could harvest either sex, but were discouraged from harvesting male deer $\leq$ 2 years-of-age according to LSSI harvest guidelines. Over the two hunting seasons we obtained 24 adult males (AM), 19 adult females (AF), 6 yearling males (YM), 7 yearling females (YF), and 11 fawns (F). All deer sampled were selected at the individual hunter's discretion.

All harvested deer were brought to a central processing station. Each deer was examined for external parasites and a necropsy performed. Tissues collected included: brain, eye, ear notch, tonsil, lymph nodes from head/throat region, heart, lung, thymus, blood (serum and plasma), liver, kidney, spleen, reproductive tract (whole for females, section of testicle for males), rumen, reticulum, omasum, abomasum, duodenum, jejunum, ileum, caecum, and spiral colon. Brain, eye, ear notch and tonsil were not collected from deer identified for trophy mounts. A subset of tissues was collected fresh for bacteriological testing. Another subset of tissues was collected frozen for virus isolation, fluorescent antibody testing and toxicological testing. A subset of each tissue was preserved in 10% buffered formalin for histological analysis. Feces were collected for parasite analysis and electron microscopic examination for virus shedding. All collected tissues were transported to the University of Georgia, College of Veterinary Medicine, Veterinary Diagnostic and Investigational Laboratory, Tifton, Georgia. Sex, weight and ages of each deer were recorded. Age was estimated according to Severinghaus (1949) as modified for fallow deer (Murphy, 1994).

In December of 2006, an additional 5 adult (>2 years) fallow deer were collected as mentioned above and sampled for abomasal parasites (Eve and Kellogg, 1977). Whole abomasums were removed, sealed in plastic bags and frozen. Abomasums were transported to the Southeastern Cooperative Wildlife Disease Study (SCWDS) at the University of Georgia, College of Veterinary Medicine, Athens, Georgia for processing. Collection procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (Permit # A2005-10150-0).

Diagnostic Testing

Histological Examination - Formalin-fixed tissues were routinely processed and embedded in paraffin. One or more 5μm thick sections were cut from each paraffin block and placed on glass slides. The slides were stained with hematoxylin and eosin (H & E), coverslipped and viewed by light microscopy for histolopathological changes in tissues.

Virus Isolation - A 10% tissue homogenate in Earle's minimal essential media (MEM) containing gentamycin was made for each deer. The homogenate was centrifuged for 10 minutes at 2000 RPM and 4 ˚C, supernatent filtered and inoculated onto a preformed monolayer of Madin Darby Bovine Kidney (MDBK) and Vero cells. Inoculated cells were incubated in a 5% CO_2

atmosphere at 37 ˚C. Cells were examined daily for virus cytopathic effect (CPE). If no CPE was observed, aliquots of the first passage were transferred to a second preformed monolayer of MDBV and Vero cells on Day 7. If no CPE was observed after a second seven days of passage, chambered slides of MDBK cells were made to examine cultures for non-cytopathic bovine virus diarrhea (BVD) virus. Inoculated monolayers demonstrating virus CPE were passed to chambered slides. All chamber slides were fixed in cold acetone and appropriate FA-tests, including BVD, done to confirm the isolates or to confirm any non-cytopathic BVD.

Fluorescent Antibody (FA) Testing **-** Virus-specific polyclonal conjugates (blue tongue, epizootic hemorrhagic disease, bovine adenovirus (BA) and bovine virus diarrhea) were applied to frozen sections of tissues (lung and spleen: BT, EHD, BA, BVD; lung, spleen, kidney and intestine: BVD) collected at necropsy and the slide incubated in 5% CO_2 at 37 ˚C for 30 minutes. The slides were rinsed twice, counter-stained with 0.5% Evans blue, dipped in distilled water, coverslipped and examined by fluorescent microscopy.

Serum Neutralization**-** Serum neutralization assays were used to quantify antibodies for BVD I and BVD II. Antibody titer was the last dilution that provided complete protection of the monolayer. Bluetongue serology was conducted using the Bluetongue Antibody Competitive Elisa test kit (VMRD, Inc., Pullman, Washington). According to manufacturer's kit insert, test sera are considered positive if they produced an optical density that is less than 50% of the mean of the negative control. Test sera that produced an optical density greater than or equal to 50% of the mean of the negative control are considered negative.

Bacterial Culture **(**routine, *Mycoplasma sp., Leptospirosis* spp.*, Mycobacterium avium paratuberculosis*) - Swabs of individual tissues (lung, spleen, liver, kidney, intestine) were streaked onto 5% bovine blood agar (BBA), Wilkins - Chalgren Anaerobe Agar, Mycoplasma agar, Lowenstein Jensen agar slant and Hektoen Enteric Agar (HE) agar (intestines only). Plates were examined daily for growth and sub-cultured onto BBA as needed. Bacterial colonies selected from pure cultures were stained using the Gram method. Cultures were inoculated into Sensititre (Trek Diagnostic Systems, Inc, Westlake, OH) Gram negative AP80 or Gram positive AP90 autoidentification plates and allowed to incubate for 18 hours at 37^{o}C prior to automated reading of the reactions per manufacturer directions.

Fecal Float – Gastrointestinal Parasites- A mixture of 1 g of feces and 5 ml of water was strained with a 2 x 3 inch single layer of gauze and mixed with Sheather's sugar solution, covered and allowed to sit for approximately one hour. The cover slip was then placed on a slide and examined for parasite ova and oocysts using light microscopy.

Electron Microscopy-Virus Shedding **-** Fecal samples were examined for virus shedding by negative stain electron microscopy. Grids were examined for viruses or virus-like particles using a Zeiss EM 900 TEM at 12,000 power magnification or greater.

Abomasal Parasite Counts - The procedure for abomasal parasite counts was conducted according to Eve and Kellogg (1977). Each sample was thoroughly scanned by 2 persons. Collected worms were placed in a vial of 5% formalin and identified to species. Male worms were used for identification of species. Total counts (1000 ml) were obtained by multiplying the number of worms in the 50-ml subsample by 20.

Toxicology **-** For the analysis of the trace elements Pb, Cu, Zn, and Fe a 3-5 gram sample of liver was digested using 10mls concentrated nitric acid (65%, Fisher Scientific, Fairlawn, NJ) plus 10mls distilled water. The digestates were analyzed by flame atomic absorption spectrophotometry (AAS, AAnalyst 100, Perkin Elmer, Norwalk, CT). Appropriate standards (Certified Reference Solution, Fisher Scientific) and controls (Standard Reference Material 2976

Mussel Tissue or 1577b Bovine Liver, National Institute of Standards and Technology, Gaithersburg, MD) were employed for each analytical run. The average of triplicate analysis was reported.

Statistical Analysis

Fisher's Exact test was used to examine disease prevalence relationships between year, sex and age. Significance was accepted at $\alpha=0.05$. Age classifications were divided into young (<2 years) and adult (>2years) animals. Toxicological values were tested for normality and consequently log transformed for analysis. Levels of copper and zinc from liver samples were examined for year, sex and age effects using a 2-way analysis of variance (ANOVA) in a general linear model (PROC GLM, Statistical Analysis Software Inc., 2003). Because the resulting data for lead levels were non-normal, we used a Wilcoxon sign rank test in SAS (Statistical Analysis Software Inc, 2003). Low sample size limited our ability to statistically analyze iron levels.

RESULTS

Deer ages ranged from 0.5 to 8.5 with a median age of 3.5. All animals examined were in moderate to excellent health and no gross evidence of disease was noted in any animals. There was no significant difference in seroprevalence of any of the disease agents tested between males and females, nor between young (<2 years) and adult (>2 years) deer using Fisher's exact test. There was no significant difference ($\alpha=0.05$) between years for all tests, therefore, years were combined for analyses.

Serology and Virology - The ELISA tests disclosed antibodies to BT virus in 2 of 57 samples (Table 3.1). No sera was positive for EHD virus. Florescent antibody tests for bovine adenovirus were positive for 11 of 58 deer sampled. All positive adenovirus results were classified as Adenovirus Group II. The ELISA antibody tests for *Mycobacterium avium paratuberculosis* (Johne's disease) were negative. Serum neutralization for bovine virus diarrhea type I (BVD I) and bovine virus diarrhea type II (BVD II) resulted in 13 of 48 positive and 7 of 32 positive, respectively. Neutralization titers ranged from 1:4 to 1:64 for BVD I and II. Titers of 1:50 or greater were considered indicative of previous exposure (Corn et al., 1990). Florescent antibody tests for either BVD I or II on 29 samples revealed one positive result. Antigen capture ELISA tests for BVD disclosed 4 positive and 6 suspect results out of 16 samples tested. Ear notch tests for BVD antigen on 48 samples resulted in one positive.

***Electron Microscopy* -** Fecal samples examined by negative stain electron microscopy detected the presence of 4 virus particles, consistent with bovine enterovirus (BEV).

***Bacteria Culture* -** Bacteria cultures were negative for *Leptospirosis* spp. and Johne's disease. Twenty species of bacteria were cultured from internal organs (intestines, lung, liver, spleen and kidney) (Table 3.2). Clinical disease was not associated with any of these bacteria. However, 3 deer had minimal to mild histological changes that may have been associated with bacterial etiologies.

***Histology* -** All fallow deer had mild to moderate eosinophilic enteritis. Rare renal calculi were noted in 24. Other histological changes were noted but were generally minimal to mild and in low prevalence ($n \leq 5$). These histological changes included perivascular dermatitis (5 deer), pneumonitis (3 deer), splenitis (2 deer), pyometra (1 deer) and pneumonia (3 deer). Pneumonitis was characterized by minimal expansion of the alveolar walls by rare neutrophils and macrophages. Splenitis was characterized by eosinophilic (both deer) and neutrophilic (1 deer) infiltrates. Pyometra was characterized by uterine luminal aggregates of neutrophils and macrophages with no infectious agents seen and no mucosal invasion observed. Pneumonia was characterized by eosinophilic and granulomatous infiltrates that were most often associated with airways.

Parasites - Abomasal counts, fecal examination and gross examination of carcasses revealed 14 species of parasites including 10 nematodes and 4 arthropods. Five nematode species were recovered from 4 of the 5 abomasums sampled (Table 3.3). Overall parasite burdens from abomasal, fecal and gross examinations were low. The abdominal worm *Setaria yehi* was found free in the abdomen of 3 fawns (< 1 year). *Trichuris* sp. was present in one fawn. Larval forms of *Cephenemyia phobifer* were found in the retropharyngeal pouch of 5 fawns and one 2.5-year-old female. The nematode, *Capillaria* sp. was found in the feces of one 2.5-year-old male. Coccidia of the genus *Eimeria* was identified in fecal samples from two 1.5-year-old females and was the only protozoan parasite recovered.

Toxicology results - Concentrations of copper (Cu) and zinc (Zn) did not differ between bucks and does {Cu; (P=0.7987) Zn (P=0.8398)}, nor young and adult deer {Cu (P=0.5228), Zn (P=0.9465)}. Mean copper concentrations for young and adult bucks in our study were 6.47 and 7.73 ppm respectively (Table 3.4). Ten of 55 samples examined for lead (Pb) showed amounts greater than zero. Iron (Fe) was only sampled from 11 deer in our study. Mean concentrations of iron in the liver of adult bucks (n=6) were higher than does. Due to the low sample size for Fe (n=11) samples were not statistically examined for year, sex and age differences.

DISCUSSION

The fallow deer on Little St. Simons Island were in good health, similar to reports from other fallow deer populations in the United States (Riemann et al. 1979; Davidson et al., 1985; Corn et al., 1990). We observed various potential pathogens but only rare morphological changes were noted and, when present, were of minimal to mild severity and not pathogen-specific. Histological changes included pneumonitis (n=3), splenitis (n=2), pyometra (n=1) and pneumonia (n=3). In most cases, eosinophils were the primary component to the inflammatory infiltrate, and were attributed to parasitism or similar hypersensitivity. However, in 4 deer other cell types were noted and potentially infectious agents identified. In these deer, it is possible that these other agents contributed either as primary or opportunistic invaders. For example, although pneumonitis was noted in 3 deer, only one deer was positive for pathogenic organisms, including BVD and BT. Further, this deer had very mild splenitis characterized by neutrophils and eosinophils. Although the eosinophils suggest a parasitic etiology or hypersensitivity, the neutrophils are more suggestive of an infectious etiology. Significant bacterial organisms were not cultured from the spleen or lung of this deer. One other case of splenitis was noted and was mild with only opportunistic organisms (*Klebsiella oxytoca*, *Citrobacter freundii*, *Streptococcus haemolytic*) isolated. In the pyometra case, the origin of the infection was not found. A uterine sample was not collected because grossly the uterus was unremarkable; however, opportunistic organisms (*Strepococcus uberis*, *Escherichia coli* and *Pantoea agglomerans*) were cultured from the kidney and thus may have been a factor in the pyometra. Additionally, pneumonia was observed in this doe and characterized by eosinophilic and granulomatous infiltrates presumed to be due to parasitism. However, opportunistic organisms similar to those cultured from the kidney were cultured from the lungs of this doe and thus may have contributed to the pulmonary changes. Finally, one deer with minimal to mild pulmonary changes was positive for Adenovirus. It is unclear if the pulmonary changes were due to Adenovirus or were incidental. In this deer, pulmonary changes were noted as involving both the interstitium (interstitial pneumonia) and airways (bronchopneumonia), with the latter being eosinophilic and granulomatous and interpreted as due to parasitism.

Adenovirus infections in North American cervids have been limited mostly to mule deer (*Odocoileus hemionus*) and black-tailed deer (*O. h. columbianus*) in California (Davidson and Nettles, 1997). In 1993, high mortality of mule deer in northern California with fatal pulmonary edema was linked to bovine adenovirus type 5 (Woods et al., 1996). Adenovirus type 5 was also associated with fatal pulmonary edema in white-tailed deer on an Iowa game farm (Sorden et al., 2000). Rarely has adenovirus infection been detected in fallow deer. Type 6 adenovirus was isolated from a single fallow deer after an outbreak of respiratory disease occurred in a Hungarian captive fallow deer herd (Boros et al., 1985). Antibodies to adenovirus group A have been found in fallow deer from Great Britain (Munro, 1994). The significance of the 19% seroprevalence of bovine adenovirus type 5 in LSSI fallow deer is unclear, given that gross or histological changes consistent with bovine adenovirus type 5 were not found.

Hemorrhagic diseases caused by BT and EHD viruses have infected several populations of fallow deer in the United States with varying rates of prevalence. Prevalence of antibodies to BT and EHD includes 33% BT in California (no tests were run for EHD) (Riemann et al., 1979) and 57% BT and 64% EHD in Texas (Corn et al., 1990). A disease survey of 5 adult free-ranging fallow deer in Kentucky revealed antibodies to EHD in 2 fallow deer, and antibodies to BT in one deer (Davidson et al., 1985). Four percent of the animals tested on LSSI had antibodies to BT and none had antibodies to EHD. Barrier island white-tailed deer populations showed a low annual incidence of BT and EHD, possibly making them susceptible to outbreaks should they occur (Stallknecht et al., 1991). Insular conditions of this population may have provided a degree of isolation from BT and EHD due to limited vector flight distance and immigration/emigration barriers. Varying prevalence rates may be affected by host preference of the vector *Culicoides* spp. (Odiawa et al., 1985). Future testing of *Culicoides* spp. and white-tailed deer from surrounding areas are needed to examine the presence of BT and EHD in coastal Glynn County, Georgia and surrounding areas. Further testing of LSSI fallow deer for BT and EHD viruses to determine specific serotypes is also needed. The LSSI fallow deer may be inherently immune to the serotypes of BT and EHD currently in coastal Georgia.

Although BVD has been rarely reported in fallow deer (Neilson et al., 2000), BVD antibodies and antigen were detected in LSSI fallow deer. Serological testing for antibodies to BVD ranged from 0% from introduced fallow deer in California (Riemann et al., 1979) to 1% in Germany (Frölich, 1995) and 2% in Texas (Corn et al., 1990). Florescent antibody tests and ear notch tests resulted in one positive deer for each test, indicating a low infection rate for LSSI fallow deer. Serum neutralization indicated 27% seroprevalence for BVD I, with 9 of 13 positive results having titers less than or equal to 1:8. Of the 7 positive results (22% seroprevalence) for BVD II only 2 had titers less than or equal to 1:8. One deer was positive by antigen capture ELISA and ear notch FA but negative for both BVD I and II using serum neutralization. This is similar to reports in cattle where calves are persistently infected with BVD until it becomes immune tolerant and then it is seronegative (Lindberg and Alenius, 1999). The lack of clinical signs and low rate of infection indicates that BVD is not a major pathogen in LSSI fallow deer.

Electron microscopy revealed 4 positive results for bovine enteroviruses (BEV). Little information exists regarding bovine enteroviruses and deer. Ley et al. (2002) found BEV in 76% of cattle and 38% of white-tailed deer sampled in Maryland. Because infections in deer are believed to be asymptomatic, the presence of BEV in the feces of LSSI fallow deer likely has little significance.

Tissue histology revealed eosinophilic enteritis in all deer samples, likely due to internal parasite migration although abomasal parasites levels were low in our study. Perivascular dermatitis noted was associated with tick bites. Although tick infestations were generally low on examined deer, increased levels of parasitism could cause stress and reduced vigor. White-tailed deer fawns are susceptible to fatal anemia from heavy infestations of hematophagic parasites such as ticks and mosquitoes (Strickland et al., 1981). In mid summer, we observed heavy infestations of mosquitoes and ticks on newborn fallow deer fawns.

Abomasal parasite counts (APC) have been used as an indicator of white-tailed deer health in the southeastern United States (Eve and Kellogg, 1977). Overall abomasum parasite burdens in the 5 samples from LSSI fallow deer (APC= 584) were low (Table 3). It is interesting to note that one sampled deer had no abomasal parasites detected. This could be a result of extremely low worm burdens earlier in the year, and lost by the December collection. Abomasal parasite counts on white-tailed deer are typically conducted in late summer when parasite levels are greatest (M. Yabsley, pers. comm.). Our APC was conducted in December due to the availability of harvested animals, and may under represent the current intensity of parasitism in LSSI fallow deer. However, Osborne et al. (1992) reported APCs over 5 years of 732-2362 for Blackbeard Island white-tailed deer in December. Abomasal parasite burdens of fallow deer appear within a range of other reports for fallow deer including a previous report for LSSI

(APC= 152; SCWDS 1969), Germany (APC=592; Barth and Matzke 1984), Italy (APC=333; Ambrosi et al. 1993), Illinois (APC=421; SCWDS 1995) and Spain (APC=719; Santin-Duran 2004).

Two nematodes, *Spiculopteragia asymmetrica* and *Osteragia osteragia* are not common in native white-tailed deer in the southeastern United States (Doster and Friend, 1971; Conti and Howerth, 1987). *Spiculopteragia asymmetrica* is one of the most common medium abomasum worms reported in fallow deer, having been reported from New Zealand (Andrews, 1973), Germany (Barth and Matzke, 1984), Italy (Ambrosi et al. 1993), and Spain (Santin-Duran et al., 2004). The first record of *S. asymmetrica* in North American was recorded by Doster and Friend (1971) in fallow deer from LSSI, and our study indicates that it remains the most abundant abomasum parasite. *Spiculopteragia assymetrica* is also present in populations of fallow deer in Kentucky (Davidson et al., 1985) and Illinois (M. Yabsley, pers. comm.). Although *Spiculopteragia assymetrica* has not been reported from white-tailed deer in the United States, it is listed as a parasite of white-tailed deer in New Zealand (Andrews, 1973).

Two abomasum parasites previously reported from LSSI, *Haemonchus contortus* and *Ostertagia dikmansi* (SCWDS 1969) were not found in our study. However, we recorded 3 species, *Mazamastrongylus odocoilei, Ostertagia ostertagi,* and *Trichostrongylus askivai* that were not reported from the prior investigation.

Other endoparasites recovered (*Setaria yehi, Trichuris* sp.*, Cephenemyia phobifera, Ostertagia mossi, Trichostrongylus askivali, Mazamastrongylus odocoilei*) are typical parasites of white-tailed deer in the southeastern United States (Davidson and Nettles, 1997; Davidson et al, 1985). To the authors' knowledge, *Cephenemyia phobifera*, *Trichuris* sp., and *Trichostrongylus askivali* have not been previously reported to parasitize fallow deer. Type specimens of *Cephenemya phobifera* recovered from LSSI fallow deer have been deposited in the Georgia Museum of Natural History entomology collections. Little is known about the role these parasites play in fallow deer health, but no significant clinical signs were observed in our examinations. The abdominal worm, *Seteria yehi* was present in fawns but not adult deer. Infections of white-tailed deer by *S. yehi* are most common among fawns and yearling deer (Prestwood and Pursglove, 1981). The presence of *S. yehi* in only fawns may indicate that fallow deer, like white-tailed deer in the Southeast develop some immunity as they become adults.

Eimeria sp. was the only protozoan parasite discovered in our study. They are known to infect a variety of ruminant hosts, and at least 4species infect white-tailed deer (Kingston, 1991). *Eimeria* sp. was reported from fallow deer in New Zealand (Mason, 1994) but is rarely reported in free-ranging populations in the United States. Infections of *Eimeria* sp. usually have no clinical effect, but in stressed animals could become pathogenic (Mason, 1994).

High concentrations of lead in 3 individuals (2.13, 3.61, 5.59 ppm) exceeded normal levels (<1.0ppm; Puls 1994), but the source of this lead is unknown. Although mean concentrations of zinc were within the normal range (30-60 ppm; Puls 1994), they were higher in all age and sex categories (Table 3.4) than fallow deer from Slovania (means 31-32 ppm; Vengušt and Vengušt, 2004) and Illinois (mean=27.6 ppm; M. Yabsley, pers. comm.), as well as red deer in Poland (mean=31 ppm; Falandysz et al, 2005). Iron concentrations were within the range (40-90 ppm) reported by Puls (1994). Mean concentrations of Fe were lower in both sexes than that reported from Slovenia (Vengušt and Vengušt 2004).

Mean concentrations of Cu in LSSI fallow deer liver were below the normal range (25-80 ppm) provided by Puls (1994) and that reported from Slovenia (Vengušt and Vengušt 2004) in all age and sex classifications, but are similar to that reported from Illinois (11.4 ppm; M. Yabsley, pers. comm). Copper deficiencies have been linked to health problems such as osteochondrosis and enzootic ataxia (Audige et al., 1995; Thompson et al., 1994). No clinical signs of Cu deficiency have been observed in LSSI fallow deer, but the low levels found in this study suggest that the potential may exist and should be monitored.

The fallow deer population on LSSI demonstrates some exposure to diseases and parasites often associated with native white-tailed deer and cattle. At least one parasite, *S. asymmetrica* was likely introduced, as this common parasite of fallow deer has not previously been documented in North American white-tailed deer. Currently, there were no clinical signs of health-related problems and the herd appears to be within carrying capacity. However, parasite loads and susceptibility to disease could increase if herd density increases. We recommend sustaining the herd at or below the current density. There is also no indication that human consumption of fallow deer venison from LSSI would be unsafe.

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Table 3.1. Serologic profile of hunter-killed fallow deer from Little St. Simons Island, Georgia, U.S.A. 2003-2005

Agent	**Number Tested**	**Number (%) Positive**
Bovine virus diarrhea I	48	13 (27)
Bovine virus diarrhea II	32	7 (22)
Bluetongue virus	57	2 (4)
Epizootic hemorrhagic disease	48	0 (0)
Bovine adenovirus	58	11 (19)
Mycobacterium avium paratuberculosis	48	0 (0)
Leptospira spp.	8	0 (0)

Table 3.2. Bacteria cultured and percentage of isolates from internal organs (lung, liver, spleen, kidney, intestine) collected from hunter-harvested fallow deer on Little St. Simons Island, Georgia, U.S.A

Bacteria	**n**	**No. of Isolates (%)**
Acinetobacter sp.	80	1 (5)
Bacillus sp.	80	6 (7.5)
Citrobacter freundii	80	7 (8.8)
Corynebacterium sp.	80	4 (5)
Enterobacter cloacae	80	13 (16.3)
Enterococcus faecalis	80	7 (8.8)
Escherichia coli	80	38 (47.5)
Hafnia alvei	80	7 (8.8)
Klebsiella pneumoniae	68	3 (4.4)
Moraxella spp.	48	2 (4.2)
Pantoea agglomerans	80	18 (22.5)
Pasteurella multocida	80	4 (5)
Pseudomonas aeruginosa	19	2 (10.5)
Pseudomonas sp.	80	8 (10)
Pseudomonas stutzeri	80	4 (5)
Shewanella putrefaciens	80	7 (8.8)
Staphylococcus sp.	80	6 (7.5)
Streptococcus alpha haemolytic	80	36 (45)
Streptococcus non-haemolytic	80	9 (11.3)
Streptococcus uberis	80	8 (10)

Table 3.3. Abomasal parasites of five fallow deer collected from Little St. Simons Island, Georgia, U.S.A. in December 2006. Average parasite count was 584.

Animal Number	**1**	**2**	**3**	**4**	**5**
Age (Sex)	4.5(F)	3.5(F)	2.5(M)	3.5(M)	2.5(F)
Weight (kg)	42.7	31.3	49.9	54.5	33.6
Abomasal Parasites					
Spiculopteragia asymmetrica	0	662	798	150	506
Mazamastrongylus odocoilei	0	0	0	0	39
Ostertagia mossi	0	142	42	150	78
Ostertagia ostertagi	0	0	0	0	78
Trichostrongylus askivali	0	236	0	0	39
Total Counts	0	1,040	840	300	740

Table 3.4. Mean concentrations in ppm, Pb, Cu, Zn, and Fe in the liver of fallow deer from Little St. Simons Island, Georgia, U.S.A.

		Lead				**Copper**				**Zinc**				**Iron**			
		n	*x*	SD	Range	*n*	*x*	SD	Range	*n*	*x*	SD	Range	*n*	*x*	SD	Range
Young (0-2)																	
	Female	12	0.02	0.06	0-0.22	12	12.35	14.84	7.76-53.53	12	36.93	14.58	18.69-60.30	1	76.86	-	-
	Male	8	0.27	0.75	0-2.13	8	6.47	2.96	3.53-13.01	8	50.42	7.75	43.63-67.89	-	-	-	-
Adult (>2)																	
	Female	14	0.7	1.7	0-5.59	14	12.01	12.6	2.33-46.79	14	49.07	9.86	21.89-65.60	4	77.92	20.69	54.77-104.79
	Male	21	0.1	0.18	0-0.51	21	7.73	9.19	1.65-34.64	21	51.98	18.39	20.62-110.56	6	133.4	89.81	57.87-301.98

CHAPTER 4

SEASONAL DIETS OF AN INSULAR POPULATION OF FALLOW DEER (*DAMA DAMA*) ON LITTLE ST. SIMONS ISLAND, GEORGIA[1]

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***Abstract*:** We examined the seasonal diets of an introduced population of fallow deer (*Dama dama*) on Little St. Simons Island, Georgia. We analyzed rumen contents from hunter-harvested deer during fall and winter of 2004-05 and 2005-06. Fecal pellets also were collected monthly from November 2004 to December 2005 and examined microscopically for unique plant cell characteristics. Fallow deer utilized a variety of food items based on seasonal availability although mast and browse were the most abundant food items in rumens. Fallow deer preferred acorns (*Quercus* spp.), but consumed more *Sabal palmetto* when acorns were less abundant. Microhistological techniques underestimated the occurrence of highly digestible items such as mast, but were more effective at identifying grasses and browse. Grasses were the most common and abundant forage class in feces, with peak grass use in the summer (67%). Fallow deer's ability to utilize a wide variety of food items including low quality forage has contributed to their success in this barrier island ecosystem. However, low productivity, suppressed body weights and small antler characteristics are likely due to a low quality diet and over-browsing.

***Keywords*:** barrier island, fecal pellets, food habits, mast, rumen

INRODUCTION

Fallow deer *(Dama dama)* are one of the most widely distributed cervid species in the world, inhabiting Europe, Asia, North America, South America, Africa, and Australia (Chapman and Chapman 1975). In the United States, fallow deer have been released in Georgia, Alabama, California, Massachusetts, Nebraska, Texas, Colorado, Kentucky, and New Mexico (Chapman and Chapman 1975). Only a few wild populations remain. One of these exists on Little St. Simons Island (LSSI), a coastal barrier island near Brunswick, Georgia.

The potential impacts of exotic deer populations on native deer species and local ecosystems are a growing concern (Davidson et al. 1985; Keiper 1985; Jackley 1991; NPS 2006). Recently, the National Park Service has recommended removal of exotic fallow deer and axis deer (*Axis axis*) from Point Reyes National Seashore, California (NPS 2006). Contributing factors in this decision stemmed from declines in native black-tailed deer (*Odocoileus hemionus columbianus*) and tule elk (*Cervus elaphus nannodes*) populations, as well as habitat degradation within the park (NPS 2006). On LSSI, there is concern that the fallow deer are inhibiting the regeneration of maritime forest and threatening other sensitive barrier island ecosystems.

Fallow deer were first introduced to LSSI during the 1920s (S. Johnson, pers. comm.). In the early 1980s, in an effort to reduce damage to native ecosystems, cattle were removed from the island and a hunting program was initiated to reduce fallow deer numbers. Current fallow deer density on LSSI is approximately 47 deer/km^2 (Morse and Miller In review), and hunting is the primary cause of mortality in the population. The historical status of native white-tailed deer (*Odocoileus virginianus*) is unknown. Sightings of white-tailed deer on LSSI in the recent past have been rare, and none were observed from 2002-2006. However, white-tailed deer are present on all the surrounding barrier islands as well as mainland Georgia, and likely have been displaced from LSSI by the exotic fallow deer.

Little is known about the ecology of fallow deer on LSSI, including their food habits and the potential negative effects browsing may have on the barrier island ecosystem. Our objective was to document seasonal food habits of fallow deer on LSSI. An understanding of food habits is important when managing an exotic herbivore, especially on an island where resources are limited. If suboptimal foods comprise the majority of the diet, it is likely that higher quality food items are over-exploited by an overabundant population (Bruno and Apollonio, 1991).

STUDY AREA

Little St. Simons Island is a privately owned, 4,340-ha coastal barrier island in Glynn County Georgia approximately 21 km northeast of Brunswick. The island is bordered by the Atlantic Ocean to the east, Altamaha River to the north and the Hampton River to the south and west with no land linkage. The island is typical of other undeveloped barrier islands in the South Atlantic/Carolinian biogeographic classification (McIntyre 2001). Most of the island (3,189 ha) consists of tidally influenced salt marshes dominated by smooth cordgrass (*Spartina alternaflora*) in lower marshes and saltgrass (*Distichlis spicata*) in higher marshes. Upland habitats include primary and secondary dune systems, maritime shrub communities dominated by wax myrtle (*Myrica cerifera*), mixed pine-oak-palmetto forest and mature maritime forests of live and laurel oak (*Quercus virginiana* and *Q. laurifolia*). Freshwater habitats are limited to a few permanent ponds and ephemeral sloughs. Floral diversity is low compared to nearby larger islands and the mainland because of the islands small size, poor soils (Rigdon and Green 1980), topographic limitations, and potential effects of fallow deer browsing pressure.

Elevations range from sea level to 9 MSL, however most of the upland habitats are <3 MSL. Marine influences provide cooler summers and warmer winters than the mainland (McIntyre 2001). January and July temperatures average 11.9ºC and 28.1ºC, respectively, and mean annual rainfall is 132.4 cm (cirrus.dnr.state.sc.us). Severe droughts and floods are common. Flooding occurs mainly from tropical storm systems and high spring tides.

Fallow deer are the only large free-ranging mammal on LSSI. Predatory mammals such as bobcats (*Lynx rufus*), foxes (*Vulpes vulpes* and *Urocyon cineroargenteus*), and coyotes (*Canis latrans*) are absent. The only potential predator of fallow deer is the American alligator (*Alligator mississippensis*). Competition for mast resources includes gray squirrels (*Sciurus carolinensis*) and raccoons (*Procyon lotor*).

METHODS

We assessed fallow deer food habits by macroscopic rumen analysis, microhistological analysis of fecal pellets and direct observation. We sampled rumen contents from hunter-harvested deer on LSSI from October 2004 to February 2005 (Year 1) and October 2005 through mid-March 2006 (Year 2). Individual rumen samples were separated into fall and winter seasons. The fall season consisted of deer harvested in October, November or December; winter consisted of deer harvested in January, February and March. We examined the contents of 54 rumens: 18 in fall 2004, 18 in winter 2005, 7 in fall 2005 and 11 in winter 2006.

Rumen analysis followed Puglisi et al. (1978). Immediately after harvest, rumens were opened and contents thoroughly mixed. One-liter samples were taken from each rumen, frozen in plastic containers and labeled appropriately. Later, rumen samples were thawed and washed with water through 2 stacked sieves (mesh size 3.36 mm and 5.66 mm). Food items were separated according to plant type and species. Once separated each plant was identified by eye, hand lens, or dissecting microscope and checked against a reference collection prepared by gathering plant specimens from LSSI. We identified each plant item to the lowest possible taxon. Unidentifiable fragments were categorized as unknown.

We determined the volume of each food by water displacement. We calculated percent seasonal occurrence by dividing frequency of occurrence of each food item (or group) by the number of rumen samples for each season. Volumes were determined using the aggregate volume method described by Martin et al. (1946). Aggregate volume is calculated by summing the volume of a particular food item in all rumen samples and dividing by the total volume of all foods in all samples, giving importance to absolute volume of food consumed by all individuals in the sample (Litvaitis et al. 1996). We considered food items found in rumens to be important if they constituted >5% of the aggregate volume, as well as >50% frequency of occurrence.

Because we could not collect rumen samples during spring and summer, we collected fecal pellets every month from November 2004 to December 2005 to examine spring and summer diet, as well as compare fall and winter diets using the two techniques. To obtain a representative sample from all parts of the island, we divided the island into 6 sections based on geography, and collected one pellet group per month from each section. We evaluated pellets in the field for relative moisture content and decomposition to ensure that samples were deposited within the sample month. Each pellet group represented one deer. Pellets were placed in plastic bags with iodized salt (J. Rentfleish, pers. comm.), labeled and shipped to Micro Composition Laboratory (Ft. Collins, CO) for analysis. Fecal contents were analyzed using microhistological techniques described in detail by Johnson et al. (1983). Pellets were ground in a Wiley mill and one slide prepared. Twenty fields were read for each sample using a 100X binocular microscope. Plant fragments were identified based on epidermal tissue characteristics using laboratory reference slides and a plant list from LSSI. All identifiable plant fragments in the 20 fields of view were counted for each pellet group. We calculated relative percent density (number of fragments of a plant divided by the number of all fragments in all samples) for each pellet group.

Items from rumen and fecal samples that could not be placed in fruit, grass, browse or forb categories were combined in an “other” category. Months were grouped into seasons for comparison. Fall and winter months are as listed above, with spring season being April, May and June, and summer being July, August and September. Food habits data collection methods were approved by the University of Georgia Institutional Animal Care and Use Committee (Permit # A2005-10150-0).

RESULTS

We were able to categorize >88% of the food items recovered from rumens to the familial or lower taxonomic level. *Vitis* spp. was the only food found in 2004 that did not occur in 2005. However, we recovered 10 foods in 2005 that did not occur in 2004.

Fruit constituted the greatest volume in rumen samples except during winter 2005. Fruit use was greater in Year 2 than Year 1, and was greater than all other food groups in winter of 2006 (Figure 4.1). Acorns (*Quercus* spp.) occurred in >55% of fallow deer rumens in both seasons and years, and >72% in winter 2005 and Year 2. Acorns were found in 100% of fall 2005 rumens, and represented 97% of the volume of all fruit consumed. The frequency of use and total volume consumed was much greater in 2005 than 2004. The only other fruits that represented >5% in any season or year were cabbage palm (*Sabal palmetto*) and Carolina laurel cherry *(Prunus caroliniana*) (Table 4.1).

Browse was the second most abundant forage class in fallow deer rumens in fall and winter (Figure 4.1). Seventeen browse items were detected. Browse items tended to be a more important component of the diet in Year 1 than Year 2, both in terms of frequency of occurrence and in volume. During both years, wax myrtle, yaupon holly (*Ilex vomitoria*), and live oak leaves were the most common browse items. *Vitis* spp. and mistletoe (*Phoradendron serotinum*) were important components of the diet in 2004, but not in 2005.

Various forbs, primarily resurrection fern *(Polypodium polypodioides*), Spanish moss (*Tillandsia usneoides*) and smartweed (*Polygonum* sp.) were common in fallow deer rumens in all seasons, but rarely comprised a significant portion of the diet (Table 4.1). Grasses, sedges, and rushes were commonly recovered from deer rumens, but only constituted a major component of the diet during the fall (Figure 4.1). Likewise, fungi and lichens were a common, but relatively unimportant component of the diet.

Microhistologic analysis of fecal pellets revealed 72 foods consumed (Table 4.2). Grasses were consumed during all seasons, and were consumed more frequently during spring and summer than the other forage classes (Figure 4.3). Grass occurred in 67% of the summer diets of fallow deer on LSSI. *Uniola* spp. was the most commonly observed grass in fecal samples. Bermuda grass (*Cynodon dactylon*), sedges (*Cyperus* spp.), salt grass (*Distichlis spicata*), and soft rush (*Juncus* spp.) were also common forage items revealed from fecal samples. *Eragrostis* spp. was an important food item in fall 2004 (9% RD).

Leaves and stems from 20 woody plant species were identified in the fecal samples. Oak leaves, likely *Quercus virginiana, Q. laurifolia, or Q. geminata*, were the most common browse item, typically comprising half of the relative percent density of all browse items recovered in feces. Red cedar (*Juniperus virginiana*) and willow (*Salix* sp.) were eaten in all seasons (Table 4.2).

Twenty-two species of forbs were detected in the feces of fallow deer (Table 4.2). Only gulf croton *(Croton punctatus*) and an unknown forb species occurred year-round. Gulf croton was an important food item in winter. Another unknown forb species contributed >5% of the diet in spring and summer seasons. Other items identified in fallow deer feces included corn kernel, an unknown flower, grass seed and glume, legume pod, unknown seed, and lichen.

Our observational data provided additional insights into fallow deer diets on LSSI. In

May 2004, we observed 3 bucks foraging exclusively on fallen magnolia *(Magnolia grandiflora*) flower petals. In August 2004, a buck readily consumed a locally abundant white mushroom. In August 2005, we observed a buck feeding in a salt marsh on smooth cordgrass *(Spartina alternaflora*). An observation of a yearling buck feeding on fallen buckthorn (*Bumelia tenax*) fruits occurred in November 2005. Additionally, we observed obvious browse or browse lines on *Smilax* spp., live oak, Carolina laurel cherry, red cedar, coralbean (*Erythrina herbaceae*), and Florida swamp privet (*Forestiera segregate*). Seeds of *Amaranthus* sp. were collected from the abomasum of one deer in December 2006.

DISCUSSION

Food habits of fallow deer have been reported from various localities, and results differ among study areas. Graminoids compose the majority of fallow deer diets in California (Wehausen and Elliott 1982), Poland (Borkowski and Obidziński 2003), and Spain (Garcia-Gonzalez and Cuartas 1992). In contrast, browse was reported as the dominant forage in New Zealand (Nugent 1990), Italy (Bruno and Apollonio 1991), and Texas (Mungall and Sheffield 1994). On LSSI, fallow deer consumed a variety of food items based on seasonal and annual availability. Our results also varied according to analytical technique used. Techniques for examining herbivore diets have been thoroughly reviewed by Holechek et al. (1982). Fecal analysis typically is more effective for species identification, whereas rumen analysis provides an assessment of the relative importance of common food items, as well as a more accurate estimate of consumption of highly digestible food items such as fruits and fungi.

Based on rumen analysis, mast was important forage during fall and winter. The increase in mast use from 2004 to 2005 reflects the abundant mast crop observed in 2005. During 2005, mast, primarily acorns, comprised more than half of the rumen content volume in both fall and winter, similar to reports of acorn use by fallow deer in England (Chapman and Chapman, 1979). The large amount of Carolina laurel cherry fruit occurring in winter 2005 came mostly from one deer (77% of rumen volume). As such, this soft mast species likely is not an important food item to fallow deer on LSSI.

Although acorns are a highly preferred food item, mast from cabbage palms is consumed frequently when acorns are less abundant. Cabbage palm fruits represented >10% of the fall and winter diets in 2004, but use dropped to <1% in 2005 when acorns were anecdotally determined to be more abundant (Figure 4.2). Similar use of cabbage palm fruits has been reported from white-tailed deer on nearby barrier islands when acorns were less abundant (Warren et al., 1990; Osborne et al. 1992). Mast failures on these barrier islands can have dramatic impacts on white-tailed deer fitness, reproduction, movements and survival (Osborne et al. 1992). It is unknown whether mast failures on barrier islands would cause similar effects in fallow deer.

Fruiting bodies were not revealed by microscopic fecal pellet examination because fruits are generally succulent, palatable and highly digestible in ruminant digestive tracts (Anthony and Smith 1974). Food items remaining in feces are less digestible and provide bias towards these items. Thus subtotals of each forage class found in the feces likely should be viewed as an index of non-mast food items consumed by deer.

The amount of browse in rumens declined from 2004 to 2005, reflecting the increase in acorn mast consumption. Wax myrtle contributed the greatest amount of browse volume and had the highest occurrence in all seasons except winter 2005. Osborne et al. (1992) reported that white-tailed deer used wax myrtle when other foods were exhausted, indicating low preference. Although fallow deer preference of wax myrtle is unknown, its abundance on LSSI and high frequency of occurrence in rumen samples indicate that it is an important food item, especially when other foods are limited. Unexpectedly wax myrtle was not detected in the fecal samples, perhaps reflecting an error in microhistological identification of this species.

There is concern that fallow deer on LSSI are inhibiting live oak regeneration in the maritime forest (W. Paulson, owner of LSSI, pers. comm.). Both rumen and fecal pellet analysis indicated use of live oak in all seasons with peaks in winter. Browse lines observed on the island provide additional evidence of live oak use by fallow deer. Browse quality generally decreases as plants mature and deer typically select younger, more digestible plants and plant parts (Cypher and Cypher 1988). By selecting young oak seedlings, fallow deer certainly could impact regeneration of this species. Oak species, including live oak, were considered important foods in the winter diets of fallow deer in Texas (Jackley 1991).

Browse lines and the absence of regeneration can indicate population overabundance and overuse of food resources (USDA 1994; Healy 1997). Browse lines and browsing were evident in certain vegetative communities of LSSI. Browse lines on Florida swamp privet is of particular concern. This shrub is listed as rare (S2) in Georgia (Chafin 2007), and should be monitored for browsing impacts and protected if necessary. On the southeastern section of LSSI, intense deer browsing damage was apparent on live oaks, yaupon holly, *Smilax* spp., red cedar, and Carolina laurel cherry, perhaps due to lower hunting pressure in this area.

Forbs were frequently used, but contributed little to the diet compared to other food items. In California, forbs are an important component of the diet of introduced fallow deer (Wehausen and Elliot 1982), whereas a Texas study indicated forbs contributed 12% of the diet (Mungall and Sheffield 1994), similar to our results. Only 5 species of forb were found in rumen contents, likely due to reduced availability at this time of year. The two most common forbs found in rumens, resurrection fern (*Polypodium polypodiodes*) and Spanish moss (*Tillandsia usneoides*), are locally abundant year-round in forested parts of LSSI, particularly after storms and strong winds. Use of Spanish moss and resurrection fern by coastal white-tailed deer (Warren et al. 1990; Osborne et al. 1992) and introduced sambar deer (Shea et al. 1990) have been reported from the southeastern U.S.

Based on fecal analyses, we did not observe dramatic seasonal fluctuations in forb use as has been reported in other studies (Warren et al. 1990; Garcia-Gonzalez and Cuartas 1992). Succulent forbs are highly digestible, making identification difficult and causing an underestimation in abundance (Litvaitis et al. 1999). Only 3 forbs constituted >5% RD, 2 of which were unidentified species. Neither Spanish moss nor resurrection fern were identified by the microhistologic technique.

Fallow deer show a marked preference for graminoids across their range (Jackson 1977; Kerridge and Bullock 1991; Garcia-Gonzalez and Cuartas 1992; Putman et al. 1993). The occurrence of grass in LSSI fallow deer rumens was high in all seasons. However, grasses did not contribute a significant volume of the fall and winter diet compared to fruit and browse. The occurrence and volume of grass in fallow deer rumens declined between fall and winter in response to decreased availability and palatability of warm season grasses. Fecal analysis indicated that grasses were common in the annual diet, particularly during spring and summer. Fallow deer may be more efficient than native white-tailed deer in digesting fiber (Hofmann 1985), and have greater relative rumen capacity than white-tailed deer allowing fallow deer to more efficiently utilize a grass-dominated diet (Henke et al. 1988). *Uniola* sp. was the most important grass consumed in all seasons. The only species of *Uniola* currently known from LSSI is sea oats (*Uniola paniculata*), which has received protection by the Sea Oats Conservation Act of 1973 (O.C.G.A. 12-5-310 to 12-5-312). However, due to similarities in cellular characteristics with slender woodoats (*Chasmanthium laxum*), we cannot differentiate between these species. Although fallow deer are not commonly seen in the fore-dune ridge areas where sea oats occurs, future monitoring of fallow deer use of this species is warranted.

Our results confirm the dietary adaptability of fallow deer and their ability to efficiently utilize a variety of food resources. Dietary preferences, coupled with high deer densities on LSSI (Morse and Miller In review) may be altering the plant community composition and structure. Our data will be most useful in combination with vegetation surveys to examine forage availability on LSSI to assess the impact fallow deer have on vegetative communities and plant species of interest.

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Table 4.1. Fall and winter rumen contents (percent occurrence and percent volume) of fallow deer on Little St. Simons Island, Georgia 2004-2006.

	Fall 2004 (Oct-Dec)		Winter 2005 (Jan-Feb)		Fall 2005 (Oct-Dec)		Winter 2006 (Jan-Mar)	
	n =18		*n* =18		*n* =7		*n* =11	
Food item	**% Occ.**	**Vol.**	**% Occ.**	**Vol.**	**% Occ.**	**Vol.**	**% Occ.**	**Vol.**
Fruit								
Quercus spp.	55.6	8.0	83.3	25.4	100.0	55.9	72.7	30.4
Phoradendron serotinum							9.1	0.1
Prunus carolinana					14.3	0.4	27.3	30.0
Serenoa repens					14.3	0.2	9.1	0.9
Ilex vomitoria					14.3	0.6	18.2	1.0
Sabal palmetto	72.2	17.4	88.9	9.8	14.3	0.2	27.3	0.2
Myrica cerifera					14.3	0.1		
Subtotal		**25.4**		**35.2**		**57.4**		**62.6**
Leaves and stems								
Myrica cerifera	83.3	7.4	88.9	16.1	28.6	0.9	72.7	7.1
Phoradendron serotinum	33.3	2.1	77.8	7.1			18.2	0.1
Quercus spp.	55.6	2.8	83.3	3.7	42.9	0.1	45.5	0.3
Ilex vomitoria	22.2	1.4	61.1	5.4	14.3	0.6	36.4	0.2
Vitis sp.	72.2	6.9	22.2	1.3				
Salicornia sp.			66.7	3.3	42.9	3.0	27.3	0.3
Zanthoxylum clava-herculis	22.2	2.6	55.6	3.0	42.9	0.9		
Juniperus virginiana	33.3	2.1	16.7	0.9	14.3	0.2	18.2	0.1
Prunus caroliniana	22.2	3.1	33.3	0.4	14.3	0.3		
Pinus sp.	5.6	0.1	11.1	0.1			18.2	0.1
Smilax sp.	16.7	0.8	50.0	1.6	14.3	0.3	9.1	0.1
Persea borbonia							18.2	0.1
Salix sp.							18.2	0.1
Baccharis halimifolia							9.1	0.1
Vaccinium arboreum					14.3	0.1	18.2	0.1
unknown stem					71.4	8.8	54.5	11.3
unknown leaves					42.9	0.9	45.5	0.4
Subtotal		**29.3**		**42.9**		**16.1**		**20.4**
Forbs								
Polygonum sp.	27.8	2.9	38.9	1.0			45.5	0.2
Polypodium polypodioides	16.7	0.2	66.7	5.5	14.3	0.1	90.9	6.8
Tillandsia usneoides	33.3	9.6	55.6	2.1	100.0	8.1		
unknown I					14.3	0.1	18.2	0.3
unknown II							9.1	0.1
Subtotal		**12.6**		**8.6**		**8.3**		**7.4**
Grass and Grasslike	88.9	26.1	55.6	2.0	100.0	14.9	81.8	8.1
Fungi/Lichen	16.7	0.4	66.7	7.3	42.9	0.8	54.5	0.5
Other	5.6	0.1			14.3	0.2	45.5	0.6
Unidentified	100.0	6.2	100.0	4.0	100.0	2.6	100.0	0.8
Total		**100.1**		**100.0**		**100.3**		**100.4**

Table 4.2. Percent relative density of food items in feces of fallow deer on Little St. Simons Island, GA 2004-2005 as determined by microcompositional analysis.

Plant	Fall 2004	Winter 2005	Spring 2005	Summer 2005	Fall 2005
	n=12	*n*=14	*n*=13	*n*=12	*n*=17
Grass and Grasslike					
Andropogon sp.				0.4	
Andropogon glomeratus		0.3			
Andropogon virginicus			0.3	0.7	0.3
Aristida sp.				0.4	
Cynodon dactylon	5.4	0.6	4.7	4.3	7.8
Cyperus sp.	1.4	2.8	5.3	8.3	6.4
Distichlis sp.	6.8	9.5	8.8	19.2	4.7
Eleocharis sp.			0.9	0.4	
Eragrostis sp.	9.0	1.5	4.4	1.4	0.8
Festuca sp.				0.4	
Fimbristylis sp.			1.6	0.7	
Juncus sp.	0.7	4.0	0.9	0.7	0.8
Rhyncospora sp.	0.7				0.3
Setaria sp.			0.3	0.7	
Setaria viridis	0.4		0.6	0.7	0.8
Spartina sp.	0.4	0.9	1.9	1.8	
Sporobolus sp.		0.3	1.3	0.4	0.6
Sporobolus virginicus			0.3	0.4	
Stenotaphrum sp.			0.3		
Stipa avenacea		0.6	0.3	3.3	
Triplasis purpurea		0.3		0.7	
Unolia/Chasmanthium spp.	30.6	9.5	23.9	19.9	13.1
unknown grass I			0.3	1.1	0.3
unknown grass II	0.7	2.2	0.6	1.1	0.6
Subtotal	**56.1**	**32.6**	**56.9**	**67.0**	**36.6**
Browse					
Acer sp.	1.4	1.2	1.9		
Bumelia sp.	0.4	0.6		0.7	1.7
Callicarpa americana		0.3		1.1	
Celtis sp.	1.4			0.4	
Hibiscus sp.				1.1	
Juniperus virginiana	1.4	5.5	3.8	1.1	0.8
Kosteletzkya virginica				0.4	1.1
Magnolia sp.		0.6			
Osmanthus sp.			0.9	0.7	0.6
Persea sp.	0.7	1.2	2.2		
Persea borbonia		3.1	0.6		

Table 4.2 continued.

Pinus sp.		0.6	2.8	0.4	0.8
Pinus taeda		0.3			
Quercus spp.	19.8	27.1	8.5	2.5	13.4
Rhododendron type		0.3			
Rhus sp.			0.3		
Rubus sp.		4.0	0.0		0.3
Salix sp.	2.2	4.9	1.3	1.4	3.4
Vaccinium sp.	0.7		1.6		
Zanthoxylum clava-herculis					0.8
Subtotal	**28.1**	**49.8**	**23.9**	**9.8**	**22.9**
Forbs					
Bidens sp.					0.3
Chenopodium sp.	0.4		0.3	0.4	0.3
Croton sp.	1.8	5.5	1.3	1.4	1.4
Ipomea sp.				0.7	0.8
Lepidium virginicum		0.9			1.1
Limonium carolinum				0.4	
Oenothera sp.			0.3		
Oxalis sp.			0.6		
Polygonum sp.		0.6		0.4	
Salicornia sp.			0.3		0.3
Salivia sp.		0.3			
Salsola sp.	0.7				
Salsola kali			0.3		
Solidago sp.				0.4	
Suada linearis					0.3
Tradescantia sp.	0.4		0.9		
Typha latifolia	0.4	0.6			0.3
Verbascum sp.			0.3		0.3
unknown forb I	3.6	4.6	1.3	1.1	20.1
unknown forb II			6.3	6.9	0.3
unknown forb III				1.4	
unknown forb IV			0.6		0.3
Subtotal	**7.2**	**12.6**	**12.6**	**13.0**	**25.7**
Other					
corn kernel			1.6		
Flower					0.6
grass seed and glume	4.0	4.6	2.8	6.9	3.6
Legume pod	0.4			1.1	0.3
Seed	4.3	0.6	2.2	1.8	10.3
Cetraria sp. (lichen)				0.4	
Subtotal	**8.6**	**5.2**	**6.6**	**10.1**	**14.8**

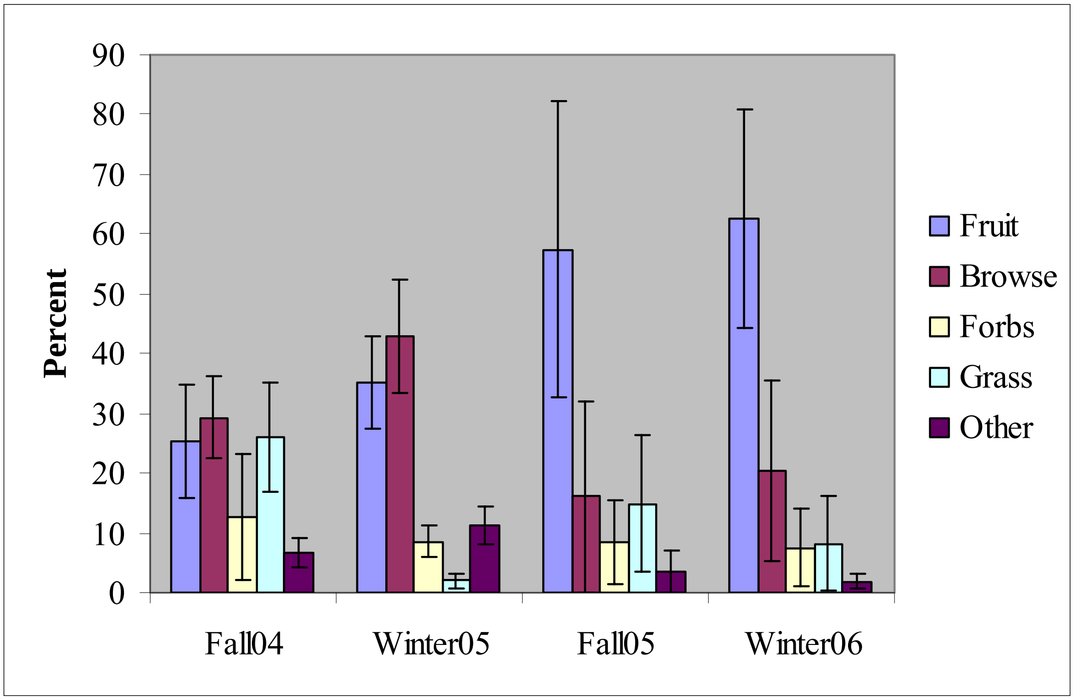

Figure 4.1. Aggregate percent volume and 95% CI of forage classes in rumens of fallow deer from Little St. Simons Island, Georgia 2004-2006.

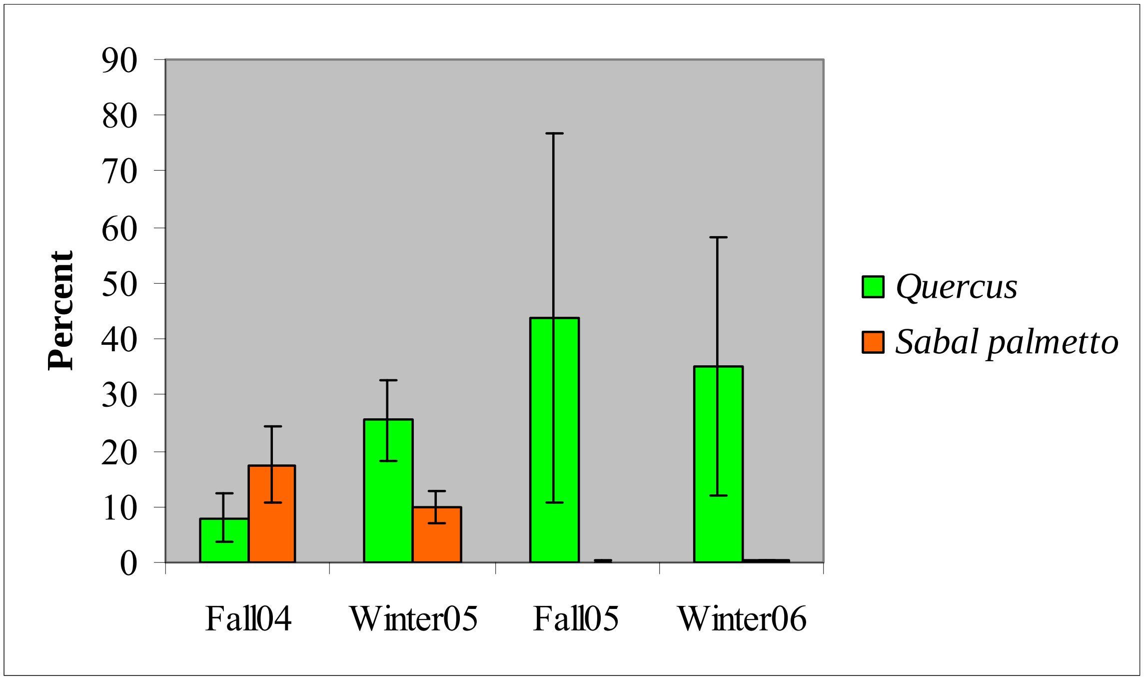

Figure 4.2. Aggregate percent volume and 95% CI for *Quercus* sp. and *Sabal palmetto* fruits from rumens of fallow deer on Little St. Simons Islands, Georgia 2004-2006.

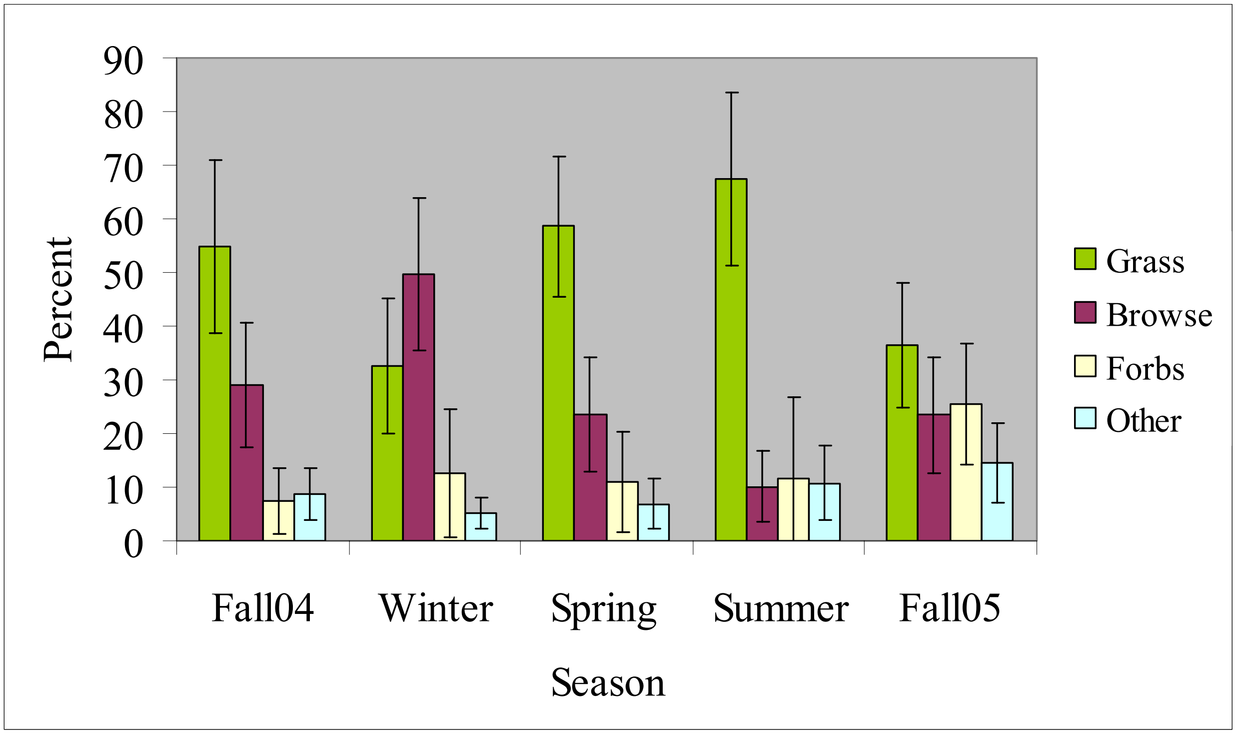

Figure 4.3. Mean percent relative density and 95% CI of forage classes by season from feces of fallow deer on Little St. Simons Island, Georgia 2004-2005.

CHAPTER 5

HOME RANGE AND HABITAT SELECTION OF AN INSULAR FALLOW DEER (*DAMA DAMA* L.) POPULATION ON LITTLE ST. SIMONS ISLAND, GEORGIA, U.S.A. [1]

[1] Morse, B. W., N. Nibbelink, D. A. Osborn, and K. V. Miller. To be submitted to the *European Journal of Wildlife Research*.

***Abstract*:** We describe annual and seasonal home range development and habitat use of an exotic insular fallow deer (*Dama dama* L.) population in coastal Georgia, U.S.A. We captured 7adult fallow deer and fitted them with GPS collars. Home ranges of females averaged 130.3 ± 0.45 ha based on a 95% local convex hull (LoCoH) nonparametric kernel method. Home ranges of adult males were highly variable, ranging from 56.9 to 354.8 ha. We examined site fidelity by analyzing shifts in core areas and percent overlap across seasons. Only one individual exhibited a seasonal range shift; all other deer demonstrated a high level of site fidelity. Based on compositional analysis of habitat use versus availability, fallow deer avoided salt marshes but showed individual variation in selection of other habitats. Maritime shrub was the most commonly preferred habitat type on the barrier island. Fallow deer have adapted to effectively use available habitats on the barrier island and successfully excluded white-tailed deer from re-colonizing LSSI.

***Keywords*:** barrier island, GPS collar, habitat, home range, LoCoH, maritime, marsh

INTRODUCTION

Resource use by ungulates varies across environmental gradients and is influenced by social behavior and feeding adaptations (Estes 1974; Gordon 1989). Further complications in assessing resource use occur when ungulates are introduced to habitats outside their natural range of distribution. Among ungulate species, fallow deer (*Dama dama*) are among the most successful at colonizing new habitats (Chapman and Chapman 1975). They have generally broad habitat requirements, often out-competing more selective native species for food resources and degrading overall habitat quality (Davidson et al. 1985; Demarais et al.1990; Putnam 1996; Focardi et al. 2006; NPS 2006).

During the 1920s, European fallow deer (*Dama dama dama*), a single sambar deer (*Cervis unicolor niger*), Barasingha (*Cervus duvauceli*), and red deer *(Cervus elaphus)* were released on Little St. Simons Island (LSSI), a barrier island off the coast of Georgia, USA (Rochester 1994). Currently, only fallow deer remain on the island and this population is thriving (Morse 2008). The number of fallow deer released is unknown, although 4 males and 2 females were purchased from the Bronx Zoo in New York and shipped to the island in 1923 (Johnson pers. comm.). The current fallow deer population is estimated at 550-970 deer (Morse and Miller, *in review*).

The historical status of native white-tailed deer (*Odocoileus virginianus*) on Little St. Simons Island is unknown, although they currently are abundant on all other local barrier islands and the adjacent mainland. It is unclear how and when fallow deer excluded the native white-tailed deer. The fallow deer population on LSSI likely functions as a closed population and thus habitat selections are based upon characteristics of the island's available habitats. To understand spatial use of the island by this non-native species, we examined home range and habitat use characteristics. Our specific objectives were to identify home range development in this high-density insular deer population and develop an understanding of habitat needs by fallow deer to assist with future management goals. We also provide baseline data for use in the future if significant habitat modifications or changes in population density occur.

STUDY AREA

The study was conducted on LSSI in Glynn County, Georgia (ca. 31° 16′ N, 81° 18′ W), a privately owned, 4,340-ha coastal barrier island located northeast of Brunswick, Georgia. The island is bounded by the Atlantic Ocean to the east, Altamaha River to the north and the Hampton River to the south and west, with no land linkage.

Floral diversity on LSSI is low compared to the mainland due to its small size, poor acidic (pH < 5.5) soils (Rigdon and Green 1980), isolation from the mainland, and limited topography. The largest habitat type on LSSI is tidally influenced salt marsh (3,189 ha). Vegetation in these marshes is dependent on the degree of salt water inundation. Low salt marshes (2698 ha; flooded daily) are dominated by smooth cordgrass (*Spartina alternaflora*). Higher marshes (498 ha; flooded occasionally) have a higher diversity of flora and are primarily composed of saltgrass (*Distichlis spicata*), glasswort (*Salicornia* spp., and sea-oxeye (*Borrichia frutescens*). We classified 3 primary upland habitats: maritime shrub communities (559 ha) composed of open grasslands, wet meadowns, and shrub/scrub dominated by wax myrtle (*Myrica cerifera*), mixed pine-palmetto (*Pinus* spp./*Sabal palmetto*/*Serenoa repends*) woodlands (270 ha) and mature maritime forest (223 ha) dominated by live and laurel oak (*Quercus virginiana* and *Q. laurifolia*). Freshwater habitats (91 ha) are limited to a few permanent ponds and ephemeral sloughs.

Elevation ranges from sea level to 9 m. Most upland habitats are <3 m above sea level and are subject to flooding from severe weather systems such as hurricanes. Marine influences provide cooler summers and warmer winters than the mainland (McIntyre 2001). Mean temperatures for January and July are 11.9ºC and 28.1ºC respectfully, and mean annual rainfall is 132.4 cm. Annual rainfall during our study period was consistently below the 59-year mean.

Tourism operations are the only anthropogenic use of the island and development is restricted to a 4.4-ha compound. There are 35 km of unpaved roads on LSSI and approximately 20 full-time staff members reside in the compound. There has been little habitat manipulation since cattle operations were removed in the 1980s, and the island remains in relatively pristine habitat. Fallow deer are the only naturalized ungulates on LSSI. Large or medium-sized mammalian predators are absent; the only potential predator of fallow deer is the American alligator (*Alligator mississippensis*).

MATERIALS AND METHODS

We captured seven adult (≥2.0 years-old) fallow deer during April–July 2005 using pneumatic rifles (Dan-Inject, Inc., Borkop, Denmark) fitted with 3 x 9 scopes to deliver transmitter darts (Pneudart Inc., Williamsport, Pennsylvania, USA) from stands overlooking bait (i.e., shelled corn) or opportunistically from a moving truck. At night, we used spotlights to locate deer. When darted, deer received an intramuscular injection of xylazine hydrochloride (3 mg/kg) and Telazol® (5 mg/kg; Fort Dodge Animal Health, Fort Dodge, Iowa, USA) in a 3 mL solution. At capture, we applied optical lubricant, and blindfolded each deer. We positioned each deer sternally and monitored vital signs (i.e., body temperature, heart rate, respiration rate). We measured neck and chest girths, estimated age by tooth eruption and wear (Murphy 1994), recorded pelage color and reproductive status, and inserted a numbered ear tag. We marked capture locations with a handheld GPS unit. Each deer was fitted with a GPS tracking collar (650g, 391 day battery life; Televilt, Lindesberg, Sweden) equipped with an activity sensor and VHF transmitter. We fitted collars loosely on bucks to allow for neck swelling during the rut. After handling, we reversed xylazine hydrochloride with yohimbine hydrochloride (6 mg/kg; ½ IV, ½ IM). Procedures for capturing and handling were approved by the University of Georgia Institutional Animal Care and Use Committee (Permit # A2005-10150-0).

We programmed collars to record locations every 3 hours for 391 days to balance the need for independent locations (Dunn and Gipson 1977) with our desire for detailed movement data and abundant locations (McNay et al. 1994). At each interval, the GPS unit recorded a deer's location coordinates. If unable to obtain a position after 2 attempts, the GPS skipped that location recording. We tracked deer weekly using a 433 MHz receiver (RX9700E, Televilt) to monitor survival and collar function, and recorded all sightings of collared deer. After the study period, we recovered collars for data retrieval. Data were downloaded and transformed into UTM coordinates using Simplex Project Manager software (Televilt, Sweden). We manually scanned locations for errors and eliminated incorrect entries. We filtered the remaining data by eliminating positions with a dilution of precision (DOP) greater than six.

Global positioning system accuracy has improved since removal of selective availability by the United States Department of Defense (Adrados et al. 2002). However, inherent biases in fix-rate success and location accuracy may include environmental factors such as forest structure, topography (Gamo et al. 2000), and animal behavior (bedding, foraging, etc.; D'Eon and Delparte 2005). The potential for bias in our study exists given the fix rate success <100%. However, topography biases are unlikely because most of LSSI is less than 9 MSL. We addressed potential biases by filtering locations by dilution of precision, removing poor quality and erroneous locations. Location data were not differentially corrected because the increase in accuracy for most wildlife applications is nominal (Dussault et al. 2001; Graves and Waller 2006). Visual inspection of the data with a high resolution, georeferenced (RMS error=0.426) aerial photograph of LSSI and a coarse classification of habitats eliminated our need to differentially correct the data. Although the relatively low fix rate success (Table 5.1) reduced the number of locations used in our analysis, it may have inadvertently strengthened the robustness of the data by lengthening the time interval between locations, thus enhancing the independence of locations.

Because LSSI forest and shrub canopies are evergreen, we did not consider seasonal variation in fix-rate success to be a significant bias. We also examined the percent of successful locations throughout a 24-hour period, and found little variation in fix rate success between diurnal and nocturnal locations and between dawn crepuscular and dusk crepuscular locations (Figure 5.2), suggesting that fix-rate success was not biased by deer behavior (i.e., bedding or feeding) across a diel period.

Home Range

We estimated annual and seasonal home ranges for each deer. Annual home ranges were estimated for deer when at least 12 months of location data were recorded. Seasons were divided according to local environmental conditions and fallow deer behavior and were distributed as follows: winter (January-March), spring (April-June), summer (July-September) and fall (October-December). Because lek mating strategies used by LSSI fallow deer (Morse 2008) could influence seasonal home ranges of males and females, we censored location data collected during 2–16 October.

Home ranges were estimated using the LoCoH tool (Getz and Wilmers 2004) in ArcGIS 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA). This tool uses a local convex hull (LoCoH) non-parametric kernel method (Getz and Wilmers 2004). We followed the "minimum spurious hole covering" (MSHC) rule (Getz and Wilmers 2004) by visually comparing constructed hulls to a high resolution (0.5-m pixel) aerial photograph of Little St. Simons Island to determine the most realistic nearest neighbor (k=20) selection. Hulls were generated to best fit 95% and 50% isopleths, with 50% isopleths representing a core use area. We calculated intensity of use as the proportion of the home range encompassed by the core area (Lent and Fike 2003). We constructed 95% minimum convex polygons using Home Range Tools (Rodgers et al. 2005) in ArcGIS 9.2 for comparison.

We quantified seasonal shifts in habitat use by examining home range fidelity. We generated mean geometric centers for each core area in each season and measured distances between pairs of seasons. Then, we calculated the mean range shift distance (m) over all seasons. We also evaluated site fidelity by calculating percent core area overlap of individual deer between seasons using ArcGIS 9.2. Percent overlap was calculated according to Chaverri et al. (2006) for all pairs of seasons.

Habitat Selection

We used a digital color aerial photograph (0.5-m pixel, 2006) and a GIS-based ecological community map (K. McIntyre, unpublished data) to delineate 6 habitat types (Figure 5.1). Using ArcGIS 9.2, we calculated the proportion of each habitat type within each deer's annual and seasonal home range (95% isopleths).

We used compositional analysis (Aebischer et al. 1993) to examine second order selection (Johnson 1980), where individual deer were the sampling unit. We defined the study area as the entire island and deer home range as the 95% isopleth for each deer. Due to our small sample size, we could not separate deer by gender or age. Therefore, habitat selection was examined using BYCOMP.SAS (Ott and Hovey 1997) using all data points. Because we identified variations in habitat use among individuals, we also examined individual habitat use (95% isopleth home range) using a chi-squared analysis (Neu et al. 1974). This analysis used a goodness of fit test if utilized habitat proportions within 95% isopleth home ranges differed from available habitat proportions (White and Garrott 1990). We calculated a G statistic and corresponding p-value for each deer's annual and seasonal home ranges.

We determined the number of locations in each habitat type within the home range and developed 90% Bonferroni confidence intervals around used proportions. Available habitat proportions were then compared to the confidence intervals to determine whether the deer preferred, avoided or proportionally used each habitat type (Neu et al. 1974). The same methodology was used to assess temporal habitat use of fallow deer. We divided each 24-hour period into diurnal [1 hour after sunrise until 1 hour before sunset], nocturnal [1 hour after sunset until 1 hour before sunrise], dawn crepuscular [1 hour before and after sunrise], and dusk crepuscular [1 hour before and after sunset]. All sunrise and sunset times were obtained from the Astronomical Applications Department, U. S. Naval Observatory, Washington, D.C. for St. Simons Island, Georgia 2005-2006. We tested the null hypothesis that deer selected habitats similarly during each time period using a chi-squared test of independence (White and Garrott 1990). Because available habitat was identical among deer, we tested for individual differences in habitat preference (White and Garrott 1990).

RESULTS

We collared 7 adult deer (2 females and 5 males) during April–July 2005. Both does were pregnant when captured, and each subsequently reared a single fawn. Location fix rate success ranged from 29.9% to 58.2% (Table 5.1). The number of recorded locations per collar ranged from 781 to 1,389. The number of 3-D locations was lower than 2-D locations for all collars, with 3-D proportions ranging from 27.7% to 38.8% of location recordings (Table 5.1). After screening the data for errors and filtering out less accurate locations, 4.4% to 6.1% of observations were omitted for each deer (Table 5.1).

We were able to estimate annual home ranges for 4 deer, and the number of seasonal home ranges varied [spring 2005 (n=5); summer 2005 (n=7); fall 2005 (n=7); winter 2006 (n=5); spring 2006 (n=4); summer 2006 (n=2)] (Table 5.2). These classifications resulted in 34 comparable home ranges. All home ranges were constructed with >55 locations per deer. Of the 34 home ranges calculated, all but 3 (8.8%) had a greater area generated by the MCP method. Minimum convex polygons were 38.6% (SE=3.74) larger than LoCoH home ranges. Mean LoCoH annual home range size for does was 128.7 ha (n=2; SE=0.45). Bucks showed greater variability with a mean annual home range of 299.8 ha (n=2; SE=50.4). Core area (50% LoCoH) varied among seasons and among individuals (Table 5.2), with intensity of use ranging from 6.1% to 73.3%. Mean intensity of use for all home ranges was 24.9% (SE=2). Mean total intensity of use was approximately twice as large for the two does (30.7%, SE=2.6) than for bucks (14.9%, SE=2.3). We observed no common pattern in seasonal home range size for bucks or does.

Mean shift distance in core area geometric centers ranged from 0.03 km to 1.13 km. Two bucks (F387 and F397) had the greatest seasonal shift in core area centers, and only buck F387 had a mean seasonal shift greater than one kilometer (1.13 km, SE=0.25 km). Distances from capture location to collar retrieval location were less than 1 km for all deer except buck F387 (1.22 km). Six of 7 maximum range shift distances involved fall-summer or fall-spring combinations. All 7 deer had home ranges that overlapped with at least one other collared deer. Six of 7 deer home ranges deer overlapped with 3 or more other collared deer. The combined home range (all 7 deer) covered 69% of the total available habitat on LSSI (low salt marsh excluded). Seasonal core area overlap was variable among the collared deer (Range = 0-85.7%). Buck F387 showed the greatest difference in seasonal home range use. All other deer showed a high degree of site fidelity across all seasonal comparisons ($\bar{x}$ = 55.1%, SE=2.4).

Compositional analysis indicated that deer used habitats differently than their availability at second order selection (Wilks' Lambda = 0.013, $F_{[5,6]}$ = 30.59, *P*=0.03). Deer avoided salt marsh in preference of other habitats (Table 5.3). Across both annual and seasonal home ranges individual deer both selected and avoided particular habitat types within their home range. However selection of habitats differed among deer (Table 5.4). All deer preferred maritime shrub for part or all of the year. Two of the 7 deer preferred maritime forest across seasons, while all other deer avoided maritime forest.

Patterns of habitat use were similar across time. Overall, deer did not show differences in habitat selection between diurnal and nocturnal time periods. Only one buck (F387) exhibited a difference in habitat selection between dawn and dusk crepuscular periods. This buck preferred maritime shrub at dawn, avoided it at dusk, and preferred pine woodlands at dusk, avoiding them at dawn.

DISCUSSION

Home range size is often influenced by habitat composition, site location, predator presence and anthropogenic activities. Home range studies for fallow deer, as well as insular populations of white-tailed deer in the southeastern United States are lacking. However, home range size constructed using MCPs for both male and female LSSI fallow deer are larger than MCPs reported in Italy (Davini et al 2004) and New Zealand (Nugent 1994), as well as home range size from the New Forest of England (Rand in Putnam 1986).

Home range estimation using LoCoH methods use data directly to construct boundaries, thus creating true boundaries as data density increases (Getz et al. 2006). Getz and Wilmers (2004) demonstrate that kernel methods performed poorly when fitted to distributions in areas that contain distinct geographic boundaries. We tested this by constructing fixed kernels to our GPS collected positions. Kernels were abandoned when 95% home range boundaries extended well into riverine barriers and other habitats that seemed unlikely for fallow deer. The LoCoH method of estimating home range was highly accurate for our site and data. The "spurious holes" created using LoCoH excluded unsuitable habitats (i.e., flooded wetland impoundments) when examined with aerial photographs that would have erroneously been included in the MCP or kernel methods.

Annual and seasonal home range sizes were highly variable among male fallow deer. For example, buck F383 had a summer home range of 60.6 ha, whereas buck F392 had a summer home range of 302.3 ha. This variability in male home range size is consistent with other fallow deer populations (Putnam 1986; Nugent 1994; Davini et al. 2004). Perhaps small areas of valuable resources may exist as pockets that constrict deer movements. This is evident by the small spring home range (7.5 ha) of deer F387.

With the exception of one male (F387), fallow deer did not shift home ranges seasonally. Deer F387 shifted his range and habitat use between spring/summer and fall/winter. This male had overlapping ranges with 3 other collared males in predominately maritime shrub habitat. Apparently food availability may not have influenced this shift as much as social pressures.

Existing fallow deer habitat selection studies have relied predominately on observational methods (Jackson 1974; Chapman and Chapman 1975; Parfitt 1985; Thirgood 1995) or small scale radio telemetry efforts (Terpening and Hawkins 1970). By using GPS technology we were able to collect abundant, fine scale data without temporal or weather-related limitations. Nevertheless, our analyses revealed few patterns of habitat use. Preferred habitats varied among individual deer, suggesting that some habitats may not be essential for all deer. The high use of freshwater areas is likely attributed to their rareness on LSSI. Many of these areas are shallow sloughs without standing water during parts of the year. This allows lush vegetation to grow, possibly attracting the deer to nutritious but limited food supplies. The avoidance of low salt marsh and occasional preference of high salt marsh indicates that the hydrology and vegetation of the high marshes are more attractive to the fallow deer. The presence of well-used paths, along with high hunter success in the high marsh areas indicates that fallow deer use these areas for travel as well as feeding. High marshes may also provide valuable nutrients and minerals to deer (Osborne et al. 1992). Of the remaining upland habitats, maritime shrub was the most preferred habitat type among all deer. Fallow deer never avoided maritime shrub in any season, with the exception of deer F387. In the spring and summer this animal stayed exclusively in maritime shrub habitat, but moved to pine woodland habitat in fall and winter.

Although roads and edges were not separated as a unique habitat type, visual inspection of areas of intense use (50% core areas) revealed a strong association with the main road transecting LSSI. This is the only road maintained by limestone gravel, and is frequently mowed during the spring and summer growing season. The associated vegetative growth alongside this road may be an important food source. Location data plotted on the aerial photograph indicated that fallow deer used roads and dikes as travel corridors, thereby avoiding movements across marshes.

This study was somewhat limited because individual deer served as experimental units. However, we compensated for low sample size with improved accuracy and numbers of locations when compared with traditional radio telemetry (Otis and White 1999; D'Eon and Serrouya 2005). Rand (in Putnam 1986) described the fallow deer ranging behavior as complex and intricate with individual and annual variation. Fallow deer on LSSI follow this description, exhibiting variation in home range size and habitat use. Although individual variation occurred, none of the monitored deer moved beyond the insular boundaries, and all deer were selective in their use of available habitats. Fallow deer on Little St. Simons have adapted well to the local habitats, and successfully out-competed native species.

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Table 5.1. Sex, age, days used, fix rate, number of locations, percent 3D locations, and percent of locations removed by individual fallow deer on Little St. Simons Island, Georgia, U.S.A. 2005-2006

Deer_ID	Sex	Age	Days in Use	Fix Rate	Locations	% 3D	% Removed*
F393	F	5	484	29.9	1161	32.4	5.6
F397	M	4	359	48.4	1389	38.8	4.4
F387	M	5	255	43.1	880	36.7	4.7
F383	M	6	183	53.3	781	27.7	6.1
F399	M	3	223	58.2	1038	34.8	5.1
F392	M	5	444	35.3	1255	38.0	4.5
F394	F	3	453	56.5	1024	34.2	5.7

* All 2D positions with a DOP >6

Table 5.2. Total, annual and seasonal home range estimations in hectares for individual fallow deer on Little St. Simons Island, Georgia, U.S.A., March 2005-September 2006

			LoCoH	
Deer ID	**Season**	**MCP (95%)**	**95% Home Range**	**50% Core Area**
F392	Annual	390	249	37
	Summer 05	351	302	51
	Fall 05	84	56	20
	Winter 06	202	80	30
	Spring 06	346	135	28
	Summer 06	420	278	85
F399	Annual	n/a	n/a	n/a
	Spring 05	86	40	13
	Summer 05	130	80	15
	Fall 05	107	127	15
F383	Annual	n/a	n/a	n/a
	Spring 05	44	50	10
	Summer 05	67	61	13
	Fall 05	51	52	11
F387	Annual	n/a	n/a	n/a
	Spring 05	153	8	6
	Summer 05	332	18	7
	Fall 05	201	116	78
	Winter 06	298	201	42
F397	Annual	917	350	42
	Spring 05	261	101	34
	Summer 05	805	254	43
	Fall 05	796	470	29
	Winter 06	456	264	45
	Spring 06	477	240	67
F394	Annual	208	129	28
	Spring 05	135	85	29
	Summer 05	168	130	31
	Fall 05	157	104	22
	Winter 06	169	117	30
	Spring 06	147	117	34
F393	Annual	258	128	32
	Summer 05	250	131	31
	Fall 05	175	134	24
	Winter 06	220	161	31
	Spring 06	180	115	25
	Summer 06	184	178	53

Table 5.3. Simplified ranking matricies for fallow deer on Little St. Simons Island, Georgia, USA 2005-2006 comparing proportional habitat use within 95% LoCoH home range with proportions of total available habitat. A triple sign represents a significant deviation from random use at *P*<0.05. Higher ranking numbers indicate higher preference.

	Habitat type						
Habitat type	Freshwater	High marsh	Maritime Forest	Maritime shrub	Salt marsh	Pine woodlands	Rank
Freshwater	·	+	+	+	+ + +	+	5
High marsh	-	·	+	-	+ + +	-	2
Maritime forest	-	-	·	-	+	-	1
Maritime shrub	-	+	+	·	+ + +	+	4
Salt marsh	- - -	- - -	-	- - -	·	- - -	0
Pine woodlands	-	+	+	-	+ + +	·	3

Table 5.4. Proportional use, Bonferroni confidence interval, and preference of 6 habitats by individual fallow deer on Little St. Simons Island, Georgia, U.S.A.

			Fallow Deer						
Habitat Type	Habitat Proportion		F392	F399	F383	F387	F397	F393	F394
Freshwater	0.021	Use	0.04	0.068	0.003	0.025	0.036	0.011	0.028
		CI	$0.026 \le P_1 \le 0.053$	$0.049 \le P_1 \le 0.088$	$-0.002 \le P_1 \le 0.008$	$0.012 \le P_1 \le 0.038$	$0.023 \le P_1 \le 0.048$	$0.003 \le P_1 \le 0.018$	$0.015 \le P_1 \le 0.042$
		Preference	prefer	prefer	avoid	none	prefer	avoid	none
High Marsh	0.115	Use	0.239	0.068	0.003	0.123	0.052	0.179	0.421
		CI	$0.208 \le P_2 \le 0.269$	$0.049 \le P_2 \le 0.088$	$-0.002 \le P_2 \le 0.008$	$0.095 \le P_2 \le 0.151$	$0.037 \le P_2 \le 0.067$	$0.150 \le P_2 \le 0.207$	$0.382 \le P_2 \le 0.460$
		Preference	prefer	avoid	avoid	none	avoid	prefer	prefer
Maritime Forest	0.051	Use	0.437	0	0	0	0.014	0.002	0.282
		CI	$0.401 \le P_3 \le 0.472$	$0 \le P_3 \le 0$	$0 \le P_3 \le 0$	$0 \le P_3 \le 0$	$0.006 \le P_3 \le 0.022$	$-0.001 \le P_3 \le 0.005$	$0.246 \le P_3 \le 0.317$
		Preference	prefer	avoid	avoid	avoid	avoid	avoid	prefer
Maritime Shrub	0.129	Use	0.223	0.892	0.999	0.565	0.853	0.231	0.224
		CI	$0.193 \le P_4 \le 0.252$	$0.868 \le P_4 \le 0.916$	$0.996 \le P_4 \le 1.002$	$0.523 \le P_4 \le 0.607$	$0.829 \le P_4 \le 0.877$	$0.199 \le P_4 \le 0.262$	$0.191 \le P_4 \le 0.257$
		Preference	prefer	prefer	prefer	prefer	prefer	prefer	prefer
Salt Marsh	0.622	Use	0.07	0.009	0	0.043	0.028	0.126	0.092
		CI	$0.052 \le P_5 \le 0.089$	$0.001 \le P_5 \le 0.016$	$0 \le P_5 \le 0$	$0.025 \le P_5 \le 0.060$	$0.017 \le P_5 \le 0.039$	$0.101 \le P_5 \le 0.151$	$0.069 \le P_5 \le 0.115$
		Preference	avoid	avoid	avoid	avoid	avoid	avoid	avoid
Pine woodland	0.062	Use	0.044	0.049	0	0.295	0.072	0.502	0.008
		CI	$0.029 \le P_6 \le 0.059$	$0.032 \le P_6 \le 0.066$	$0 \le P_6 \le 0$	$0.256 \le P_6 \le 0.333$	$0.054 \le P_6 \le 0.089$	$0.465 \le P_6 \le 0.540$	$0.001 \le P_6 \le 0.014$
		Preference	avoid	none	none	prefer	none	prefer	avoid

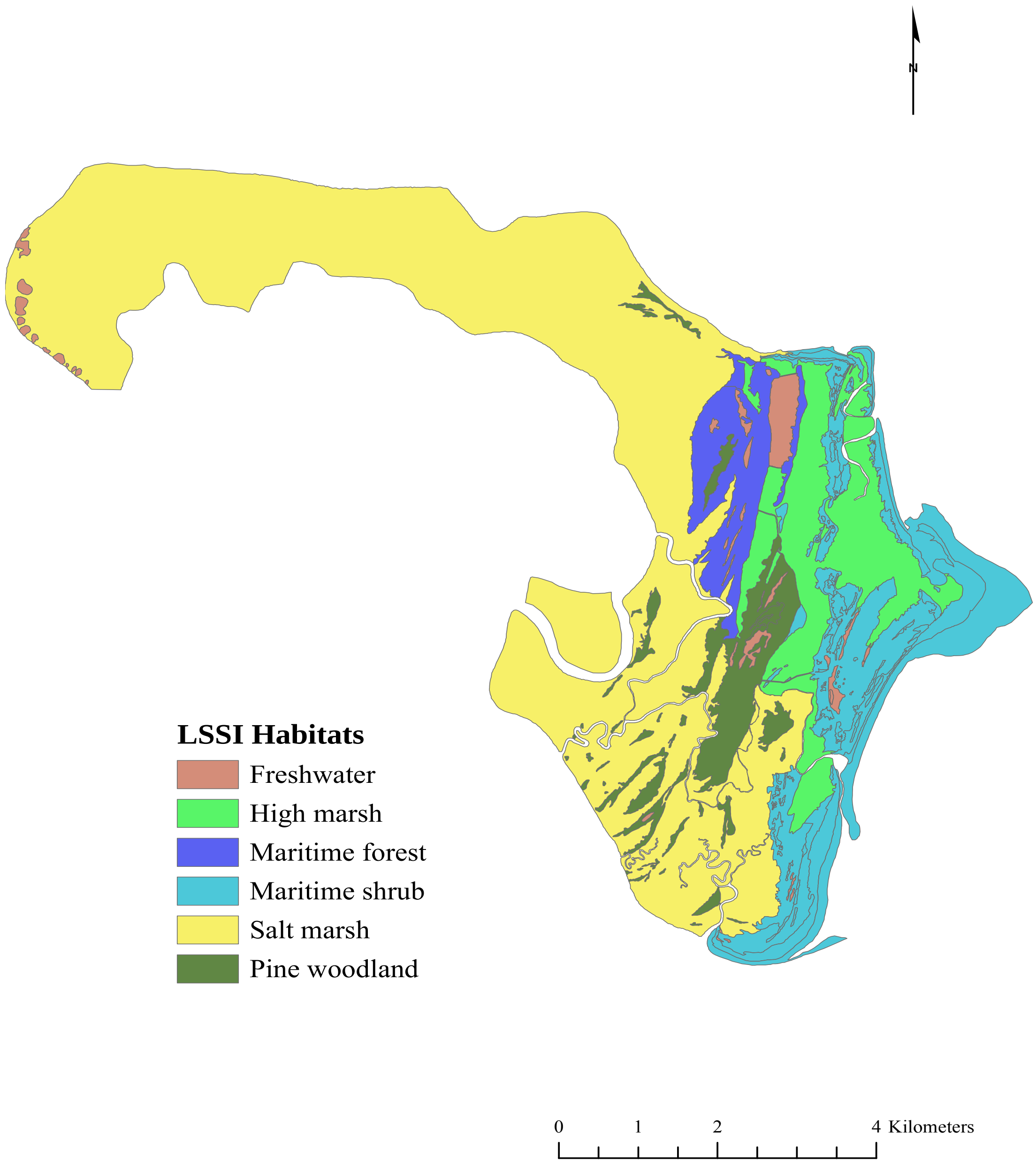

Figure 5.1. Habitat types of Little St. Simons Island, Georgia, U.S.A. 2006

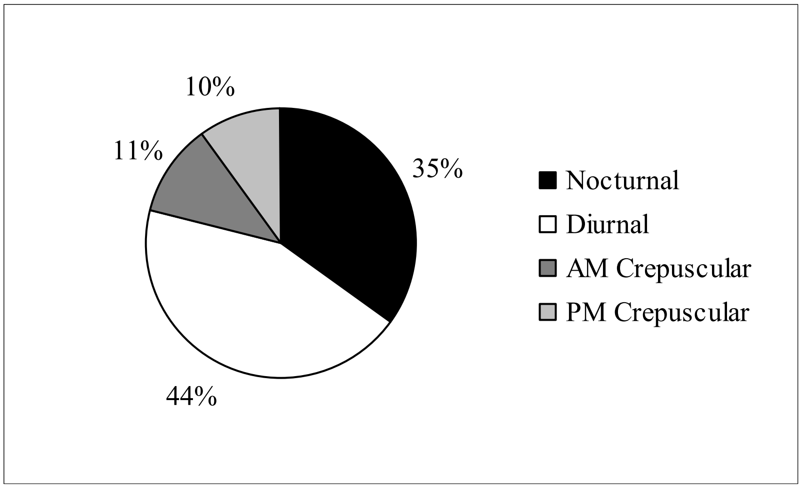

Figure 5.2. Percentage of GPS collar location fixes by time period on Little St. Simons Island, Georgia, U.S.A.

CHAPTER 6

SUMMARY AND MANAGEMENT IMPLICATIONS

SUMMARY

Fallow deer have become an iconic aspect of the fauna on Little St. Simons Island and are popular among visitors and hunters. However, this species has displaced native white-tailed deer and replaced them as the keystone species on LSSI. Furthermore, overabundance of the fallow deer could be detrimental to the health of the population as well as the plant communities on LSSI and their associated fauna. This project was initiated to develop a better understanding of the ecological relationships between this exotic deer species and the barrier island it inhabits, and to provide island managers with the biological background to properly manage the herd and sustain the ecological integrity of the island. One of the few feral fallow deer populations in the United States, the herd on LSSI is unique to the region. They have adapted to the insular environment and morphological and behavioral changes were minor. Fallow deer on LSSI are smaller morphologically (particularly males) and antler measurements are less than other populations in the world. The use of leks, timing of the rut, and antler development cycles were all similar to other fallow deer populations. High herd density and depressed reproduction rates were observed on Little St. Simons Island. The health of the fallow deer population was excellent. There were no signs of clinical disease, and parasite burdens were below levels normally associated with density stress or nutritional limitations. Although fallow deer antibody levels indicated previous exposure to diseases of native white-tailed deer and cattle, they are likely not carriers of these diseases and pose little risk to native species, livestock, or humans. Fallow deer consumed a wide variety of plant species and food items based on seasonal availability. Rumen contents differed from plant fragments identified in fecal pellets. Therefore, a combination of these methods portrays a more accurate picture of fallow deer food habits. Grasses were the most important forage class consumed by fallow deer and likely sustain the high densities of deer found on LSSI. Masts, particularly acorns, as well as browse were important food items in fall and winter diets. Because fallow deer can subsist on the lower quality foods found on LSSI, relationships between acorn production and recruitment and hunter success are not as pronounced as white-tailed deer populations on neighboring barrier islands. Consumption of certain species of interest including live oak, sea oats, and Florida swamp privet was observed and may be intensified with higher deer densities.

Monitoring home ranges, movements, and habitat use was enhanced using GPS collars on fallow deer. They provided abundant locations with considerably less effort and higher accuracy than would have been obtained using traditional radio telemetry. Large home ranges indicated that fallow deer need larger areas to fulfill their needs on LSSI. High variability among bucks was observed in home range size, location and seasonal overlap. Habitat relationships were highly variable and no patterns of association were observed Individual deer demonstrated different habitat preferences, although use of maritime shrub was consistent among all deer monitored, and salt marsh was avoided.

MANAGEMENT IMPLICATIONS

The presence of fallow deer on Little St. Simons Island presents a wildlife management dilemma. Should the herd be eradicated as an invasive exotic, or managed as a unique resource? The fallow deer on Little St. Simons Island have demonstrated that, like other areas where this species has been introduced, it can out-compete native cervids. The current population is persisting at a high density, but with depressed body weights, antler size and reproductive recruitment. The research contained in this thesis did not identify a significant natural cause of mortality. Fallow deer can efficiently use the low-quality food resources available on the island, are resistant to diseases, and lack significant mortality from natural predators. Although recruitment was limited this population appears to be slowly increasing. Hunting is the only significant cause of mortality and plays an important role in controlling herd size. However, current hunting efforts are not decreasing or even maintaining this population. The fallow deer on LSSI have likely not yet reached a biological carrying capacity, but have exceeded the ecological carrying capacity of the barrier island. Further increases in density could lead to a decline in body conditions and disease and parasite influences. Population censuses similar to those presented in this thesis should be done annually to closely monitor population growth. Harvest records and hunter observation data collection should also continue to be collected so trends can be analyzed over time. The health of the herd can be monitored with health checks conducted every 5 years.

With higher deer densities, the large home ranges indicated in this study may cause an increase in emigration off of LSSI onto surrounding islands. A reduction in herd size would lower the herd to numbers that could be controlled by the present LSSI hunting effort. Based on estimated sex ratios and the limited reproduction exhibited by this population, a balanced reduction of males and females would be ideal. On other barrier islands in the southeastern U.S., bobcats (*Lynx rufus*) have significant roles in deer control, accounting for up to 70% of fawn mortality (Diefenbach et al., In Press; Roberts, 2007). Although not presently on LSSI, bobcat reintroduction efforts on Cumberland Island, Georgia successfully helped control white-tailed deer numbers, allowing regeneration of live oak (*Quercus virginiana*) in previously over-browsed areas (Diefenbach et al., 2007). The fallow deer forage on live oak browse and acorns. However, they can more efficiently use other food resources allowing them to thrive at higher densities.

Reducing the size of the LSSI fallow deer herd may also have beneficial impacts on plant communities, easing the browsing pressure on sensitive species. The manipulation of habitats to open areas from dense shrub may also benefit deer management efforts. The fallow deer showed a common preference for maritime shrub habitat on LSSI at least part of the year, and manipulation of this habitat may result in the greatest impact to the herd. Controlling the dense vegetation growth, and promoting grasses and forbs in this community may reduce pressure on more limited food sources such as live oak. Also these more open habitats would improve hunter success which is currently constrained by limited access and visibility. The introduction of exotic deer such as fallow would not be recommended if managing for native deer. Managers and biologists should also make efforts to limit the spread of these species to new areas.

LITERATURE CITED

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APPENDIX A

Table A.1. Biological data collected from captured fallow deer on Little St. Simons Island, Georgia March-July 2005.

Deer ID	Sex	Age	Color	Temp.(Celsius)	Neck (cm)	Chest (cm)	Reproductive Status
399	Male	3	Black	38.6	.	.	
380	Male	2	Black	38.6	35	84.5	
394	Female	3	Black	38.9	26	86.5	pregnant
383	Male	6	Black	38.6	41	99.5	
388	Male	5	Black	39.4	38.5	100.5	
392	Male	5	White	39.1	36.75	96	
393	Female	5	Black	37.8	34	82.5	pregnant
387	Male	5	Menil	39.8	32.5	92.5	
397	Male	4	Common	38.9	35	84.5	
384	Male	4	Black	39.8	37.5	84	