ABSTRACT

WALKER, MICAH JOHN. Evaluation of the Use of GonaCon™ on Wild White-Tailed Deer and a Comparison of Two Darting Techniques. (Under the direction of Dr. Christopher S. DePerno).

In 2014, we initiated a 5 year project to stabilize the local deer population on Bald Head Island, North Carolina using the immunocontraceptive GonaCon™. Since 2014, we captured and inoculated 77 female deer GonaCon™. From 2017 - 2018 we evaluated the efficacy and cost of GonaCon™ at reducing pregnancy in adult female white-tailed deer on the unfenced wild white-tailed deer population on Bald Head Island. We obtained blood samples from 50 deer that had received either one or two doses of GonaCon™ and blood samples from 19 female deer that had received no GonaCon™ for pregnancy analysis using the pregnancy specific protein B assay. All untreated deer sampled were pregnant (n = 19), 67% of deer sampled that received only a single dose were pregnant (n = 27), and 14% of deer that received two doses (n = 22) were pregnant. Thus, two doses of GonaCon™ were necessary to reduce pregnancy rates below 50%. The total direct cost of the five-year immunocontraception project was $320,030.52 and averaged $2,078.12/capture with an overall efficacy of 33% for one dose and 86% for two doses of GonaCon™. Conversely, the estimated cost for the Village of Bald Head Island to cull 30 deer in 2018 was $16,163.63 or $538.79/deer. The estimated population from 2014 (based upon spotlight surveys) was 113 and increased to 198 individuals by 2018. Further population projections suggest that the white-tailed deer population is projected to reach 342 individuals by 2022. Although two doses of GonaCon™ was effective at reducing pregnancy, its administration across the BHI deer population was not successful in eliminating growth of the deer population and culling will be necessary to eliminate population growth.

2017 and 2018 data from the five year project was analyzed to compare the two capture methods used: darting from a baited blind (n= 43) and opportunistically darting from a golf cart (n=19). Six variables (method, distance animal traveled, maximum core temperature, good hit y/n, booster needed, and time spent searching) were used to perform one-way and two-way ANOVAs to look for significant differences between methods. The total number of hours spent and the total number of animals captured by each method were used to determine efficiency. Time spent searching was significantly affected by the interaction between good hit and method. Search time was 12-33 minutes less for a good hit than a bad hit, regardless of the darting method. The blind method was 7% more likely to result in a good hit; however capturing a deer using the blind method took 8 hours more than the opportunistic method. Wildlife managers should use the opportunistic method if efficiency is critical to the project. The blind method should be used if managers wish to reduce the amount of time spent searching for darted deer. Bald Head Island managers found a combination of these two methods was more successful than any one method; there were no capture related mortalities during the duration of the study.

Evaluation of the Immunocontraceptive GonaCon™ on Wild White-Tailed Deer and a Comparison of Darting Techniques.

by
Micah John Walker

A thesis submitted to the Graduate Faculty of
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DEDICATION

I dedicate my thesis to my family, for their constant encouragement to follow my passion for wildlife.

BIOGRAPHY

Micah John Walker was born in Wilmington, Delaware on July 1, 1991. As a child, Micah and his family vacationed by backpacking and canoe camping through many great North American wilderness areas and national parks. These experiences cemented his love of the woods and all the creatures that inhabit it. Micah earned a Bachelor of Science degree in Wildlife Conservation at the University of Delaware in 2013. Between 2013 and 2017, Micah worked 8 seasonal wildlife jobs in places such as: Olympic National Park, Superior National Forest, and Bald Head Island. Through those jobs, Micah has managed and studied a variety of animals such as: gray wolves, American black bears, mountain goats, white-tailed deer, coyotes, Rocky Mountain elk, and wood thrush. In 2017, Micah returned to school to pursue his Master of Science in Fisheries, Wildlife, and Conservation Biology at North Carolina State University. Micah is currently working as the Lead Wildlife Biologist for the Eastern Band of Cherokee Indians.

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I would also like to thank the Village of Bald Head Island, BHI Friends of Deer, Bald Head Limited, Bald Head Association, and Bald Head Island residents that let us conduct capture operations on their property. A special thanks to the North Carolina Wildlife Resources Commission for allowing us to borrow a dart projector and offering capture advice. I would like to thank the Fisheries, Wildlife, and Conservation Biology Program at North Carolina State University for all of the support I received during my graduate work.

Finally, I would like to thank my family who have always been there encouraging me to follow and achieve my dreams.

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Efficacy and Cost of GonaCon™ for Population Control in a Free-ranging White-tailed Deer Population

Abstract

In 2014, we initiated a 5 year project to stabilize the local deer population on Bald Head Island, North Carolina using the immunocontraceptive GonaCon™. Since 2014, we captured and inoculated 77 female deer GonaCon™. From 2017 - 2018 we evaluated the efficacy and cost of GonaCon™ at reducing pregnancy in adult female white-tailed deer on the unfenced wild white-tailed deer population on Bald Head Island. We obtained blood samples from 50 deer that had received either one or two doses of GonaCon™ and blood samples from 19 female deer that had received no GonaCon™ for pregnancy analysis using the pregnancy specific protein B assay. All untreated deer sampled were pregnant (n = 19), 67% of deer sampled that received only a single dose were pregnant (n = 27), and 14% of deer that received two doses (n = 22) were pregnant. Thus, two doses of GonaCon™ were necessary to reduce pregnancy rates below 50%. The total direct cost of the five-year immunocontraception project was $320,030.52 and averaged $2,078.12/capture with an overall efficacy of 33% for one dose and 86% for two doses of GonaCon™. Conversely, the estimated cost for the Village of Bald Head Island to cull 30 deer in 2018 was $16,163.63 or $538.79/deer. The estimated population from 2014 (based upon spotlight surveys) was 113 and increased to 198 individuals by 2018. Further population projections suggest that the white-tailed deer population is projected to reach 342 individuals by 2022. Although two doses of GonaCon™ was effective at reducing pregnancy, its administration across the BHI deer population was not successful in eliminating growth of the deer population and culling will be necessary to eliminate population growth.

Introduction

Over the past several decades, white-tailed deer (*Odocoileus virginianus*) populations in the Southeastern United States have steadily increased, becoming locally overabundant in many urban and suburban communities (McShae et al.1997a, Daigle and Crete 1999, DeNicola et al. 2000) resulting in ecological and economic problems. In the United States, an estimated 1-2 million wildlife-vehicle collisions occur in the United States, with deer (Cervidae) accounting for 99.2% and causing an estimated $6.2 billion (US) in damage (Huijser et. al 2009). Also, white-tailed deer damage ornamental plants in residential areas (Rooney and Waller 2003), alter the forest plant biodiversity through overgrazing, and remove understory vegetation resulting in a reduction in avian biomass and diversity (DeNicola et al. 2000, McShea and Rappole 2000, Horsley et al. 2003).

As white-tailed deer populations increase in developed areas, management becomes necessary to control or reduce their populations. Traditionally, white-tailed deer populations have been managed through hunting or targeted removal (i.e., culling). However, increased suburbanization has led to concerns about safety and the legality of using firearms to remove deer when conducted in close proximity to humans. Additionally, negative attitudes towards lethal control and limitations of using firearms near houses, have prompted many communities to pursue non-lethal techniques (e.g., immunocontraception, surgical sterilization, and capture and relocation) for white-tailed deer population control (McCullough et al. 1997, DeNicola et al. 2000, Lauber et al. 2007, Williams et al. 2013).

Two non-lethal deer management techniques of current interest are surgical sterilization and immunocontraception (Warren 2011, Boulanger et al. 2012). Surgical sterilization involves the disruption or removal of the reproductive organs, usually in female deer (MacLean et al.

2006, Boulanger et al. 2012, Boulanger and Curtis 2016). Tubal ligation and complete removal of the ovaries in female deer has achieved nearly 100% pregnancy reduction in studies to date (Boulanger and Curtis 2016). Drawbacks to surgical sterilization are the high cost, need for a sterile surgical environment, and specially trained staff (Boulanger et al. 2012). Porcine zona pellucida (PZP) vaccine is an immunocontraceptive designed to produce antibodies that block sperm from binding to the receptors on the ova preventing conception (McShea et al. 1997b, Rutberg et al. 2013, Naz and Savor et al. 2015). It has been successfully used on female white-tailed deer (Rutberg et al. 2013) and feral horses (Berchert et al. 2013). PZP does not prevent female deer from entering the estrus cycle resulting in extended breeding seasons and increased energetic demand that may lead to higher mortality (Hobbs 1989, McShae et al. 1997b). Although PZP can reduce pregnancy rates by ~45% in wild white-tailed deer (Rutberg et al. 2013), PZP requires yearly reimmunization to remain effective long-term (McShae et al. 1997b, Rudolph et al. 2000, Bechert et al. 2013).

To avoid the shortcomings of surgical sterilization and PZP, studies have evaluated gonadotropin releasing hormone immunocontraceptive vaccines (Kirkpatrick et al. 2011, Naz and Saver 2015). These vaccines elicit an immune response towards gonadotropin releasing hormone (GnRH) (Miller et al. 2004). Gonadotropin releasing hormone is a peptide hormone produced within the hypothalamus and responsible for triggering the production of follicle stimulating hormone (FSH) and luteinizing hormone (LH); these are produced in the anterior pituitary to facilitate follicular development and ovulation (Becker et al. 1995, 1999, Miller et al. 2004, Pratap et al. 2017). In the early 2000s, a single shot variant of a gonadotropin releasing hormone vaccine (i.e., GonaCon™) was created by the National Wildlife Research Center and has been used on a many wildlife species including white-tailed deer (Gionfriddo et al. 2009, Miller et al. 2008), elk (*Cervus elaphus*; Killian et al. 2009), wild boar (*Sus scrofa*; Massei et al. 2012), and Eastern fox squirrel (*Sciurus niger*; Krause et al. 2014). GonaCon™ consists of a conjugate of mollusk hemocyanin proteins covered by attached synthetic GnRH molecules. The adjuvant is heat treated *Mycobacterium avium* and mineral oil (Miller et al. 2008). The animal's immune system recognizes GnRH as a foreign pathogen and elicits an immune response against it (Miller et al. 2008). The combination of the conjugate and adjuvant in GonaCon™ stimulates the animal's immune system to create antibodies against the gonadotropin-releasing hormone, which in turn results in reduced concentrations of sex hormones, inhibiting a vaccinated animal's ability to reproduce. (U.S. Department of Agriculture 2007, Miller et al. 2008).

In studies using fenced white-tailed deer, a single dose of GonaCon™ prevented pregnancies in 67-88% of treated deer one year after administration and 47-48% treated deer the second year after administration (Gionfriddo et al. 2009, 2011). The anamnestic response to a second dose is an important factor in design of immunocontraception approaches (Baker et al. 2018). While there have been several studies conducted on the efficacy of immunocontraception in fenced deer populations (Gionfriddo et al. 2009, 2011), little research has been conducted on the efficacy of GonaCon™ on unfenced wild deer populations. Our objective was to evaluate the efficacy and cost of GonaCon™ at reducing pregnancy in adult female white-tailed deer on an unfenced wild white-tailed deer population.

Study Area

Bald Head Island (Figure 1) is located 4.8 km southeast of Southport in Brunswick County, North Carolina (Ray et al. 2001). The island consists of 620 hectares of upland habitat and is 5.5 km long by 1.5 km wide with an elevation ranging from sea level to 15m on top of the primary dune ridges (Cooper and Satterthwaite 1964, Ray et al. 2001, Sherrill et al. 2010). The main landcover of the island includes maritime forest (275 hectares), dunes/strands (171 hectares), tidal marsh, and suburban development (85 hectares) (Sherrill et al. 2010, Taggart and Long 2015). Bald Head Island has one of the last remaining intact maritime forests in North Carolina and is composed mostly of live oak (*Quercus virginianus*), red bay (*Persea borbonia*), laurel oak (*Quercus hemisphericus*), eastern red cedar (*Juniperus virginiana*), Carolina cherry laurel (*Prunus caroliniana*), youpon holly (*Ilex vomitoria*) (Bourdeau and Oostings 1959).

Suburban development is concentrated on 85 hectares on the western side of Bald Head Island (Sherrill et al. 2010). Bald Head Island has a year-round human population of 158 that increases to several thousand with summer visitation (U.S. Census Bureau 2010). The use of car on the island is restricted to emergency personnel, tram service, and contractor vehicles. Instead of gasoline powered vehicles, residents and visitors use electrically powered golf carts as their primary means of transportation.

The white-tailed deer population occupies the entire island and was first documented in the mid-1980's. (Ray et al. 2001). In the absence of population control, the population has exceeded over 350 individuals (56/km^2), causing concern for the potential to over-browse and significantly damage the sensitive dune and maritime forest vegetation (Sherrill et al. 2010). Culling was periodically used to manage the deer population, but the practice was terminated due to its unpopularity among the island residents. As a result, the Village of Bald Head Island (the municipality governing body) initiated an immunocontraception program in 2014. Although the white-tailed deer population is free-ranging, earlier studies determined that emigration from Bald Head Island was minimal and the population was likely closed suggesting immunocontraception might be a population management option (Sherrill et al. 2010).

Starting in January 2014, 77 female white-tailed deer were captured and inoculated with GonaCon™ as part of a five-year project in cooperation with the Village of Bald Head Island, Bald Head Island Conservancy, North Carolina Wildlife Resources Commission (NCWRC), and a group of concerned citizens called "The Friends of Deer". Capture efforts were initially led by a private wildlife company, but the project was taken over by Bald Head Island Conservancy in fall 2014. The NCWRC permit to administer GonaCon™ required managers leave 30 viable female deer on Bald Head Island to maintain genetic diversity in the population. In fall 2014, a captured female left the island and swam to the mainland and returned to the island a few weeks later, establishing that the deer population on Bald Head Island was not completely isolated from the mainland. To eliminate the concern that hunters from areas adjacent to Bald Head Island would consume deer that had been treated with anesthetic drugs, NCWRC then prohibited use of anesthetic drugs on all future BHI deer captures from 90 days prior to the start of the hunting season to hunting season end. However, none of the remaining 76 female white-tailed deer are known to have traveled to the mainland during the remainder of the project.

Methods

Deer Capture

White-tailed deer capture and handling protocols were approved by the NCWRC and the Institutional Animal Care and Use Committee at North Carolina State University (17-175-O). From January – April, 2017 – 2018 , we captured adult female white-tailed deer using CO_2 powered dart rifles (Model JM Standard, Dan Inject, Inc., Borkop, Denmark) (Xcalibur, Pneu-Dart, Williamsport, Pennsylvania, USA) and single use, 2mL, wire barbed transmitter darts (Pneu-Dart, Williamsport, Pennsylvania, USA). To anesthetize each white-tailed deer, we administered 2.0mL of BAM™ (27.3 mg Butorphanol, 9.1 mg Azaperone, 10.9 Medetomidine per 11mL vial), ZooPharm, Windsor, Colorado, USA) intramuscularly. If a deer was not fully anesthetized when located, we administered up to 1.0mL of additional BAM™ intramuscularly via syringe. We darted deer from pop-up blinds or ground blinds baited with whole kernel corn 10-20 yds from the blind and from golf carts in the evening using a red spotlight.

Deer Processing

Once anesthetized, we applied a blindfold and monitored rectal temperature, respiration, and heart rate every 10 minutes. We removed the dart, cleaned the wound with Hibiclens® (Mölnlycke Health Care US, LLC, Norcross Georgia), and applied antibiotic cream (Neosporin®, Johnson & Johnson, Inc., New Brunswick, New Jersey, USA). We determined sex and age class of the deer as fawn (< 1year), yearling (1.5 years), and adult >1.5 years) (Severinghaus 1949) and attached uniquely numbered cattle tags into both ears of newly captured deer. We hand injected 1.0mL of the GonCon™ intramuscularly into the hindquarters of yearling and adult female deer. From 2017 through 2018, we took blood from deer regardless of prior capture history. We considered deer that had never received GonaCon™ prior to capture the control group. We shipped blood samples to the BioTracking lab (Moscow, Idaho, USA) to test for the presence of the pregnancy specific protein b (PSPB), a protein produced only as the result of a pregnancy. We abdominally palpated deer to check for pregnancy and also checked for lactation. We fitted captured deer with a mortality sensing VHF radiocollar (Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA). Once handling was completed, we reversed the deer with 4.0 mL atipamezole and 0.5 mL naltrexone (ZooPharm, Windsor, Colorado, USA) via intramuscular injection.

We located all deer daily for the first two weeks post-capture to monitor for capture myopathy and subsequently located each collared deer once per week to check for mortality using a 3-element folding yagi antenna and portable radio receiver (R-1000, Communications Specialists, Inc., Orange, California, USA). If a deer died, we conducted a field necropsy to determine the cause of death (White et al. 1987).

Population Estimate - Camera Index

In November 2015-2018, we conducted population indices to determine white-tailed deer population size on Bald Head Island. We established 12 camera stations across the island, checking them daily to replace memory cards and batteries as needed and bait them with 2.5-5 kg of whole corn. We programmed cameras to take pictures in bursts of three with 5 seconds between pictures and a 3 minute quiet period and considered each set of three photos as one trigger. We examined five random triggers per site per day and the number of untagged female deer, tagged female deer, and fawns were recorded for each trigger. We estimated the female white-tailed deer population size using the Chapman variation of the Peterson formulas using pooled data (Schneider 2000).

$$N=(M+1)(C+1)/(R+1)$$

Where N = population estimate, M = number of marked individuals in the population, C = total number of female deer occurrences (marked and unmarked), and R = total number of marked occurrences. We summed the values of C and R from all sites each day and throughout the index to calculate N and considered the population index complete once the daily population estimate stabilized. We used the female/male ratio from the summer spotlight surveys to estimate the number of male white-tailed deer on the island and calculated a female/fawn ratio from the fall index.

Population Estimate – Summer Spotlight

During June - July 2005-2018, we conducted spotlight surveys for a total of 25 nights over an established route across Bald Head Island and a portion of Middle Island (Figure 2) and randomized starting location. We determined the observable habitat along the spotlight route using field observations and GIS software and excluded impermeable surfaces, structures, bodies of water, and tidal zones. Three individuals used a golf cart traveling between 8-13 km/h and began the survey approximately 30 minutes after sunset. Two individuals spotlighted deer from both sides of the cart while another individual drove and recorded data. We recorded the number of deer, sex of each deer and presence of fawns. We calculated a total population index by comparing the ratio of deer seen per observable available deer habitat along the spotlight route to the total available habitat across the island.

Population Projection

We projected the potential population growth of the white-tailed deer on Bald Head Island from 2019 through 2022 with no additional GonaCon™ administered and no culling occurring. We used the efficacy rate of one and two doses of GonaCon™ to account treated deer that would become pregnant. We obtained the starting population size for the post GonaCon™ population projection from the 2018 camera index. Also, we projected potential population growth of the white-tailed deer on Bald Head Island from 2014 through 2022 as if GonaCon™ had never been administered. We obtained the starting population size for the No GonaCon™ population projection from the 2014 camera index. We used the following parameters for both population projections. We set fecundity at 1.56 fawns per doe (Dapson et al. 1979). We estimated fawn survival at 0.54 from the number of expected fawns born in 2018, from untreated and treated does at respective GonaCon™ efficacy rates, and number of fawns estimated at the 2018 November camera index. We used survival rates from studies with non-hunted white-tailed deer populations and set the 6-month old fawn survival rate at 0.85 for females and 0.8 for males (Campbell et al. 2005). We set adult female survival at 0.92, and adult male survival at 0.82 (Campbell et al. 2005, Bowman et al. 2005). We projected the population using Microsoft Excel Version 16.16.16 (Microsoft Corporation, Redmond, Washington, 2018)

Cost Analysis

We recorded costs for the 5-year immunocontraception project and population indices with expenses separated as basic supplies (e.g., bait, batteries), equipment (e.g., dart projectors, CO2, trail cameras), pharmacy (e.g., Anesthetic drugs, pregnancy test, GonaCon™), and team expenses (deer team salaries, staff hours, ferry tickets, parking). We were unable to calculate costs attributed to some overhead from The Bald Head Island Conservancy, golf cart maintenance, housing cost, and electricity used by project activities; therefore, our cost estimates are conservative. We obtained white-tailed deer culling costs from the Village of Bald Head Island which used cost data from past culls in 2006, 2009, 2011, and 2013 to estimate the number of hours required for culling 30 and 100 deer. Projected costs were divided into salary, fuel/supplies, bait, refrigeration truck rental, meat processing, mileage, barge expense, and miscellaneous (e.g., ammo, ice).

Data Analysis

We used Fischer's exact test of independence to compare pregnancy results across years and across treatment groups (Connelly 2016). We compared the proportion of pregnant deer between the treatment groups (single dose and double dose) and control group against the null hypothesis of no difference in proportion of pregnant deer between groups. All analyses were performed in R version 3.5.1 (R Core Team, Vienna, Austria, 2016) with a significance level of α<0.05.

Results

Across 2017 and 2018, we collected 49 blood samples from adult female white-tailed deer that had received one or two doses of GonaCon™ and 19 blood samples from adult female white-tailed deer that had not been treated with GonaCon™ (Tables 1-4). In 2017, we collected 8 blood samples from adult female white-tailed deer that had not been previously captured nor received GonaCon™, 8 samples from deer that had received one dose of GonaCon™ and 3 samples from deer that had received two doses of GonaCon™ (Table 1). In 2018, we collected 11 blood samples from adult female white-tailed deer that had not been previously captured and not received GonaCon™, 19 blood samples from deer that had received one dose of GonaCon™ and 19 blood samples from deer that had received two doses of GonaCon™ (Table 1).

All female deer (100%) not treated with GonaCon™ (n=19) tested positive for pregnancy. Thirty-three percent (n=9) of female deer that received one dose of GonaCon™ (n=27) were not pregnant which differed from pregnancy rates of deer (n =19) (0% efficacy) not treated with GonaCon™ ($P = 0.0062$, df = 1, $\alpha = 0.05$). Of the 19 single dose deer collected in 2018, 16% (n = 3) were not pregnant and 75% (n = 6) of single dose deer in 2017 (n = 8) were not pregnant. Of the single dose deer that we sampled between 2017 and 2018, 16 were sampled one year after receiving GonaCon™ with a 44% efficacy rate (n=9), and 7 were sample two years after receiving GonaCon™ with a 29% efficacy rate.

Eighty-six percent (n = 19) of deer that received two doses of GonaCon™ (n = 22) were not pregnant and differed from deer that did not receive GonaCon™ (n =19) (100% pregnant) ($P<0.0001$, df = 1, $\alpha = 0.05$). Of the double dosed deer captured in 2018 (n = 19), 84% (n = 16) were not pregnant and 100% (n = 3) captured in 2017 (n = 3) were not pregnant (Table 2).

Pregnancy rates of double dose deer (n= 22) (86% efficacy) differed from pregnancy rates of single dosed deer (n = 27) (33% efficacy) (P=0.0004, df = 1, α=0.05) (Tables 3, 4).

Using spotlight surveys, we estimated a total white-tailed deer population of 113 in 2014 and 198 in 2018 (Figure 3). Using camera indices, we estimated a total white-tailed deer population of 183 in 2015 and 199 in 2018 (Figure 3). Camera indices were not performed in previous years due to a lack of uniquely marked deer. In the absence of GonaCon™, the population projection showed a rise from 113 individuals in 2014 to 568 individuals in 2022. With no additional GonaCon™ administered after 2018, the population projection showed a rise from 199 in 2018 to 325 individuals in 2022 (Figure 3).

The cost of the five-year immunocontraception project and population indices was $320,030.52. Over the five-year project, 132 captures occurred where GonaCon™ was administered and 22 captures of double dosed deer occurred where no GonaCon™ was administered but blood was collected to test for pregnancy. Overall, the 154 essential captures cost $2,078.12/capture with an overall efficacy of 33% for one dose and 86% for two doses of GonaCon™. The estimated cost for the Village of Bald Head Island to cull 30 deer in 2018 was $16,163.63 or $538.79 per deer and the estimated cost for the Village of Bald Head Island to cull 100 deer in 2018 was $55,272.17, or $552.72 per deer.

Discussion

We documented efficacy rates in single dose deer at 44% one year after receiving GonaCon™ and 29% two years after receiving GonaCon™. Previous studies (Gionfriddo et al. 2009, 2011) demonstrated a single dose efficacy rate of 67% and 88% after one year and 43% and 47% efficacy rate after two years. Although immune response has been linked to nutrition levels, all of our study animals appeared physically healthy upon capture (Homsey et al. 1986, Chandra and Amorin 1992). Our study differed from Gionfriddo (2009, 2011) in that GonaCon™ was primarily administered from January through April and not July through August which may indicate that a single dose of GonaCon™ is less effective when administered From January-April. Our study was temporally similar to Evans et al. (2015) who administered GonaCon™ to adult female white-tailed deer using syringe darts and hand injections from February to March; they demonstrated that 50% (n=6) of the deer that received GonaCon™ via hand injection were pregnant after one year.

A unique aspect of our study was the administration of two doses of GonaCon™ to a large number of deer (N=55); this had not previously been done on such a large scale with free-ranging white-tailed deer (Gionfriddo et al. 2009, 2011). Our results indicated a second dose greatly increased the efficacy of the drug blocking conception. However, it is possible that, as single dose efficacy wanes over time, double dose efficacy may do the same (Gionfriddo et al. 2009, 2011). Studies looking at an earlier version of GonaCon™ concluded that efficacy waned by 14% in multi-dosed female deer 2 years after administration of the final dose (Miller and Killian 2000).

The white-tailed deer population at Bald Head Island has continued to increase despite many female deer receiving two doses of GonaCon™. With 30 fertile females required to remain, and in the absence of culling, our population estimate (based on the current level of GonaCon™ treatment) indicates the population could increase to pre-2010 levels by 2022. In the complete absence of GonaCon™, the population was projected to have reached 264 in 2018 but was estimated at 195 and 199 with our spotlight survey and camera index suggesting the use of GonaCon™ slowed the growth of the overall population, although it still increased. In 2004, white-tailed deer density on Bald Head Island was estimated at 80 deer/km^2 and Bald Head

Island managers implemented three culls between 2005 and 2009 resulting in a decrease to 15-17 deer/km^2 (Sherril et al. 2010) suggesting that culling effectively reduced the deer population. Coyotes have recently established on the island, with the earliest report in 2012. It is unclear the magnitude of coyote predation effect on the deer population. However, based upon studies of coyote predation of white-tailed deer in the Southeast, coyotes could be a locally important source of mortality, especially on neonates (Saalfeld and Ditchkoff 2007, Kilgo et al. 2010, Kilgo et al. 2012, Jackson and Ditchkoff 2013, Chitwood et al. 2015, Bragina et al. 2019).

Much of the existing literature on GonaCon™ and white-tailed deer focused on fenced or habituated deer populations (Miller et al. 2008, Gionfriddo et al. 2009, 2011, Evans et al. 2015). Deer on Bald Head Island proved difficult to capture year to year. While some individuals were extremely habituated, most stayed well out of darting range or remained hidden in dense cover. Consequently, not all of the deer on Bald Head Island could be recaptured and re-dosed the very next year. Additionally, some deer went more than a year between receiving their first and second doses and pregnancy check (Tables 3-5). We believe the resulting irregular treatment is a realistic limitation for using GonaCon™ on a free-ranging wild white-tailed deer population.

The reported cost of the immunocontraception project only reflects expenses directly related to GonaCon™ administration. When evaluating the total cost of an immunocontraception project, it is important to include the cost over multiple years because the initial startup cost can be high and training a new or inexperienced team can result in a lower number of deer captured. Nevertheless, one dose of GonaCon™ was 73% higher than the cost of culling and only resulted in an overall efficacy of 44% after one year and 29% after two years. Administering two doses of GonaCon™ was ~87% higher than the cost of culling and resulted in an overall efficacy rate of 86%, and the length of efficacy of GonaCon™ in wild free-ranging deer is still unknown.

Management Implications

Our data indicates the use of GonaCon™ in combination with culling may help maintain white-tailed deer populations at desired levels. The difference in cost between immunocontraception and culling was ~$1500 per deer if GonaCon™ was administered once and ~$3600 per deer if GonaCon™ was administered twice. Immunocontraception could lower the number of deer needing to be culled in future years and slow the growth of the deer population, thus reducing the costs and frequency of future culls. However, avoiding treated deer would result in fewer deer available for culling, increasing search time and thus the cost of culling. Importantly, future research is needed to determine the longevity of GonaCon™ in wild white-tailed deer populations as short-term efficacy will increase future costs of immunocontraception administration. Our results indicate that administration of GonaCon™ across a wild white-tailed deer population was not successful in eliminating growth of the population and that culling will be required to reduce white-tailed deer population growth. Importantly, managers will have to weigh the much greater financial cost of immunocontraception with permanent removal of animals through culling and will need to work with their state agencies to determine when GonaCon™ can be administered.

Literature Cited

Baker, D. L., J. G. Powers, J. I. Ransom, B. E. McCann, M.W. Oehler, J. E. Bruemmer, N. L. Galloway, D. C. Eckery, and T. M. Nett. 2018. Reimmunization increases effectiveness of gonadotropin-releasing hormone vaccine (GonaCon-Equine) in free-ranging horses (*Equus caballus*): Limitations and side effects. PLoS ONE 13:7, e0201570

Becker, S. E., and L.S. Katz. 1995. Effects of a gonadotropin-releasing hormone agonist on serum luteinizing hormone concentrations in female white-tailed deer. Small Ruminant Research 18:145-150.

Becker, S. E., W. J. Enright, and L. S. Katz. 1999. Active immunization against gonadotropin-releasing hormone in female white-tailed deer. Zoo Biology: Published in affiliation with the American Zoo and Aquarium Association 18:385-396.

Bechert, U., J. Bartell, M. Kutzler, A. Menino Jr, R. Bildfell, M. Anderson, and M. Fraker. 2013. Effects of two porcine zona pellucida immunocontraceptive vaccines on ovarian activity in horses. The Journal of Wildlife Management 77:1386-1400.

Boulanger, J. R., and P.D. Curtis. 2016. Efficacy of surgical sterilization for managing overabundant suburban white-tailed deer. Wildlife Society Bulletin 40:727-735.

Boulanger, J. R., P.D. Curtis, E. G. Cooch, and A. J. DeNicola. 2012. Sterilization as an alternative deer control technique: a review. Human–Wildlife Interactions 6: 9.

Bourdeau, P.F., and H.J. Oosting. 1959. The Maritime live oak forest in North Carolina. Ecology 40:148-152

Bowman, J. L., H. A. Jacobson, D. S. Coggin, J. R. Heffelfinger, and B. D. Leopold. 2007.

Survival and cause-specific mortality in adult male white-tailed deer managed under the Quality Deer Management paradigm. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 61: 76-81.

Bragina, E. V., R. Kays, A. Hody, C. E. Moorman, C. S. DePerno, L.S. Mills. 2019. Effects on White-tailed deer following Eastern coyote colonization. The Journal of Wildlife Management 83 (4):916-924.

Campbell, T. A., B. R. Laster, W.M. Ford, and K. V. Miller. 2005. Population characteristics of a central Appalachian white-tailed deer herd. Wildlife Society Bulletin 33:212-221.

Chandra, R. K., and S. A. D. Amorin. 1992. Lipids and immunoregulation. Nutrition Research 12:S137–S145.

Chitwood, M. C., M. A. Lashley, J. C. Kilgo, C. E. Moorman, & C. S. & DePerno. 2015. White-tailed deer population dynamics and adult female survival in the presence of a novel predator. The Journal of Wildlife Management 79: 211-219.

Connelly, L. M. 2016. Fisher's exact test. MedSurg Nursing 25: 58-60.

Cooper, A.W., and S. Satterthwaite. 1964. Smith Island and the Cape Fear Peninsula: a comprehensive report on an outstanding natural area. Wildlife Preserves, Inc., Raleigh, North Carolina, USA.

Daigle, C., and M. Crête. 1999. Management of indigenous North American deer at the end of the 20th century in relation to large predators and primary production. Acta Veterinaria Hungarica 47: 1-16.

Dapson, R. W. , P. R. Ramsey, M. H. Smith, and D. F. Urbston. 1979. Demographic differences in contiguous populations of white-tailed deer. Journal of Wildlife Management 43:889-898.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments. Cornell Cooperative Extension, Ithaca, New York, USA.

Evans, C. S., A. J. DeNicola, J. D. Eisemann, and R. J. Warren. 2015. Administering GonaCon™ to white-tailed deer via hand-injection versus syringe-dart. Human–Wildlife Interactions 9: 265-272.

Gionfriddo, J. P., A. J. DeNicola, L. A. Miller, and K. A. Fagerstone. 2011. Efficacy of GnRH immunocontraception of wild white-tailed deer in New Jersey. Wildlife Society Bulletin 35:142–148.

Gionfriddo, J. P., J. D. Eisemann, K. J. Sullivan, R. S. Healey, L. A. Miller, K. A. Fagerstone, R. M. Engeman, and C. A. Yoder. 2009. Field test of a single-injection gonadotrophin-releasing hormone immunocontraceptive vaccine in female white-tailed deer. Wildlife Research 36:177- 184.

Hobbs, N. T. 1989. Linking energy balance to survival in mule deer: development and test of a simulation model. Wildlife Monographs 101: 39pp.

Homsy, J., W. J. W. Morrow, and J. A. Levy. 1986. Nutrition and autoimmunity: a review. Clinical Experimental Immunology 65:473–488.

Horsley, S.B., S.L. Stout, and D.S. DeCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13:98- 118.

Huijser, M.P., Duffield, J.W., Clevenger, A.P., Ament, R.J., McGowen, P.T., 2009. Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. Ecology and Society 14(2): 15.

Jackson, A. M., & S. S. Ditchkoff. 2013. Survival estimates of white-tailed deer fawns at Fort

Rucker, Alabama. The American Midland Naturalist, 170: 184-191.

Kilgo, J. C., H. S. Ray, C. Ruth, & K. V. Miller. 2010. Can coyotes affect deer populations in southeastern North America. The Journal of Wildlife Management, 74: 929-933.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. Journal of Wildlife Management 76:1420–1430.

Killian, G., T. J. Kreeger, J. Rhyan, K. Fagerstone, and L. Miller. 2009. Observations on the use of GonaCon™ TM in captive female elk (Cervus elaphus). Journal of Wildlife Diseases, 45: 184-188.

Kirkpatrick, J. F., R. O. Lyda, and K. M. Frank. 2011. Contraceptive vaccines for wildlife: a review. American Journal of Reproductive Immunology 66: 40-50.

Krause, S. K., D. A. Kelt, J. P. Gionfriddo, and D. H. Van Vuren. 2014. Efficacy and health effects of a wildlife immunocontraceptive vaccine on fox squirrels. The Journal of Wildlife Management 78: 12-23.

Lauber, T., B. A. Knuth, J. A. Tantillo, and P. D. Curtis. 2007. The role of ethical judgments related to wildlife fertility control. Society and Natural Resources 20: 119-133.

Massei, G., D. P. Cowan, J. Coats, F. Bellamy, R. Quy, S. Pietravalle, M. Brash, and L. A. Miller. 2012. Long-term effects of immunocontraception on wild boar fertility, physiology and behavior. Wildlife Research, 39: 378-385.

MacLean, R. A., N. E. Mathews, D. M. Grove, E. S. Frank, and J. Paul-Murphy. 2006. Surgical technique for tubal ligation in white-tailed deer (Odocoileus virginianus). Journal of Zoo and Wildlife Medicine 37: 354-361.

McCullough, D. R., K. W. Jennings, N. B. Gates, B. G. Elliott, and J. E. DiDonato. 1997.

Overabundant deer populations in California. Wildlife Society Bulletin 25:478-483.

McShea, W. J., H. B. Underwood, and J. H. Rappole. 1997a. The science of overabundance: deer and ecology and population management. Smithsonian Institution Press, Washington, D.C. 402 p

McShea, W. J., and J. H. Rappole. 2000. Managing the abundance and diversity of breeding bird populations through manipulation of deer populations. Conservation Biology 14: 1161-1170.

McShea, W. J., S. L. Monfort, S. Hakim, J. Kirkpatrick, I. Liu, J. W. Turner Jr, L. Chassy and L. Munson. 1997b. The effect of immunocontraception on the behavior and reproduction of white-tailed deer. The Journal of wildlife management 61: 560-569.

Miller, L. A., and G. J. Killian. 2000. Seven years of white-tailed deer immunocontraceptive research at Penn State University: a comparison of two vaccines Pages 59 – 69, in proceedings of the 14th Wildlife Damage Management Conference, October 2000.

Miller, L. A., J. P. Gionfriddo, K. A. Fagerstone, J. C. Rhyan, and G. J. Killian. 2008. The single-shot GnRH immunocontraceptive vaccine (GonaCon™) in white-tailed deer: comparison of several GnRH preparations. American Journal of Reproductive Immunology 60: 214-223.

Miller, L. A., J. Rhyan, and G. J. Killian. 2004. GonaCon™, a versatile GnRH contraceptive for a large variety of past animal problems. 21: 269-273 in proceedings of the Vertebrate Pest Conference, March 2004.

Naz, R. K., and A.E. Saver. 2015. Immunocontraception for animals: current status and future perspective. American Journal of Reproductive Immunology 75: 426-439.

Pratap, A., K. L. Garner, M. Voliotis, K. Tsaneva-Atanasova, and C. A. McArdle. 2017.

Mathematical modeling of gonadotropin-releasing hormone signaling. Molecular and Cellular Endocrinology 449: 42-55.

Ray, D. K., E. G. Bolen, and W. D. Webster. 2001. Characteristics of a barrier island deer population in the southeastern United States. J. Elisha Mitchell Science Society 117:133–122.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. Forest Ecology and Management 181: 165-176.

Rudolph, B. A.,W. F. Porter, and H. B. Underwood. 2000. Evaluating immunocontraception for managing suburban white-tailed deer in Irondequoit, New York. The Journal of Wildlife Management 64: 463-473.

Rutberg, A. T., R. E. Naugle, J. W. Turner, M. A. Fraker, and D. R. Flanagan. 2013. Field testing of single-administration porcine zona pellucida contraceptive vaccines in white-tailed deer (Odocoileus virginianus). Wildlife Research 40: 281-288.

Saalfeld, S. T., & S. S Ditchkoff 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of wildlife management, 71: 940-944.

Schneider, J. C. 2000. Chapter 8: Lake Fish Population Estimates. In Manual of Fisheries Survey Methods II: With periodic updates. Ann Arbor, MI: Michigan Department of Natural Resources.

Severinghaus, C. W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13: 195-216.

Sherrill, B. L., A. G. Snider, and C. S. DePerno. 2010. White-tailed deer on a barrier island:

implications for preserving an ecologically important maritime forest. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 64:38-43.

Taggart, J., and Z. Long. 2015. Effects of white-tailed deer (Odocoileus virginianus) on the Maritime Forest of Bald Head Island, North Carolina. The American Midland Naturalist 173: 283-293

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2007. GonaCon™ Birth Control for Deer: Questions and Answers [Factsheet]. Retrieved from https://www.aphis.usda.gov/wildlife_damage/nwrc/downloads/faq_gonacon_07.pdf

U.S. Census Bureau 2010. Profile of General Population and Housing Characteristics , Bald Head Island Village, North Carolina. Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=DEC_10_DP_DPDP1&prodType=table

Warren, R. J. 2011. Deer overabundance in the USA: recent advances in population control. Animal Production Science 51: 259-266.

White, G. C., R. A. Garrott, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Survival of mule deer in northwest Colorado. Journal of Wildlife Management 51:852–859.

Williams, S. C., A. J. DeNicola, T. Almendinger, and J. Maddock. 2013. Evaluation of organized hunting as a management technique for overabundant white-tailed deer in suburban landscapes. Wildlife Society Bulletin 37: 137–145.

Table 1: Pregnancy results for adult white-tailed deer that had received; no GonaCon™, single dose of GonaCon™, and double dose of GonaCon™, Bald Head Island, North Carolina, 2017 and 2018.

Year Collected	Zero Dose Pregnant	Single Dose Pregnant	Double Dose Pregnant
2017	8/8 (100%)	2/8 (25%)	0/3 (0%)
2018	11/11 (100%)	16/19 (84%)	3/19 (16%)
Cumulative	19/19 (100%)	18/27 (67%)	3/22 (14%)

Table 2: Pregnancy results from adult white-tailed deer 1-4 years after a single dose of GonaCon™, Bald Head Island, North Carolina, 2014-2018.

Spring (January-April) Inoculation			Fall Inoculation
1 year since dose	2 years since dose	4 years since dose	4 years since dose
9/16 (56%) pregnant	5/7 (71%) pregnant	3/3 (100%) pregnant	1/1 (100%) pregnant

Table 3: Pregnancy results of two doses of GonaCon™ with first dose given in the Fall, Bald Head Island, North Carolina, 2014-2018.

First dose given in fall		
2 years between doses		3 years between doses
1 year since last dose	2 years since last dose	One year since last dose
0/3 (0%) pregnant	1/5 (20%) pregnant	0/1 (0%) pregnant

Table 4: Pregnancy results of two doses of GonaCon™ with all doses administered during Spring, Bald Head Island, North Carolina, 2014-2018.

All doses given in Spring			1st dose given in Spring
1 year between doses	2 years between doses	2 doses in the same season	2 doses in same year
1 year since last dose	2 years since last dose	1 year since last dose	4 years since last dose
0/8 (0%) Pregnant	(50%) 1/2 pregnant	(50%) 1/2 Pregnant	(0%) 0/1 pregnant

Figure 1: Bald Head Island (outlined in red) with Middle and Bluff islands visible to the north, the mouth of the Cape Fear River to the west, and the Atlantic Ocean to the east and south.

Figure 2: The spotlight survey route on Bald Head and Middle Island (depicted in blue) Bald Head Island and Middle Island are outlined in red., Bald Head Island, North Carolina, 2014-2018.

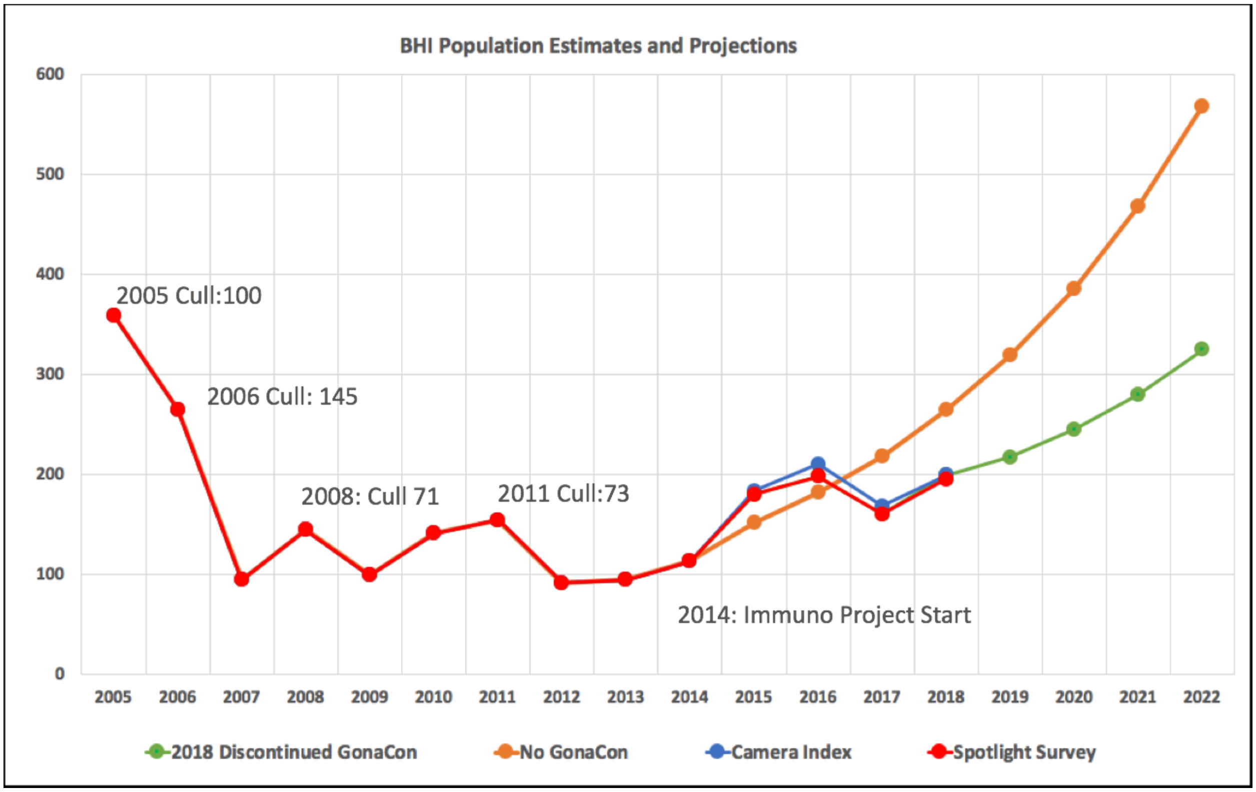

Figure 3: Discontinued GonaCon™ 2018 population projection, No GonaCon™ population projection, historic spotlight survey and camera index population estimates with the number of deer removed from culling, Bald Head Island, North Carolina, 2005-2018.

A Comparison of Two Darting Methods for White-tailed Deer

Abstract

From 2017-2018, white-tailed deer (*Odocoileus virginianus*) on Bald Head Island, NC were captured using two distinct methods, darting from a baited blind and darting opportunistically from a golf cart. We compared animal safety and efficacy of the blind method (n= 43) with the opportunistic method (n=19). We used 6 variables (method, distance animal traveled, maximum core temperature, good hit y/n , booster needed, and time spent searching) to perform both a one-way and two-way analysis of variance (ANOVA) to look for significant differences between methods. We examined the total number of hours spent and the total number of animals captured using each method to determine efficiency. Time spent searching was significantly affected by the interaction between good hit and method. Search time was 12-33 minutes less for a good hit than a bad hit regardless of darting method. The blind method was 7% more likely to result in a good hit. However, capturing a deer using the blind method took 8 hours more than the opportunistic method. Wildlife managers should use the opportunistic method if efficiency is critical to the project. The blind method should be used if managers wish to reduce the amount of time spent searching for darted deer. Bald Head Island managers found a combination of these two methods was more successful than any one method, with no capture related mortalities during the duration of the study.

Introduction

White-tailed deer (*Odocoileus virginianus*) are the most abundant and widespread deer species in the Americas, with populations throughout the contiguous United States and as far south as Peru (Hewitt 2011). Over the past few decades, North American white-tailed deer populations have grown substantially and are abundant in many urban and suburban areas (Daigle and Crete 1999, DeNicola et al. 2000, McShae et al., 1997). With urban deer populations exceeding their social carrying capacities, management has become necessary to reduce their numbers (DeNicola et al. 2000). Historically, white-tailed deer populations have been reduced through hunting and culling; however, increased urbanization has led to concerns about safety and the legality of using firearms to remove deer in urban environments. Due to animal welfare concerns and negative attitudes towards lethal control, many communities have looked towards non-lethal techniques for white-tailed deer population control such as immunocontraception or capture and relocation (DeNicola et al. 1997 & 2000, McCullough et al. 1997, Williams et al. 2013).

During capture, white-tailed deer are often subject to increased body temperatures due to physical exertion combined with thermoregulatory inhibition resulting from the use of anesthesia drugs (DelGiudice et al. 2001, 2005, DeNicola et al. 1997). Higher core body temperature has been associated with lower post capture survival rates in white-tailed deer and other animals (Delgiudice et al. 2001, Kocan et al. 1980, Seal et al. 1978). Previous studies have determined that different capture techniques, such as clover traps and net gunning, for white-tailed deer had resulted in different overall core body temperature during captures (Delgiudice et al. 2001). Animal welfare-minded communities looking to capture deer in the safest way possible may be more interested in using methods that result in safer core body temperature ranges for captured deer. Bald Head Island is one community that has employed two different deer capture methods including 1) blind method and 2) opportunistic method. The blind method involves darting deer from a baited, camouflaged blind. The opportunistic method involves driving across the island in a golf cart and darting deer spotted along roadsides. While these two methods have been employed on Bald Head Island for several years, no study has compared the safety or efficacy of these methods. Hence, our objective was to quantify time efficiency and animal safety between the two darting methods.

Study Area

Bald Head Island (Figure 1) is located 4.8 km southeast of Southport in Brunswick County, North Carolina (Ray et al. 2001). The island consists of 620 hectares of upland habitat and is 5.5 km long by 1.5 km wide with an elevation ranging from sea level to 15m on top of the primary dune ridges (Cooper and Satterthwaite 1964, Ray et al. 2001, Sherrill et al. 2010). The main landcover of the island includes maritime forest (275 hectares), dunes/strands (171 hectares), tidal marsh, and suburban development (85 hectares) (Sherrill et al. 2010, Taggart and Long 2015). Bald Head Island has one of the last remaining intact maritime forests in North Carolina and is composed mostly of live oak (*Quercus virginianus*), red bay (*Persea borbonia*), laurel oak (*Quercus hemisphericus*), eastern red cedar (*Juniperus virginiana*), Carolina cherry laurel (*Prunus caroliniana*), youpon holly (*Ilex vomitoria*) (Bourdeau and Oostings 1959).

Suburban development is concentrated on 85 hectares on the western side of Bald Head Island (Sherrill et al. 2010). Bald Head Island has a year-round human population of 158 that increases to several thousand with summer visitation (U.S. Census Bureau 2010). The use of car on the island is restricted to emergency personnel, tram service, and contractor vehicles. Instead of gasoline powered vehicles, residents and visitors use electrically powered golf carts as their primary means of transportation.

The white-tailed deer population occupies the entire island and was first documented in the mid-1980's. (Ray et al. 2001). In the absence of population control, the population has exceeded over 350 individuals (56/km^2), causing concern for the potential to over-browse and significantly damage the sensitive dune and maritime forest vegetation (Sherrill et al. 2010). Culling was periodically used to manage the deer population, but the practice was terminated due to its unpopularity among the island residents. As a result, the Village of Bald Head Island (the municipality governing body) initiated an immunocontraception program in 2014. Although the white-tailed deer population is free-ranging, earlier studies determined that emigration from Bald Head Island was minimal and the population was likely closed suggesting immunocontraception might be a population management option (Sherrill et al. 2010).

Starting in January 2014, 77 female white-tailed deer were captured and inoculated with GonaCon™ as part of a five-year project in cooperation with the Village of Bald Head Island, Bald Head Island Conservancy, North Carolina Wildlife Resources Commission (NCWRC), and a group of concerned citizens called "The Friends of Deer". Capture efforts were initially led by a private wildlife company, but the project was taken over by Bald Head Island Conservancy in fall 2014. The NCWRC permit to administer GonaCon™ required managers leave 30 viable female deer on Bald Head Island to maintain genetic diversity in the population. In fall 2014, a captured female left the island and swam to the mainland and returned to the island a few weeks later, establishing that the deer population on Bald Head Island was not completely isolated from the mainland. To eliminate the concern that hunters from areas adjacent to Bald Head Island would consume deer that had been treated with anesthetic drugs, NCWRC then prohibited use of anesthetic drugs on all future BHI deer captures from 90 days prior to the start of the hunting season to hunting season end. However, none of the remaining 76 female white-tailed deer are known to have traveled to the mainland during the remainder of the project.

Methods

Darting

From January-April of 2017 - 2018, we darted white-tailed deer from a stationary blind and opportunistically from golf carts. For the blind method, we darted deer from pop-up blinds or ground blinds baited with whole kernel corn 3-5 m from the blind. For the targets of opportunity method, we darted deer from golf carts in the mornings and evening using a red spotlight. We used CO_2 powered dart rifles (Model JM Standard, Dan Inject, Inc., Borkop, Denmark)(Xcalibur, Pneu-Dart, Williamsport, Pennsylvania, USA) and single use, 2cc, wire barbed transmitter darts (Pneu-Dart, Williamsport, Pennsylvania, USA). To anesthetize white-tailed deer, we administered 2.0mL of BAM™ (27.3 mg Butorphanol, 9.1 mg Azaperone, 10.9 Medetomidine per 11mL vial), ZooPharm, Windsor, Colorado, USA) intramuscularly. When a target deer was spotted, we verified distance to the deer to ensure there were adequate CO_2 levels in the dart rifle. We attached radio transmitters to the darts to ensure darted deer were located quickly. If a deer was not fully anesthetized when located, we administered up to 1.0mL of additional BAM™ intramuscularly via hand syringe.

Deer Handling

Once the deer were anesthetized, we applied a blindfold, monitored rectal temperature, respiration, and heart rate every 10 minutes. We removed the dart, cleaned the wound with Hibiclens® (Mölnlycke Health Care US, LLC, Norcross Georgia), and applied antibiotic cream to the dart wound (Neosporin®, Johnson & Johnson, Inc., New Brunswick, New Jersey, USA). We determined sex and, through dental characteristics, age class of the deer as fawn (<1year), yearling (1.5 years), and adult (>1.5 years). We fitted captured deer with a mortality sensing VHF radiocollar, leaving approximately 1.5 inches of space while the collar was positioned at the base of the neck (Advanced Telemetry Systems, Inc., Isanti, Minnesota, USA). Once handling, data collection, and collar attachment was completed, we reversed the deer with 4.0 mL of Atipamezole and 0.5 mL of Naltrexone (ZooPharm, Windsor, Colorado, USA) via intramuscular injection. White-tailed deer capture and handling protocols were approved by the NCWRC and the Institutional Animal Care and Use Committee at North Carolina State University (17-175-O).

Time spent on each capture method was recorded nightly from 2016-2018. To calculate capture time for each method, we summed hours for each method and divided by the number of deer captured using that method.

Statistical Materials and Methods

We examined six variables in our statistical analyses: method (i.e., blind or opportunistic), distance traveled, maximum temperature, good hit, booster, and search time. Method was a two level categorical variable that represented the two capture methods used, blind and opportunistic. Distance traveled was the distance the deer traveled in meters from where the deer was darted to where it went down. Maximum temperature was the maximum body temperature recorded during capture. Good hit was a two level yes/no categorical variable where a "yes" indicated the dart struck the deer in a good location and remained in the deer until the capture teams removed the dart. A "no" indicated the dart either did not hit the deer in an ideal location and/or the dart fell out before the deer could be located. Booster was a two level yes/no variable where a "yes" indicated the deer required an anesthetic supplement to proceed with the processing and a "no" indicated that no additional chemical immobilization drugs were necessary. Search time was the amount of time in minutes between the time the deer was darted and the time that capture teams located the immobilized deer.

We used RStudio® for statistical analyses and SAS Enterprise Guide® 9.14 to verify results obtained in RStudio®. We checked variables for normality using density plots, pairs.panel function, and scatter plots. Variables were scaled using the scale function in R version 5.5.1 (R Core Team, Vienna, Austria, 2019). Additionally, we checked for correlation between numeric variables using Pearson's correlation coefficient and checked the linear model assumptions with plot function in R version 3.5.1 (R Core Team, Vienna, Austria, 2019).

We used one-way ANOVA to compare the difference in means between distance by method, maxtemp by method, and search by method. Additionally, we used ANOVA to compare the following: difference in means between distance by method with an interaction of booster and goodhit, maxtemp by method with an interaction of booster and goodhit, and search by method with an interaction of booster and goodhit. We used Tukey HSD test if the interaction was significant and set alpha at 0.05.

Results

We captured 62 white-tailed deer; 43 from a ground blind and 19 opportunistically (Table 5). The total hours spent using the blind method was 1359.55 hours. The total hours spent using the opportunistic method was 394.27 hours. The average amount of time spent per capture using the blind method was 23.44 hours. The average time to capture a deer using the opportunistic method was 15.77 hours. Eighty one percent (n = 35) of deer darted using the blind method resulted in a good hit while 74% percent (n = 14) of deer darted using the opportunistic method resulted in a good hit.

Distance traveled (F = 0.1155, df = 1, P = 0.7352), mean maximum temperature (F = 0.5975, df = 1, P = 0.4426), and search time (F = 0.0002, df = 1, P = 0.9897) were not impacted by darting method. Distance traveled was not affected by the interaction between darting method and booster ($F = 0.5479$, $df = 1$, $P = 0.4621$). Distance traveled was affected by the interaction between darting method and good hit ($F = 8.3044$, $df = 1$, $p = 0.0055$). However, Tukey HSD pairs comparing methods were not significant, only the pair comparing a good hit vs a bad hit on blind method was significant. Maximum temperature was not affected by the interaction between darting method and good hit ($F = 0.9846$, $df = 1$, $P = 0.0.3252$) or the interaction between darting method and booster given ($F = 2.2416$, $df = 1$, $P = 0.1398$). Search time was not affected by the interaction between darting method and booster ($F = 1.2139$, $df = 1$, $P = 0.2751$). However, search time was affected by the interaction of darting method and good hit ($F = 4.6767$, $df = 1$, $P = 0.0347$) (Table 6).

Discussion

The opportunistic method was nearly 8 hours more efficient per deer captured than the blind method which is due in part to the amount of area covered during opportunistic searching. Additionally, using the active opportunistic capture technique, white-tailed deer were seen almost every night. Conversely, the blind method was a passive capture technique and white-tailed deer were not always observed at the bait pile.

Distance traveled, search time, and maximum temperature were similar by darting method. The percent of good hits using the blind method was 7% greater than the opportunistic method which could be because deer were alert during the opportunistic method. When white-tailed deer were alert, they responded faster to the sound of the dart gun and had a greater chance of moving resulting in a lower quality hit. For example, white-tailed deer sometimes ducked, moved forward or backward resulting in a poor quality hit. Additionally, many shots had to be rushed during the opportunistic method because alert deer were more likely to run as the golf cart approached. Good hits resulted in less search time. In fact, search time was 12-33 minutes less for a good hit than a bad hit regardless of darting method (Table 2).

Management Implications

Although the blind method resulted in more good hits than the opportunistic method, and the interaction between method and good hit significantly reduced search time, the blind method did take 8 hours more per individual deer captured. Additionally, the blind method required additional time to set up the blinds and bait them daily, the amount of time varied by how many blinds were deployed. If minimizing time spent searching for darted deer is a top priority, managers should focus on the blind method. The blind method provided easier shots, with deer usually closer and unaware. However, the deer that often came to the bait pile were usually the same few individuals. Additionally, groups of non-target males would often dominate the bait pile and keep target females out of range. These factors, along with time and effort of establishing maintaining bait sites will contribute to the time and cost of bait required of managers to successfully dart females.

If capture time and a greater distribution of animals captured are critical components of a deer management program, then wildlife managers should focus on the opportunistic method. Covering a greater distance resulted in more deer seen and more potential targets, but may lead to greater time searching for darted deer. It will be up to the manager's priorities based upon animal welfare and time and resources available. On Bald Head Island, managers found that a combination of the two methods was more successful in capturing deer than employing any one particular method, with no capture related mortalities during the duration of this study.

Literature Cited

Daigle, C., & Crête, M. (1999). Management of indigenous North American deer at the end of the 20th century in relation to large predators and primary production. Acta Veterinaria Hungarica, 47(1), 1-16.

DelGiudice, G. D., Sampson, B. A., Kuehn, D. W., Powell, M. C., & Fieberg, J. (2005). Understanding margins of safe capture, chemical immobilization, and handling of free-ranging white-tailed deer. Wildlife Society Bulletin, 33(2), 677-687.

DelGiudice, G. D., Mangipane, B. A., Sampson, B. A., & Kochanny, C. O. (2001). Chemical immobilization, body temperature, and post-release mortality of white-tailed deer captured by Clover trap and net-gun. Wildlife Society Bulletin, 1147-1157.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments. Cornell Cooperative Extension, Ithaca, New York, USA.

DeNicola, A. J., & Swihart, R. K. (1997). Capture-induced stress in white-tailed deer. Wildlife Society Bulletin, 25(2), 500-503.

Hewitt, D. G. (Ed.). (2011). Biology and Management of White-Tailed Deer. CRC Press.

Kocan, A. A., Thedford, T. R., Glenn, B. L., Shaw, M. G., & Wood, R. (1980). Myopathy associated with immobilization in captive white-tailed deer. Journal of the American Veterinary Medical Association, 177(9), 879-881.

McCullough, D. R., K. W. Jennings, N. B. Gates, B. G. Elliott, and J. E. DiDonato. 1997. Overabundant deer populations in California. Wildlife Society Bulletin 25:478-483.

McShea, W. J., H. B. Underwood, and J. H. Rappole (eds.). 1997. The science of overabundance: deer and ecology and population management. Smithsonian Institution Press, Washington, D.C. 402 p

SEAL, U. S., ERICKSON, A. W., & MAYO, J. G. (1970). Drug immobilisation of the Carnivora11. International Zoo Yearbook, 10(1), 157-170.

Williams, S. C., DeNicola, A. J., Almendinger, T. and Maddock, J. (2013), Evaluation of organized hunting as a management technique for overabundant white-tailed deer in suburban landscapes. Wildlife Society Bulletin, 37: 137–145.

Table 5: A summary of data collected from white-tailed deer captures on Bald Head Island including counts, minimum measurements, mean measurements and maximum measurements.

Method	Distance (meters)	Search (minutes)	Max Temp (Fahrenheit)	Good Hit	Booster
Blind: 43	Min: 46 Mean: 262 Max: 540	Min: 5 Mean: 26 Max: 65	Min: 98.8 Mean: 101.9 Max: 103.5	No: 8 Yes: 35 81% Good Hit	No: 38 Yes: 5 88% No
Opportunistic: 19	Min: 97 Mean: 272 Max: 510	Min: 6 Mean: 28 Max: 104	Min: 99.7 Mean: 102 Max: 103.5	No: 5 Yes: 14 74% Good Hit	No: 14 Yes: 5 73% No

Table 6: Tukey HSD results of Search by Method and Good Hit. The n's and y's on the left refer to a good hit no or yes result for each method type. The pairs comparing a good hit to a bad hit show that when there is a good hit, search time is less and the adjusted p-values are significant.

	Difference	LWR	UPR	Adjusted p
Opportunistic: n - Blind: n	12.12	-7.08	31.33	0.3486
Blind: y – Blind: n	-15.04	-28.25	-1.85	0.0194
Opportunistic: y – Blind: n	-20.87	-35.80	-5.95	0.0027
Blind: y – Opportunistic n	-27.17	-43.28	-11.07	0.0002
Opportunistic: y – Opportunistic: n	-33.00	-50.55	-15.45	<0.0001
Opportunistic: y – Blind: y	-5.82	-16.48	4.82	0.4756