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Research Article

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

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ABSTRACT As white-tailed deer populations increase in developed and urban areas, lethal management is necessary to control population growth. However, concerns about safety and negative attitudes towards lethal control and using firearms near houses have prompted many communities to pursue nonlethal techniques. Therefore, in 2014 we initiated a 5-year project to attempt to stabilize the local deer population on Bald Head Island (BHI), North Carolina, using the immunocontraceptive GonaCon™. Since 2014 we captured and inoculated 77 female deer with GonaCon™. From 2017 to 2018 we evaluated the efficacy and cost of GonaCon™ at reducing pregnancy in adult female white-tailed deer on BHI. We obtained blood samples from 49 deer that had received either 1 or 2 doses of GonaCon™, and 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), whereas 67% of deer sampled that received only a single dose were pregnant (n = 27), and 14% of deer that received 2 doses (n = 22) were pregnant. Thus, 2 doses of GonaCon™ were necessary to reduce pregnancy rates below 50%. The total direct cost of the 5-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 2 doses of GonaCon™. Conversely, the estimated cost for the local government (i.e., Village of Bald Head Island) to cull 30 deer in 2018 was $16,163.63, or $538.79/deer. The estimated deer population was 113 in 2014 and increased to 198 individuals by 2018. Further population projections suggested the white-tailed deer population is projected to reach 342 individuals by 2022. Although 2 doses of GonaCon™ were effective at reducing pregnancy, administration across the BHI deer population was not successful in reducing the deer population, and culling will likely be necessary to reduce the population.

KEY WORDS GonaCon™, immunocontraception, North Carolina, *Odocoileus virginianus*, white-tailed deer.

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 (McShea et al. 1997*b*, Daigle and Crête 1999, DeNicola et al. 2000). In the United States, an estimated 1–2 million wildlife-vehicle collisions occur each year, with deer (Cervidae) accounting for 99% of those accidents and causing an estimated $6.2 billion (US) in damage (Huijser et al. 2009). Additionally, white-tailed deer damage ornamental plants in residential areas (Rooney and Waller 2003), alter the forest plant biodiversity through overbrowsing, 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 nonlethal

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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 nonlethal deer management techniques currently in use 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 has resulted in nearly 100% reduction in pregnancy (Boulanger and Curtis 2016). Cost of surgical sterilization in female deer is estimated to be approximately $1,000 per deer (Boulanger et al. 2012). 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 (McShea et al. 1997*a*, Rutberg et al. 2013, Naz and Saver 2015). Porcine zona pellucida has been successfully used on female white-tailed deer (Rutberg et al. 2013) and feral horses (Bechert et al. 2013). Interestingly, PZP does not prevent female deer from entering the estrous cycle, resulting in extended breeding seasons and increased energetic demands that may lead to greater female mortality (Hobbs 1989, McShea et al. 1997*a*). Previous research estimated vaccinations to cost $1,100 per deer (Peck and Stahl 1997). Although PZP can reduce pregnancy rates by 45% in wild white-tailed deer (Rutberg et al. 2013), it requires yearly reimmunization to remain effective for the long term (McShea et al. 1997*a*, Rudolph et al. 2000, Bechert et al. 2013).

To avoid the shortcomings of surgical sterilization and PZP, studies have evaluated immunocontraceptive vaccines that elicit an immune response towards gonadotropin-releasing hormone (GnRH; Miller et al. 2004, Kirkpatrick et al. 2011, Naz and Saver 2015). Gonadotropin-releasing hormone is a peptide hormone produced within the hypothalamus and is responsible for triggering the production of follicle stimulating hormone (FSH) and luteinizing hormone (LH); FSH and LH are produced in the anterior pituitary to facilitate follicular development and ovulation (Becker and Katz 1995, Becker et al. 1999, Miller et al. 2004, Pratap et al. 2017). A single shot variant of a gonadotropin-releasing hormone vaccine (i.e., GonaCon™) was created by the National Wildlife Research Center (Fort Collins, CO, USA) and has been used on many wildlife species including white-tailed deer (Miller et al. 2008, Gionfriddo et al. 2009), 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 (Miller et al. 2008). The combination of the conjugate and adjuvant in GonaCon™ stimulates the animal's immune system to create antibodies against the GnRH, 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). GonaCon™ is less effective in white-tailed deer fawns, possibly due to a less developed immune system (Gionfriddo et al. 2011). Although there have been several studies conducted on the efficacy of a single dose of GonaCon™ in fenced deer populations (Gionfriddo et al. 2009, 2011), we were unable to locate published research on the efficacy of GonaCon™ on unfenced, wild white-tailed deer populations. Therefore, our objective was to evaluate the efficacy and cost of GonaCon™ at reducing pregnancy in adult female white-tailed deer on a wild white-tailed deer population.

STUDY AREA

Bald Head Island (BHI; Fig. 1) was located 4.8 km southeast of Southport in Brunswick County, North Carolina, USA (Ray et al. 2001). The island consisted of 620 hectares of upland habitat and measured 5.5 km long by 1.5 km wide with an elevation ranging from sea level to 15 m 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 included maritime forest (275 hectares), dunes or strands (171 hectares), tidal marsh, and suburban development (85 hectares; Sherrill et al. 2010, Taggart and Long 2015). Bald Head Island had one of the last remaining intact maritime forests in North Carolina and was composed mostly of live oak (*Quercus virginiana*), red bay (*Persea borbonia*), laurel oak (*Quercus hemisphericus*), eastern red cedar (*Juniperus virginiana*), Carolina cherry laurel (*Prunus caroliniana*), and yaupon holly (*Ilex vomitoria*; Bourdeau and Oosting 1959).

Suburban development was concentrated on 85 hectares on the western side of Bald Head Island (Sherrill et al. 2010). Bald Head Island had a year-round human population of 268 that increased to several thousand with summer visitation (U.S. Census Bureau 2020). The use of cars on the island was restricted to emergency personnel, tram service, and contractor vehicles. Instead of gasoline powered vehicles, residents and visitors used electrically powered golf carts as their primary means of transportation.

The white-tailed deer population occupied the entire island and was first documented in the mid-1980's (Ray et al. 2001). In the absence of population control, the deer population on BHI exceeded 350 individuals (56/km^2), causing concern for the potential to overbrowse and damage the sensitive dune and maritime forest vegetation (Sherrill

Figure 1. Bald Head Island (outlined in red), North Carolina, USA, 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.

et al. 2010). A prior study determined that a density of 15–17 deer/km^2 did not negatively affect the maritime forest on BHI (Taggart and Long 2015). To reduce the deer population on BHI, culling was periodically used, but the practice was terminated due to its unpopularity among island residents. As a result, the Village of Bald Head Island (the municipality governing body) initiated an immunocontraception program in 2014 to keep the white-tailed deer population under 200 individuals. Although the white-tailed deer population was 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 5-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 the private wildlife company White Buffalo (Moodus, CT, USA), but the project was taken over by Bald Head Island Conservancy in fall 2014. The NCWRC permit to administer GonaCon™ required managers to leave 30 viable female deer on Bald Head Island to maintain genetic diversity in the population. In fall 2014, a VHF collared female left the island and swam to the mainland and returned to the island a few weeks later, indicating 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 prohibited the 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.

METHODS

Deer Capture and Processing

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; X-Calibur, Pneu-Dart, Williamsport, PA, USA) and single use, 2 mL, wire barbed transmitter darts (Pneu-Dart, Williamsport, PA, USA). To anesthetize each white-tailed deer, we administered 2.0 mL of BAM™ (ZooPharm, Windsor, CO, USA) intramuscularly. If a deer was not fully anesthetized when located, we administered up to 1.0 mL of additional BAM™ intramuscularly via syringe. We darted deer from pop-up blinds or ground blinds at sites baited with whole kernel corn 10–20 m from the blind and from golf carts in the evening using a spotlight with a red lens.

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 GA, USA), and applied antibiotic cream (Neosporin®, Johnson & Johnson, Inc., New Brunswick, NJ, USA). We determined sex and age class of the deer using the following criteria: fawns were <1 year, yearlings were 1.5 years, and adult were >1.5 years (Severinghaus 1949) and attached uniquely-numbered cattle tags into both ears of newly captured deer. We hand injected 1.0 mL of the GonaCon™

intramuscularly into the hindquarters of yearling and adult female deer. From 2017 through 2018, we took blood from the jugular or lateral saphenous vein of the deer regardless of prior capture history. Deer captured in 2017 and 2018 that had never received GonaCon™ prior to capture were assigned to the control group. We shipped blood samples to the BioTracking lab (Moscow, ID, 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 evidence of lactation. We fitted captured deer with a mortality sensing VHF radiocollar (Advanced Telemetry Systems, Inc., Isanti, MN, USA). Once handling was completed, we reversed the anesthezia with 4.0 mL atipamezole and 0.5 mL naltrexone (ZooPharm, Windsor, CO, USA) via intramuscular injection. We located all deer daily for the first 2 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, CA, USA). If a deer died, we conducted a field necropsy to determine the cause of death (White et al. 1987).

Population Estimates & Projection

In November 2015–2018, we conducted population surveys to determine white-tailed deer population size on Bald Head Island. We established 12 camera stations across the island, checked them daily to replace memory cards and batteries as needed, maintained camera functionality, and baited each site with 2.5–5 kg of whole corn. We programmed cameras to take pictures in bursts of 3 with 5 seconds between pictures followed by a 3-minute period before it could be triggered again and considered each set of 3 photos as one trigger. We examined 5 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.

During June–July 2005–2018, we conducted spotlight surveys for a total of 25 nights per year over an established route across Bald Head Island and a portion of Middle Island (Fig. 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

Figure 2. The observable deer habitat from the spotlight survey route (depicted in blue) on Bald Head and Middle islands (outlined in red), North Carolina, USA, 2014–2018.

comparing the ratio of deer seen per observable available deer habitat along the spotlight route to the total available habitat across the island.

We modelled population growth of 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 1 and 2 doses of GonaCon™ to account for 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 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: fecundity of 1.56 fawns per doe (Dapson et al. 1979); estimated fawn survival of 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 during the 2018 November camera index; survival rates from studies with non-hunted white-tailed deer populations and set the survival rate of 6-month old fawns at 0.85 for females and 0.80 for males (Campbell et al. 2005), and adult female and male survival of 0.92 and 0.82, respectively (Campbell et al. 2005, Bowman et al. 2007). We projected the population using Microsoft Excel Version 16.16.16 (Microsoft Corporation, Redmond, WA, 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 (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 and supplies, bait, refrigeration truck rental, meat processing, mileage, barge expense, and miscellaneous (e.g., ammunition, ice).

Data Analysis

We used Fisher's exact test of independence to compare pregnancy results from the PSHB blood tests across treatment groups (Connelly 2016). We included the odds ratios (OR) to gauge the strength of any correlation. We used the Haldane-Anscombe correction when one of the cells had a value of zero (Anscombe 1956, Haldane 1956). 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 2018) with a significance level of $\alpha < 0.05$.

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

Dose given in Spring (January-April)			Dose given in Fall
1 year since dose	2 years since dose	4 years since dose	4 years since dose
7/16 (44%) not pregnant	2/7 (29%) not pregnant	0/3 (0%) not pregnant	0/1 (0%) not pregnant

RESULTS

During 2017 and 2018, we collected 49 blood samples from adult female white-tailed deer that had received 1 or 2 doses of GonaCon™ and 19 blood samples from adult female white-tailed deer that had not been treated with GonaCon™. All female deer not treated with GonaCon™ (n = 19) were pregnant. Thirty-three percent (n = 9) of female deer that received one dose of GonaCon™ (n = 27) were not pregnant, which differed from pregnancy results of deer (n = 19; 0% efficacy) not treated with GonaCon™ ($OR_{(1)} = 0.099$, CI = 0.002-0.8137, $P = 0.016$). Of the single dose deer that we sampled between 2017 and 2018, 16 were sampled one year after receiving GonaCon™ with 7 testing as not pregnant (44% efficacy) and 7 were sampled 2 years after receiving GonaCon™ with 2 testing as not pregnant (29% efficacy; Table 1). Eighty-six percent (n = 19) of deer that received 2 doses of GonaCon™ (n = 22) were not pregnant and differed from deer that did not receive GonaCon™ (n = 19; 100% pregnant; $OR_{(1)} = 1.012$, CI = 0.0002-0.1088, $P < 0.001$). Pregnancy results of double dose deer (n = 22; 86% efficacy) differed from pregnancy results of single dosed deer (n = 27; 33% efficacy; $OR_{(1)} = 0.084$, CI = 0.0126-0.3905, $P < 0.001$; Tables 2 and 3).

Using spotlight surveys, we estimated a total white-tailed deer population of 113 in 2014 and 198 in 2018 (Fig. 3). Using camera indices, we estimated a total white-tailed deer population of 183 (168–198) in 2015, 208 (194–222) in 2016, 158 (150–166) in 2017 and 199 (187–211) in 2018. 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

Table 2. Pregnancy results of 2 doses of GonaCon™ with first dose given in the Fall, Bald Head Island, North Carolina, USA, 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	1 year since last dose
3/3 (100%) not pregnant	4/5 (80%) not pregnant	1/1 (100%) not pregnant

Table 3. Pregnancy results of two doses of GonaCon™ with all doses administered during Spring, Bald Head Island, North Carolina, USA, 2014–2018.

All doses administered in Spring			1st dose administered in Spring
1 year between doses 1 year since last dose 8/8 (100%) not pregnant	2 years between doses 2 years since last dose 1/2 (50%) not pregnant	2 doses in the same season 1 year since last dose 1/2 (50%) not pregnant	2 doses in same year 4 years since last dose 1/1(100%) not pregnant

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.

The cost of the 5-year immunocontraception project was $320,030.52. Over the 5-year project, 154 captures occurred. In total, 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 captures cost $2,078.12/capture with an overall efficacy of 33% for one dose and 86% for 2 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 single-dose efficacy at 44% one year after receiving GonaCon™ and 29% 2 years after receiving GonaCon™. Previous studies (Gionfriddo et al. 2009, 2011) demonstrated single-dose efficacy at 67% and 88% after one year, and 43% and 47% efficacy after 2 years. Although immune response has been linked to nutrition levels, all of our study animals appeared physically healthy upon capture (Homsy et al. 1986, Chandra and Amorin 1992). Our study differed from Gionfriddo at al. (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, wherein they demonstrated that 50% of the deer that received GonaCon™ via hand injection were pregnant after one year.

A unique aspect of our study was the administration of 2 doses of GonaCon™ to a large number of deer; 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 in 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 examining 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 55 female deer receiving 2 doses of GonaCon™. Based on the current level of GonaCon™ treatment, our population model indicates the population could increase to pre-2010 levels by 2022. In the complete absence of GonaCon™, the modelled population

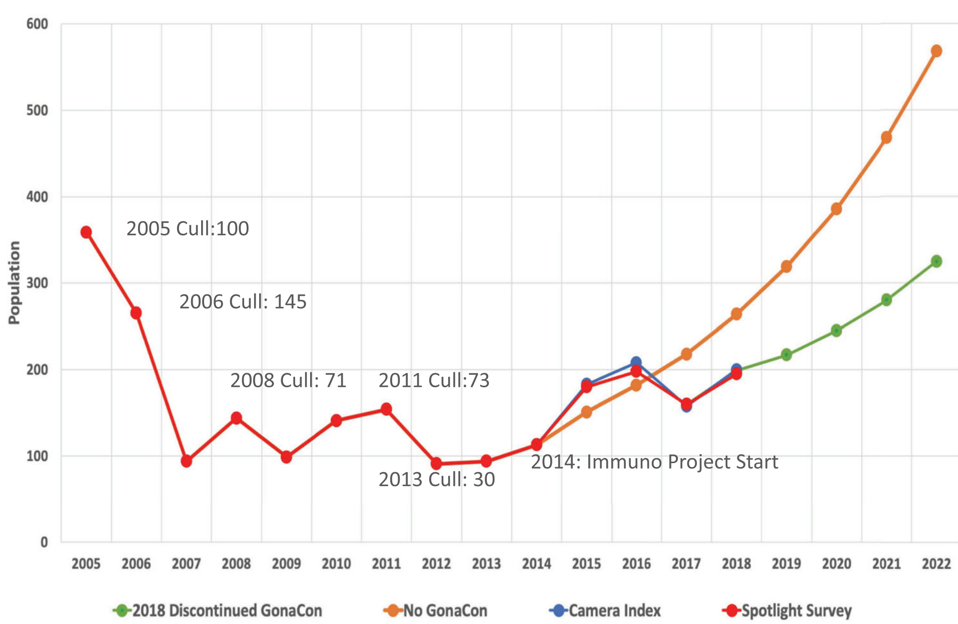

Figure 3. Discontinued GonaCon™ 2018 and no GonaCon™ population projections, historic spotlight survey, and camera index population estimates with the number of deer removed from culling, Bald Head Island, North Carolina, USA, 2005–2018.

was projected to have reached 264 in 2018. However, our spotlight surveys and camera indices estimated the deer population at 195 and 199, respectively, suggesting the use of GonaCon™ slowed the growth of the overall population, although population size 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 3 culls between 2005 and 2009, resulting in a decrease to 15–17 deer/km^2 (Sherrill et al. 2010).

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. Although 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 redosed the very next year. Additionally, some deer went more than a year between receiving their first and second doses and pregnancy check. We believe the resulting irregular treatment is a realistic limitation for using GonaCon™ on a free-ranging, 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% more expensive than the cost of culling and only resulted in an overall efficacy of 44% after one year and 29% after 2 years. Administering 2 doses of GonaCon™ was 87% greater than the cost of culling and resulted in an overall efficacy of 86%, and the length of efficacy of GonaCon™ in wild free-ranging deer is still unknown.

MANAGEMENT IMPLICATIONS

Our data 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 population growth. The difference in cost between immunocontraception and culling was $1500 per deer if GonaCon™ was administered once and $3600 per deer if it 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. Additionally, managers must take into consideration the possibility that deer captures could be restricted by state wildlife agencies to outside of hunting seasons and some unvaccinated deer may be required to remain in the population to maintain genetic diversity in deer populations that are closed or have restricted movements. Also, managers should account for increased difficulty in recapturing deer to administer a second dose as deer may learn and become more wary after being darted once. Importantly, managers will have to weigh the 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.

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