Field Test of GonaCon™ Immunocontraceptive Vaccine in Free-Ranging Female Fallow Deer

James P. Gionfriddo
USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado
Natalie B. Gates
USDI National Park Service, Point Reyes National Seashore, Point Reyes, California
Anthony J. DeNicola
White Buffalo, Inc., Moodus, Connecticut
Kathleen A. Fagerstone and **Lowell A. Miller**
USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado

ABSTRACT: Resident populations of two exotic deer species, fallow deer and axis deer, are having adverse impacts on their habitat and on native plant and animal communities at Point Reyes National Seashore (PRNS) in California. These non-native cervids were released intentionally for recreational hunting on the property now known as PRNS during the period 1942-1954. Approximately 860 fallow deer and 250 axis deer now inhabit PRNS. Under an approved non-native deer management plan, fallow and axis deer populations will be removed from PRNS by 2021 via culling of animals by sharpshooting and by treatment of some of the female fallow deer with GonaCon™ Immunocontraceptive Vaccine. During July-August 2007, 69 fallow does were captured, equipped with numbered ear tags and radiotelemetry collars, and injected with GonaCon™ vaccine before being released. Control animals include 10 does that were captured, marked, and given "sham" injections during July-August 2007, and 19 does that were captured and marked (but not injected) during 2005. Reproductive activity, as indicated by lactation and fecal concentrations of progesterone among the GonaCon™-treated and control does, will be monitored and compared for two years, and will be used to determine the efficacy of GonaCon™ as a cervid contraceptive agent. Traditional methods of population control, such as regulated harvest by licensed hunters, often are impractical or illegal in settings such as national and state parks, and the use of firearms may be prohibited in some urban and suburban environments. The development of safe and effective wildlife contraceptives such as GonaCon™ is needed to control locally overabundant populations in situations where traditional management tools cannot be employed.

KEY WORDS: contraception, *Dama dama*, fallow deer, fertility, GnRH, gonadotropin-releasing hormone, overabundant, Point Reyes National Seashore (CA), population control, vaccine

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INTRODUCTION

Locally overabundant cervid populations are causing serious ecological damage (Tilghman 1989, Rooney and Waller 2003, Côté et al. 2004) and conflicts with human activities and interests (Conover 2002) in many parts of the United States. White-tailed deer (*Odocoileus virginianus*) populations provide the best-known examples of cervid overabundance, but some populations of elk (*Cervus elaphus*) and other species also are overabundant. At Point Reyes National Seashore (PRNS) in California, burgeoning populations of two non-native deer species, fallow deer (*Dama dama*) and axis deer (*Axis axis*), have had adverse effects on some of the Seashore's other natural resources. These exotic ungulates compete with and displace native Tule elk (*Cervus elaphus nannodes*) and Columbian black-tailed deer (*Odocoileus hemionus columbianus*) at PRNS, and have the potential to transmit disease to these native cervids (National Park Service 2006b). Fallow and axis deer congregate seasonally in very large herds that damage fragile soils and native vegetation, especially in ecologically sensitive riparian areas that provide critical habitat for several special status species such as the California red-legged frog (*Rana aurora draytonii*), Coho (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*), and steelhead trout (*Oncorhynchus mykiss*). During the breeding season, fallow deer denude large patches of woodland through their lekking activities (Fellers and Osbourn 2006).

Fallow and axis deer from the San Francisco Zoo were introduced by a landowner during the 1940s and 1950s, for recreational hunting, on the property that later became PRNS. After PRNS was established in 1962, the non-native deer populations grew rapidly, and conflicts between non-native deer and ranching interests (livestock ranches remained as permitees within PRNS) prompted deer management (control) in 1968 (Gogan et al. 2001). Fallow and axis deer were lethally removed under various management programs until 1994, when deer control programs were discontinued because of the lack of an approved management plan and funding difficulties.

NPS lands such as PRNS are specifically mandated to control or eradicate exotic species and to re-establish natural functions and processes in park areas where human disturbances, which include the introduction of exotic species, have altered the natural ecosystems (National Park Service 2006a). To curtail and reverse the damage done at PRNS by these exotic ungulates, and to restore the ecological integrity of plant and animal communities, the NPS recently implemented a combina-

tion of deer contraception and lethal removal of deer to eradicate fallow and axis deer at PRNS by the year 2021.

The use of a combination of contraception and lethal removal of fallow and axis deer was selected from a series of non-native deer management options that were described and analyzed in a final environmental impact statement (FEIS) in 2006 (National Park Service 2006b). Other management options described in that document included passive management (no action), lethal removal of all non-native deer with no use of contraception, and reduction of deer numbers to pre-determined levels through lethal removal alone or in combination with contraception. The FEIS identified two options as being environmentally preferable (removal of all non-native deer by lethal removal, or by a combination of lethal removal and contraception) and one option as preferred (removal of all non-native deer by a combination of lethal removal and contraception).

Safe, effective, and practical wildlife contraceptive agents remain elusive. Despite decades of research and development, only one compound (nicarbazin) is commercially available in the United States for use in the contraception of wildlife. Nicarbazin, which is the active ingredient in two registered contraceptive products, decreases egg production and hatching in birds (Bynum et al. 2005). It is registered for use only in certain avian species (OvoControl-P® for Rock Doves [pigeons; *Columba livia*], and OvoControl-G® for Canada Geese [*Branta canadensis*] and for domestic mallard ducks [*Anas platyrhynchos*], domestic Muscovy ducks [*Cairina moschata*], and hybrids thereof).

An injectable contraceptive agent called GonaCon™ Immunocontraceptive Vaccine has been developed by United States Department of Agriculture (USDA) scientists at the National Wildlife Research Center (NWRC) in Fort Collins, Colorado. GonaCon™ shows great potential as a more widely-applicable contraceptive agent, but it is not yet registered for commercial use, and so it can only be used under strictly controlled conditions in approved, highly regulated, experimental studies. GonaCon™ was selected for experimental use at PRNS.

The practicality of administering contraceptive agents to fallow and axis deer differs because of fundamental differences in the reproductive biology of the two species. Fallow deer at PRNS exhibit a distinct annual breeding season during autumn, and breeding activity and subsequent fawning in the spring are relatively synchronized among individuals within the population. In axis deer, on the other hand, reproductive activity occurs throughout the year, rather than being confined to a specific season. During any given month, the axis deer population at PRNS contains females and males in all stages of the reproductive cycle: females may be breeding, pregnant, fawning, or reproductively acquiescent; males may be in any stage of annual antler development. Axis fawns in various stages of development are present at any time of year. Immunocontraceptive vaccines such as GonaCon™ are most effective if administered several months prior to the onset of breeding activity, to allow sufficient time for a strong immune response (that causes infertility) to develop. To induce infertility in most of the adult females in an axis deer population, several applications of GonaCon™ would be needed. Ideally, each application would target those females that would undergo estrus 2 to 3 months later. Identification of such animals, especially under field conditions, would be problematic. Administering multiple doses of GonaCon™ to individual animals would not harm the deer, but it would confound the experimental effort to evaluate the contraceptive's efficacy. For these reasons, GonaCon™ was administered only to fallow deer at PRNS. In addition, GonaCon™ treatment at PRNS was limited to female fallow deer because of potential adverse effects on antler development in males (Killian et al. 2005).

GonaCon™ causes temporary infertility by stimulating the production and release of GnRH (gonadotropin-releasing hormone)-specific antibody from the β-cells into the bloodstream. The antibody circulates throughout the body and eventually reaches the capillary region of the hypothalamus, where it comes into contact with native GnRH that is produced in the hypothalamus. The GnRH and its antibody bind together, forming large molecules ("immune-complexes") that travel to the anterior pituitary gland, where they are unable to diffuse out of the bloodstream through the capillary beds because of their large size. Instead, the immune-complexes remain in the venous blood and leave the pituitary without stimulating the release of luteinizing hormone (LH) and follicle stimulating hormone (FSH). In the absence of LH and FSH, which normally stimulate the synthesis of reproductive steroids in the gonads, animals of both sexes remain in a non-reproductive state. All reproductive activity is suspended and animals remain non-reproductive as long as sufficient antibody is present to bind to all of the GnRH that is circulating in the hypothalamic/pituitary portal system (Miller et al. 2000).

Initially formulated as a two-shot contraceptive agent, GonaCon™ Immunocontraceptive Vaccine has been refined so that a single injection can produce infertility for multiple years without boosting. The single-injection formulation of the vaccine has been tested successfully in many mammalian species, including California ground squirrels (*Spermophilus beecheyi*; Nash et al. 2004), domestic cats (*Felis catus*; Levy et al. 2004), domestic and feral swine (*Sus scrofa*; Killian et al. 2003, 2006b; Miller et al. 2003), wild horses (*Equus caballus*; Killian et al. 2004, 2006a), bison (*Bison bison*; Miller et al. 2004), and white-tailed deer (Miller et al. 2000, Gionfriddo et al. 2006).

METHODS

Fallow deer were captured during July and early August 2007, 4 to 8 weeks prior to the expected onset of the annual breeding season, with drop nets and with tranquilizer darts fired from specially modified rifles. Drop nets were pre-baited for 20 days to attract and acclimate deer to the nets before capturing began. Captured deer were tranquilized beneath the drop nets with a hand-injected mixture of ketamine and xylazine. Tranquilizer darts used to remotely capture fallow deer contained a mixture of Telazol® (tiletamine and zolazepam) and xylazine. Each captured doe was fitted with numbered, plastic ear tags and a radiotelemetry

collar. Ear tags bore the message "DO NOT CONSUME" and a National Park Service telephone number. An expandable, highly-reflective, red plastic collar was also placed on each animal to improve visibility of study deer during the remainder of the capture operation and during subsequent cull activities.

Captured deer were randomly assigned to treatment groups (GonaCon™ treatment or control), with a target ratio of about 7 GonaCon™ deer to 1 control deer, to ensure a sufficiently large sample size for vaccinated animals. The assignment of fewer deer to the control group was acceptable for two reasons. First, additional adult female deer, which were previously marked and equipped with radiotelemetry transmitters (although not injected), were present at PRNS and available for use as control animals in this study. Second, the need for control deer was reduced by the existence of abundant data from previous pen and field studies of GonaCon™ in deer (Miller et al. 2000, Gionfriddo et al. 2006). Only does at least 1 year old were included in the study; younger animals captured with drop nets were released without being marked or injected. Each GonaCon™-treated doe received a 1.0-ml injection of the contraceptive vaccine. The 1.0-ml sham injection given to each control doe consisted of mollusk stabilizing buffer (MSB) and AdjuVac™ adjuvant, in a water and oil emulsion. The sham material was identical to the GonaCon™ vaccine except that it lacked the GnRH-blue protein carrier conjugate. All injections (vaccine and sham material) were delivered deeply into the musculature of the upper hind leg with a 3-ml syringe equipped with a 1½-inch, 19-gauge hypodermic needle.

Vital signs were monitored as deer were processed, and eye ointment was used to prevent desiccation of the eyes. A blood sample was collected from each captured doe for laboratory analysis for the presence of antibodies to *Mycobacterium avium* to determine if the animal had been exposed to Johne's disease, which is caused by *M. a. paratuberculosis*. Several studies have shown that *M. a. paratuberculosis* is endemic in fallow deer, axis deer (Riemann et al. 1979), and Tule elk populations (Jessup et al. 1981, Cook et al. 1997, Manning et al. 2003) at PRNS. A fecal sample also was collected at the time of capture for testing for the presence of *M. a. paratuberculosis*. Testing for prior exposure to Johne's disease was important because deer that had been exposed to the disease might mount a stronger immune response to the GonaCon™ vaccine, which contains killed *M. avium* in its adjuvant, than deer not previously exposed. Data collected for each deer at capture included the date, ear tag numbers, radiotelemetry transmitter frequency, method and location of capture, estimated weight and age (based on tooth wear patterns), location of the vaccine or sham injection site, location of the tranquilizer dart injection (if applicable), drugs and dosages used, times of capture and remobilization, an assessment of overall body condition (Riney 1960) and pregnancy status, blood sample number, and values for vital signs (heart and respiration rates, body temperature) monitored during animal processing. An intravenous injection of Tolazine® (tolazoline hydrochloride) was given to each doe to reverse anesthesia and hasten recovery. Deer were released at capture sites.

All vaccinated and control deer will be monitored by NPS staff for mortality and for continued presence at PRNS via radiotelemetry for 2 years or until their telemetry collars fail. Each radiotransmitter has a mortality switch that would be activated if the deer (i.e., the collar) were motionless for more than 4 hours, enabling researchers to locate deer carcasses or lost collars.

The contraceptive efficacy of GonaCon™ will be determined annually for 2 years. Two methods will be used to compare the proportion of treated does that become pregnant with the proportion of untreated does that become pregnant. First, field observations of experimental fallow deer during the springs and summers of 2008 and 2009 will be used to assess reproductive status. Observations of udder development and condition will be used to determine which does are lactating, and lactation will be used as an indicator of current or recent pregnancy. Such observations will not permit a determination of the number of fawns a given doe produced that year, nor will they permit a determination of the survivorship of fawns. They will, however, provide the critical information we seek: whether or not pregnancy occurred.

The second method of evaluating GonaCon™'s contraceptive efficacy will use standard radioimmunoassay (RIA) or enzyme-linked immunoassay (ELISA) techniques to measure deer fecal progesterone levels as indicators of pregnancy. An effort will be made to collect at least 1 fecal sample from each experimental doe per year during late winter-early spring, when fallow deer at PRNS are typically in the last trimester of pregnancy. Fecal samples will be collected using a technique that has been employed in elk studies at PRNS (Stoops et al. 1999, Shideler 2000).

RESULTS

Eighty adult female fallow deer were captured (66 with drop nets and 14 with tranquilizer darts) at PRNS from July 16 to August 2, 2007. Sixty-nine does were vaccinated with GonaCon™ Immunocontraceptive Vaccine, 10 (control animals) were injected with the sham material, and one animal was (inadvertently) not injected with either the vaccine or sham material. Nineteen additional does that had been captured, marked, and released (without injections) by NPS scientists at PRNS during 2005 also were included in this study as controls. No deer were injured or killed during the capture operation, and all deer were released at their capture sites without incident.

DISCUSSION

Fallow deer at PRNS will be culled with a goal of eradication under an approved non-native deer management plan during the next 13 years. GonaCon™ Immunocontraceptive Vaccine is being used experimentally in fallow deer at PRNS to evaluate the safety and efficacy of the vaccine and to reduce the reproductive output of deer and thereby reduce the number of deer that must be killed to achieve eradication. Data from this field study could be submitted to the U.S. Environmental Protection Agency as part of the registration process for GonaCon™ as a new wildlife contraceptive agent.

We anticipate that GonaCon™ vaccine will become a useful addition to the tools used by wildlife professionals to manage populations of overabundant wild animals in settings where other methods such as regulated sport hunting cannot be applied. It must be emphasized that GonaCon™ vaccine and other infertility agents will be applied predominantly where traditional management methods cannot be used and that they will not replace lethal control methods as the primary means of managing wildlife populations.

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