Sterilization as an alternative deer control technique: a review

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Abstract: Burgeoning white-tailed deer (*Odocoileus virginianus*) populations in suburban landscapes continue to impact communities and challenge natural resource managers. Increased deer-related damage to vegetation, ecosystems, and automobiles can exceed the tolerance of local stakeholders. We provide an overview of the potential efficacy of using surgical sterilization to help manage populations and conflicts associated with locally overabundant white-tailed deer populations. We review theoretical and field studies pertaining to deer sterilization, and provide research priorities to help guide future sterilization efforts. Recent field studies suggest that sterilization of female deer remains expensive, at approximately $1,000 per surgery. Sterilization may provide an alternative management technique for reducing suburban deer herds in communities willing to endure the costs of a long-term effort and where lethal deer removal is unacceptable or impractical. Surgical sterilization is scale-limited based on the ability to capture and sterilize 80% or more of the female deer in a population and maintain that proportion of the population treated over time. Overall success will be greatest for closed or insular deer herds where the effects of immigration can be minimized.

Key words: control, human–wildlife conflicts, *Odocoileus virginianus*, sterilization, surgery, white-tailed deer.

Effective control of overabundant white-tailed deer (*Odocoileus virginianus*) populations is of increasing concern to the public and wildlife managers. White-tailed deer have reached unprecedented population levels in some areas of the eastern United States as aesthetic preferences for forested suburban landscapes have created large areas of habitat with low predation risk (Diamond 1992, McCullough et al. 1997). Deer-related damages to vegetation, ecosystems, and automobiles in these areas frequently exceed the tolerance of local communities (Decker and Connelly 1989, Diamond 1992, McCullough et al. 1997, Waller and Alverson 1997, Curtis et al. 1998).

Control of white-tailed deer population densities has conventionally focused on lethal removal (i.e., sharpshooting or hunting). In an increasing number of communities, however, lethal management strategies are rejected based on legal, safety, or ethical concerns (Decker and Connelly 1989, Wright 1993, McCullough et al. 1997), fostering interest in alternatives, including translocation, contraception (McShea et al. 1997, Warren 1997, Malcolm et al. 2010), and surgical sterilization (MacLean et al. 2006, Merrill et al. 2006, Boulanger et al. 2009, Gilman et al. 2010). Translocation is rarely feasible due to cost, limited potential release sites, stress experienced by deer during transport, and risks of disease transmission (McCullough et al. 1997, Waas et al. 1999, Beringer et al. 2002, DeNicola and Williams 2008). Predator reintroduction also has been proposed, but this method evokes safety concerns for many stakeholders because of the potential for negative human–predator interactions (Diamond 1992, Warren 2011).

Fertility control has been attempted on terrestrial and avian wildlife species (Fayrer-Hosken et al. 1997, Pech et al. 1997, Hundgen et al. 2000, Fagerstone et al. 2010). For example, experimental use of immunocontraceptive vaccines has been attempted on overabundant white-tailed deer populations (Fagerstone et al. 2010), and surgical sterilization of coyotes (*Canis latrans*) has been used to protect livestock (Bromley and Gese 2001) and to control hybridization with endangered red wolves (*Canis rufus*; Fredrickson and Hedrick 2006, Roth et al. 2008). Many studies agree, in theory, that fertility control might reduce and maintain some animal populations at desired levels (Sturtevant 1970, Knipling and McGuire 1972, Chambers et al. 1999, Twigg and Williams 1999).

Implementation with larger mammals, such as deer, however, may be difficult, and published assessments of the feasibility of managing these populations via fertility control have varied widely (Seagle and Close 1996, Barlow et al. 1997, Hobbs et al. 2000, Rudolph et al. 2000). Porter et al. (2004) suggest that female suburban white-tailed deer possess behavioral attributes, such as smaller home ranges (when compared to their rural counterparts), limited seasonal movements, and high site fidelity that may enhance feasibility of culling or contraception programs at smaller geographic scales (5 to 10 km$^{2)}$, but the authors warn that dispersal may complicate management. Some studies suggest that fertility control may be more effective than culling because treated individuals are able to contribute to resource limitation and density-dependence in reproduction (Knipling and McGuire 1972, Boone and Weigert 1994). Other studies suggest that culling is more effective and must be included as part of a fertility control program (Nielsen et al. 1997, Hobbs et al. 2000). The Wildlife Society's (2008) final position statement on wildlife fertility control suggests that such application may potentially have use in urban or suburban locales or other areas with little immigration and where lethal deer control (e.g., hunting) is restricted.

Duration of fertility control can vary from transient (i.e., temporary) to permanent (e.g., surgical sterilization; Merrill et al. 2003). Early studies in deer contraception using steroids reported limited success, but concerns over secondary consumption by nontarget animals (e.g., scavengers) and humans limited this type of treatment (Turner et al. 1992). In a recent study, intrauterine devices that were implanted prior to the breeding season prevented pregnancy in 6 of 8 female deer during a 2-year period (Malcolm et al. 2010). While progress has been made with immunocontraceptive vaccines and their safety, continued refinement in their development and delivery systems is still needed (Cowan et al. 2003). Moreover, further acceptance of fertility control by the public and natural resources agencies may be necessary (Fagerstone et al. 2002, 2010). Immunocontraception may be unsuitable in some communities because of prohibitive long-term costs, uncertainty in identifying treated individuals in free-ranging deer, and

the need for repeated treatments (Kirkpatrick et al. 1997, Rudolph et al. 2000, Curtis et al. 2002, Merrill et al. 2003). GonaCon™ (National Wildlife Research Center, Fort Collins, Col.), a gonadotrophin-releasing hormone (GnRH) immunocontraceptive vaccine, is currently registered with the U.S. Environmental Protection Agency for use on female white-tailed deer 1 year of age or older (Fagerstone et al. 2010). In a recent field study, a single shot of GonaCon™ was administered to female white-tailed deer; 88% and 47% of treated deer did not become pregnant during the first and second years, respectively (Gionfriddo et al. 2009).

Although previous model-based (Barlow et al. 1997, Hobbs et al. 2000, Merrill et al. 2003) and field studies (MacLean et al. 2006) have suggested that sterilization of female deer has the potential to regulate or reduce overabundant ungulate populations, the efficacy and practicality of this technique has not been established. Despite this fact, several experimental sterilization studies have been or are being conducted to help control deer overabundance. With the increase in research and a continued demand for nonlethal deer control options, timely information will better inform researchers, managers, and stakeholders who may be considering this technique. We review theoretical and field studies pertaining to deer sterilization and provide research priorities to help guide future sterilization efforts. Because surgery is currently the only reliable means to permanently sterilize female deer (MacLean 2006), we focus our review on this technique as a means to manage locally overabundant white-tailed deer herds (Figure 1).

Theoretical application of sterilization

Modeling studies have suggested that sterilization may reduce ungulate overabundance (Barlow et al. 1997, Hobbs et al. 2000). Boone and Wiegert (1994) identified sterilization of deer as a viable alternative to lethal control when used to supplement hunting pressure. Seagle and Close (1996) examined the effects of various sterilization proportions, and suggested that treating at least 50% of breeding-age females was expected to reduce white-tailed deer populations.

Figure 1. Adult female white-tailed deer undergoes surgical sterilization at the Cornell University Hospital for Animals.

Even with higher rates, however, a 5- to 10-year planning horizon was necessary to see reductions in population size (Seagle and Close 1996). Hobbs et al. (2000) demonstrated that fertility control of varying duration could regulate ungulate populations under some circumstances, but they evaluated models over infinite time horizons and did not consider the relative efficiency for fixed-time horizons. Thus, communities experiencing deer damage had little information on which to predict success of fertility control programs within 5- or 10-year timelines, scales over which stakeholder decisions are often made.

Unlike previous studies, modeling by Merrill et al. (2003) considered impacts of survival and fertility rates of all gender classes, uncertainty in birth and survival rates across all sterilization levels, and the relationship between annual sterilization rates and the expected time to specific population reduction. Merrill et al. (2003) determined that a hypothetical, closed white-tailed deer population may be reduced by 30 to 60% in 4 to 10 years if 25 to 50% of the fertile females could be sterilized annually. However, assuming high birth and survival rates typical for many suburban deer herds, a 75% reduction would require approximately 7 years at an 80% annual sterilization rate (Merrill et al. 2003).

Merrill et al. (2006) noted that previous modeling which tested the plausibility and efficacy of sterilization as a potential management strategy relied on several assumptions: (1) complete control in sterilizing deer in a population; (2) deterministic models

reliably predict outcomes; (3) no behavioral changes in deer post sterilization; and (4) deer populations that are closed. In reality, managers will not likely have control over the difficulty associated with deer capture. For example, males and recaptured sterilized deer may confound trapping efforts. Moreover, a lack of access to suitable capture sites could be an obstacle to reaching a minimum proportion of females (Rudolph et al. 2000). The second assumption of deterministic models is problematic because of the complex effects of environmental and demographic stochasticity. In northern climates, for example, periodic mild winters lead to periodic increases in productivity, which could intermittently limit the effectiveness of controlling deer populations. In the third assumption, a sterilized deer may become trap-averse or exhibit trap affinity to baited stations. Lastly, the assumption of closed populations suggests that sterilization would be effective if birth rates were lowered. In an open population, however, recruitment consists of both in situ recruitment (local births) and immigration, while sterilization only reduces births from female deer. Modelling by Merrill et al. (2006) accounted for stochasticity and demonstrated a low probability of sterilization alone as a successful management technique in an open deer population.

Sterilization will likely be more successful in a closed or insular population of white-tailed deer. In a truly closed population, however, N may be constant, implying that birth and death rates are equal, which is an unlikely scenario for most deer populations. With immigration, the absolute number of deaths must be greater than births and new immigrants to reduce deer abundance. In some deer populations, the number of deaths may be insufficient to outnumber immigrants. Thus, lowering birth rates via sterilization might slow growth, but it is unlikely to reduce the population unless immigration rates are low or mortality rates (e.g., deer–vehicle collisions [DVCs]) are high. Merrill et al. (2006) note that in closed populations the only new annual recruits are fawns with minimal reproductive capacity. In open populations, however, increased sterilization efforts may be required because new immigrants include adult females that can reproduce at maximum capacity. However,

immigration from an expanding deer population may be slow because adult female white-tailed deer tend to be highly philopatric (Porter et al. 1991, 2004, Rudolph et al. 2000, Kilpatrick et al. 2001). Porter et al. (2004) demonstrated the importance of considering closure when using fertility control to manage localized suburban deer populations, and suggested that emigration may be another complicating factor. Merrill et al. (2006) suggest that reducing survival rates for reproductive-age females is the most effective means for reducing deer populations and that controlling immigration may be more effective than controlling birth rates in suburban deer herds.

Field studies in surgical sterilization

Research pertaining to surgical sterilization as a technique to control deer populations is still in its infancy. Vasectomy was used to permanently sterilize male white-tailed deer (Frank and Sajdak 1993). Sterilization of male deer, however, is unlikely to be effective due to their polygynous mating and the effort involved in treating nearly all males (Merrill et al. 2003). Thus, control of deer population growth is more practically attained by managing fertility of females (Porter et al. 2004). Techniques used to sterilize female deer have included laparotomy or laparoscopy with tubal ligation, tubal transection, or ovariohysterectomy (Frank and Sajdak 1993, MacLean et al. 2006). MacLean et al. (2006) favored laparotomy over laparoscopic procedures for logistical reasons and to avoid the risk of damaging the uterus of pregnant females. Adult females with an abundance of omental fat may also hinder laparoscopic procedures (Frank and Sajdak 1993). Unlike surgical procedures that remove ovaries, tubal ligation prevents reproduction without altering normal hormonal function, which results in repeated estrus cycling during subsequent years. Pregnant does receiving tubal ligation surgery will carry their current fetuses to term if captured in winter, but will not become pregnant thereafter. Warlock (1997) studied the effects of tubal ligation on behaviors of a captive white-tailed deer population and suggested that sterilization was not detrimental to treated does.

While surgical sterilization of female deer was effective in preventing pregnancies, there are few published accounts of its implementation in free-ranging populations. Frank and Sajdak (1993) reported that sterilization slowed population growth of a white-tailed deer population on the grounds of the Milwaukee County Zoo (Milwaukee, Wis.). From 1990 to 1992, 14 (8 male and 6 female) deer were sterilized; the population was reduced to 2 animals by March 1993 (Frank and Sajdak 1993). During the time of this study, the cost of surgical procedures (e.g., drugs, materials, veterinarian and zoo personnel salary) for bucks and does ranged from approximately $46 to $83 and $94 to $210, respectively.

The city of Highland Park, Illinois, like other suburban areas with unhunted deer populations, was experiencing overabundance and a concomitant increase in negative human–deer interactions (Skinner 2007). The deer density in Highland Park was estimated to be 4 to 5 deer/km^2 (MacLean et al. 2006). In 2002, a program was implemented in Highland Park to investigate the long-term effects of permanent female sterilization on free-ranging white-tailed deer behavior and abundance (Maclean et al. 2006). In that study, 67 female deer were sterilized under field conditions using a mobile surgical unit and tubal ligation (n = 64), tubal transection (n = 2), and ovariohysterectomy (n = 1) surgeries. Two years post-sterilization, no sterilized does were observed with fawns. Researchers concluded that the surgical procedures provided effective sterilization with low mortality rates in suburban deer (Maclean et al. 2006). In this study, however, it was reported that sterilized females had significantly higher deer–vehicle collision mortality rates when compared to a control group of fertile females; greater movement of non-gravid females was suggested to be the cause (Skinner 2007, Gilman et al. 2010)."

Modeling suggested that surgical sterilization could control the deer population to the desired goal of 2 deer/km^2 by treating 32% of females annually, albeit with long-term maintenance (i.e., 9.5 years; Skinner 2007). The average cost per deer sterilization, including capture time, was >$1,000 (N. Mathews et al., University of Wisconsin, unpublished data). The direct cost for the veterinarian's work was approximately $750 per deer, including $150 in drugs per deer and veterinarian's time.

The city of Town and Country, Missouri, a suburb of St. Louis, comprised of suburban and commercial development, parks, and other open spaces, implemented a surgical sterilization and sharpshooting program from November to December 2009 in response to burgeoning deer populations (A. J. DeNicola, White Buffalo Inc., unpublished data). Twelve days of fieldwork were required to capture and sterilize 100 does, utilizing a mobile surgical trailer and part-time veterinary surgeon. Methods followed those from Highland Park, Illinois (MacLean et al. 2006), except that ovariectomies were performed through mid-line incisions (not lateral incisions or tubal ligations). Program staff expended 690 person-hours for the capture and surgical sterilization efforts. Capture effort (time to drop-net or dart and locate deer) was 449 person-hours. Surgery effort (i. e., time to bring deer from the location of recumbency to surgery trailer, conduct the ovariectomy, and return to point of capture) was 241 person-hours. The approximate cost per deer sterilized in the Town and Country program was $960 per deer (A. J. DeNicola, White Buffalo Inc., unpublished data).

Surgical sterilization in Ithaca, New York

The residents of Cayuga Heights, an affluent suburban community in the town of Ithaca, New York, were experiencing an increasing population of white-tailed deer and associated impacts (Chase et al. 1999, Shanahan et al. 2001). In surveys of Cayuga Heights residents, respondents expressed concern regarding DVCs, damage to plantings, and Lyme disease (Shanahan et al. 2001). Over 80% of respondents reported damage to trees, shrubs, and flower gardens and 23 to 25% reported experience with deer-related auto accidents (Shanahan et al. 2001). In response to these impacts, Cayuga Heights implemented a surgical sterilization program to reduce the population of overabundant deer (Boulanger et al. 2009). Between 2002 and 2004, 24 female deer were surgically sterilized via tubal ligation (n = 8), ovariectomy (n = 15), and hysterectomy (n=1).

Captured deer were fitted with numerical ear tags, radio collars, and infrared-triggered cameras and Program NOREMARK (White 1996) with Bowden's ratio estimator was used to estimate deer abundance during the study (Curtis et al. 2009). Deer population estimates and 95% confidence intervals for 2000, 2002, and 2004 were 124 (104, 148), 157 (115, 214), and 87 (67, 113), respectively (Boulanger et al. 2009, Curtis et al. 2009). Sterilization alone was unlikely the sole cause of the reduction in deer numbers at Cayuga Heights. Based on Merrill et al. (2003, 2006), a response was not expected, as the sterilized fraction of females was below suggested thresholds for impact, and enough time may not have elapsed for an effect to be discerned in population abundance. Moreover, the harsh winter of 2002–2003 may have decreased survival rates. In that season, there was 82 cm more snow than the long-term average, ranking sixth for the highest recorded snowfall in Ithaca since 1893. Moreover, there were 32 more days with snow on the ground than the long-term average, ranking eighth for most snow on the ground (National Oceanic and Atmospheric Administration, Northeast Regional Climate Center at Cornell University, Ithaca, New York). Sterilization costs were >$1,000 per deer during the study, which included $550 for pharmaceutical supplies, anesthesia, equipment sanitizing, and laundry, and $525 labor costs to capture and mark each deer. Cornell University's Large Animal Hospital donated surgery expenses for resident surgical training (Boulanger et al. 2009).

Information from the Cayuga Heights study, in part, has led to continued research of surgical sterilization on Cornell University (Ithaca, New York) lands to supplement a controlled deer hunting program (Boulanger et al. 2009). For this 5-year study, Cornell lands were divided into 2 zones: a core campus area (446 ha) where sterilization was the main management technique and outlying areas (582 ha) containing agricultural fields, woodlots, and natural areas where hunting has been permitted for decades (Boulanger et al. 2009). The primary objective for the core campus zone was to reduce deer damage to unique plant collections and research plots while minimizing safety risks associated with deer. We continue to monitor complaints about deer damage to plants, reported DVCs, and deer abundance. The primary objective for the hunting zone was to reduce deer damage to agricultural fields and natural areas through an intensely managed Earn-a-Buck hunting

program (Ferrigno et al. 2002, Boulanger et al. 2009, Van Deelen et al. 2010), focusing on the increased harvest of female deer. Closer to campus, archery hunting is the primary approach; use of firearms is permitted in more distant areas (Boulanger et al. 2009).

Infrared-triggered camera methods outlined by Curtis et al. (2009) were used to estimate 93 (95% CI = 84,102; ~21 deer/km^2) deer on the Cornell University campus in March 2009 (Boulanger et al. 2009). From October 2007 through March 2009, 58 sterilization surgeries were performed on white-tailed deer captured on the Cornell campus; 11 deer in this group received ovariectomies, and 47 deer received tubal ligations (Boulanger et al. 2009). The approximate cost per deer sterilized in this study was >$1,000, which included expendables, such as pharmaceutical supplies, anesthesia, equipment sanitizing, and laundry, as well as labor costs for capture and marking; surgery expenses were donated for Cornell veterinary staff and resident surgical training (Boulanger et al. 2009). Deer that received ovariectomies were not subsequently observed with fawns; however, 1 tubal ligation surgery failed, resulting in parturition.

Discussion

Deer abundance may be managed with surgical sterilization in specific situations and may be more realistic at smaller, local scales (e.g., 5 to 10 km^2). For example, Frank and Sajdak (1993) demonstrated a reduction in deer numbers because they started out with a small herd of deer. Clearly, sterilization efforts will be more difficult and costly in a community suffering the effects of overabundance from hundreds of deer over a large geographic range. Communities ready to commit to sterilization control should be prepared for a long-term effort (e.g., ≥10 years). Based on Merrill et al. (2003), we recommend that >80% of female deer be targeted for sterilization surgery due to the white-tailed deer's high survival and reproductive rates in suburban landscapes. However, we recognize that treating such a large proportion of deer is not feasible for some communities. If a longer timeline is possible, a community may consider treating a smaller proportion of deer, but if a community cannot initially target at least 50% of the local

population, then sterilization should not be implemented due to cost and lack of efficacy. Ultimately, factors that would influence efficacy of sterilization at the population level include the proportion of females that could be treated, failed surgeries, compensatory responses (e.g., increased survival of treated females and increased reproduction in untreated females), and mortality and dispersal rates.

Controversy over lethal versus nonlethal means to control deer populations in urban and suburban areas continues to spark interest in alternative fertility control methods, such as surgical sterilization. While tubal ligation has been safely used for urban white-tailed deer, Skinner (2007) found increased vehicle mortality for sterilized female deer, and Gilman et al. (2010) suggested increased non-maternal movement as a possible cause. These collateral impacts may be confounding to biologists attempting to reduce DVCs and use these data to assess management effects. Paradoxically, this increased mortality may benefit wildlife managers trying to reduce deer population levels, but it may not end the debate over lethal control. Conversely, Rutberg and Naugle (2008) found no correlation between deer treated with immunocontraceptives and DVCs, and suggested that any added behavior effects caused from treatment are likely to be small and offset by the benefits of population management. The relationship between sterilization, deer densities, and DVCs deserves further investigation.

Results from modeling do not bode well for the feasibility of surgical sterilization as the sole tool for reducing open deer populations, especially if immigration offsets decreases in population size (Merrill et al. 2006). With the exception of some gated residential communities and government reservations, for example, most communities experiencing impacts will have open populations of white-tailed deer. Sterilization programs that include an initial effort of lethal control may be more successful in reducing overabundant herds. Once a population is reduced, efficacy of sterilization may be greater than lethal control in maintaining desired population levels (Merrill et al. 2003). Also, fewer deer will need to be surgically treated, which may lower overall program expenses. If a combined-methods

program is chosen, we recommend that surgeries be performed first, as capturing deer is more difficult than sharpshooting or hunting. Deer that are most susceptible to capture can be sterilized, and the less accessible deer may be targeted by lethal techniques. Further research is needed to assess the effects of immigration and the use of lethal control as a complement to sterilization.

Surgical sterilization as a management option may not be as cost effective as culling (Curtis et al. 1998). Start-up expenses, drugs, surgeries, and deer capture comprise just a few of the costs associated with this technique (Merrill et al. 2003). Boone and Wiegert (1994) suggested that effective applications may require a large number of animals to initially be sterilized, demanding high start-up costs. Initial efforts would need to be sustained for several years and then relaxed as the number of sterilized females increased (Nielsen et al. 1997). Capture costs also will be related to deer behavioral responses and access to adequate capture sites. Trap-averse deer would result in a lower recapture rate and allow for unsterilized animals to be captured, while trap affinity of deer at baited capture sites would increase costs (Merrill et al. 2003). Recent reports suggest that actual costs of surgical sterilization will be approximately $1,000 per deer. The cost per deer, however, is not constant. Initial captures may be cost efficient, but cost per deer may increase exponentially for the last percentile of targeted deer, which are the most difficult to catch (Rudolph et al. 2000). Direct comparisons of cost among studies are difficult because of differences in year of study, sterilization techniques, capture techniques, staff time, and number of deer treated.

Surgical sterilization currently may be more cost effective than transient fertility control techniques, such as immunocontraceptive vaccines (e.g., GonaCon™) that are not 100% efficacious, and require booster shots. Curtis et al. (1998) estimated minimum costs ($296 to $703 per deer) to capture and treat a female deer with contraceptive vaccines in Irondequoit, New York. While these estimates were lower than current costs for surgical sterilization, the vaccines required subsequent booster shots for each treated deer. As contraceptive vaccines and surgical sterilization techniques improve, cost-benefit analyses will be needed to discern short- and long-term differences between these fertility control methods.

Research is needed to quantify the effects of surgical sterilization. For example, female deer released from the energetic costs of reproduction may experience higher survival rates. Also, female deer receiving tubal ligation surgery will experience repeated estrous cycles during winter and spring. Consequently, females may attract more bucks into their home range, which may increase DVCs or rubbing damage to valuable ornamental plantings. In addition, the hormonal or physiological effects of surgical ovariectomies remain unclear.

Initial field studies using surgical sterilization demonstrated the potential for reducing suburban deer herds, albeit with a substantial initial effort and cost relative to some types of lethal control. While progress has been made with contraception, we suggest long-term cost savings when using surgical techniques that preclude the need for deer recapture. Should communities be willing to endure the costs of a long-term effort, surgical sterilization may be a viable option for reducing deer populations where lethal deer removal is impractical. In addition, such applications will be scale-limited based on the ability to capture and maintain a high percentage of sterilized deer each field season. Additional field research is needed to measure immigration and emigration rates for suburban deer herds, as this will affect the effectiveness and time scale for proposed fertility control programs.

Acknowledgments

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