**WEST HANTS REGIONAL MUNICIPALITY REPORT**

| Information X | Recommendation ☐ | Decision Request ☐ | Councillor Activity ☐ |
|---|---|---|---|

**To:** Mayor Zebian and Members of West Hants Regional Municipal Council

**Submitted by:** ___________________________________

Sara Poirier, Director of Planning and Development

**Date:** 2024-06-11

**Subject:** Deer Management

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## LEGISLATIVE AUTHORITY

N/A

## RECOMMENDATION or DECISION REQUEST

This report is provided for information purposes only.

## BACKGROUND

| Property ☐ | Public Opinion ☐ | Environment ☐ | Social ☐ | Economic X | Councillor Activity ☐ |
|---|---|---|---|---|---|

At the April 23, 2024 Council meeting Council approved the following motion:

> …COUNCIL DIRECTS THE CAO TO DIRECT STAFF TO PROVIDE AN INFORMATION REPORT ON DEER MANAGEMENT FOR THE JUNE COMMITTEE OF THE WHOLE MEETING.

## DISCUSSION

This information report was requested by Council as deer have been seen in larger groups in more urban areas of the Municipality, where they are protected from hunting, have wooded areas and fields to rest, and have an abundant food source. They have been becoming a nuisance when traveling close to or across roadways or eating resident's gardens. This information report is provided to outline the hunting regulations in Nova Scotia, Provincial resources available, what the current practice is in WHRM and what other municipal units, such as Truro, has done to combat the urban deer population.

**Hunting Regulations in Nova Scotia**

The Department of Natural Resource and Renewables provides regulations on hunting in Nova Scotia. In Nova Scotia a hunter must:

- Complete and pass the Canadian Firearms Safety Course;
- Complete and pass the Nova Scotia Hunter Education course; and
- Purchase a hunting license.

The *2023 Hunting and Furharvesting Summary of Regulations* on the Department of Natural Resources and Renewables website outlines the regulations related to hunting in Nova Scotia, including setbacks for hunting and trapping (Attachment B). More information can be found at https://novascotia.ca/natr/hunt/pdf/hunting-and-furharvesting-summary-of-regulations.pdf

**Department of Natural Resources and Renewables**

Following the direction of Council in April, staff reached out to the Department of Natural Resources and Renewables for information on urban deer management. The Department has not yet developed educational materials however is planning to host an information webinar for interested municipalities later this year, as they have been receiving increased request for information related to urban deer management.

The Department of Natural Resources and Renewables did provide a copy of a report entitled *"Methods for Managing Deer in Populated Areas"* by the Association of Fish and Wildlife Agencies. This report provides a variety of deer management and mitigation options for Council to consider (Attachment C).

**West Hants Regional Municipality**

In addition to the Provincial requirements for hunting, the Municipality has a Firearms By-law in the former Town of Windsor which does not permit use of a bow, crossbow, gun, air rifle or firearm of any kind within the former Town limits. Hunting is permitted in other areas of the Municipality provided all Provincial regulations are met.

In relation to animals, the WHRM By-law Enforcement Officers enforce dogs running at large or fierce or dangerous dogs in accordance with the Regional Dog By-law and the keeping of exotic pets in accordance with the Exotic Pet By-law for the former District of West Hants and former Town of Windsor. Development Officers enforce livestock complaints in accordance with the relevant Land Use By-law. Any complaints about nuisance deer should be reported to the Department of Natural Resources and Renewables.

**Town of Truro Deer Management Strategy**

The Town of Truro approved a Deer Management Strategy in 2021, following several years of discussions with the Department of Natural Resources and Renewables. The Department of Natural Resources and Renewables required sufficient baseline data before they would allow any action to be taken in Truro. The Town has been collecting annual data since 2016 to identify trends relating to the urban deer population.

In accordance with the Town of Truro Deer Management Strategy, controlled managed hunts have taken place since winter 2022. The Town website states that *"the purpose of the Town's Deer Management Strategy is to reduce the deer population numbers within the Town of Truro for the benefit of natural ecosystems, and citizen landscapes, reducing Deer-Vehicle Collisions (DVC's), public health concerns, the possible presence of deer predators, and an overall reduction of deer human conflict."* The Town collaborates with community partners to ensure there is no waste from the managed hunts.

More information can be found at https://www.truro.ca/urban-deer-management.html#:~:text=Town%20Council%20approved%20the%20Deer,within%20the%20Town%20of%20Truro and https://hub-connect-townoftruro.hub.arcgis.com/apps/e3fee988e7e14531b0036afb804bdc6e/explore

**NEXT STEPS**

N/A

**FINANCIAL IMPLICATIONS**

There are no financial implications in relation to the filing of this report.

**ALTERNATIVES**

N/A

**ATTACHMENTS**

| | |
|---|---|
| Attachment A | 2024-04-04 Report from Councillor Smith to CoTW: Deer Population |
| Attachment B | Excerpt from 2023 Hunting and Furharvesting Summary of Regulations – Setbacks for Hunting |
| Attachment C | *Methods for Managing Deer in Populated Areas* by Association of Fish and Wildlife Agencies |

**CHIEF ADMINISTRATIVE OFFICER REVIEW**

Report Prepared by: ___________________________________

Sara Poirier, Director of Planning and Development

Report Reviewed by: ___________________________________
Shawn Levy and Ryan Parker, By-law Enforcement Officers

Report Approved by: ___________________________________
Mark Phillips, Chief Administrative Officer

**Attachment A**

West Hants
something inspiring awaits

**WEST HANTS REGIONAL MUNICIPALITY REPORT**

| | | | |
|---|---|---|---|
| Information X☐ | Recommendation ☐ | Decision Request ☐ | Councillor Activity ☐ |

**To:** **CoTW**

**Submitted by:** John Smith Councilor District 9

**Date:** April 4,2024

**Subject:** **Deer Population**

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**LEGISLATIVE AUTHORITY**

(State where ability for consideration comes from if applicable)

**RECOMMENDATION or DECISION REQUEST**

Information Report

**BACKGROUND**

| | | | | | |
|---|---|---|---|---|---|
| Property ☐ | Public Opinion X☐ | Environment X☐ | Social ☐ | Economic ☐ | Councillor Activity ☐ |

(Provide the Who, What, When, Where and Why. If a Councillor Activity Report check "Councillor Activity" and provide your update/info below in the "Discussion" section.)

**DISCUSSION**

I bring this discussion because it affects many of the residents and there seems to be misinformation about the situation so it would be desirable to have accurate information recorded in the minutes.

There is a large and growing deer population living in District 9. Fifteen years ago it was common to see one or two deer every now and then but the population has grown and it is common to see deer roaming the neighborhoods in large numbers, sometimes as many as 30 deer in one residential area. Falmouth is an ideal habitat for deer, they are protected from hunting because of the houses, they have plenty of woodland and fields to rest in and many shrubs to flowers to eat.  In addition to eating peoples gardens the deer are a road hazard, many have been struck by vehicles causing hardship to both the drivers and the deer. I realize this type of wildlife situation is a Provincial jurisdiction but I'm wondering if other areas of our municipality have the same problem? Does the municipality have any means to help with this situation? Does the bylaw enforcement officer have any responsibility?

**NEXT STEPS**

**FINANCIAL IMPLICATIONS**

**ALTERNATIVES**

**ATTACHMENTS**

(List any attachment to the report, if anything.)

**CHIEF ADMINISTRATIVE OFFICER REVIEW**

Staff will discuss the matter prior to the COTW meeting for an understanding of Provincial jurisdiction, educational programs and any control measures available under the Provincial Departments.  Additionally, communities such as Truro have experienced deer population increases.  We'll do a quick search to see if there are "best practices" that can be considered.

Report Prepared by:   John Smith_Councilor District 9

Report Reviewed by: ______________________________
Mark Phillips, Chief Administrative Officer

**Attachment B**

**Excerpt from 2023 Hunting and Furharvesting Summary of Regulations – Setbacks for Hunting**



## Minimum hunting setback distances where people live, work, and play

| WEAPON | School | Business and other areas (b) | Highway | Dwelling (c) |
|---|---|---|---|---|
| Bow | 804m | 182m | 30m | 182m (c) |
| Crossbow | 804m | 182m | 30m | 182m (c) |
| Shotgun/shot only | 804m | 182m | 30m | 182m (c) |
| | 804m | 402m | 30m | 402m (c) |
| Rifle | 804m | 402m | 30m | 402m (c) |

(a) Hunting is permitted at or beyond the setback distances in table

(b) Includes playground, athletic field, business, woods operation, Christmas tree operation, special forestry operation, golf course, public building other than school, agricultural building.

(c) The owner or occupier of a dwelling or a person permitted by them who is licensed may hunt within these distances if point of discharge is not within prescribed distance of other dwelling or business and other areas.

# Methods for Managing Deer in Populated Areas

A PRODUCT OF THE
HUMAN WILDLIFE CONFLICTS WORKING GROUP

SPONSORED BY THE
ASSOCIATION OF FISH AND WILDLIFE AGENCIES

**Table of Contents**

# Introduction

*What is the Association of Fish and Wildlife Agencies (AFWA)?*

The Association of Fish & Wildlife Agencies represents North America's fish and wildlife agencies to advance sound, science-based management and conservation of fish and wildlife and their habitats in the public interest.

The Association represents its members on Capitol Hill and before the Administration to advance favorable fish and wildlife conservation policy and funding and works to ensure that all entities work collaboratively on the most important issues.

The Association also provides member agencies with coordination services on cross-cutting as well as species-based programs that range from birds, fish habitat and energy development to climate change, wildlife action plans, conservation education, leadership training and international relations.

Working together, the Association's member agencies are ensuring that North American fish and wildlife management has a clear and collective voice.

*Purpose of document*

The Human Wildlife Conflicts Working Group of the Association of Fish and Wildlife Agencies formed a task force to document methods used to manage deer conflicts within areas of high human densities. Throughout the document we will refer to these areas as "urban" areas. However, deer conflict situations arise in suburban, ex-urban, and other areas of high human densities and the content of this document applies to those areas as well. This document offers management options to communities and agency leadership for resolving common human conflicts with urban deer. It provides an overview of the common issues and identifies common management practices with their associated benefits and challenges. Because wildlife agencies often adopt management practices for dealing with urban deer conflicts for reasons that are not associated with the efficacy of the practice itself (e.g., social acceptance), this document is not designed to endorse specific practices over others. Instead, this document is designed to describe the various management practices in use, as well as the benefits and challenges associated with each practice and to provide defensible management options to North American agency leadership as they determine which practices will be employed in a particular state, province, region, or situation. In addition, this document can help articulate current information regarding urban deer conflict situations to administrators, leaders and legislators that oversee urban areas..

**Acknowledgements**
While many state and provincial agencies have managed deer for over a half a century, managing deer in populated areas poses many new challenges that don't exist with rural deer management. This document was compiled using many of the leading wildlife biologists in North America with expertise in managing deer-human conflict situations. Special thanks go to:
Geoff Westerfield (Ohio Division of Wildlife), Erin Shank (Missouri Department of Conservation), Carole Stanko (New Jersey Division of Fish & Wildlife), Justin Shannon (Utah Division of Wildlife Resources), Ben Layton (Tennessee Wildlife Resource Agency), Orrin Duvuvuei (New Mexico Department of Game and Fish), Emma Vost (Nova Scotia Department of Natural Resources), Michael Boudreau (Nova Scotia Department of Natural Resources), Nathan Snow (USDA/APHIS/Wildlife Services-National Wildlife Research Center), Richard Heilbrun (Texas Parks and Wildlife Department), Bryant White (Association of Fish and Wildlife Agencies), Brian Wakeling (Nevada Department of Wildlife Game), Thomas Decker (US Fish & Wildlife Service), and Mike O'Brien ( Nova Scotia Department of Natural Resources). This document was requested, reviewed, and approved by the Association of Fish and Wildlife Agencies' (AFWA) Human-Wildlife Conflict Working Group and Wildlife Resource Policy Committee on behalf of the AFWA..

***History of deer management***

North America is inhabited by white-tailed, mule, and black-tailed deer. While all species have seen their populations fluctuate with changes in anthropogenic management, deer are a flagship success story.It is estimated that the white-tailed deer population in the U.S. was only about 300,000 in the 1930s. Today, that population has grown to an estimated 30 million; a 1,000 fold increase in less than 100 years. Deer are managed under the North American model of wildlife conservation and they provide many societal benefits. Deer are the most sought- after game animal on the North American continent and all North American deer species are enjoyed as a healthy and nutritious table fare. Prior to European settlement, white-tailed deer were common throughout most of North America providing meat and hides to the native Americans. However, during the late 1800s, unregulated hunting, including commercial market hunting, led to the extirpation of white-tailed deer throughout much of its range. During the early to mid-1900s, led by a widespread conservation movement across North America, many wildlife agencies initiated reintroduction efforts to reestablish white-tailed deer populations. Those reintroduction efforts lead to quickly growing white-tailed deer populationsThis growth continued throughout the 20th century, and white-tailed deer adapted to living in areas of higher human populations to take advantage of reduced predation and increased forage resources. This growth eventually led to increasing deer populations in many areas highly populated by humans.

While white-tailed deer have demonstrated the greatest numeric challenge in this urban situation, mule deer and black-tailed deer have adapted similarly and created identical challenges in portions of their range. State and provincial agencies have had to:

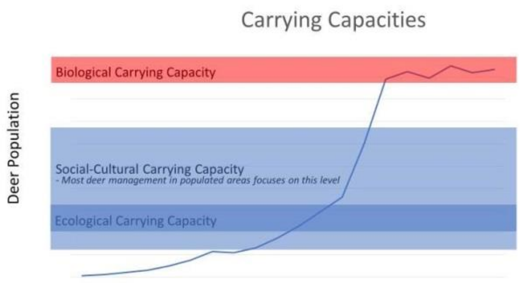
- Reassess how traditional deer management techniques can be used in these populated areas
- Develop new deer management strategies for these populated areas
- Encourage research into additional deer management tools for managing deer in populated areas
- Learn how best to work with government officials and city leaders together to address concerns regarding deer

***The Concept of Carrying Capacity***

When managing deer in populated areas, the question of how many deer should be in a given area is a crucial question. Three types of carrying capacities may be considered in this context: biological, ecological, and social-cultural.

- Biological Carrying Capacity (BCC) - The simplest concept is to consider the maximum number of deer that the habitat could support on a continuous, long-term basis. This level is referred to as the biological carrying capacity of the population. The biological carrying capacity however may not be the actual desired level. A deer population at biological carrying capacity will be able to sustain itself, but deer numbers at this level may influence plant and animal communities in this association. The biological carrying capacity in urban areas may be much higher than in a wild environment due to the increased availability of artificial sources of forage and water.
- Ecological Carrying Capacity (ECC) - The population level at which deer do not negatively influence native plants and animals and allow for the natural succession of the habitat is referred to as the ecological carrying capacity. Prior to the 1500s and major European settlement of North America, deer densities were likely 3.1-4.2/km2 throughout their range (McCabe and McCabe 1984, McCabe and McCabe 1997). Research in the eastern half of North America indicates ecological carrying capacity for white-tailed deer in the range of 3- 10 deer/$km^2$ (Healy 1997, Schmitz and Sinclair 1997). Beyond these densities, deer browse impacts the regeneration of certain plant life which in turn impacts other wildlife species which also depend on those habitats (DeCalesta, 1994, Tilghman 1989). Deer numbers at this level can still present challenges like deer-vehicle collisions or damage to artificial landscapes and gardens.
- Social-Cultural Carrying Capacity (SCC or CCC) - The deer population level at which the local human population can tolerate or accept the problems associated with a deer herd is commonly referred to as the social or cultural carrying capacity. In most cases when managing deer in populated areas, local human residents will determine the social carrying capacity for the deer herd and the desired deer population. Because of the variety of tolerances of multiple

stakeholders for deer within a particular area, the appropriate deer density will vary..




***Consequences of Overabundant Deer***

The consequences of overabundant deer in urban and suburban settings range from mild to severe. The most significant concerns perceived by the public are human injuries, death, and property damage from deer-vehicle collisions (Connelly et al. 1987, Curtis and Lynch 2001). Collisions with deer are extremely frequent, estimated at >1 million each year in the United States (Conover et al. 1995). These collisions occur in all landscapes where deer and roads exist, but occur more regularly in urban and suburban areas where both deer and motorist are abundant (Nielsen et al. 2003).

Deer-vehicle collisions generate the highest amount of monetary damage from wildlife-vehicle collisions, averaging $6,717 per collision (Huijser et al. 2008). Since 1990, human fatalities from such collisions with wildlife, mostly deer, have increased 104% (Sullivan 2011). In addition, a large number of deer are killed in these collisions resulting in loss of recreational opportunities and their many intrinsic benefits (Huijser et al. 2008). An estimated 92% of deer involved in collisions die from the trauma (Allen and McCullough 1976). Human-deer conflict in **Princeton, New Jersey** arose after a no-firearms discharge law within the township was passed in the 1970s. From 1972 to 1982, there was a 436% increase in deer-vehicle collisions.

Another major concern expressed by the public is the risk of disease from deer (Connelly et al. 1987, Curtis and Lynch 2001). As with many species of wildlife residing in close proximity to human dwellings, deer are implicated as reservoirs and transmitters of zoonotic diseases. Specifically, urban white-tailed deer host a stage of the transmittable Lyme disease (Adams et al. 2006). Lyme disease is contracted by humans through an injection of the bacterium, *Borrelia burgdorferi*, during the bite of a deer tick (*Ixodes* spp.). These ticks require large mammals, such as deer, as a host for feeding and mating during the adult stage of the tick. The ticks lay eggs that hatch, after which the nymphs feed on small mammals or birds and become infected with the *B. burgdorferi*. The nymphs or adults then can move onto humans and bite, infecting the human. Incidents of Lyme disease have risen since the mid-1990s, with 2015 representing one of the highest years on record with 28,453 cases (www.cdc.gov/lyme/stats). The majority of cases occur along states in the northeast USA, but more cases are being reported throughout the Midwest region of the country in recent years. Other Lyme-like diseases such as Ehrlichiosis and Bourbon Virus are of increasing concern throughout portions of North America. Incidence of Ehrlichiosis has increased dramatically since the mid-1990s. Isolated but serious cases of Bourbon Virus and Heartland Virus in Missouri have raised concerns about deer densities and human exposure to tick-borne diseases.

Deer generate other consequences that are less obvious than collisions or disease, but nonetheless substantial. In particular, overabundant deer alter landscapes via intensive browsing and indirectly reduce the abundances of other wildlife (Waller and Alverson 1997). Hence, deer are considered a keystone herbivore. Deer in urban and suburban settings can become overabundant, reaching densities of 78 deer/km2 (Magnarelli et al. 1995). Overabundant deer browse heavily on forest understories until the vegetative community is mostly gone (Adams et al. 2006). This overbrowsing influences the distribution and abundance of species at multiple trophic levels that depend on those vegetative communities, and modifies the relative abundance of species that compete with deer (Waller and Alverson 1997). This type of intensive herbivory is not confined to forests. About 4% of urban and suburban households reported damage from deer herbivory to gardens, yards, and ornamental plants (Conover 2001). These types of damages average $73 per household.

Although rare, deer may be aggressive toward humans in areas of high human density where deer are abundant (Hubbard and Nielsen 2009). For example, 13 attacks on humans were reported at Southern Illinois University–Carbondale during 2005, including injuries to humans involving broken and dislocated bones, lacerations, scrapes, and bruises. These attacks were speculated to be female deer protecting fawns. Other attacks on humans have included male deer during the breeding season, likely in territorial defense as rutting behavior (Conover 2001).

### *City Challenges with Urban Deer*

In many parts of the United States and Canada, deer populations have increased in urban environments. Elected city officials are often asked and expected to solve urban deer-related issues, but there are a variety of challenges that must be overcome to address issues and reduce conflicts. The first challenge is to identify the problem and set clear objectives to achieve success. This can be difficult because social tolerance of deer in municipalities varies, with some residents viewing deer as a benefit to the community and others viewing deer as a detriment. This lack of consensus among residents has increasingly become a source of controversy for elected officials, as their polarized constituents propose fundamentally different solutions to address urban deer-related challenges. Residents in favor of having deer in town promote the philosophy that local citizens need to learn to live and co-exist with wildlife. Those opposed to urban deer often call for strategies to decrease deer densities in an effort to reduce deer-vehicle collisions, address zoonotic diseases risks to humans, alleviate material damage to lawns and gardens, and address public safety concerns.

One challenge that city officials are faced with is the lack of management authority over wildlife species. That authority generally rests with the state or provincial wildlife management agency. Elected officials must work with state or provincial agencies to determine and achieve defined objectives. If cities believe that urban deer is entirely a wildlife agency problem and not a city problem, little progress will be made in reducing conflicts. Coordination and collaboration is critical.

Wildlife management agencies primarily limit deer population size by using regulated public hunting to harvest bucks and does. Cities usually have ordinances and other laws that prohibit the discharge of firearms in city limits due to the impracticality of its use in areas of high human density. The inability to use hunters to regulate deer populations eliminates the primary tool used by wildlife agencies to reduce herd size. Humans in urban areas often have greater mutualistic views of wildlife, and may not be accepting of utilitarian views of hunting or firearms in general. Yet, in some areas the public is becoming increasingly accepting of hunting as a management tool to obtain locally grown, organic protein, such as locavores. Exacerbating the problems, many cities do not prohibit feeding of deer. Protection from harvest and added forage resources can create a refuge for deer and increase deer densities in urban environments.

Jurisdictions with the most pronounced deer problems are generally those with high deer abundance and restricted hunting regulations. These regulations may apply to an entire state or province (such as restrictions in New York state due to fears of low deer numbers in the mid-1900s) or they may be related to weapons restrictions at the municipal level (no weapon discharge within town limits or within a certain distance of houses). Many suburban communities integrate green spaces, such as large gardens or recreational areas within close proximity of houses and weapons cannot be discharged under normal conditions. Changes to regulations (e.g., allowances for harvest) may take years to enact, and communities may be reluctant to approve even those hunting methods with limited range and noise, such as archery hunts. Consequently, communities may struggle to determine appropriate solutions while the deer population, and human conflicts with deer, continues to increase.

In 6 different New England communities during the late 1980s, human-deer conflicts began to emerge as a threat to human safety with increased vehicle collisions and an increase in detected cases of Lyme disease, along with increased nuisance complaints due to deer browsing in local gardens. These jurisdictions recognized the need for deer population control, but varying levels of public support limited their abilities to implement uniform strategies in a timely manner. The creation of local deer management committees and the comprehensive consultation process implemented by the larger communities limited action when consensus could not be reached. In the 2 largest communities, solutions to the urban deer overpopulation were delayed by over ten years as pressure from animal rights groups and local residents limited implementation of deer management committee recommendations.

In **Cayuga Heights, New York**, 40 meetings were held over 3 years, finally resulting in an experimentation stage before a management solution could be agreed upon 2 years later. In another instance, intervention from the local Humane Society in **Amherst, New York** resulted in suspension of a bait-and-shoot program implemented 2 years earlier. Several consultants were hired by the town to determine the best course of action. Three years passed with the deer population continuing to cause nuisance to the local community before an agreement was made to implement 1 year immuno-contraceptive study followed by bait-and-shoot.

In many situations, solutions to deer conflict issues require the joint coordination of multiple jurisdictions. In **Cook County, Illinois**, for example, the legal custodian of wildlife is the Illinois Department of Conservation; the legal custodian of the habitat, however, is the Cook County Forest Preserve District. A successful urban deer management program requires the cooperation of all levels of government, with funding, staffing, and communication distributed in such a way as to promote shared responsibility.

Consultation and deliberation is important to democratic representation within public trust process. Yet delays in decision-making can greatly affect local communities as deer populations increase along with human conflicts if their growth is not limited in some fashion.

***Wildlife Agency Challenges with Urban Deer***

State and provincial wildlife agencies also have challenges to solving urban deer issues. Similar to most cities, many wildlife agencies have limited funds that are primarily generated through license sales, and they may not have a dedicated budget to address urban deer issues. Limitations exist on using federal funds raised through excise taxes (i.e., Wildlife Restoration Funds) to address nuisance wildlife. Agencies have not been able to hire and support staff in urban settings at the same rate at which urban deer problems have developed.

Another set of challenges for state and provincial wildlife agencies is prioritizing which communities to help and how many resources to devote to the problems. Some wildlife agencies have well defined plans or policies outlining the processes they will take to help communities manage urban deer conflicts. These plans may set criteria, provide direction and consistency, and define management options when working with elected city officials. In the absence of urban deer plans or policies, objectively prioritizing which cities to help and allocating resources may be difficult.

Community leaders often call upon wildlife agencies to remove urban deer, but each technique present specific limitations. Lethal removal by sharp shooters with firearms can be challenging in many instances, and having the proper training and equipment is necessary before culling deer in urban environments. Trap and cull measures may be perceived as safer, but substantial expense, equipment, and expertise is required. Efforts should target removal of resident deer, as deer that migrate through urban areas may contribute little to the challenge. In addition, removing deer may solve challenges only temporarily if the attractants are not removed because additional deer may move into the urban area.

In many cases, lethal removal is socially unacceptable and wildlife agencies are asked to translocate urban deer. Aside from mortality from capture related stress (capture myopathy), moving urban deer can be expensive, logistically challenging, and may spread wildlife diseases to healthy deer herds where the animals may be released. Cost-benefit analyses should be conducted prior to translocation efforts, and disease histories and risks should be factored into the decision making processes (WAFWA 2014). Wildlife agencies should do all they can to prevent the spread of disease, particularly chronic wasting disease. Translocating deer involves a great amount of risk and could have negative biological impacts on deer populations if disease is spread from one population to another.

Fertility control is another socially popular alternative to culling and translocation. These efforts are expensive, highly invasive, logistically challenging to implement, and not entirely effective (WAFWA 2015).

***Defining Success in Urban Deer Management***

Identifying the challenges of cities and wildlife agencies is an important first step in addressing urban deer issues. Cities and wildlife agencies need to work together to identify the challenges of urban deer and jointly craft solutions that are acceptable to all.

Urban deer management has three main components: 1) determining where we are, 2) identifying where we want to be, and 3) bridging the gap between the two places.

Determining “where we are” often involves an understanding of the densities and growth rates of deer are in a given area, the number of deer/vehicle collisions, the amount of property damage that is occurring, and the social tolerance of citizens towards deer.

Identifying "where we want to be" involves determining what success looks like for a given municipality. Wildlife agencies should work with cities to define goals and objectives in some form of management or action plan. Examples of defining success can involve working towards reaching a socially acceptable deer density, reducing deer/vehicle collisions and property damage (e.g. deer eating flowers or plants in gardens), and surveying the public to obtain their opinions.

When defining success, wildlife agencies should work directly with elected officials when possible because they represent the voice of the citizens. Having elected officials help determine a socially acceptable number of deer for a given city will help wildlife officials know how to best address urban deer issues, and it will provide direction when neighboring landowners disagree about how many deer should be in a given area.

Determining how to "bridge the gap between the two places" involves selecting a strategy to reduce urban deer and reach management goals and objectives. Each strategy has benefits and drawbacks, and they should be carefully considered before being implemented.

If communities and wildlife agencies are going to make progress towards solving urban deer challenges, they must communicate well and work together in a true partnership. Determining what success looks like and implementing agreed upon strategies to achieve goals are important components to addressing urban deer issues.

## *Biology of Deer in Populated Areas*

Wildlife populations residing in human populated areas face stresses that differ from their counterparts in rural settings (Ditchkoff et al. 2006). Due to these stresses, wildlife living in populated areas may modify their behavior or life-history strategies to successfully avoid or cope with the different stresses. For deer, behavioral modifications may include shifts in habitat use, diets, feeding behavior, movement patterns, and home range sizes while life-histories may differ in reproductive rates, survival, and disease transmission rates.

### Behavioral Adaptations

Although deer appear to avoid human disturbance when possible, they easily habituate to human development and readily use residential areas that contain sufficient cover (Swihart et al. 1995, Kilpatrick and Spohr 2000). Compared to their wildland counterparts, deer in human populated areas make use of vastly different habitat types such as golf courses, lawns, and ornamental shrub rows. With the human development, anthropogenic food sources (e.g., wildlife feeders, gardens, ornamental plants) are introduced on the landscape and deer modify their behavior and movements to exploit these artificial food sources. For example, suburban deer in Connecticut browsed more heavily near houses, which was attributed to the anthropogenic food sources found near the human dwellings (Swihard et al. 1995).

In general, size of deer home ranges decrease as development and human dwellings increase (Kilpatrick and Spohr 2000, Grund et al. 2002, Storm et al. 2007, Hygnstrom et al. 2011). This could be a result of habitat composition and configuration across the rural-urban gradient and an increase in movement barriers (e.g., highways, railroads, housing developments, and fences) as human development increases (Grund and Woolf 2002, Storm et al. 2007, Wakeling et al. 2015). Wildlife living among developed areas may be forced into smaller home ranges due to limited access to smaller patches of suitable habitat (Ditchkoff et al. 2006). Alternatively, deer living in developed areas may be able to exploit higher concentrations of food and other resources which allow them to decrease their home range sizes while meeting their annual needs (Tufto et al. 1996, Kie et al. 2002, Saïd and Servanty 2005).

Similar to deer in rural settings, movement of deer in developed areas varies by season. During the non-growing season (fall, winter), deer move more than they do during the growing seasons (spring, summer) (Storm et al. 2007, Walter et al. 2010). As food becomes scarcer during the non-growing season, deer increase their movements. Difference in movement may be greater for deer in developed areas as they travel further distances to find suitable resources during the non-growing season. Additionally, deer in populated areas tend to shift their movements toward dwellings in the winter (Vogel 1989, Cornicelli et al. 1996, Kilpatrick and Spohr 2000, Grund et al. 2002. Storm et al. 2007); this can be partially explained by the supplemental food sources and the radiant heat and wind breaks provided by homes (Swihart et al. 1995, Grund et al. 2002).

### Biological Adaptations

Densities of deer in areas with higher human densities are typically greater than densities in undeveloped landscapes and areas can become overpopulated due to a lack of natural predators, reduced hunting pressure, increased recruitment, and favorable habitat conditions. Due to the anthropogenic food sources, resources may be less limiting for deer in populated areas and individuals may be in good health despite high population densities (Etter et al. 2002, DeNicola et al. 2008). Further, urban landscaping often provides a constant source of food for the deer and deer within urban areas, especially when at medium-low deer densities, tend to be in optimal health.

As nutrition improves, wildlife reproductive rates increase and result in higher offspring survival, and ultimately greater densities (Robbins 1993). Because of the favorable conditions, deer may experience higher reproduction in urban settings than in rural populations (Etter et al. 2002). This could be attributed to the artificially abundant food sources which allow females to reproduce without the density dependent effects experienced in nonurban landscapes. However, barriers to movement and other stresses may affect deer breeding success and offspring survival (Wakeling et al. 2015). Ditchkoff et al. (2006) documented a high rate of fawn abandonment near populated areas, possibly as a result of human disturbance.

Because of differences in hunting pressure, road densities, and predator ecology, deer experience different rates of mortality in rural, exurban, and suburban areas. Deer survival in populated areas is typically higher than rates in rural landscapes due to lack of hunting and natural predators (Bateman and Fleming 2012, Etter et al. 2002). This difference in survival rate is greater for male than female deer because male deer are generally hunted by humans to a larger extent.

Deer in human populated areas are often buffered from natural limiting factors that their counterparts experience in rural and wilderness landscapes. In developed areas, deer often face less pressure from predators and have ample food. However, deer near human populated areas face a different suite of stresses, predators, and obstacles. Anthropogenic factors such as deer-vehicle collisions, entanglement in lawn structures, drowning in pools, and attacks by domestic dogs may account for alternate mortality for deer in populated areas (Harveson et al. 2007).

Deer-vehicle collisions are the principle cause of mortality in areas where deer and humans coexist (Etter et al. 2002, Wakeling et al. 2015). As road density increase, deer vehicle collisions make up a larger portion of deer mortalities (Forman and Alexander 1998). Although does are killed by vehicles in proportion to their availability on the landscape, bucks are killed at a higher rate than their availability because of the increased buck movements associated with breeding seasons (Olson et al. 2014, Wakeling et al. 2015).

Although natural predator densities may be lower in human dominated areas than in rural habitats, human pets may prey on wildlife at rates similar to natural predators (Ditchkoff et al. 2006). Additionally, Ditchkoff et al. (2006) found that coyote predation on white-tailed deer neonates in urban areas exceeds rates found in rural areas. In deer populations that artificially or naturally exceed carrying capacity, abundant deer can reduce hiding cover for neonates and increase their predation risk, which may lower fawn survival (Piccolo et al. 2010). For fawns in one overpopulated area, the primary cause of mortality from birth to 14 days was emaciation, whereas coyote predation was the primary cause in older fawns (Sams et al. 1996). Low fawn survival may explain why some high density populations in developed areas do not experience growth despite high adult survival and fecundity (Etter et al. 2002).

Disease and Environmental Differences

Land use and land cover alterations have changed the amount and configuration of habitat available to wildlife. In the West, much human development occurred on deer winter range where deer congregate seasonally; development restricts the available habitat in these seasonal areas with high deer densities and further concentrates deer into smaller areas. Local factors such as gardens, desired ornamental shrubs, and artificial feeding around residences can also concentrate deer at relatively few locations on the landscape and result in smaller home ranges for local populations. Large numbers of animals in close proximity for extended periods of time increases the likelihood of exposure to any diseases that individual deer may carry.

The landscape changes in developed areas may accelerate contact rates with infectious agents and influence the dynamics of disease transmission (Ditchkoff et al. 2006, Joly et al. 2006, Miller et al. 2007). As a result, deer disease prevalence in human populated areas can be greater than that found in rural landscapes and can become a major source of mortality (Ricca et al. 2002, Ditchkoff et al. 2006).

Because deer survival is typically higher in populated areas where hunting pressure is low and predator populations are reduced, infected deer may live longer, allowing more time to shed infectious agent. Additionally, infected carcasses may last longer on the landscape allowing the disease more time for transmission.

Prevalence of chronic wasting disease (CWD) was almost twice as high in developed areas than in undeveloped landscapes (Farnsworth et al. 2005). Because development tends to reduce hunting pressure and increase survival, adult deer, particularly adult males, tend to live longer in human developed areas. Because of this, males were 2–2.5 times more likely to test positive for CWD in human populated versus rural landscapes while the difference in CWD prevalence was relatively insignificant for females.

High deer densities and concentration areas, such as that resulting from human development and supplemental feeding, are factors that most likely resulted in the establishment of self-sustaining bovine tuberculosis (TB) in a free-ranging deer population in Michigan (Schmitts et al. 1997). The unnatural concentrations and close contact that results from human development and artificial baiting provides ideal conditions for the transmission of bovine TB through inhalation of infectious aerosols and ingestion of contaminated feed (Whipple and Palmer 2000).

# Role of Wildlife Agencies in Managing Deer

The basic tenet of North American wildlife law is the Public Trust Doctrine which affirms that, while natural resources, such as wildlife, belong to the public, government is the entity entrusted to manage wildlife for the conservation and sustainability of that renewable resource and for the benefit of current and future generations. State fish and wildlife boards and commissions set laws and regulations to manage deer as trustees according to this doctrine, and employ the experts that collect the data and provide recommendations pertinent to each state's deer population as trust managers. State fish and wildlife agencies are the best resource for providing biological data, local effects of deer on the environment, laws pertaining to wildlife, advice on how to determine if there is a deer overabundance issue, and the options to address issues. State agencies also monitor the health and disease status of the deer herd,and issue any permits necessary for various management activities such as contraception and sterilization, capture and tagging, translocation, culling, and hunting. However, the public is entitled to hold the trustee responsible for its efforts in managing wildlife and may redress against management actions.

Many states have specialized programs or regulations for managing overabundant deer where hunting is not practical or desirable. There is often a wealth of information on the state agency's website on options for addressing deer from a homeowner and a community perspective. The state wildlife agency may have staff available to a municipality to provide educational presentations, review information and data pertaining to the issue, and to answer questions on management options.

Although state agencies are the experts in deer management and the best source of information, the community and the community leaders generally determine the social carrying capacity of the wildlife. If problems are detected, the community should work with the wildlife agency to develop an objective and methods to achieve that objective.

Deliberative discussions are needed to assess local community values, economic effects, available science, and resident feedback. These conversations are often emotional, and reaching consensus may be difficult and time-consuming. State wildlife agencies can guide communities in methodologies to gather resident opinion through non-biased surveys and in the estimation of deer populations.  No single deer density estimate will be acceptable in all situations, and indices of conflict may be more suitable to measure and manage in some instances.  Some indices include: levels of deer-vehicle collisions, property damage, environmental degradation, incidence of Lyme disease, and tolerance levels of residents.

Generally, communities require a substantial amount of time to reach the point of consensus and plan development. Implementation actions to address overabundant deer could be a year or two away, which allows deer populations, which can double every other year, to continue to grow in the interim. The amount of human resources will depend on the selected management activity; some programs can rely primarily on volunteers while others require municipal employees. Each community should assist in selecting the best option for their community. Deer management will require annual maintenance. Deer will continue to reproduce and immigrate from surrounding areas. Any deer management program should be evaluated annually for progress toward objective, revisions to improve efficiency, and

**The Northeast Section of The Wildlife Society, in their position statement entitled Managing Chronically Overabundant Deer, suggests the following steps to formulating a deer management plan in developed areas:**

1. Identify positive and negative deer impacts
2. Define objectives to measure progress towards alleviating or eliminating negative impacts and continuing or enhancing positive impacts
3. Collect data on problematic deer impacts
4. Review management options
5. Invoke decision-making process – legal, social, logistical, and economic
6. Develop and implement a communication plan
7. Ensure state wildlife agency and local government agencies have the ability to authorize regulated harvest where special local hunts may be needed and enhance management authority where possible
8. Identify permitting requirements
9. Implement management actions
10. Monitor changes in deer impact levels
11. Review and modify management actions

current biological and social conditions.

Population trend is the directional movement in relative abundance or other key parameters through time (sensu Skalski et al. 2005),and is discussed with great detail as applies to deer monitoring in Keegan et al. (2011). Trend indices are measures that are presumed to correlate with population abundance (or other parameters); thus, trend indices may indicate whether a population has increased, declined, or remained stable over time, if certain assumptions are met. Trend indices are also sometimes used to infer magnitude of annual changes, and, if collected over multiple years, trend indices can also be analyzed to provide a quantitative estimate of magnitude of population change by linear or nonlinear modeling. Trend indices can be either direct (involve direct counts of deer) or indirect (involve counts of indirect evidence of deer presence, such as scat or tracks).

Despite widespread use of trend indices in wildlife management, there is much uncertainty regarding usefulness of these indices (Anderson 2001, Williams et al. 2001, Lancia et al. 2005), including debate as to whether they should be used at all (Anderson 2001, Williams et al. 2001). Also, statistical power of trend indices to detect an actual change in population abundance is often very low. Consequently, changes in population size often have to be quite large (e.g., halving or doubling of the population) to be detected by trend indices. Similarly, statistical theory underlying trend indices has received very little study (Skalski et al. 2005). Despite these questions, trend indices are frequently used, primarily because of cost-efficient application over large geographic areas and challenges involved in developing valid estimates of abundance.

Trend indices are most frequently used to index changes in population abundance, although they may also be used to index trends in age structure, adult sex ratios, or productivity or recruitment ratios. Whereas a great variety of trend indices exist, the underlying assumption is that there exists a homogenous (across time, habitats) and proportional relationship between a change in the trend index and a change in abundance or other population parameter. Thus, before using any trend index managers need to consider 3 key questions:

1. Does a change in abundance result in a change in the index?
2. What is the relationship between deer abundance and the index? Frequently, the relationship is assumed to be linear, but often is not.
3. Are the data for the index collected consistently over time and is the sampling representative of the population? Both of these must be true for a trend index to have any real relationship to abundance.

The primary problem with most trend indices is the relationship between the index and abundance has not been determined. Despite this, trend indices are often treated as if they accurately and precisely reflect population abundance even though such a relationship has not been demonstrated. Because of this uncertainty, trend indices are most correctly applied only to determine a relative (as opposed to absolute) change in abundance. A second important problem among trend indices is difficulty in meeting assumptions. Failure to meet explicit assumptions or apply methods to account for unmet assumptions may result in failure of an index to adequately reflect change in populations.

For most trend indices, the relationship between index and deer abundance is not only unknown, but also likely not consistent. Rather, it varies over time and among areas due to changes in environmental factors (season, habitat, weather, deer behavior), human influences (hunter behavior, differing observers), and sampling protocols (sampling effort, plots vs. belt transects). A variety of techniques are used to deal with this variation, which cause violation of the assumption of a homogenous and proportional relationship between abundance and the index. First, sampling strategies are frequently systematic or stratified random as opposed to purely random. These former sampling strategies attempt to account for vegetation type or other environmental attributes varying among survey areas or times. By blocking surveys according to these differences, the overall index should better represent the entire population.

Systematic or stratified random surveys are also often easier to implement than completely randomized designs, especially when surveys are associated with roads or trails which are not randomly located across the landscape. A potential negative effect of systematic sampling is you may not capture all of the environmental variation across the landscape due to your sampling not being random. However, this problem can be overcome by ensuring stratification (blocking) includes all relevant variables in the stratification (e.g., all habitats likely to be used by mule deer). A second way to deal with environmental variables that may affect the relationship between abundance and index includes standardization of survey methodology, which is most often used to account for weather and observer effects. Third, important environmental factors can be included and accounted for in models to relate abundance to the index under "constant" conditions.

Many trend indices (such as pellet-group counts, harvest-per-unit-effort, track surveys,) have been extrapolated to provide estimates of population abundance, creating considerable overlap between trend indices and abundance estimators. Methods most commonly used as abundance estimators require additional assumptions for extrapolation from index to abundance that is beyond this discussion of trend indices and will be covered in the Abundance and Density section.

*Minimum aerial counts and classification*. — A minimum count represents the absolute minimum number of deer known to be present in a given area (while recognizing an unknown proportion of the population was not seen or counted). Counts and classifications are frequently accomplished through helicopter or fixed-wing surveys; however, several other techniques (e.g., ground counts, spotlight counts) can also yield minimum counts. Counts are often standardized to effort, such as numbers seen per hour of flight time or miles of survey route.

Advantages

- Sample sizes obtained from aircraft, and thus minimum estimates, are usually much greater than from ground-based methods.
- Helicopter counts presumably provide more accurate counts and sex and age classification than do ground-based counts because of independence of roads, ability to observe deer in inaccessible areas, longer observation times, closer proximity to deer, and ability to herd deer to provide optimal viewing opportunities (however, observing undisturbed deer from the ground with enhanced optics also allows accurate classification). This may not be true if substantial vegetation cover significantly obscures deer or allows only "fleeting" glimpses of deer.
- A segment of the public strongly favors census and minimum counts over samplebased population estimation. Sample-based estimates are frequently called into question and dismissed by the public if they do not mirror perceptions.
- Provides an absolute minimum population estimate which is understood and accepted by the public (sampling techniques, statistical inference, and probability are poorly understood by many constituents).

Note: the last 2 bullets represent challenges to agencies in educating constituents about the value of sampled-based methods.

Disadvantages

- There are very few cases where mule deer census is possible. Radiomarking studies have shown even very intensive efforts covering 100% of an area fail to account for all individuals due to concealment or observer factors (Bartmann et al. 1986).
- Costs are high compared to most other indices.
- Cost for a census would be prohibitive except for small, mostly confined areas.
- Although presumed to be more accurate than ground-based methods, validation is lacking, particularly for fixed-wing aircraft.
- Significantly more hazardous for biologists than ground-based methods.
- Minimum counts are frequently smaller than annual harvests, causing the public to question survey data and permit allocations.
- Motion sickness or marginally skilled pilots can result in poor viewing opportunities and highly biased data (e.g., large proportions of groups flee to cover before classification).
- Relationship to true population size often unknown or uncertain.

Assumptions

- Census – all members of the population in a given area are detected and accurately counted.
- Minimum count – members of the population counted in a given area are representative of the actual population.
- If minimum counts collected across time, a consistent proportion of the population is counted.
- If population components are separated, sex and age classes are correctly identified.
- Detectability is similar across sex and age classes, or counts are conducted during biological periods where free intermixing occurs between target sex and age classes (Samuel et al. 1987, Bender 2006).

Techniques

Both population censuses and minimum counts are usually conducted from either helicopter or fixed-wing aircraft, with flight protocols (such as airspeed, altitude above ground level, and spacing of transect lines) and observer behavior (including number of observers, direction of observation, and width of transect lines observed) held constant among surveys. Because population census is seldom feasible for free-ranging deer, remote sensing techniques are being evaluated to increase efficiency and improve detection rates (Lancia et al. 2005). Experimental techniques that have been tried include use of aerial photographs to obtain counts of concentrated individuals or thermal imaging. Forward looking infrared (FLIR) sensing has been used for a variety of ungulates with limited success outside of smaller or enclosed areas (Dunn et al. 2002, Drake et al. 2005). Additionally, remotely operated vehicles (ROVs) are being explored as a means to decrease risks to biologists (K. Williams, U.S. Geological Survey, personal communication). However, remote methods seem to have limited applicability, particularly with respect to classification.

Minimum aerial counts are the most commonly used trend index for mule deer. Minimum counts are frequently converted to estimates of population abundance in 1 of 3 ways:

1. Correcting counts for different likelihoods of observing deer based on habitats.
2. Altering size of sampling units based on habitat (Bartmann et al. 1986, Freddy et al. 2004).
3. Assuming all deer along the aerial transect were seen and estimating the width of the transect using distance sampling methods to correct for varying detection probabilities based on habitat, transect width, or other variables.

Uncorrected aerial surveys flown with consistent flight protocols to ensure consistent and near total coverage of sampled areas are converted to deer observed/unit area or deer observed/hour to obtain a population index. Aerial counts for population trend, as contrasted with counts used solely for sex and age composition, usually have much more specific survey protocols, similar to those required for abundance estimators such as sightability models. Despite this, as with sightability models and similar methods, estimates will always be negatively biased because topography and other visual barriers will prevent complete observation of survey units.

*Spotlight surveys and ground counts*.— Spotlight surveys and ground counts are similar, with spotlight surveys representing a special case of ground surveys. Spotlight surveys are conducted at night when deer may be less reluctant to use open habitats or areas adjacent to roads (Harwell et al. 1979, Uno et al. 2006). Both spotlight surveys and ground counts are used to collect minimum count and herd composition data. Typically, routes are standardized, replicated, and usually conducted from motor vehicles (especially for spotlight surveys); ground counts may be conducted on foot or from horseback as well. Surveys can be based on continuous observation along a route or restricted to observation points. Distance sampling methods, including stratification by habitats, are occasionally used to extrapolate minimum counts to abundance estimates.

Advantages

- Easy to conduct, inexpensive compared to aerial surveys, and can cover large geographic areas.
- Produce F:D ratios similar to those from aerial surveys (Bender et al. 2003).

Disadvantages

- Roads do not occur randomly across the landscape and their location likely biases proximity of deer (e.g., may be along a riparian area).
- Buck age structure and sex ratio data likely biased because of poorer sighting conditions and behavior of bucks as compared to helicopter surveys.
- Detection probabilities vary with habitat conditions, weather, observers, disturbance.
- Amount of traffic along trails or roads can affect proximity of deer.
- Sample sizes usually low compared to aerial surveys.
- Low light capability of optics influences results.
- May generate disturbance to adjacent human residents and frequent reports of illegal hunting.

Assumptions

- Sample is representative of the population.
- Index reflects changes in population size rather than changes in deer distribution or detectability.
- Roadsides or trailsides representative of area in general or non-changing over time, or surveys stratified by habitat.

- Deer are equally observable every time the survey is conducted (e.g., vegetation screening between seasons or years is not variable).
- Methods consistent among years and groups counted without error.
- Sex and age classes correctly identified and have similar detectability.
- Observers are equally skilled.
- Extrapolation to population size or density requires further assumptions outlined under distance sampling and sightability models in the Abundance and Density section.

Techniques

Methods used include horseback counts, hiking counts, and counts from motorized vehicles. Ground counts can involve riding, driving, or hiking along a route or between observation points. Surveyors move along a standard route, traveling from one location to another that provides a good vantage point for searching for deer. If using specific observation points, after spending a specified amount of time at an observation point, the observer moves farther along the survey route until the next observation point is reached. Survey data can be interpreted as minimum numbers counted, numbers observed/mile, or used as inputs into distance sampling models to estimate abundance.

Spotlight surveys are usually conducted in habitats that are representative of the unit or area being surveyed. They are conducted shortly after dark, when deer are active and may be less reluctant to use areas close to roads. A driver navigates a vehicle along a permanently established route, while an observer (or 2) shines a spotlight along the side of the route and records all deer seen and classifies deer by sex and age class. Typically, number of deer seen/mile of route serves as an index to deer abundance and sex and age composition provides trend information on population demographics. Data are occasionally used as inputs in distance sampling models. However, managers should recognize deer distribution is likely not independent of roads and a rigorous sampling approach is necessary.

For both ground and spotlight surveys, routes are usually repeated several times each year to account for variability in survey conditions and reduce the chance of an unusually high or low count being used to index population trend. Occasionally, the highest total among replicated surveys is used to index the population as it reflects the minimum number of individuals known to be present.

*Harvest per unit effort (HPUE)*.— Harvest per unit effort scales total harvest by some estimate of hunter effort, most commonly number of hunters or number of hunter-days (i.e., the total number of days hunters actually spent hunting). As the estimate of effort becomes more refined (hunter-days instead of hunters), the trend estimate is considered more sensitive to changes in abundance.

Advantages

- Relatively easy and inexpensive to collect effort data through harvest surveys.
- Presumably more accurate than harvest uncorrected for effort.
- Strong empirical background in fisheries management.

Disadvantages

- Subject to response distortion biases present in social surveys.
- Vulnerable to changes in hunter behavior.
- Influenced by changes in deer vulnerability (e.g., weather conditions, road closures, hunter access, antler restrictions, allocation among weapon types, rutting behavior of bucks).
- High hunter densities may cause interference in harvest rate and bias HPUE estimates.
- Low hunter densities, limited-entry harvest strategies, and mature-buck management strategies can result in significant hunter selectivity and thus decouple any relationship between HPUE and deer density.

Assumptions

- Harvest and effort data are accurate and unbiased.
- Population closed during hunting season except for harvest removals.
- Probability of harvest constant during the season (can be corrected for differential vulnerability among areas).
- Harvest is proportional to population size.
- Effort measure is constant (i.e., hunters equally skilled).

Techniques

Harvest and effort data are most commonly collected from hunter surveys or check stations. The HPUE index, such as 0.05 deer harvested/hunter-day, is often used as a stand-alone trend index to compare changes within a management unit and is considered to be more reflective of actual changes in population abundance than harvest alone because of the accounting for hunter effort (Roseberry and Woolf 1991). However, HPUE does not account for variation in harvest rates due to effects of weather or other factors that could impact harvest. Hence, running averages across multiple years are often used to reduce effects of annual variation in these factors. Comparisons among management units differing significantly in habitat is a problem, because HPUE reflects both abundance and vulnerability of deer, and vulnerability can change significantly with the amount of security cover. Roseberry and Woolf (1991) found some HPUE models to be very useful for monitoring white-tailed deer population trends based on harvest data.

*Total harvest*.— The simplest trend index is an estimate of total harvest. This index assumes encounters between hunters and deer, and thus harvest, increase as deer abundance increases and decline as abundance declines.

Advantages

- Data easily and frequently collected, primarily from surveys of hunter effort and harvest.

Disadvantages

- Annual variation in harvest estimates can be extremely high and thus provides limited inference for population trend.
- Vulnerability to harvest changes with changes in hunter behavior (e.g., regulation changes, equipment changes).
- Vulnerability to harvest changes with environmental conditions (e.g., weather conditions, changes in access, habitat changes).
- Harvest rate varies with hunter and deer density.
- Many potential sources of bias (response distortion) in hunter questionnaires, which are frequently not accounted for.
- Often estimated without variance, thus providing no basis for statistical inference.
- Often of poor or unknown accuracy.
- Generally more effective with very intensive buck harvest strategies such as open entry seasons.

Assumptions

- Harvest data are accurate.
- Harvest is proportional to population size.
- There is no response or non-response bias if collected through hunter questionnaires.
- Harvest rate (proportion of population harvested) is constant among areas or time periods being compared.
- Population is closed during hunting season except for known harvest removals (e.g., no in-season migratory movements).

Techniques

Harvest data are most often collected via hunter surveys or, less commonly, hunter check stations. If season length and other harvest regulations are the same among seasons, then total harvest alone is often used as a trend index within management units. Because of the substantial influence of habitat on deer vulnerability, total harvest should not be used as an index among dissimilar management units. As limitations on harvest increase relative to deer abundance (e.g., reducing hunter numbers through limited entry), value of harvest as an index declines. Thus, because female harvest is often more limited, harvest indices are generally based on buck harvest. If season lengths vary, harvest may be modified to harvest/day or daily harvest modeled as a function of season length or numbers previously harvested, with the latter used to estimate population abundance (Davis and Winstead 1980, Lancia et al. 2005). Age-at-harvest data are used in many population reconstruction models (Williams et al. 2001, Gove et al. 2002, Skalski et al. 2005).

*Track surveys*.— Track surveys involve counting numbers of individual tracks or track sets that cross a road or trail, usually with direction of movement limited to one- way to reduce double counting (McCaffery 1976). Surveys are usually conducted following clearing of roads or trails of old track sets by dragging or following snowfall that covers previous tracks. Data are used most commonly as a relative index or minimum count, but can be used to calculate densities (Overton 1969).

Advantages

- Simple to conduct, relatively inexpensive, and cover a large geographic area.
- May be used for preliminary sampling to implement a more robust method.

Disadvantages

- Limited rigorous validation.
- Difficulty in distinguishing among individuals or species if several ungulate species are present.

- Dependent on activity levels and movement patterns.
- Very dependent upon proper weather or substrate conditions for accurate counts.
- Multiple counts of the same individuals very likely.
- Mild weather conditions that minimize use of winter ranges in some years may result in unreliable data.
- Number of individuals may be indiscernible when deer travel in groups. Assumptions
- Methods consistent among years and groups counted without error.
- Index reflects changes in population size rather than changes in deer distribution or activity levels.
- Extrapolation to population density requires further assumptions (Overton 1969).

Techniques
Tracks are most commonly counted along dirt or sand roads, which are dragged before counting, or during deer migrations, usually when leaving winter ranges. In the former, roads are dragged to obliterate any tracks that are present; then routes are revisited after some time period (often 1 week, assuming no disturbance to survey substrate, e.g., rain that washes away tracks) and number of track sets counted. The index is usually presented as number of track sets/mile if collected over the same amount of time annually, but can be converted into density by making several assumptions about deer movement patterns (Overton 1969). For winter range counts, survey routes are established so they run essentially perpendicular to travel routes between winter and spring ranges. These survey routes are then counted periodically after the start of migration to spring ranges (WGFD 1982). Only deer tracks moving away from winter ranges are counted, with counts run after fresh snowfall or after dragging routes to clear existing tracks. The index in this case is usually presented as the minimum number of individuals counted or number of tracks/mile if routes are run for the same time period each year (usually the entire migration period).

*Pellet counts*.— Pellet group surveys involve counting the number of fecal pellet groups encountered in plots or belt transects. Mean number of groups can be used as a trend index or is occasionally converted to estimates of population size by integrating defecation rates and number of days indexed (Marques et al. 2001). Pellet group counts for population trend are most frequently conducted on winter ranges. Because habitats are not uniform and pellet group distribution depends on relative habitat use, pellet group transects are most often stratified among vegetation types (Neff 1968, Härkönen and Heikkilä 1999). For greatest accuracy, permanent transects that are cleared of old pellet groups after each survey should be used to eliminate confusion in aging pellet groups.

Advantages
- Easy to conduct, little equipment needed, can cover a large geographic area.
- Have been correlated with other trend indices including aerial counts and hunter observations (Härkönen and Heikkilä 1999).
- Can provide data on relative use of habitats (Leopold et al. 1984).

Disadvantages
- Power to detect trends frequently low, particularly for low density populations.
- Size and shape of plots (e.g., belt transects vs. circular plots) and sampling effort strongly affect results (Härkönen and Heikkilä 1999).
- Bias associated with inclusion or exclusion of groups lying along plot boundaries.
- Difficult to distinguish species in the field if several species of ungulate are present.
- More appropriate for areas of seasonal concentration such as winter ranges.
- Degradation of pellets varies in different environmental conditions and with populations of scavengers such as dung beetles.
- For abundance estimation, there is little validation of most commonly used daily defecation rates which undoubtedly vary with season, diet.
- Labor intensive to conduct over large area.
- Potential for observer bias in aging pellet groups if transects not cleared after each counting.

Assumptions
- Methods consistent among years and groups counted without error.
- Index reflects changes in population size rather than changes in deer distribution, activity levels, or behavior.
- Extrapolation to population abundance requires further assumptions including 1) constant defecation rates, 2) exact knowledge of time of use in days, and 3) population density uniform throughout range.

Techniques
This method involves clearing permanent plots or belt transects of accumulated pellet groups and returning after a specified time period to count the number of new pellet groups. Number of pellet groups/unit area or transect serves as the index to abundance. Pellet group surveys are often used on winter ranges at the end of winter. Pellet group counts are commonly converted to densities by dividing by number of times a deer defecates/day and number of days plots were exposed. For example, if you assume a deer defecates 10 times/day and after 10 days you find 700 pellet groups/acre, it is assumed 7 deer were present (7 deer × 10 days × 10 pellet groups/day/deer) (Neff 1968, Härkönen and Heikkilä 1999). Although used as a trend index or abundance estimator, pellet group counts are usually more valuable in determining relative habitat use patterns (Neff 1968, Leopold et al. 1984, Härkönen and Heikkilä 1999).

Pellet group data are inherently non-normal in distribution, so more complex analysis techniques are useful in teasing out inferences. The negative binomial distribution (Bowden et al. 1969, White and Eberhardt 1980) is particularly useful for examining pellet group data.

*Hunter observation surveys*.— Hunter observation indices involve having hunters record the number, and occasionally sex and age classes, of deer seen during hunts. Because hunter numbers and effort can be extremely large and are confined to a relatively narrow time frame, numbers of animals seen and herd composition samples collected by hunters can be large and have been correlated with other independent estimates of population size, trend, and composition (Ericsson and Wallin 1999).

Advantages
- Tremendous number of person-days of effort with little cost to agencies.
- Extremely large sample sizes in some cases.
- Have been correlated with other trend indices and with aerial survey data (for other species).
- Provides hunting public with a sense of "ownership" of population data.
- Provides a method requiring little agency time to corroborate other trend indices.

Disadvantages
- Sensitive to response distortion biases of hunters.
- Untrained observers may not count or classify deer accurately.
- Independence of observations unknown (but can be accounted for if double counts are assumed when constructing confidence intervals around ratio estimates).
- Detection of target species varies among habitats and thus changes in distribution may be confused with changes in population size unless stratified by habitat.
- Relationships between abundance and observation index vary among areas.
- Precision of estimates low or undefined.

Assumptions
- Numbers of deer observed and recorded without bias.
- Sex and age classification correctly identified and reported.
- Number of hunter-days is consistent or observations are standardized per hunter day.
- Hunters equally skilled in detecting deer (for abundance trend only).

Techniques
Hunters are provided data forms and asked to record numbers and sex and age classes of deer seen during their hunts and number of days (or similar measure of effort) hunted. Data are usually converted to a standard measure of effort such as deer seen/hunter-day for the trend index (Ericsson and Wallin 1999). Data for deer seen/hunter-day are usually compared within an area between years to estimate annual rate of change in population size. Because ability to detect (observe) deer varies among habitats, this index (as well as all other direct indices) should not be used to compare management units differing in habitats. Although infrequently used for mule deer, estimates of annual population change and calf:cow ratios obtained from this method have been shown to be similar to aerial survey counts for moose (*Alces alces*, Ericsson and Wallin 1999). These data are much less expensive to collect, suggesting this method may provide a useable index for mule deer management with further development of the technique.

**Abundance and Density**

Estimates of abundance or density (i.e., abundance per unit area) over broad geographical areas are often desired to empirically manage mule deer populations. Because mule deer are widespread and often inconspicuous, total counts have proven to be impractical, even when localized and in fairly open habitats. As a result, statistically-based sampling methods offer the only realistic way to estimate mule deer numbers on the scale of most management units. Cover and terrain often make deer inconspicuous; therefore, methods used to estimate abundance must account for incomplete detectability of deer in the sampling areas. Based on studies with radiomarked deer and counts of known numbers of deer in large enclosures, detectability is often considerably less than 100% even when the census effort is very intensive (McCullough 1979, Bartmann et al. 1986, Beringer et al. 1998). To help address problems related to widespread distribution and incomplete detectability, abundance and density estimates are usually made during winter when mule deer are more concentrated and more visible against snow cover. Estimates of mule deer abundance and density are further complicated because numbers are dynamic and populations are seldom geographically discrete. Deer are born, die, immigrate, emigrate, and frequently move back and forth across management unit or sampling frame boundaries. Methods for estimating abundance and density must take into account whether the population of interest is assumed to be geographically and demographically closed or open during the sampling period. Population modeling offers an alternative to sample-based population estimation by using demographic parameters such as harvest mortality, sex and age ratios, and survival estimates to predict population numbers. Unfortunately, the public can sometimes be highly skeptical of credible model-based population estimates that do not conform to their perceptions because actual deer are not being counted (Freddy et al. 2004).

Sample-based Methods

*Distance sampling*.— Distance sampling can be used to estimate number of deer within a fixed distance away from a line or from a point based on distribution of decreasing detection probabilities as distance increases (i.e., deer farther away are harder to see) (Buckland et al. 2001, 2004; Thomas et al. 2010). Distribution of detection probabilities can be estimated based on the assumptions that 1) all deer on the line of travel will be detected or accurately estimated, 2) detection will decrease as distance from the line increases, and 3) deer distribution is independent of sampling design. Population size can be extrapolated from numbers of deer in a sample of line transects or plots that can be stratified by deer density or habitat. Distance sampling for ungulates is usually done along transects from a fixed-wing airplane or helicopter and has been used primarily for species such as pronghorn (*Antilocapra americana*) that occur in relatively flat, open habitats (Johnson et al. 1991, Guenzel 1997, Whittaker et al. 2003, Lukacs 2009). A similar method has been evaluated for mule deer in pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) habitat in a large enclosure with relatively small bias (White et al. 1989). Use of distance sampling for roadside surveys or spotlight surveys is not recommended because the assumption that deer distribution is independent of transect location is unlikely to be valid when roads are used as transects. Violating the assumption of independent distribution can result in highly biased estimates.

Advantages

- Robust method with relatively few constraining assumptions compared to other methods.
- Provides a probabilistic estimate that accounts for detectability and does not require marked deer if all deer on the line of travel are assumed to be 100% detectable.
- Can be relatively inexpensive if used in fairly open and flat areas where use of fixed-wing aircraft is practical.
- Relatively easy to design and conduct using geographic information system (GIS) software and global positioning system (GPS) units.
- Can be applied to ground mortality transects as well as aerial population surveys.

Disadvantages

- Only realistic in open areas with little terrain relief where deer close to the line of travel are almost 100% detectable. For mule deer, this method would probably be limited to habitats such as upland plains, open agricultural areas, or perhaps some sagebrush (*Artemisia tridentata*)-steppe winter ranges. Even in these habitats, a helicopter would often be required as the sighting platform to achieve acceptable detectability.
- Confidence intervals can be wide (e.g., 95% CI > ±25%) when there is high variability in deer densities between transects within a stratum.
- Dependent on assigning individual deer or clusters of deer to the correct distance interval or accurately determining distance from the line of travel. This can sometimes be problematic, especially with high deer densities.

- Observer fatigue can become an issue during prolonged surveys.
- Can be relatively expensive if a helicopter is used.

Assumptions

- All deer on the line of travel are detected or accurately estimated.
- Distances are accurately measured or deer are recorded in the correct distance band.
- Detection probability decreases as distance from the line of travel increases.
- Deer distribution is not related to transect distribution.
- All deer within a detected group are accurately counted (if group or cluster is the sampling unit). If the individual is the sampling unit, this assumption no longer applies.
- Deer are detected in their original position before any movement related to the survey effort. Deer are not recounted during the survey.

Techniques

Aerial distance sampling for ungulates usually involves:

1. Establishing a set of lines of known length across the area of interest that delineate centerlines of a set of fixed-width transects.
2. Flying along each line while maintaining height above ground level (AGL) as constant as possible (with fixed-wing aircraft the flight path may be offset from the line to compensate for the blind spot directly below the aircraft).
3. Accurately assigning individual deer or clusters of deer to fixed-width bands that delineate specific distance intervals away from and perpendicular to the line of travel.

Transects are usually parallel and systematically spaced across the area of interest with a random starting point. Stratification based on deer density or habitat can be used to help reduce variance. As an alternative to 2 and 3 above, actual distances of deer or clusters perpendicular to the line can be determined using a laser range finder and the sighting angle. However, for species such as mule deer that often occur in numerous, small groups, use of distance intervals rather than actual distances is a much more practical method (Guenzel 1997). Fortunately, little bias usually results from assigning deer to distance intervals as opposed to measuring actual distances (Thomas et al. 2010). Distance intervals can be delineated using strut markers (fixed-wing aircraft) or window markers (helicopters) that have been calibrated for a specific AGL (e.g., usually between 75-300 ft [25-100 m] depending on aircraft type, cover, and terrain) to demarcate distance intervals perpendicular to the line of travel using a specific eye position (Guenzel 1997). The AGL can be accurately measured using a digital radar altimeter or a laser rangefinder mounted on the belly of the aircraft. For each observation, AGL should be automatically saved to a computer to allow distance measurements to be corrected, if necessary, for actual AGL. Effective transect width (i.e., truncation limits) and width of distance intervals depend on predicted detectability (i.e., narrower widths are used as detectability decreases). Four or five distance intervals are typically used to estimate an adequate detection function.

Program DISTANCE was specifically designed to estimate population size from distance sampling data (Thomas et al. 2010). This software:

1. Models detection probabilities as a function of distance from the line of travel when 100% detectability is assumed on the line of travel.
2. Allows covariates (e.g., cluster size, habitat, weather conditions) to be considered in the distance model.
3. Allows mark-recapture data to be incorporated when detection is 200% larger when transects and detection probabilities were used compared to quadrat sampling with a generic sightability correction, leaving doubt as to which method was more biased.

When detection on the line of travel is not certain, simultaneous double counts using 2 independent observers or a sample of radiomarked deer can be used to correct for incomplete detectability (e.g., Kissling et al. 2006). Cluster size bias can occur using distance sampling because, as distance from the line increases, deer in large groups (i.e., clusters) are more easily detected than individual deer or small clusters. Program DISTANCE can correct for cluster bias using regression methods based on the number of deer counted in each cluster relative to their distance from the line.

*Strip-transect sampling*.— In areas where cover and terrain make distance sampling infeasible, fixed-width (strip) transect sampling can still be used to obtain a minimum count that can be adjusted using generic or survey-specific detection rates based on detectability of marked deer. Population size can then be extrapolated from the sample of strip transects corrected for detection rates. Helicopter line transects have been evaluated for mule deer and white-tailed deer with satisfactory results (White et al. 1989, Beringer et al. 1998). However, Freddy (1991) compared quadrat sampling to transect sampling for mule deer in sagebrush habitat and reported estimates >200% larger when transects and detection probabilities were used compared to quadrat sampling with a generic sightability correction, leaving doubt as to which method was more biased.

Advantages

- Allows transect sampling to be used in some situations where distance sampling is not feasible because of low detectability or terrain.
- Transect sampling designs are relatively easy to lay out with GIS and are easy to fly with GPS units.
- Provides a probabilistic estimate of the number of detectable deer that can be adjusted using detection probabilities.
- Usually does not require handling and marking of deer.

Disadvantages

- Detection probabilities often must be determined using a sample of radiomarked deer which can substantially add to costs. Depending on diversity of habitats being sampled, different detection probabilities may be required for different strata, transects, and even within individual transects.
- Relatively expensive because an aircraft is required and considerable flying may be needed depending on size of the sampling frame, deer distribution, cover, and desired precision. In areas with substantial cover and terrain, transect widths must be reduced.

Assumptions

- Transect width can accurately be determined and deer can be correctly identified as being in or out of the transect.
- Deer do not move out of a transect before detection and they are not recounted in subsequent transects.
- Detection rate estimates are unbiased and accurately represent actual detection rates. Marked deer have the same probability of being sighted as unmarked deer.

Techniques

Transect counts for mule deer are usually flown using a helicopter. Transect width can be delineated by tape on the windows that has been calibrated for a specific AGL height. Unlike distance sampling, there is no need to demarcate distance intervals. Similar to distance sampling, sample transects usually run parallel, are evenly spaced across the area to be surveyed, and have a random starting point. Stratification based on deer density or habitat can be used to help reduce variance. Habitat should be fairly homogenous within each stratum to minimize the number of unique detection probabilities required.

*Plot sampling using quadrats*.— Quadrat sampling is similar to transect sampling except population size is extrapolated from a sample of randomly selected polygons that are often square and, prior to GPS technology, usually laid out using cadastral coordinates (e.g., section lines). Small (i.e., usually ≤2.6 km$^2$), intensively surveyed quadrats are used as sampling units in an attempt to improve detectability. Quadrats are usually stratified based on habitat or prior deer density information. Sampling designs can include random, random spatially balanced, and hybrid census and sampling combinations. Quadrat sampling methods for mule deer were described by Kufeld et al. (1980) and Bartmann et al. (1986).

Advantages

- Provides a probabilistic estimate of number of detectable deer.
- Fairly straightforward design that can be laid out with GIS (prior knowledge of deer distribution is very helpful) and flown using GPS.
- Does not require handling and marking of deer.

Disadvantages

- Relatively expensive because a helicopter is usually required and considerable flying may be needed depending on size of the sampling frame, deer distribution, and desired precision.
- Confidence intervals can be wide (e.g., 95% CI > ±25%) irrespective of sample size, especially when deer occur in an unpredictable or clumped distribution.
- Does not include an inherent detectability correction, so actual population size is unknown. Generic sightability factors can be used to adjust the population estimate, but they can be of questionable value because a number of variables can influence

sightability (e.g., group size, cover, terrain, snow cover, time of day).

- When deer densities are high, it can be difficult to keep track of deer that have already been counted.
- Deer may move out of a quadrat in response to the aircraft before they are counted.

Assumptions

- Each quadrat within a stratum that may contain deer has a known (often equal) probability of being selected for sampling.
- Deer are detected at a fairly high rate (e.g., >60%), are not double counted, are not erroneously accounted for by being forced into or out of a quadrat, and are accurately identified as being in or out of a quadrat when close to the perimeter.
- Generic sightability factors accurately represent actual detection probabilities.

Techniques

Quadrat methods often use sampling polygons with small areas (0.25-1 mi2 [0.65-2.6 km2 ]) to increase detection rates. Smaller quadrats are used in areas with considerable cover such as pinyon-juniper woodlands, whereas larger quadrats can be used in more open areas such as sagebrush-steppe. Using similar-sized quadrats tends to decrease among-quadrat variation, but is not required. In the past, sampling designs were usually based on cadastral section lines, but GIS and GPS units have greatly increased design flexibility. Use of GPS units has also made quadrat sampling much more practical because quadrats can be accurately flown without landmarks. Stratification can be useful for increasing precision and for optimally allocating sampling effort based on expected deer density. When there is sufficient prior knowledge of deer distribution, stratification can most effectively be achieved on a quadrat by quadrat basis rather than by geographical area.

Quadrat methods for estimating mule deer numbers can require considerable helicopter time (e.g., 20-40 hours is typical for management units in western CO, Kufeld et al. 1980). Extensive amounts of flying can cause observer fatigue and result in prolonged surveys because of weather and conflicting work assignments. Use of multiple helicopters and crews is recommended to finish counts in a timely manner under preferred conditions when snow cover is present. Quadrats should be flown by first following the perimeter to identify deer close to the boundary as being in or out. The interior of the quadrat should then be flown with sufficient intensity to count all detectable deer. Even though the quadrat method attempts to maximize detectability compared to sampling using transects or larger area units, unknown detectability remains an obvious issue. Survey-specific detection probabilities could be determined by including a sample of radiomarked deer or using sightability covariates, but the small size of the quadrats and high cost of the quadrat method make this impractical in many cases. In lieu of specific detection probabilities, generic sightability factors developed using radiocollared deer in similar habitats have been used to adjust quadrat population estimates. In Colorado, a sightability factor of 0.67 is typically used for quadrats in pinyon-juniper winter range and 0.75 is used for sagebrush-steppe (Bartmann et al. 1986; Colorado Division of Wildlife [CDOW], unpublished data). For generic sightability factors to be applicable, quadrats should be flown with as many variables as possible similar to those that occurred when sightability factors were developed (e.g., high percentage of snow cover, same number of observers, quadrats with the same area). However, even when effort is made to keep survey protocols as consistent as possible, the validity of using generic sightability factors can be questionable because of the number of variables that can affect detectability (e.g., group size, deer activity, time of day, cloud cover, type of helicopter, experience of observers).

*Plot sampling using sightability models*.— This method is similar to quadrat sampling except that 1) it includes a model developed using logistic regression methods to account for undetected deer based on a variety of sightability covariates, 2) size of sampling units can be considerably larger than those typically used for quadrat sampling, and 3) sample unit boundaries can be based on terrain features such as drainages instead of cadastral units or GPS coordinates (Ackerman 1988, Samuel et al. 1987, Freddy et al. 2004). A sightability model is developed for a specific survey intensity (i.e., survey time at a given elevation and airspeed per sampling unit area) by relating detectability of radiomarked deer to variables such as habitat, group size, deer activity, screening cover, terrain, snow cover, type of helicopter, and observer experience. Sightability models account for a more comprehensive set of detectability variables than generic sightability factors often used with intense quadrat sampling and allow the contribution that each variable makes to detectability to be evaluated using a stepwise approach. Once the sightability model is developed for a specific survey intensity, covariates supplant the need for determining detection probabilities using radiocollared deer. Even when survey intensity is kept relatively constant, sampling units should be similar in size to help eliminate variables such as increased observer fatigue when larger units are surveyed. Population size can be extrapolated from a set of representative sampling units.

Advantages

- Provides a probabilistic population estimate that includes a sightability correction.
- Once established, sightability covariates are easier and less expensive to measure than detection probabilities.
- Larger sampling units can be flown than with quadrat sampling as long as the sightability model was developed using sampling units similar in size to those being flown and sampling intensity is consistent.
- Larger sampling units are usually less affected by some potential sources of error than small quadrats (e.g., pushing deer out of the sample unit before they are detected, determining whether a deer is in or out of the sample unit, double counting the same deer when densities are high).
- Stratified random sampling of sample units produces precise estimates for lowest costs.

Disadvantages

- High initial costs to develop sightability models. Radiomarked deer must be used to develop different sightability functions for a wide variety of habitats and conditions.
- Relatively high ongoing costs due to extensive helicopter time required to conduct surveys on a management unit basis.
- A sightability model only applies to the specific conditions for which it was developed. Transferability of sightability models to habitats, survey intensities, and conditions different than those used to develop the models is not recommended and could result in highly biased results.
- Variance is likely to increase as detectability decreases.
- Population size can be underestimated if all deer in detected groups are not accurately counted (Cogan and Diefenbach 1998).
- Sampling units based on geographical features such as drainages may not be random, but drawing sampling units under stratified random sampling produces unbiased estimates.

Assumptions

- Probability of detecting deer is >0 and detectability can accurately be predicted using sightability covariates under a variety of circumstances (i.e., model captures all significant variation in sighting probabilities where it will be used).
- Sampling units are representative of the overall sampling frame and those sampling units are analogous to randomly distributed units.
- Deer in detected groups are accurately counted.

Techniques

Unlike quadrat methods that rely on small sampling units to increase sightability, use of sightability covariates allows sampling units to be larger and less intensively flown as long as applicable models have been developed. Sampling units are often defined based on geographical features such as drainages instead of constant-sized quadrats. Similar to quadrat and transect methods, precision of population estimates using sightability models can often be increased by stratifying the sample area by habitat and deer density. Ideally, sampling units should be selected at random or spatially balanced. However, when terrain features such as drainages are to be used as sample units, sample units should be selected to be as representative as possible of each stratum. Population size can be extrapolated from a set of representative sampling units. Sampling units may be stratified according to deer density, thereby reducing variability of a population estimate. All deer in detected groups must be accurately counted to avoid underestimating population size (Cogan and Diefenbach 1998). Sightability survey techniques were described in detail by Unsworth et al. (1994, 1999a).

*Mark-resight and mark-recapture*.— Mark-recapture methods use the ratio of marked (i.e., identifiable) to unmarked deer in population samples to estimate population size (Thompson et al. 1998). The population of interest must be defined in time and space and identified as being geographically and demographically closed or open. Basic mark-recapture models include the Petersen or Lincoln Index (Caughley 1977) for closed populations and the Jolly-Seber Model (Jolly 1965, Seber 1982) for open populations. These basic models have limited practical value because the assumptions required are usually violated when applied to field situations. To address the need for more practical assumptions, a variety of more complex and flexible mark recapture models have been developed that often require computer-assisted solutions (i.e., no closed form estimator is available). The programs MARK and NOREMARK have been specifically developed for this purpose (White 1996, White and Burnham 1999).

More traditional mark-recapture methods are usually based on sampling without replacement whereby the method of recapture (i.e., being caught in a trap) effectively prevents an individual from being counted more than once per sampling occasion. Although these methods can be very useful for small, inconspicuous, or furtive species, actual recapture is seldom feasible or desirable for more conspicuous large mammals such as deer. As a result, mark-recapture methods that use resighting, with or without replacement, instead of recapture have been developed for more conspicuous species. These mark-resight methods allow relatively noninvasive monitoring instead of actual recapture and subsequent marking of unmarked deer, thereby reducing stress on the deer and costs.

Mark-resight methods have been used to effectively estimate localized mule deer numbers (Bartmann et al. 1987, Wolfe et al. 2004) and newer mark-resight models that incorporate maximum likelihood have improved this method and its potential application to mule deer (McClintock et al. 2009a, b). Unfortunately, mark-resight methods may not be practical for estimating deer abundance on a large scale (e.g., management unit) because of the cost and time required to mark adequate numbers of deer and conduct resighting surveys. As an alternative, quasi mark-resight approaches have been developed that use mark-resight data to calculate correction factors (i.e., detection probabilities) for incomplete counts (Bartmann et al. 1986, Mackie et al. 1998) or that use simultaneous double-counting to obviate the need for marking deer (Magnusson et al. 1978, Potvin and Breton 2005).

Advantages

- Usually considered one of the most reliable methods for estimating abundance of wildlife populations when sample sizes are adequate and assumptions are not critically violated.
- Unlike most other sampling methods, mark-resight methods explicitly account for detectability (even deer with essentially no detectability).
- Multiple resighting surveys (aerial or ground) can be done over time to increase precision and allow modeling of individual heterogeneity in detection probabilities among individual deer (Bowden et al. 1984, Bowden and Kufeld 1995, McClintock et al. 2009a, b).
- Provides a probabilistic estimate of population size and, with some more advanced models, allows some demographic parameters to be estimated.
- Can be applied using a wide variety of distinct marks (e.g., tags, collars, radio transmitters, paint, DNA, radioisotopes, physical characteristics, simultaneous duplicate counts) and resight methods (e.g., motion-triggered infrared cameras, hair snags, pit tag scanners, hunter harvest).

Disadvantages

- Can be expensive and labor intensive to achieve an adequate sample of marked deer, ensure marks are available for resighting, and conduct resighting surveys.
- Usually not practical over a large geographical area with a widely distributed species such as mule deer.
- Although the precision of mark-resight estimates is determined by a variety of factors (e.g., number of marks, detection probabilities, number of resight occasions), confidence intervals can be wide (e.g., 95% CI > ±25% for practical applications.
- Dependent on a variety of assumptions, that if violated, can result in spurious results. Methods with less restrictive assumptions may result in reduced precision and accuracy.
- Marked deer may become conditioned to avoid resighting.
- Some quasi mark-resight methods such as simultaneous double-counts can be much less reliable and inherently biased because of individual deer heterogeneity.

Assumptions (Assumptions vary depending on the estimator being used [White 1996]). Basic assumptions include

- Population in the area of interest is to a large extent geographically and demographically closed unless gain and loss are equal or can be reliably estimated.
- Each deer in the population has an equal probability of being marked and marks are distributed randomly or systematically throughout the population of interest.
- Number of marks available for resighting in the sampling area is known or can be reliably estimated.

- Each deer in the population, marked or unmarked, has an equal probability of being sighted or individual sighting probabilities (i.e., resighting heterogeneity) can be estimated.
- Marks are retained during the resight sampling period.
- Deer are correctly identified as being marked or unmarked when sighted.

Techniques

Most mark-resight population estimates of wild ungulates use radiomarked animals. Radiomarks have the advantages of allowing confirmation of the number of marked deer available for resighting within the area of interest and identification of individual deer. Radiomarks have some disadvantages however (e.g., deer usually need to be captured to attached radios, equipment is expensive, radios can fail). In lieu of radiomarks, a variety of other marks have been used with mixed success for deer including ear tags, neck bands, a variety of temporary marks (e.g., paint balls, Pauley and Crenshaw 2006), and external features such as antler characteristics (Jacobson et al. 1997). Regardless of the marking method, marked deer should not be more or less visible than unmarked deer (e.g., fluorescent orange neck bands could make marked deer stand out more than unmarked deer). Nor should the marking method influence the resighting probability of marked versus unmarked deer (e.g., deer captured and marked using helicopter netgunning may avoid a helicopter more than unmarked deer during resighting surveys). Marks can be generic or individually identifiable. The latter has the advantage of allowing estimation of individual detection probabilities which can greatly improve some models.

Collection of DNA from scat or hair has become an increasingly popular method for identifying individual animals in mark-recapture studies. Use of DNA has the major advantages that deer do not need to be handled for marking, sampling is non-invasive and relatively easy, and the technique can be applied to situations where sighting surveys are not feasible (e.g., densely vegetated habitats or furtive species). Potential downsides include genotyping errors and variable relationships between the DNA source (e.g., fecal pellets) and the deer. Brinkman et al. (2011) used DNA from fecal pellets to estimate free-ranging Sitka black-tailed deer (*O. h. sitkensis*) abundance using the Huggins closed model in Program MARK.

Model choice should be carefully considered before beginning mark-resight surveys because different models are based on different assumptions. Mark-resight models that have been used over the years include the joint hypergeometric estimator (JHE, Bartmann et al. 1987), Bowden's estimator (Bowden 1993, Bowden and Kufeld 1995), and the beta-binomial estimator (McClintock et al. 2006). Bowden's estimator has been one of the most useful mark-resight models for deer and other wild ungulates. Unlike some other models, Bowden's estimator does not assume all deer have the same sighting probability (i.e., allows for resighting heterogeneity), populations can be sampled with or without replacement (i.e., individual deer can be observed only once or multiple times per survey), and all marks do not need to be individually identifiable. More recently, maximum likelihood estimators have been developed with similar practical assumptions. These estimators include 1) the mixed logit-normal model (McClintock et al. 2009b) when sampling is done without replacement and the number of marks is known, and 2) the Poisson-log normal model (McClintock et al. 2009a) when sampling is done with replacement or the exact number of marks is unknown. These maximum likelihood methods have the major advantage of allowing information-theoretic model selection based on Akaike's Information Criterion (Burnham and Anderson 1998). Methods for Monitoring Mule Deer Populations 42 Program NOREMARK was specifically developed to calculate population estimates based on resight data when animals are not being recaptured (White 1996). The program includes the JHE (Bartmann et al. 1987), Minta-Mangel (Minta and Mangel 1989), and Bowden's (Bowden 1993, Bowden and Kufeld 1995) estimators. More recently, the mixed logit-normal (McClintock et al. 2009b) and the Poisson-log normal (McClintock et al. 2009a) mark-resight models have been included in Program MARK along with a variety of other mark-recapture models (White and Burnham 1999, White et al. 2001, White 2008).

A quasi-mark-resight method that can be more effectively applied on a management unit scale, particularly when deer are fairly detectable, is to correct minimum counts for the resight rate of a sample of marked deer (Bartmann et al. 1986, Mackie et al. 1998). This approach does not use the ratio of marked to unmarked deer to estimate population size per se, but rather the ratio of observed marked deer to total marked deer to adjust samplebased estimates for incomplete detectability similar to methods used for correcting transect and sample area counts discussed previously. Mark-resight adjustment factors can be survey-specific (i.e., based on resight of marked deer during the survey) or generic (i.e., based on previous resight probabilities under similar conditions).

Simultaneous double-counting is another quasi form of mark-resight whereby a population estimate is derived based on the ratio of total number of deer counted (marked deer) to number of duplicated sightings (resighted deer) using independent observers (Magnusson et al. 1978, Potvin and Breton 2005). For ungulates, simultaneous doublecounting is usually done from a helicopter or fixed-wing aircraft and can be applied to a wide area because it has the obvious advantage of not requiring marked deer. Two observers in the same or different aircraft independently record the location, time, and group characteristics of all deer observed. For population estimation, this method assumes all deer are potentially detectable and observers are independent. Both assumptions are often questionable and there is inherent bias towards underestimating true population size to an unknown extent, which raises substantial concern about the appropriateness of this approach. In cases where sighting probabilities of deer are low (<0.45, Potvin and Breton 2005) or unknown, simultaneous double-counts are more appropriately interpreted as adjusted minimum counts rather than population estimates. To adjust for the inherent bias of the simultaneous double-count method, the method can be used in combination with a known sample of marked deer or sightability covariates to adjust the estimate for sighting probabilities (Lubow and Ransom 2007).

*Thermal imaging and aerial photography*.—Thermal imaging and aerial photography frequently appeal to the public as ostensibly practical methods to census wild ungulates. Although these methods have some potential for estimating mule deer numbers under the right conditions, they have often failed to show much advantage over standard counting methods because of highly variable detection rates (Haroldson et al. 2003, Potvin and Breton 2005).

Advantages

- Create a visual record that can be reviewed, analyzed, and archived.
- Do not rely on real time observations that could be in error.

Disadvantages

- Potential inability to 1) detect deer under cover, 2) differentiate deer from the background, and 3) differentiate mule deer from other species.
- Highly variable results that can be influenced by a wide variety of factors.
- Require relatively expensive equipment and flight costs, but often result in little or no benefit over standard counting methods.
- Thermal imaging flights must be conducted within a narrow range of environmental conditions.

Assumptions

- A high percentage of deer can be individually detected and accurately differentiated from other species and inanimate objects.

Techniques

Thermal imaging typically uses a wide-angle FLIR system mounted on a helicopter or airplane. Random or systematic transects are most commonly flown, but a variety of sampling designs are possible. The system can make a video record of the flight that can be reviewed and analyzed at a later date. Thermal imaging cannot penetrate dense vegetation and differentiating deer from inanimate objects is sensitive to temperature gradients and heat loading. Night flights when deer are more likely to be in the open and heat loading is minimal are seldom practical from a safety standpoint. Surveys using FLIR are usually relegated to a narrow window of time after daybreak. Species identification can be problematic in areas where there are other large species such as livestock, elk, white-tailed deer, pronghorn, and bighorn sheep (Ovis spp.). Although FLIR surveys often assume detection probabilities approaching 1, actual detection rates can be highly variable (Haroldson et al. 2003, Potvin and Breton 2005). Therefore, FLIR surveys can have little advantage over visual counts because both methods usually must be corrected for incomplete detectability. Population estimation using aerial photography involves making a photographic record of the area of interest from an altitude that does not cause disturbance to the deer. Use of aerial photographs has had little utility for deer because they are relatively small and seldom in areas with little or no cover. An attempt to use aerial photographs in Colorado to quantify elk numbers in open areas during winter was unsuccessful because individual elk could not be reliably identified (CDOW, unpublished data).

**Population Modeling**

Population modeling can be used to provide biologically realistic, mathematical simulations of deer populations based on demographic parameters that can be estimated using routinely collected field data. Modeling allows populations to regularly be estimated at a scale that would seldom be feasible with sample-based population methods. There are 2 basic types of population models: cumulative and point-estimate. Cumulative models use a balance sheet approach of adding (recruitment and immigration) and subtracting (mortality and emigration) deer over time from an initial population, whereas point-estimate models predict population size at a single point in time independent of prior history. Cumulative models can be evaluated using objective model selection criteria based on how closely model predictions align with field observations over time and how many parameters are used. Evaluation of point estimate models is generally more subjective or requires comparison with sample-based estimates. Cumulative models allow multiple sources of data to be integrated and considered over many successive years. This can result in a much more data-rich estimate of population size than single-point estimates because all relevant sources of data over time are considered. Because initial population size and the numbers of deer to add and subtract annually are seldom known, cumulative models rely on parameters that are more easily estimated to allow population gain and loss to be calculated. These parameters typically include harvest and wounding loss, post hunt sex and age ratios, natural survival rates, and, in some cases, immigration and emigration rates. In practice, field estimates of some of these parameters are often not available, and even when they are measured, they often contain sampling error as well as process variance (White and Lubow 2002, Lukacs et al. 2009). Therefore, it is usually necessary to roughly estimate or adjust some parameters to better align model outputs with observed values. Most cumulative population models for deer are based primarily on alignment of modeled and observed post-hunt B:D ratios. Cumulative models work the best when 1) the data set extends over several years, 2) field data are unbiased, and 3) adult male harvest rates are fairly high. All models are dependent on the quantity and quality of data used. The public and some wildlife professionals can often be highly skeptical of modeled population estimates for mule deer (Freddy et al. 2004). Although there can be legitimate reasons for this skepticism, it is too often focused on how models work rather than quality of data going into models, with the latter being a crucial component. In addition to their use for estimating population size, population models can also be useful for predicting outcomes of different management actions, evaluating density-dependent effects, and understanding effects of stochastic events on population dynamics.

# Damage Control Methods

Two fundamentally different approaches may be used to address overabundant deer: damage control and damage mitigation. Damage control deals with the management of the damage inflicted by overabundant deer, whereas damage mitigation deals with methods to reduce the numbers of the overabundant deer. Because deer become overabundant in response to anthropogenic resources, damage control measures may limit access to resources and result in mitigation of deer abundance.

Many methods exist to manage damage resulting from high deer densities in urban situations. In most cases, use of multiple methods usually increase the success of damage control measures. For deer management in urban settings to be successful, attention should be paid to both damage control methods and mitigation techniques. At times, public support may be greater for damage control than for mitigation, but both approaches can help achieve clearly defined objectives more quickly. (Pierce and Wiggers, 1997)

## *Fencing*

Fencing may be constructed to create a physical barrier which will exclude deer from accessing areas where they can cause damage, or they are not wanted. When properly constructed and maintained to assure efficacy, fencing can be an extremely effective damage control technique (Conover, 2001). Fencing may be constructed along a roadway to minimize deer vehicular accidents, but in most cases in populated areas, it is used to protect private property such as gardens, ornamental trees, landscaping or small orchards. Consideration needs to be given to the cost of construction and maintenance of the fencing in comparison to the value of the property being protected.

Wildlife agencies in general will not cover fencing costs. Landowners, municipalities or neighborhood associations should expect to provide the financing to construct and maintain whatever type of fence is chosen.

Many types of fencing and construction techniques are available. An excellent synopsis is found in Curtis et al, 2017. Attention to detail in fence construction and maintenance is critical for fencing to be an effective deterrent to deer damage.

Nonelectric Fencing

Wire fencing that is not electrified can create an effective physical barrier to deer when constructed properly. There are numerous material and construction options including woven-wire, chain-link, barbed wire, or larger diameter high-tensile smooth wire. Common exclusion fencing should not have spikes or spears on posts. Deer can easily become impaled or tangled on these fences. They are not appropriate for areas of medium or high deer densities. Fencing that is not electrified must be tall enough (at least 3 meters) to prevent deer from jumping over. It must also make solid contact with the ground, so deer can't crawl under. It should also be constructed such that the strands are close enough together (8-10 inches apart) and taunt enough (200+ pounds of tension) so that deer can't slide between them. It is also important to maintain an area of cleared ground about 6-10 feet wide around the periphery of the fence, so deer have an opportunity to see the fence before they make contact and potentially damage the fence or harm themselves.

If the goal is to protect a small, single tree, trees can be fenced individually with the use of woven wire type fence that is only 4 feet high, as long as the area enclosed is not large enough for a deer to jump into and the fence is far enough away from the tree to prevent browsing. Larger trees that are browse resistant due to height, can be protected from antler rubbing by using a plastic tree wrap (Vexar ®), tubing (Tubex ®) or a woven wire cylinder.

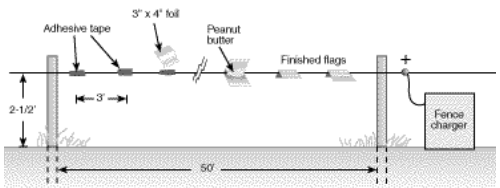
Advantages:
Woven wire fencing constructed of quality components should be expected to last 20-30 years with little maintenance.

Disadvantages:
Initial costs of fencing material and construction are high. Some types of fencing may be prohibited in certain municipalities due to it not being aesthetically pleasing. Professionals are typically needed to install this type of fencing.

Electric Fencing
Electric fences provide inexpensive protection for many gardens. They are easy to construct, do not require rigid corners, and use readily available materials. The fences are designed to attract attention and administer a strong but harmless electric shock (high voltage, low amperage) when a deer touches the fence with its nose. Deer become conditioned to avoid the fence. These fences are easily installed and removed. The major cost associated with temporary

electric fencing is the fence charger. Such fences require weekly inspection and maintenance.

The peanut butter fence has been shown to be an effective and inexpensive fence design in a number of field conditions. It is best used for gardens, nurseries, and yards that are subject to moderate deer pressure. Check the fence weekly for damage by deer and for grounding vegetation.




*Peanut butter fence*

A single strand of 17-gauge wire is suspended about 30 inches above the ground by 4-foot fiberglass rods at 30- to 60-foot intervals. Wood corner posts provide support. Aluminum foil "flags" (foil squares 4 inches by 4 inches folded over the wire) are attached to the wire at 20- to 50-foot intervals using tape or paper clips to hold them in place. Aluminum flashing can also be used and has the advantage of not being damaged or blown off. Closer spacing may be necessary near existing deer trails and during the first few months the fence is used, when deer behavior is being modified. The underside of the flags is baited with a 1:1 mixture of peanut butter and vegetable oil. The smell attracts the deer, which touch or sniff the flags and receive an electric shock. The flags should be rebaited every 4 to 8 weeks, depending on weather conditions. As deer learn to avoid the shock of the fence, bait can be reduced or eliminated.

The effectiveness of the original peanut butter fence has been greatly enhanced by using polywire or polytape, rather than the 17-gauge wire. It has the advantage of being more visible to deer, especially at night. It is also easier to roll up and remove. Polywire has a life expectancy of 5 to 7 years.

Polywire is composed of three, six, or nine strands of metal filament braided with strands of brightly colored polyethylene. A wider polytape is also available and has the advantage of being stronger and more visible, but also more expensive. Although both polywire and polytape come in a wide variety of colors, many users claim that white provides the greatest contrast to most backgrounds and is easier for deer to see, especially at night. Loss of voltage over long distances of polywire/polytape can be a problem. Purchase materials with the least electrical resistance (ohms per 1,000 ft) for these applications. In its simplest application, an electrified single strand of polywire is suspended about 30 inches above the ground by 4-foot fiberglass rods at 20- to 50-foot intervals and baited in the same way as the original peanut butter fence. This basic design can be enhanced. A second wire can be added to increase effectiveness: one wire placed 18 inches from the ground and the top wire at 36 inches above the ground. This prevents fawns from walking under the fence and also increases the chance that one wire will remain electrified if deer should knock the fence over. Usually only the top wire is baited. In small areas, such as home gardens, more wires can be added on taller poles if desired, and closely spaced bottom wires can keep out rabbits and woodchucks. It is important that vegetation be mowed or removed under the fence so it does not short out.

Fiberglass rods usually do not provide enough support for use as corner posts. At corners it is better to use 4-foot metal fence stakes with a bottom plate that provides stability when it is pushed into the ground. A piece of thin-walled 1-inch PVC pipe can be slipped over the metal stake to act as an insulator with the polywire or polytape wrapped around a few times. This allows the stringing of the wire with sufficient tension to hold the flags. A variety of wooden posts with plastic insulators will also work well.

While single or multiple strands of electric fencing may be somewhat effective (baited or un-baited), electric fencing constructed with an offset of double-fence design (with a taller two-strand fence on the outside and a shorter one strand fence about 38 inches to the inside) is also very effective. This type of electric fence creates a three-dimensional barrier that is both physical and psychological and will discourage deer from jumping over or crawling under to avoid electrocution. As with the peanut butter fence, polywire or polytape should be used for fence construction for maximum visibility to deer.

When using electric fencing in general, at least 3000 volts should be maintained at the farthest end of the fence for effectiveness. An area around the periphery of the fence should be cleared for at least 6-10 feet, so that deer see the fence before making contact.

The use of electric fences in and around home sites can cause concern for children and visitors. One option is to put the fence charger on a timer so that it comes on only from dusk to dawn. This method provides adequate protection in areas where deer are not a problem during the daytime hours. Electric fences should also be signed to warn away unsuspecting wanderers.

Advantages:
Electric fencing tends to be cheaper to construct than woven wire fencing (discussed below).

Disadvantages:
Electric fencing is a bit more expensive to maintain than non-electrified fencing. Weeding is necessary to prevent the fence from shorting out and vigilance is required to remove fallen branches or repair breaks that can render the fence useless. During periods of deep snow, strands of the fence in contact with snow must be disconnected. Also, electric fencing may be prohibited in some municipalities.

## *Tree Shelters*

The tree shelter is a transparent, corrugated polypropylene tube that is placed around seedlings at the time of planting. The tube is supported by a 1-inch by 1-inch wooden stake located next to the shelter. An ultraviolet inhibitor is added to the polypropylene to prevent it from breaking down too rapidly when exposed to sunlight. The shelter disintegrates after 7 to 10 years.

A 4-foot shelter is commonly used and will prevent deer from browsing on tree seedlings. A 5-foot shelter may be needed in areas with excessive browsing or snowfall. The tube has the added benefit of promoting rapid height growth of the seedling by acting like a mini greenhouse.

## *Repellents*

Repellents can help reduce deer damage to gardens and ornamental plants. Repellents are most valuable when integrated into a damage-abatement program that includes several repellents, fencing, scare devices and herd management.

There are two kinds of repellents: contact repellents and area repellents. Apply contact repellents directly to plants; their taste repels deer. They are most effective on dormant trees and shrubs. Contact repellents may reduce the palatability of garden items and should not be used on plants or fruits destined for human consumption.

Area repellents deter deer by odor and should be applied near plants you want to protect. Border applications of area repellents protect larger areas at relatively low cost. Because such repellents are not applied directly to plants, they can be used to protect home garden crops grown for human consumption.

People who utilize repellants should understand several basic principles:

- Repellents do not eliminate browsing, they only reduce it; therefore, repellent success should be measured by the reduction, not elimination, of damage. Even if minimal damage is intolerable, 8-foot fencing is the best option.
- Rainfall will wash off many repellents, so they will need to be reapplied. Some repellents will weather better than others.
- Repellents reduce antler rubbing only to the extent that they help keep deer out of an area.
- The availability of other, more palatable deer food dictates the effectiveness of repellents. When food is scarce, deer may ignore both taste and odor repellents. In addition, deer may become habituated to certain repellants over time, reducing their effectiveness.
- If you use repellents, do not overlook new preparations, products, or creative ways to use old ones. New products are constantly appearing on the market.
- Growers who are facing a long-term problem should compare the costs of repellents and fencing over time.
- Repellents that work in one area may not work elsewhere, even for similar crops and conditions.

<u>Application of commercial repellents</u>
Application methods for commercial repellents range from machine sprayers to manual backpack sprayers. Remember, as labor intensifies, costs rise.
Apply contact repellents on dry days when temperatures are above freezing. Young trees should be completely treated. The cost of treating older trees can be reduced by limiting repellent application to the terminal growth within reach of deer (6 feet above the deepest snow). New growth that appears after treatment is unprotected.

As a preventive measure, the first repellent application should take place within two weeks of budbreak. During the growing season, repellents should be applied as necessary to protect new growth, usually every three to four weeks. For dormant season protection, midfall and early winter applications are recommended. Fall applications may also prevent antler rubbing.

Regardless of the type of application used, every program should be planned in advance and implemented on schedule. Periodic monitoring is essential to determine the necessity and timing of subsequent applications.

*Available commercial repellents*
The following discussion of repellents may be incomplete, but it indicates the variety of materials available. Repellents are grouped by active ingredient and include a brief description of use, application rates and costs. Product labels provide all necessary information on use and must be followed to the letter to achieve maximum success.

- Putrescent egg solid: This contact repellent smells and tastes like rotten eggs. It has been reported to be 85 to 100 percent effective in field studies. Apply it to all susceptible new growth and leaders. Applications weather well and are effective for two to six months.
- Ammonium soaps of higher fatty acids: This is an area repellent that smells like ammonia and is one of the few registered for use on edible crops. Applications can be made directly to vegetables, ornamentals and fruit trees. Its effectiveness is usually limited to 2 to 4 weeks but varies because of weather and application technique. Reapplication may be necessary after heavy rains.
- Thiram (11 to 42 percent tetramethylthiuram disulfide). Thiram is a fungicide that acts as a contact (taste) deer repellent. It is sold under several trade names. It is most often used on dormant trees and shrubs. A liquid formulation is sprayed or painted on individual trees. Although thiram itself does not weather well, adhesives can be added to the mixture to resist weathering.
- 2.5% capsaicin. This contact (taste) repellent is registered for use on ornamental, Christmas and fruit trees. Apply it with a backpack or trigger sprayer to all susceptible new growth, such as leaders and young leaves. Do not apply to fruitbearing plants after fruit set. Vegetable crops also can be protected if sprayed before the development of edible parts. Weatherability can be improved by adding an antitranspirant such.
- Benzl diethyl (2,6 xylylcarbomoyl) methyl, ammonium saccharide (0.065%), thymol (0.035%): Repels deer with its extremely bitter taste. Apply once each year to new growth. It is not recommended for use on edible crops. It can be applied at full strength on trees, ornamentals and flowers.

*Noncommercial repellents*
All noncommercial are odor-based repellents that are applied to trees, shrubs and vines. When using noncommercial repellents, make sure you are using a registered material for that application. For example, "home remedies" such as mothballs are not registered for this use, and they should not be considered for this purpose. To deter deer in an urban or suburban environment, use scents that are not naturally found in those areas. Three noncommercial repellents are tankage, human hair and bar soap. All are odor-based repellents.

- Cayenne pepper and egg solutions: Cayenne pepper and/ or eggs can be mixed with water and sprayed directly on non-edible plants to protect them from browse. There are numerous online recipes available. These repellants should not be used on edibles and will need to be reapplied periodically and after rain.
- Hair bags (human hair): Human hair is a repellent that costs very little but has not consistently repelled deer. Place two handfuls of hair in fine-meshed bags (onion bags, nylon stockings). When damage is severe, hang hair bags on the outer branches of trees with no more than 3 feet between bags. For larger areas, hang several bags, 3 feet apart, from fence or cord around the perimeter of the area to be protected. Attach the bags early in spring and replace them monthly through the growing season.
- Bar soap. Studies and numerous testimonials indicate that ordinary bars of soap applied in the same manner as hair bags can reduce deer damage. Drill a hole in each bar and suspend it with a twist tie or string. Each bar appears to protect a radius of about 1 yard. Any tallow-based brand of bar soap will work.

## *Landscape plants*

While virtually no plant is “deer proof”, there are several ways to control deer damage through plant selection. Sayre et al. (1992) noted that damage can vary regionally and by differences in site characteristics. Some site characteristics that may affect the amount of deer damage on a particular landscape planting are:

- Proximity to other more/less desired plants
- Travel behavior of the deer in the area
- Amount on landscaping planted
- Deer density in the area
- Types of plants used in landscaping
- Level of deer resistance to the plants used
- The amount of natural food available in an area (which can differ annually)
- Artificial feeding in the area

*Plant Selection*
A simple search online can generate many lists of plants that are “deer resistant”. However, many of those lists as they are often generated not off of any scientific research but rather on anecdotal information or by simply copying plants from another existing list. However, there are three lists that have utilized some scientific research into plant resistance of deer damage. A three-year study in **Wildwood, Missouri** led to a list of native plants resistant to deer. **Cornell University, NY** also conducted a study of deer resistant plants and published Dr. Brigden’s List of Plants Deer Do Not Like to Eat. Finally, the **Cincinnati Zoo, OH** conducted a survey of over 400 nurserymen, educators, naturalists, and garden enthusiasts of deer resistant plants that commonly appeared on over 40 different lists that were collected from around the Midwest. Their survey resulted in a condensed list of plants most frequently agreed upon by those surveyed that were deer resistant.

Another consideration that should be used in landscape design and plant choices is the use of native versus non-native plants.
Native plants may persist better than nonnative plants because native plants have evolutionarily grown in the presence of deer and have learned to sustain deer damage. However, often the selection of native plants at standard nurseries can make locating native plants challenging. However, increasingly nurseries are beginning to offer a wider selection of native plants. Efforts should be made to plant species that are native to the area and avoid invasive species.

By incorporating many of the other damage control options in conjunction with dealing with landscape planting there tends to be higher success in protecting the plants.

## *Harassment and Scare Tactics*
Harassment and scare tactics are used to frighten deer from areas where they may cause damage or where they are not wanted. Efforts to frighten deer should be initiated as soon as sign of deer activity is noticed. Once deer have established a movement or behavior pattern or become accustomed to feeding in a particular area, the behaviors are difficult to modify.

**Noise Making Devices**

Various types of noise making devices such as fireworks, gun shots or gas exploders may be effective at frightening deer from an area. Noises should be made at irregular intervals, primarily during times of greatest deer movement.

Advantages
Devices that frighten deer are generally inexpensive.

Disadvantages
Loud noises are often considered a nuisance to humans as well, and as such, may not be allowed within city limits. Efficacy is often short term as deer quickly habituate to noises that do no harm them.

**Guard Dogs**

Guard dogs may be used to frighten deer from an area. Typically, the dog’s movement should be restricted by an invisible fence encircling the area to be protected. A single dog can be expected to cover only a small area unless the dog is taught to patrol at times of day when deer movement is greatest, typically dawn and dusk.

Advantages
Deer will not habituate to the dog.

Disadvantages
Care of dogs can be time consuming, and the invisible fencing to restrict dog movement can be costly to construct and maintain.

## *Supplemental or Diversionary Feeding*

Supplemental or diversionary feeding of deer may be considered as a method to draw deer away from urban areas where they are not wanted. However, this practice may actually exacerbate existing problems and create new ones. (The Wildlife Society

2007). Increasing access to anthropogenic foods will likely attract even more deer into an area where there may already be an overabundant population thus increasing conflicts Likewise,concern about the spread of Chronic Wasting Disease and other diseases should be paramount, as concentrating many deer at one feeding area can exacerbate and promote the transmission of disease.

With supplemental feeding, deer will continue to browse on natural vegetation, with increased damage near feeding sites. Fed deer may become reliant on supplemental food and they are more likely to become tame as they associate food with people, increasing the likelihood of conflict with or even danger to humans.

## *Roadside warning devices*

*Motorist warning devices.*—Many options to reduce motorist speed or alert motorists of potential for deer-vehicle collisions are available (Romin and Bissonette 1996, Putnam 1997, Farrell et al. 2002). These range from static signs that reduce speed limits to technologically-advanced animal detection systems in which signs are activated only when wildlife are present. The intent behind all motorist warning systems is to alert the driver to potential hazards with wildlife on the roadway and cause the driver to slow enough to completely avoid a collision or collide at a slower speed to reduce the severity of the accident (Huijser et al. 2009).

Permanent signs are likely the earliest form of motorist warning to reduce wildlife-vehicle collisions. On many roads, departments of transportation have placed signs with silhouettes of wildlife in an attempt to forewarn motorists of potential for collisions with wildlife. Little research has been conducted on effectiveness of permanent signs, however there is a general consensus that they are ineffective for long-term mitigation of deer-vehicle collisions because motorists tend to largely ignore them. If permanent signs are used, placement should focus on high deer-vehicle collision area to reduce motorist complacency (Pojar et al. 1975, Knapp and Yi 2004, Found and Boyce 2011*b*). Temporary signs appear to be more effective than permanent signs as signs are in place for a shorter period of time, increasing the likelihood for motorists to note and react to new signage. Sullivan et al. (2004) documented a 50% decrease in collisions with mule deer during migrations using temporary warning signs with flashing lights along 5 highways in 3 different states. Hardy et al. (2006) also reported that portable dynamic message signs were more effective at reducing driver speed than permanent signs along I-90 in Montana.

Signs that are activated by wildlife should be the most effective at reducing motorist speeds because there is limited opportunity for motorists to become habituated to them. Animal detection systems have been in existence since the late 1970s, and their performance has varied. Ward et al. (1980) documented a 100% reduction in deer-vehicle collisions, although their data was limited. Huijser et al. (2009) tested various models of detection systems and found that their reliability was influenced by a range of environmental conditions. Detection systems that cover large expanses of road and require many signs and detection devices fail more often due to environmental factors such as vegetation, rain, and snow. Overall, many systems have been tested in field settings and most were unreliable, producing substantial false positives or negatives (Huijser and McGowen 2003). The systems that were most effective were used on lower traffic volume roads and combined with fencing to limit wildlife access to the road at a finite location. This reduced the potential for electronic malfunction (see below; Gordon et al. 2004, Gagnon et al. 2010). Recent studies in Arizona on animal-activated systems that include technologically-advanced software which acquire and identify specific targets before signaling their presence have had fewer incorrect classifications; electromagnetic sensors are still being tested in Colorado. Remote detection and warning of wildlife at roadways remains an area of active research and development.

Wildlife "crosswalks" are a combination of fencing and gaps in the fence that allow animals to cross roadways at designated areas. Crosswalks have been minimally tested, though Lehnert and Bissonette (1997) reported moderate effectiveness of crosswalks along 2 and 4-lane highways in Utah. These crosswalks included static or continuously activated signs warning motorists of crossing mule deer. Although they documented minimal motorist response, likely due to motorists becoming accustomed to and ignoring static or continuously-activated signs, there was still a decrease in mule deer mortality. Gordon et al. (2004) documented a minimal reduction in speeds, overall about 4 mph with the animal activated motorist warning signs along US Highway 30 in Wyoming. When a deer decoy was visible to approaching motorists in combination with the flashing lights, speeds decreased by up to 12 mph. Gagnon et al. (2010)

documented a 97% decrease in elk-vehicle collisions and a nearly 10 mph reduction in motorist speeds at a crosswalk with animal-activated motorist warning sign. Crosswalks can function as an at-grade wildlife crossing in some circumstances, but they should not be used on high-speed highways (Gordon et al. 2004, Gagnon et al. 2010). When using crosswalks in lieu of other wildlife crossings, similar requirements for spacing between crosswalks along the roadway should be considered. Traffic volumes must be taken into consideration for crosswalks as high traffic can provide an impermeable barrier.

Speed reduction zones in areas where wildlife-vehicle collisions occur can reduce potential for more severe accidents. Enforcement of speed limits is key to their success as many motorists ignore speed limit signs. In general, speed reduction zones are considered ineffective at reducing deer-vehicle collisions (Romin and Bissonette 1996, Bissonette and Kassar 2008). Highway lighting is an ineffective method to reduce deer-vehicle collisions (Reed and Woodard 1981, Romin and Bissonette 1996). Anecdotal information indicates that highway lighting can cause areas beyond the lighting to appear even darker to motorists, reducing detection of deer once leaving the lighted area.

*Benefits and Challenges*

Accurate animal detection systems that reduce motorist habituation combined with funnel-fencing to restrict detection coverage area are effective at reducing motorist speed and alertness (Gagnon et al. 2010). Animal detection systems by themselves when deployed across large expanses of road show little benefit in reducing deer-vehicle collision. Overall, animal detection systems have the potential to be an effective tool in mitigating deer-vehicle collision (Huijser and McGowen 2003). However, in many cases they do not reduce deer-vehicle collisions, primarily due to environmental conditions that cause system failures that lead to excessive false positives, in turn causing motorists to ignore the warning signs, or false negatives that fail to inform the driver of an animal in the road (Huijser et al. 2009). Further research on new technologies and devices that overcome these environmental factors is warranted. When working with transportation agencies on mitigation measures to reduce deer-vehicle collision, it is essential to selectively recommend methods that have a high potential for success. Failure to meet this goal can cause reluctance by transportation agencies to spend time and funding on potential solutions in the future.

*Financial Assessment*

Motorist warning systems can be relatively inexpensive, yet they are ineffective in many cases. Animal detection systems that provide warning to motorists only when deer or other wildlife are present are the best solution when wildlife crossings are not an option. If possible the warning systems should be combined with funnel fencing and electrified mats, which restrict possible movements of wildlife while crossing the roadway, to reduce potential for malfunction due to environmental conditions. The actual expenses for these types of systems may run from $50,000 to $200,000 depending on complexity and design. Costs for the regular maintenance of the warning system may additionally include full time staff or a private contractor to regularly check on these systems.

*Decoy deterrents.*—Decoy deterrents are intended to make motorists react to the visual cue of seeing the decoy and respond by slowing down. Research evaluating the effects of deer decoys as a stand-alone deterrent for deer-vehicle collisions is lacking, but several studies have evaluated decoys or simulations used in conjunction with other techniques. Using a cross section of a full-body taxidermy mount, Reed and Woodard (1981) evaluated deer simulations and highway lighting as a potential means to reduce deer vehicle collisions in Colorado. They found that highway lighting did not affect the location of deer crossings, location of accidents, nor mean vehicle speeds. The presence of a deer decoy placed in the emergency lane in lighted view of oncoming traffic, however, decreased mean vehicle speeds by 8.7 mph.

In Wyoming, Gordon et al. (2004) evaluated the effectiveness of the FLASH™ (Flashing Light Animal Sensing Host) system, designed to detect deer presence on the highway and warn motorists by triggering flashing lights associated with a sign. In addition, they experimentally tested various treatments involving the sign, the lights, and the presence of a deer decoy (full-body taxidermy mount of a mule deer doe). Automobiles traveling in the day failed to reduce speeds substantially in response to the activated system, however, speeds at night were reduced an average of 4 mph. Speeds were reduced an average of 12.5 mph in response to flashing lights and a deer decoy placed along the highway.

*Benefits and challenges*

The limited published research and lack of published management protocol on the use of deer decoys to deter vehicle collisions presents challenges for evaluating their efficacy. Research suggests that vehicles will reduce speeds in presence of deer decoys, but duration and actual application of the technique needs further evaluation. Reed and Woodard (1981) observed brake lights on 51% of the vehicles approaching the deer decoy during night, but evaluation was discontinued because of risk to motorists caused by 5–10% of the vehicles that either slowed drastically or stopped near the simulation. Placing decoys near roads could actually cause vehicle-vehicle collisions, placing substantial liabilities on management agencies that used them. There is currently no plausible rationale for using a decoy for slowing vehicle speed due to the risk of human injury due to human responses.

*Financial assessment*

Current costs of a full body taxidermy deer mount will range depending on location and taxidermist, but range between $1,500–2,500. Simulated decoys are available for substantially less. The potential for accidents and injuries place a substantial liability on any agency that may choose to use this approach.

*Auditory Stimuli.*—Several devices have been developed to stimulate an auditory response in deer to alter their behavior to avoid collisions with vehicles. "Deer whistles," which are attached to vehicles and emit a high-frequency sound, are perhaps one of the most common of these devices used by motorists. However, contrary to popular belief, assessments of deer whistles indicated deer did not respond differently to vehicles equipped with whistles than to those that were not equipped (Romin and Dalton 1992, Romin and Bissonette 1996). Scheifele et al. (2003) tested several deer whistles and concluded they were likely to be ineffective based on several aspects of acoustic performance and deer auditory responses. Valitzski et al. (2009) tested vehicle-mounted devices that produced pure tones, similar to sounds produced by deer whistles, at 5 different frequencies. They found deer responses were not adequate to reduce collisions and concluded deer may not have adequate time to react as desired, may not have the ability (neurologically) to process the sound as an alarm such that they respond as desired, or may not perceive the sounds they tested as threatening. Ujvári et al. (2004) found deer demonstrated relatively quick habituation (≤10 days) to sounds of acoustic highway markers activated by passing vehicles. A stimulus system (high-pitched sound in combination with a strobe light) activated by vehicle headlights reduced wildlife-vehicle collisions by 85–93% in Austria (Huijser et al. 2008), but this effect has yet to be replicated.

Incorporation of alarm or distress calls in an auditory stimulus system designed to reduce collisions may warrant additional investigation. Use of such bioacoustics to reduce deer presence in areas of highly preferred forages (e.g., crops, orchards) has produced mixed results. In some cases, deer easily became habituated to bioacoustics or the sounds were deemed ineffective (Belant et al. 1998, VerCauteren et al. 2005). However, Hildreth et al. (2013) documented a 99% reduction in deer entry into baited sites where deer-activated, bioacoustic frightening devices were deployed. Such systems may deter deer from crossing highways, but further testing is needed.

*Benefits and Challenges*

Primary benefits of auditory stimulus systems are their relative simplicity and low cost. If appropriate sounds could be produced to effectively alter deer behavior in a desired manner, such systems could result in substantial reductions in deer-vehicle collisions. Challenges include lack of effectiveness (i.e., deer do not respond or do not alter their behavior as desired) and habituation of deer to the sounds (i.e., deer may respond as desired for a short time, but responses decline after repeated exposure).

*Financial Assessment*

Deer whistles and other auditory stimuli are relatively inexpensive, generally between $10–100. However, tests of auditory stimuli have been inconclusive or have shown that the devices were ineffective for reducing deer-vehicle collisions. A technical working group formed to evaluate mitigation methods for wildlife-vehicle collisions concluded neither research nor construction resources should be used for audio signals (in the right-of-way or on vehicles; Huijser et al. 2008). Given the high costs and liability associated with deer-vehicle collisions, advocating use of auditory stimuli devices as a sole deterrent to avoid collisions should be avoided.

## ***Roadway design***

*Wildlife crossings.* —Wildlife crossings (underpasses and overpasses), when combined with funnel-fencing, have been widely recognized as the most effective method to simultaneously reduce wildlife-vehicle collisions while maintaining habitat connectivity (Ward et al. 1980, Clevenger and Waltho 2000, Dodd et al. 2012, Sawyer et al. 2012).

Wildlife crossings are designed so that wildlife can pass safely over or under roads, removing wildlife from roadways, and reducing the effect of traffic on wildlife movements (Gagnon et al. 2007*a*, *b*; Dodd and Gagnon 2011). The numbers of wildlife crossings throughout North America are numerous and continue to grow (Bissonette and Cramer 2008).

Underpasses provide mule deer and other wildlife the opportunity to pass below the highway while allowing traffic to pass overhead. Underpasses and culverts in many cases dually facilitate wildlife and water flow. Underpasses are generally considered the larger of the 2 types and are used to bridge larger areas like rivers and canyons, whereas culverts generally comprise smaller, fully or partially precast concrete or metal pipe better suited for smaller creeks or washes.

Research on the effectiveness of underpasses to safely pass mule deer began in the mid-1970s (Reed et al. 1975, Ward et al. 1980). Underpasses of various sizes and shapes have been shown effective for mule deer passage, but recommendations on optimal size are an ongoing and heavily-debated topic, particularly given cost restraints usually placed on construction projects. Openness ratio ((width x height)/length) is a commonly used term describing wildlife crossings, and many wildlife species prefer to pass through more open structures that appear shorter in length than those that are perceived as long, narrow tunnels. There is conflicting data on the optimal openness ratio for mule deer from recent research and understanding of wildlife behavior (Reed et al. 1975, Foster and Humphrey 1995, Jacobson et al. 2007, Schwender 2013), but width seems more important than height (Foster and Humphrey 1995, Clevenger and Waltho 2000, Cramer 2013) and length is likely even more important than width (Clevenger and Waltho 2000, Cramer 2013). Most studies on mule deer use of underpasses indicate that mule deer are more reluctant to use narrower structures than wider structures. Current studies, specifically for mule deer, indicate that minimum size for underpasses should be 8–10 feet in height and a minimum of 20 feet in width (Gordon and Anderson 2004, Cramer 2013), while length should not exceed 120 feet if possible (Cramer 2013). In areas where underpasses exceed 120 feet, such as 4-lane divided highways, providing an open median may help increase mule deer crossing success by reducing the overall length into 2 shorter sections (Foster and Humphrey 1995, Gagnon et al. 2005). These measurements are considered minimum requirements for mule deer, and planners should develop more open structures where possible to help ensure success of the underpasses. Where possible, culverts should have earthen bottoms to eliminate echoing and provide natural footing. Earthen fill between the top of the culvert and the road is also useful to reduce sound and vibration when vehicles pass overhead. Rip-rap (large rocks used to dissipate water flows) may be used in small amounts to help reduce regular erosion, but a natural soil pathway must be available for wildlife to navigate through the structure. Another method being implemented in Nevada is placing a rip-rap layer under several inches of native soil that will protect the structures during larger storm events, while providing a natural pathway for wildlife. After a large storm event the earthen pathway may require maintenance, but the overall structure will remain stable. In some instances, uncovered rip-rap can be used to guide wildlife into the desired pathway.

Because of their cost, overpasses are used relatively infrequently when compared with underpasses. Although overpasses have been implemented throughout North America for many wildlife species (Clevenger and Waltho 2005, Olsson et al. 2008), relatively few studies have evaluated mule deer use of overpasses until recently. Prior to 2000, only 5 wildlife overpasses existed in North America and limited data are available to evaluate the effectiveness of overpasses. The first wildlife overpass in North America was constructed in Utah along I-15 and is only 21 feet wide. Recent studies show that this 30-year-old overpass successfully facilitates mule deer movement (Cramer 2013). In British Columbia, the 19-foot-wide Trepanier overpass was built to facilitate wildlife movement over the Okanagan Connector (Highway 97C) and use by mule deer has been documented for this structure (Sielecki 2007). In Banff National Park, Alberta, Canada, overpasses were built primarily for the safe passage of grizzly bear across the Trans-Canada Highway, and mule deer benefited from these structures. Of 15 structures for mule deer to select from, 67% of all crossings by deer (mule deer and white-tailed deer combined) occurred at the 2 160-foot-wide overpasses (Clevenger and Waltho 2005).

Mule deer will use both overpasses and underpasses and learn to use them more over time. Recently, studies to evaluate mule deer use of overpasses along US 93 in Nevada documented >13,000 crossings in a 2-year period (Simpson 2012), with >35,000 crossing in the first 4 years (N. Simpson, Nevada Department of Transportation, personal communication). Simpson (2012) found that mule deer preferred overpasses to underpasses, especially in the first years following construction. Mule deer continued to adapt to the underpasses over time. A recent Wyoming study found mule deer preferred crossing US 191 through underpasses rather than overpasses. This study included 2 sites, each with 1 overpass and 3 underpasses, and documented 60,000 mule deer and 25,000 pronghorn crossings in 3 years (H. Sawyer, personal communication). Three overpasses completed along the Trans-Canada Highway in Yoho National Park in 2011 will benefit mule deer along with other species. At this time, overpasses that would facilitate mule deer passage are also planned or under construction in Washington along I-90 and Nevada along I-80, which includes an overpass of 200 feet in width. As the number of overpasses and underpasses increase in mule deer habitat, evaluation of their effectiveness will provide insight to optimal design.

Proper placement of wildlife crossings (underpasses and overpasses) is essential to ensure mule deer encounter them during daily or seasonal movements (Gagnon et al. 2011, Sawyer et al. 2012, Coe et al. 2015). Along large stretches of road, spacing of wildlife crossings needs to be considered. Underpasses need to be close enough together to allow mule deer to encounter them within a reasonable distance. Bissonette and Adair (2008) recommended that wildlife crossings be placed about 1 mile apart for mule deer in areas where deer are frequently hit or regularly cross. Coe et al. (2015) noted that crossings could be placed more irregularly based on actual mule deer migration corridors or data that indicate high deer-vehicle collision areas. Similarly, escape ramps should be placed frequently enough that deer and other ungulates trapped inside fencing are can escape the right-of-way before collisions occur.

Ungulate-proof fencing is likely the most important factor in the success of wildlife crossing structures. When properly designed and located, fences funnel deer towards crossing structures helping to overcome any minor flaws in design and placement. In most cases mule deer will not immediately use crossing structures and a learning period will be required (Gagnon et al. 2011, Sawyer et al. 2012). For example, along US Highway 30 in Wyoming, mule deer took about 3 years to fully adapt to underpasses and fencing (Sawyer et al. 2012). Migratory mule deer are more likely than resident mule deer to use smaller underpasses, when combined with fencing, because of their need to move to seasonal ranges. Installing larger underpasses and culverts will increase permeability, whereas smaller structures increase the likelihood that mule deer may avoid the designed crossing. In areas with reduced permeability, mule deer will find other areas to attempt crossings, such as the end of the fence, jump outs, or small gaps.

Highway retrofitting has been used increasingly to reduce wildlife-vehicle collisions while maintaining habitat connectivity (Gagnon et al. 2010, Cramer 2013). Retrofitting typically employs fencing to funnel wildlife to existing structures that are suitable for wildlife passage. This would include bridges and culverts that already facilitate water flow, but in some cases can include low use roads (Ward 1982). In many cases, implementation of highway construction projects may not occur for decades, and retrofitting can provide a temporary solution. When retrofitting existing structures, each crossing structure must be acceptable for mule deer use; improper combinations of fencing and inadequate crossing structures will completely inhibit mule deer movement across the highway corridor.

*Benefits and Challenges*

Properly designed and located wildlife crossings with funnel fencing will ultimately provide the most effective method for reducing collisions with mule deer, and other wildlife species in the area must be considered as well. For example, elk generally use similar habitats as mule deer, but may be reluctant to use structures that mule deer may readily use (Dodd et al. 2007, Gagnon et al. 2011, Cramer 2013). When dealing with mule deer collisions and connectivity in areas where there are elk present, designs for elk should be considered which will allow effective use by both species. Another consideration is smaller wildlife that reside in the area. Although recommendations for mule deer provide for about 1-mile spacing between structures, other smaller wildlife may not travel as far to locate a safe crossing opportunity, which may make the roadway a more substantive barrier for these species (Bissonette and Adair 2008). Allowing access to culverts too small for ungulate use may help to facilitate habitat connectivity for some of these smaller species (Clevenger et al. 2001).

*Financial Assessment*

Wildlife crossings with ungulate-proof fencing are in many cases the most expensive solution, but they are by far the most effective. Culverts generally are the least expensive and can be installed for about \$200,000, whereas overpasses and bridges can cost \$2–10 million. Sufficient excess fill must be available to maintain grade and install enlarged culverts, or the highway must be raised by obtaining and hauling fill, an alternative so costly as to be prohibitive. Underpasses are usually more practical for transportation departments when they are located in drainages where water flow already requires such an accommodation. Costs to upgrade underpasses in these situations are somewhat less. Overpasses are generally designed solely for wildlife and expenses can be harder to justify. In general, overpasses are 4 to 6 times more expensive than underpasses. In some situations, topography may not be conducive to underpasses and overpasses may be the only option. When considering placement of wildlife-dedicated overpasses, using natural ridgelines where the roadway cuts through a terrain feature can help reduce costs associated with substantial fill requirements. Retrofits of existing structures may be among the least expensive solutions for collision reduction and connectivity for mule deer if adequate terrain features exist.

Nevada observed a 50% decrease in the number of deer-vehicle collisions with each subsequent migration in a single location until the numbers reached ≤2 reported collisions/migration (Simpson et al. 2012). Additionally, an analysis of expenses on the same set of crossing structures showed a financial benefit of $1.58 for every $1.00 in cost for these features (Attah et al. 2012). With the observed decrease in the number of deer-vehicle collisions, and the positive benefit-cost score, the cost of the construction will be recuperated by taxpayers, insurance companies, and management agencies because of the decrease in human injuries and infrastructure damage (McCollister and Van Manen 2010).

*Nighttime and seasonal speed limits.* —Speed is a factor that influences the probability of collisions in general. At slower speeds, motorists generally have more time to detect, identify, and react to obstacles in their path than if they were travelling at greater speeds. Yet studies that attempt to document the relationship between deer-vehicle collision and posted speed limits provide mixed results and generally do not confirm a relationship (Bissonette and Kassar 2008). Reasons for these mixed results stem from the limited relationship between actual speed with posted speed limit (Bashore et al. 1985) where deer-vehicle collisions are common. Roadway characteristics, deer behavior, deer distribution, landscape, and environmental factors have a greater influence on deer-roadway interactions regardless of posted speed limit (Bashore et al. 1985, Finder et al. 1999, Farrell and Tappe 2007, Found and Boyce 2011*a*, Lobo and Millar 2013). With these overriding factors in mind, strategic use of speed limit reduction during discrete deer movement periods and in locations of concentrated deer-vehicle collision may provide positive results. Temporary warning signs can be effective when used on roads with concentrated deer-vehicle collision peaks and isolated to narrow corridors. Motorists can become complacent with static signage over time (Sullivan et al. 2004). Periodic use of portable message signs can help overcome driver complacency and reduce vehicular speeds more than permanent dynamic message signs (Hardy et al. 2006). Providing a message identifying shorter distances to watch for deer can increase driver attention span for those distances (Hardy et al. 2006). Like most deer species, mule deer are generally crepuscular with increased movements during dusk and dawn. Deer often migrate seasonally, so reducing speed limits at times of the day or year when deer are most active may reduce the probability of wildlife-vehicle collisions. Regardless, given that increased vehicular speeds correlates with increased accident severity and property damage, strategically placed signs both temporally and spatially may ultimately save human lives.

*Benefits and challenges*

Traffic signage identifying appropriate speed is relatively inexpensive to implement. Enforcement can be difficult, and compliance for most highway signage is variable. If seasonal changes are needed to deal with migration periods, signage can be adjusted with minimal effort. Temporary dynamic message signs work better than standard static speed limit signs (Hardy et al. 2006). Lawful determination of appropriate speed limits can require administrative review and approval.

Logically, reducing vehicle speed should similarly reduce wildlife-vehicle collisions. Yet wildlife often cross unexpectedly, making reduced speed limits less effective in avoiding collisions. For instance, bighorn sheep have a relatively high rate of collisions with vehicles along US Highway 191 in southeastern Arizona (Wakeling et al. 2007) even though the roadway precludes high rates of speed and allows for good visibility. This winding section of US Highway 191 keeps vehicles from exceeding about 35 mph, whereas other nearby sections can be traversed at 55 mph and wildlife vehicle collisions are not correspondingly higher. In this situation, the proximity and juxtaposition of suitable habitat increases the likelihood that bighorn sheep will frequent and cross these roadways.

Additionally, motorists tend to ignore frequent signage designating slow speeds if the roadway itself is suitable for faster traffic. Motorists tend to respond to signs that alert them through specific stimuli, such as flashing lights that only exhibit the stimuli when a particular threat initiates it. Gagnon et al. (2010) noted a nearly 10-mph speed reduction and a 68% increase in motorist braking response over multiple years when warning signs were activated by wildlife at the end of a 3-mile stretch of exclusion fencing. Frequent, static signs that simply note "wildlife crossing" are often ignored, and low speed limits on good roadways (with high frequencies of wildlife crossing attempts) are often overlooked as well. Seasonal signs noting deer or elk migrations are more effective in some instances. Vegetative plantings in highway rights-of-way sometimes attract or obscure wildlife and contribute to causes for wildlife-vehicle incidents.

Colorado experienced the confounding effects of implementing reduced speed zones to amend motorist behavior along a 100-mile section of highway with 14 experimental wildlife speed reduction zones. While data showed a minor improvement on average accident history throughout the total treatment area, 6 of the 14 segments (43%) exhibited worse accident history following implementation. Based on the inconclusive data, Colorado Department of Transportation removed the signage because changing driver behavior was found to be ineffective with the program (Colorado Department of Transportation, unpublished data). Both wildlife agencies and state departments of transportation agree that reduced speed limits are not particularly effective at influencing wildlife-vehicle collisions (Sullivan and Messmer 2003).

*Financial assessment*

Expenses associated with changing highway speed limit signage are relatively minimal. The administrative cost of the appropriate review and authorization for changes in speed limits is generally higher than that of simply changing out signs. As noted earlier, animal detection systems that provide warning to motorists, like temporary changes in speed limits, only when deer or other wildlife are present are the best solution when wildlife crossings are not an option. The actual expenses for these types of systems may run from $50,000 to $200,000 depending on complexity and design. Costs for the regular maintenance of the warning system may additionally include full time staff or a private contractor to regularly check on these systems. Less expensive is temporary flashing portable signage that may be used seasonally, but costs may still approach $10,000 to implement. Simply changing static speed limit signs are inexpensive, yet ineffective in reducing deer-vehicle collisions.

# Mitigation Options

Damage mitigation deals with methods that are typically used by agencies to reducean overabundant deer population. When city leaders are determining how best to mitigate deer issues within their community they often look for the one particular option that best fits their situation. However, the best solution is to implement an integrated approach using multiple mitigation options, rather than rely on one single method (Conover 2002). Authorities must weigh the positives and negatives of allowing each mitigation technique within their city limits. This section will help identify the application and limitations of several techniques. While the various mitigation techniques are divided into broad categories, within each category there are typically several options for tailoring a program to a community's needs, resident's tolerances, and the landscape within a particular city. It must be noted that with any deer management program public support is critical. Having well defined objectives and outcomes for the management program and clearly articulating these to the public should assist with gaining public support.

## ***Regulated Public Hunting***

*Efficacy*: Regulated public hunting is the most economical option for managing deer within an urban area and is the primary option used for overall deer management by state/provincial game/wildlife agencies throughout North America. Depending on the level of usage within an urban area, the initial efficacy can be high. Hunting allows localized management by the residents to address varying levels of deer and conflicts on their properties (as deer numbers go up more deer can be harvested, as deer numbers go down fewer deer can be taken). Hunting, unlike some other forms of management, also allows for the resource to be used for food by hunters and their families, by property owners, or venison can be donated to food assistance programs. The use of regulated public hunting is strongly supported by the North American model of wildlife conservation that has successfully guided deer management in the modern era.

*Options*: Perhaps the best option for managing overabundant deer is to allow regulated public hunting where hunters follow regulations set by the wildlife/game agency. There is no oversight required by the city or cost associated with this option. An example of a city that uses this technique is **Cuyahoga Falls, Ohio** in the annexed portion of the city. When the city annexed the rest of the township, the allowance for hunting was left intact. Another option is to conduct a controlled hunt within the city limits such has been used in **Princeton, New Jersey and municipalities of St. Louis County, Missouri**. The city chooses the number of hunters that will be allowed to hunt within its boundaries and the locations where those hunters can hunt. The city then advertises for the opportunity for hunters to put their name into a drawing/lottery. Hunters that are successful in the drawing are afforded the opportunity to hunt within the city limits. In most cases the city has identified areas, often city owned/managed properties, where hunting will be allowed.. The city has the ability to set specific rules for the hunt. The final option for hunting is to allow hunting after a hunter/landowner follows a city developed process for allowance of hunting such as in **Columbia, Missouri** where a hunter must attend a 1-hour safety course prior to being allowed to hunt within the city limits. During the course hunters are made aware of the locations where they may hunt, the laws and regulations they must follow, and they are issued a permit that must be displayed in the window of their vehicle while it is parked in an area where they are hunting. Some cities, like **Independence, Ohio,** even require a hunter to take an archery proficiency test prior to being allowed to hunt within the city limits. Hunting within city limits can be carefully regulated so that harvest objectives are met, such as creating a requirement to remove a certain number of does before a buck may be harvested as is done in **Hidden Valley, Indiana**. Cities may also approach their game/wildlife agency to discuss the option for establishing a deer management zone like has been done around **Silver City, New Mexico.** The city worked with the state game agency to designate an "urban management unit" around the city to allow additional deer to be taken in accordance with state deer regulations. While the program does not address deer specifically within the city limits, it does allow hunters to address immigration of deer into the city. Some jurisdictions may even allow baiting as a means of increasing the harvest and more efficiently reducing the deer population. For example, when Connecticut permitted baiting of deer, the hunter success rate was increased by 16.8%.

*Limitations*: If the initial deer population in an urban area is extremely high (30+ deer/sq mile), it can be challenging for hunters to quickly reduce the deer population to a tolerable level. To be most effective, hunting should be used consistently and on an annualized basis. It should be noted that as the number of restrictions imposed on hunting increase within an urban area, the effectiveness for reducing the deer population will decrease. Any restrictions imposed on hunters such as the types of weapons that may be used, baiting regulations, and permit acquisition, should be supportive of hunters to ensure successful management outcomes. Also, ensuring that hunters arehave access to enough land to hunt so that harvest objectives can be reached is also critical.

It must also be kept in mind that deer are a charismatic species and some citizens will vehemently oppose the use of hunting, while others will be highly supportive. Agencies and or municipalities should be able to clearly articulate to all citizens the objectives and expected outcomes of the use of hunting as a management action. Some citizens may oppose hunting from the aspect of a concern for safety believing that they may be endangered by the discharge of weapons, even arrows from bows or crossbows. Authorities should be able to alleviate these fears by creating regulations that will ensure the safety of the public such as limiting how close to an established dwelling hunters may discharge a weapon and restricting hunting to public areas or private properties by permission only.

*Maintenance Required*: Open regulated public hunting requires little or no maintenance, however, cities may need to periodically review and update ordinances and/or city rules for hunting to be used most effectively. Periodic changes to regulations may be needed to address the number of hunters as a result of changing deer numbers or the inclusion/exclusion of hunting areas. Hunting can be an excellent tool to manage a deer population and it is likely most effective when used consistently and annually.

*Regulatory Aspects*: Most agencies encourage the use of hunting where possible but the use of hunting in urban areas may require local ordinance modifications. This has been successfully done by eleven municipalities in the **St. Louis, Missouri** metropolitan area and six communities in the **Cleveland, Ohio** metropolitan area.

## *Sharpshooting*

*Efficacy*: For a good discussion of sharpshooting deer and how a program can be managed and initiated by multiple agencies working together, see Stradtmann et al. (1995). Because sharpshooting, using trained personnel to systematically remove deer, is highly controlled, the immediate efficacy of it is usually very high if the appropriate number of deer can be removed over a short, 2-4 year, timeframe. Sharpshooting can be an effective technique in smaller areas where the use of hunting is limited. Efficacy is dependent on access to private properties. Managers should be aware that not all property owners will be willing to participate in lethal removal. Typically, to curb population growth, at least 60% of the deer must be removed annually. In **DuPage County, Illinois**, deer densities were estimated at 68 deer/km$^2$ before four consecutive years of sharpshooting (in 1997, 1998, 1999, and 2000) reduced the population to the desired 15 to 20 deer/km$^2$ density.

*Options*: There are a variety of personnel to consider when planning a sharpshooting operation: shooters, baiters, security, and logistics personnel who will handle the deer and day-to-day planning of the operation. While community staff can be used for many of the needed tasks, because of the level of marksmanship needed to shoot deer within an urban area so that public safety is ensured, the use of highly trained personnel is usually needed. One option is to use police personnel, such as SWAT, to shoot deer as is done in **Mentor, Ohio**. Another option is to contract with USDA-Wildlife Services which has been done in **Ann Arbor, Michigan**. This agency, which does a substantial amount of wildlife damage control throughout the United States, uses highly trained federal staff to shoot deer. Another option is to use a non-profit organization, such as White Buffalo, Inc. The cities of **Town & Country, Missouri** and Eden Prairie, Minnesota contract with sharpshooters to harvest deer annually to address their deer population. Another option for deer removal by sharp shooting is to contract with a private contractor, as has been done in **Highland, Utah**.. Often these companies privately contract to control other nuisance wildlife in cities and are permitted by the game/wildlife agency to control deer as well. In most cases the personnel used to shoot deer can provide personnel to meet the other aspects of a sharpshooting program affording a city many options for implementing a program. **Town & Country, Missouri** has an ongoing bait-and-sharpshooting program to reduce and maintain the deer population, through annual culling efforts.

*Limitations*: Sharpshooting can be one of the most costly options to manage a deer herd especially if the work is contracted out. While a city can save expenses by using their own staff, this usually comes at the expense of either additional cost in overtime for staff or in a loss of man-power for the typical duties of the personnel assigned. To be most effective, staff operating on a sharpshooting operation, including non-law enforcement personnel, will likely need to be dedicated to this program and their normal duties assigned to other city personnel. If the community doesn't own/manage a significant amount of acreage then they must resort to using private property as well. This technique will also require the highest level of city planning of any of the techniques. In most cases deer are processed for food pantries, but identifying a processor that will work within the timeframe as well as being able to handle the volume of deer can pose a challenge at times.

*Maintenance Required*: Long-term efficacy can be achieved using sharpshooting but, if this is the only technique used, it will usually require indefinite use.

*Regulatory Aspects*: Depending on which options are used and during what time of the year, state/provincial regulations may require special permitting for the city to conduct a sharpshooting program. In addition, if suppressed weapons are used the city will also need a federal Bureau of Alcohol, Tobacco, Firearms, and Explosives permit which may take several months to obtain.

## *Live Capture Techniques*

Various techniques are available for the safe and humane live capture of deer. Some of the primary methods used are the Stephenson box trap, Clover trap, rocket net and dart gun. These techniques have been evaluated for efficacy and animal welfare concerns (Haulton et al. 2001, Anderson and Nielsen 2002). Netted cage traps and their use is discussed at length by Vercauteren et al. (1999) and they reported only 4% of captured deer (n = 1000+) sustained injuries. Drop nets have also been successfully used for the capture of both white-tailed deer (Ramsey 1968, Conner et al. 1987, DeNiocla and Swihart 1997, Silvy et al. 1997, Lopez et al. 1998, Jedrzejewski and Kamler 2004) and mule deer (White and Bartmann 1994, D'Eon 2003). Net guns fired from helicopters offer yet another technique that has been successfully used (Ballard et al 1998, Webb et al. 2008).

With all of these techniques, if deer are to be released rather than euthanized after capture, handling time should be minimized to reduce stress on the animals (Beringer et al. 1996). Likewise, safety during the capture event of animals and personnel capturing them is also a critical concern. Injury to some animals may occur and some mortality of captured animals due to injury or capture myopathy should be expected. The terrain of the capture location, cost effectiveness and safety concerns may dictate which technique is best used in a given situation.

Those opposed to lethal control of deer often cite live capture and translocation as an option that is more humane than lethal removal with hunting or sharp shooting (see previous discussions of these techniques). However, numerous studies have shown that as a population reduction method, live capture is more expensive, relatively inefficient and does not significantly extend the life span of individual animals that are relocated (Ishmael and Rongstad 1984, O'Bryan and McCollough 1985, Withman and Jones 1990). As a result, while live capture techniques will always have their place in research and management, they should likely not be the first choices for managing urban deer if the goal is to affect a long-term decrease in the population. However, in certain situations live capture may be the only or most desirable option so we will discuss several techniques.

If captured deer are not to be euthanized (relocation is discussed in more detail later) a location that can handle the volume of deer to be relocated, following capture, must be identified and equipment to properly transport the deer is needed. This, coupled with the cost to move the deer, greatly increases the overall cost of a relocation program. Most states have banned the interstate movement of any wild member of the cervid family (with exceptions for elk) Intrastate movements still pose the risk of the potential to spread diseases (e.g., Chronic Wasting Disease, tuberculosis, etc.) and severely limits this option. Further, there may be no other places within a given state or province where having more deer is desirable. It has also been shown that some relocated deer may move back to urban areas and they can increase crop depredation in areas where they have been moved (Ishmael et al. 1995). This may be considered simply as "putting the problem into someone else's backyard" and not an effective solution to the problem

## Trapping:

Efficacy: Traps are typically designed to capture only one deer at a time. Other techniques (e.g., drop nets, rocket nets) offer options for multiple capture, but due to this limitation, trapping does not have the highest efficacy rate. Traps should be placed in areas that have high deer usage to increase efficacy. Traps should also be placed away from roads or areas where they can be seen by the public to further increase efficacy and to reduce stress on captured deer.

*Options*: There are two primary trap types used for trapping deer; the Stephenson box trap or Clover trap... The Stephenson box trap is similar to a cage trap used for capturing raccoons or groundhogs, except that it is much larger. Box traps used for deer capture are typically made of plywood sheets attached to an angle iron frame that is 4x4x6 feet (1.2x1.2x1.8 m) in size. These trapscan be baited, set, and left unattended. Pre-baiting of traps with apples or corn is generally required before traps are actually set, in order to give deer time to habituate to the presence of traps and enter them calmly. The trap is activated by a trip wire. The traps must be checked at regular intervals (at least once daily) so that captured deer are not left in the traps for an extended period. These traps have been used successfully in **Pepper Pike, Ohio** and River Hills, Wisconsin to name a few places.

Clover traps or netted cage traps are similar in size to box traps. They are typically made of mesh netting or, in the case of Clover traps, sometimes chain-link fencing material, covering a metal frame. These traps typically have only one door, whereas box traps sometimes have two doors. Bait, such as corn or apples, is used to attract a deer into the trap. The trap is activated by a trip wire that, once sprung, allows the door to drop and capture the deer. These traps have been used successfully in **Silver City, New Mexico** and in many other places

Traps do not discriminate relative to the deer captured and any deer (buck, doe, fawn) is likely to be caught in the trap. Other forms of capture (e.g., drop nets, rocket nets, net guns, dart guns (discussed later) can be more selective. Once deer are captured there are several options for removing deer from the trap. If deer are to be euthanized, a firearm or captive bolt gun may be used. Captive bolt guns have been used to euthanize deer in traps **Princeton, New Jersey**. Firearms have also been used (.22 caliber rimfire) to euthanize deer in urban settings but their use can only be considered when the landscape where the trap will be placed allows discharge of a firearm, such as was the case in the Village of North Oaks, Minnesota (Jordan et al. 1995) Euthanizing trapped deer is usually the less desirable approach but regulatory considerations often make this the only feasible option for urban deer population control. However, in **Bountiful, Utah** a trap and relocate program was successfully implemented as a technique to help address local urban deer problems.

*Limitations*: Trapping usually requires some type of bait (corn, apples, etc.) to entice the deer into the trap or area to be trapped. Pre-baiting traps is usually required to engender efficiency once traps are set. Traps should not be set until it is certain deer are entering the trap.
Deer are most susceptible to trapping during late winter to early spring when they are potentially food stressed (Vercauteren et al. 1999).

*Maintenance Required*: Traps will need to be checked on regular intervals, at least once every 24 hours once set. As needed, traps will have to be repaired or replaced.

*Regulatory Aspects*: The use of traps will likely require a state or provincial game/wildlife agency permit, especially when deer are relocated. In addition, trap monitoring regulations will likely be arequired to ensure traps are checked and animals dispatched at regular intervals. City and/or state/provincial regulations may also dictate whether baiting can be used.

## Cannon/Rocket Nets:

Efficacy: Cannon/rocket netting has been used to capture deer safely and effectively (Hawkins et al. 1968, Dill 1969). Multiple deer maybe be captured at the same time using these techniques, but recommendations are that no more than 3 deer should be captured at once (Beringer et al. 1996).

Options: For a thorough discussion and instructions on the use of rocket/cannon netting see http://wildlifematerials.com/infosheets/Rocket%20Nets%20Capture%20Instructions.pdf . The use of this technique employs nylon netting, electrical wire (for firing the charges), launchers, powder charges, weights (attached to the nets) and a ground blind (for hiding captors). After the netting is set up, wiring connected, and launchers charged, deer are lured into position, typically with bait. Pre-baiting an area for one to two weeks is typically required. A small bait pile (which limits the number of deer that will be feeding at any given time) should be placed 8-10 feet in front of the rolled-up netting and launchers. When deer are in position, captors may select when to fire the nets to capture the desired number, sex or age of deer etc. The capture event itself, compounded by noise of the cannons/rockets and presence of numerous human handlers is stressful for deer, so handling time should be minimized. Also, deer should be restrained with ropes (all four legs tied) and rolled up with brisket down, instead of left lying on their sides, due to the potential of bloating. Deer should be blindfolded immediately after capture (a simple cut off sweatshirt sleeve is effective for this) to reduce stress.

Limitations: There is always the possibility of injury to animals or personnel during the use of these devices. Animals may be injured by being struck by weights when the net is fired over them or after capture since netted animals typically thrash about. Animals may injure personnel attempting to restrain them. Safety of personnel is always a concern with the use of powder charges and safety protocols for wiring charges should be rigorously followed. Public safety may be a concern. The use of loud charges in residential areas may be undesirable. Rocket discharge has been known to start fires, whereas cannons do not. Air cannons (Net Blaster®), which require no explosives to fire the net, may also be used and they are considered safer than those that do use explosives.

Maintenance Required: Nets may need to be repaired and have debris removed after each firing. Rocket threads should be greased occasionally to prevent them rusting shut making it impossible to inset charges. Rockets and cannons must be cleaned after firing.

Regulatory Aspects:
Permitting by the state or provincial game agency is required for the use of this technique.

## Drop Nets:

Efficacy: Drop nets have been successfully used for the capture of both white-tailed deer (Ramsey 1968, Conner et al. 1987, DeNiocla and Swihart 1997, Silvy et al. 1997, Lopez et al. 1998, Jedrzejewski and Kamler 2004) and mule deer (White and Bartmann 1994, D'Eon 2003). They have also been used successfully in **Princeton, New Jersey** for urban deer management, and many other places for the safe and efficient capture of deer and other species. Drop nets require personnel to be on hand to initiate the trap and then handle the deer. While this option is costlier than the use of traps, it allows personnel to determine which deer are trapped and when to initiate the trap. In addition, multiple deer can be trapped at one time if enough personnel are available.

Options: For a thorough discussion and instructions on the use of drop netting see http://wildlifematerials.com/infosheets/Drop%20Net%20Capture%20Instructions.pdf . The use of this technique requires a large drop net (often 50x50 feet or larger), tall poles (usually 8 feet for deer) which are placed at each corner to hold up the net, electrical wire, blasting caps and a ground blind (for hiding the captor who will fire the net). A block and tackle, come-along or other device for stretching the nets is also required. Bait is used to attract deer to the area where the capture will occur, and it should be placed in the center of the area below the net. Areas are typically pre-baited for one to two weeks prior to the anticipated capture. When deer are in position, captors may select when to fire the nets to capture the desired number, sex or age of deer etc. The capture event itself, compounded by noise of the cannons/rockets and presence of numerous human handlers is stressful for deer, so handling time of deer should be minimized. Also, deer should be restrained with ropes (all four legs tied) and rolled up with brisket down, instead of left lying on their sides, due to the potential of bloating. Deer should be blindfolded immediately after capture (a simple cut off sweatshirt sleeve is effective for this) to reduce stress.

Limitations: As with other live capture techniques, there is always the possibility of injury to deer or personnel during the use of these devices. Deer may be injured after capture because netted animals typically thrash about. Deer may injure personnel attempting to restrain them. Safety of personnel is always a concern with the use of blasting caps and safety protocols for wiring should be rigorously followed. Public safety may be a concern. The use of loud charges in residential areas may be undesirable

Maintenance Required: Nets may need to be repaired and have debris removed after each drop.

Regulatory Aspects: Permitting by the state or provincial game agency is required for the use of this technique.

## Net Guns:

Efficacy: Net guns fired from helicopters offer another technique that has been successfully and safely used to live capture deer (Barrett et al. 1982, Krausman et al. 1985, DeYoung 1988, Potvin and Breton 1988, Ballard et al. 1998, DelGuidice et al. 2001, Haulton et al. 2001, Webb et al. 2008). We are not aware of the use of this technique for the management of deer in urban areas, however, the situation where it could be used is imaginable.

Options: The use of this technique requires very skilled personnel. Helicopters are typically used to locate and then chase deer until a single deer is in range of the net gun operator, who then fires the net over the deer. Following this, another person is typically dispatched from the helicopter, often referred to as a "mugger", who wrestles the deer to the ground and restrains it. The net gun itself is loaded with a "blank", often .308 caliber, which fires the net. Nets are typically about 15 x 15 feet square with 6-inch mesh, however various manufacturers produce custom nets. This technique is extremely selective as operators choose which animal to pursue and capture. Chemical immobilization of deer is typically not required.

Limitations: This technique can be used in a variety of habitat types and at various animal densities, however, areas must be open enough to assure safe maneuvering of the helicopter. Deer may be injured during capture or suffer myopathy post capture and handling. However, Webb et al. (2008) reported only 1% capture myopathy and a .6% direct mortality during capture. Likewise, besides broken antlers, only 1.6% of deer sustained injury during capture where total capture was 3,350 white-tailed deer.

Maintenance Required: Nets may need occasional repair. Helicopters require maintenance per number of hours used.

Regulatory Aspects: Agency permitting, and FAA regulations apply to this form of live capture.

## Darting Guns:

Efficacy: An excellent discussion of the use of chemical immobilization for the capture of wildlife in urban areas is found in Kreeger (2012). Darting guns have been effectively used for the capture of deer (Haulton et al. 2001). Darting guns use a .22 caliber blank or $CO_2$ cartridge to fire a "dart" (flying syringe) that injects an animal with an immobilizing drug upon contact. The effective range is typically no more than 75 meters, and often less. Guns that use $CO_2$ cartridges to fire allow the user to adjust velocity (and hence range) by a metering device. It is critical that the syringe only penetrates the skin of the animal with the needle upon contact, so the operator must make adjustments for the proper velocity or range. A miscalculation could result in the needle not penetrating the skin, or the entire syringe penetrating the skin and potentially killing or severely wounding the deer. Shot placement is also critical and typically the fore or hind quarters are targeted for an intramuscular injection. Darting guns can be fired from the ground, a tree stand or even from a helicopter to capture deer.

Options: Considerable practice may be required to use a darting gun effectively. Correct velocity and range calculation must be made, and each gun should be calibrated with various dart sizes and chemical loads in advance of attempted capture. Various gun and dart types are available and the use of each will require training. Chemically immobilized deer require the monitoring of vital signs, especially respiration and body temperature, should release for relocation be the desired outcome of the capture.

Limitations: The use of chemical immobilization techniques requires training and certification. Use of the correct type of drug (immobilizing agent and antagonist) for the deer, and the correct dosage for weight must be made. A combination of Telazol plus (4.4 mg/kg) and xylazine (2.2 mg/kg) are typically used to immobilize deer, with tolazoline (2.0 mg.kg) acting as an antagonist if needed. However, other drugs combinations may be effective as well. (Kreeger 2012). Deer should also be blindfolded and placed on their brisket and not allowed to lay on their side while immobilized. In addition, a tube for the release of gas may need to be inserted into the mouth.

Maintenance Required: Darting guns should be cleaned to assure accurate firing. Recertification for the use of chemical immobilization is required periodically.

Regulatory Aspects: In addition, to agency permitting to chemically immobilize deer, special regulations govern the purchase, use and storage of the various pharmaceuticals used as immobilizing agents and antagonists. Typically, only a licensed veterinarian would be able to purchase these drugs and some drugs may only be used by them, or in their presence by certified personnel.

## *Fertility Control*

*Efficacy*: Unless coupled with other management options, fertility control does not typically have an immediate impact on deer densities. Because of the limitations associated with contraception, contraception is not an efficient means of reducing overabundant, deer populations (Swihart and DeNicola 1995, Warren et al. 1995). In addition, often the use of fertility control can increase the longevity of deer further hampering short-term efficacy. Most research has identified the need for over 90% of the female deer within the population to be rendered permanently infertile for it to be effective.

*Options*: There are two general categories of fertility control: contraceptives and sterilization. Surgical sterilization of does has been conducted in **Town & Country, Missouri**. The City funded the trap and sterilization of 130 does over two years in conjunction with a culling program. The sterilization (ovariectomy and tubal ligation) procedure was successful in that it eliminated reproduction for treated does. However, because deer were then placed back out on the landscape, resulting population decline did not follow. After two years, the city abandoned the sterilization effort due to the high cost ($1,300 per treated doe) and currently conducts annual culling to maintain lower deer densities.

There are two contraceptives developed for deer: PZP, often referred to by the tradename SpayVac ®, which has been used in research studies in cities such as **Bridgeport, Connecticut** and GonaCon ® which has been used in **Princeton, New Jersey**. Only GonaCon ® is EPA approved for use at this time. PZP creates antibodies that blocks the fertilization of the egg by sperm and is only applicable to female deer. GonaCon ®, developed by the National Wildlife Research Center (NWRC), the research arm of the USDA-APHIS Wildlife Services, works by creating antibodies that bind to the gonadotropin releasing hormone (GnRH) which renders the deer, male or female, non-productive by reducing the production of sex hormones. Label use is only for adult females. With GonaCon ® female deer stop going into estrus. Sterilization can be done either in males which **Staten Island, New York** has looked into or females as has been researched in **Fairfax City, Virginia**. In order to reduce production in a polygamous species, the females of a population need to be treated. Because of this any sterilization of males would need to be done in conjunction with a control technique on females. Cornell University in **Ithaca, New York** tried using a combination program using archery hunting and sterilization using tubal ligation on female deer. They surgically sterilized 77 does and combined this with an "earn-a-buck" hunting program for the outlying areas. It became apparent over the course of the study that although the surgery supposedly prevented does from becoming pregnant, it did not remove their estrus cycles, meaning that they constantly cycled into heat—attracting bucks from outside the study area even after the rutting season. Thus, although the birth rate initially decreased, after five years the number of deer on campus remained the same.

*Limitations*: Reductions in populations may not be apparent for five to ten years or longer, depending on percentage of the population that remains vaccinated, and this timeframe may be too long for those communities dealing with the immediate worry of human-deer conflicts. Deer that are controlled through any of the methods of fertility control generally will endure less stress and therefore potential increased longevity. A metropolitan park district in **Columbus, Ohio** had a deer that was contracepted with PZP live over 20 years. In most cases there is no barrier, such as a fence, that hinders deer wandering into and out of the city. When contraceptives are used, periodic boosters are needed which requires repeated capture of individuals. Over time, the deer become incrementally more difficult to capture and treat. Deer are also susceptible to stress when being captured and/or being sterilized which may lead to their death. Because of the high amount of limitations and low efficacy in most situations, fertility control is considered in most cases to be research oriented and not a technique for population control. PZP is currently not registered for use in the United States as a management tool in part because the deer are unfit for human consumption. Because PZP only works on the egg it is only applicable for use in female deer. In addition, it can induce multiple estrus cycles lengthening the breeding period and movement of bucks into the population. There is no approved contraceptive for use in feed because it is impossible to control dosage levels. Deer must be given any contraceptive by darting or hand injecting. GonaCon® has a 70% efficacy rate and can only be used, as per USDA label instructions, in adult female deer, and must be hand-injected. Based on the efficacy rate in adult does and up to 40% of fawns breeding in highly productive areas, as is the case in NJ, using GonaCon® will result in up to a 29% *increase* in the deer population, without factoring in immigration and mortality sources. **Angel Island, California** attempted to use chemo-sterilization by capturing between 80 and 90% of the female deer population with no success. This was in part because the amount of effort to capture the remaining deer became harder as the number of already captured deer increased. Ultimately, this project was abandoned with only 15 adult does receiving the treatment.

*Maintenance Required*: For most cities there is no barrier to deer movement, so annual treatment of new deer into the population is required. Annual monitoring of the deer is also required to ensure that at least 90% of the population has been handled. Additionally, the female fawns born of non-contracepted adult does and last year's fawns will need to be trapped and inoculated every year.

*Regulatory Aspects*: The use of any fertility control will almost certainly require a permit from at least the state game/wildlife agency.

## *Relocation of the deer*

*Efficacy*: Relocation/translocation of deer is typically not a viable management option, in part because of low survival rates of translocated animals. In 1985, 29 deer were captured at Ardenwood Regional Park in Fremont, **California**. Two of the deer died during the capture. These animals were then released into a wilderness area. A follow-up study determined that by the end of the year, 23 of the 27 deer had died, with three unaccounted for. It was found that the deer were not able to cope with the presence of predators, and most of the deaths were attributed to predation (Mayer et al. 1995).

Similarly, on **Angel Island, California** (Mayer et al. 1995) 215 deer were captured using Clover traps, panel traps, drop nets, and drive nets, and 12 of these deer died during capture. The remaining 203 deer were relocated to a nearby 54,362-acre recreation area. In an effort to monitor the effectiveness of this translocation, 15 deer were fitted with radio collars and monitored during the following six months. Subsequent surveillance determined that only 15% of relocated deer survived the entire year. This high mortality rate was attributed to poor physical condition due to the stress of the Island environment, and a failure to recognize hazards such as predators and traffic (factors not found in their previous habitat).

A translocation program in **River Hills, Wisconsin** (Ishmael et al. 1995) found poor survival rates as well. Of 310 deer translocated to state-owned lands between 1987 and 1992, 54% were reported dead within a year post-release. It was discovered that mortality rates of translocated radio-collared deer were more than twice that reported for ear-tagged deer during the same period (96% compared to 45%).

From 1999-2001, Missouri Department of Conservation cooperated with the City of Town and Country to trap and relocate 90 deer from the St. Louis metropolitan area to a rural area of Missouri. Survival rate for translocated deer was 30% (Beringer et al. 2002). The method was suspended in early 2001 due to the threat of spreading CWD, as well as the low survival rates of relocated deer.

In 2013, the Utah Division of Wildlife Resources used a helicopter and net gun to capture 102 deer in **Parawon, Utah** and released them 144 km away to Holden Utah. Annual survival rates of translocated deer were 52% the first year. During the second year, however, survival rates of translocated deer were 85%, which was similar to survival rates of resident deer in the area (Smedley 2016). This research also showed that younger deer were twice as likely to survive post-translocation compared to older deer, and translocated deer had high site fidelity to release sites (Smedley 2016). No deer died during the capture operation.

*Options*: See Regulatory Aspects section.

*Limitations*: Low survival rates of translocated deer is only one factor to consider when evaluating the efficacy of relocation efforts. The potential to spread parasites and disease, such as exotic lice and CWD, should also be heavily considered before initiating an urban deer translocation program. The long-term negative consequences of translocating deer will outweigh the short-term benefits of reducing deer densities if CWD or other diseases are spread to deer populations. Because of these disease risks, most wildlife agencies do not allow the translocation of deer. In states that do allow translocation, it is highly recommended that deer in or near CWD positive areas, or in areas that have not been adequately tested for CWD, should not be translocated.

Another limitation of translocating deer is cost. In Utah, the Division of Wildlife Resources has worked with a few municipalities to translocate deer from city limits (these municipalities are far removed from CWD positive areas, and a high sample size of roadkill and hunter harvested deer that have never tested positive for CWD). Cities generally have personnel committed to help set and bait traps. These cities also pay $200 per deer, and the costs are projected to increase in the future. The Utah Division of Wildlife Resources also employees three full time employees to work with cities to resolve urban deer issues. With high deer densities in many parts of the country, cities and state agencies may not have the funds to remove enough animals to have a measurable impact.

Many parts of the country do not have adequate suitable habitat to release translocated deer. These areas include locations with high human densities, high deer densities, or poor deer habitat. Additionally, trap and relocation efforts will have little benefit if deer populations can quickly reestablish within the trapping area.

*Maintenance Required*: If translocation is used as a management strategy, an adequate number of deer would need to be moved in order to reduce deer densities. This effort would need to continue until a socially acceptable number of deer is reached in a given area. Efforts should be made to reduce immigration of deer into city limits.

*Regulatory Aspects*: Most governments recognize that relocations, although possibly of value for experimental research or repopulation, are not an appropriate management tool for overpopulated deer communities. The Southeastern Wildlife Disease Study Cooperative discourages the relocation of wildlife due to the threat of spreading disease. Relocation involves the transport of an entire biological package, including parasites and disease, which could be inadvertently introduced to another population by human efforts. Any relocation would require approval from the state wildlife agency and/or the state department of agriculture. Because of the disease risks, high costs, and other limitations associated with translocating urban deer, most wildlife agencies have policies against translocating urban deer. While there is value in addressing urban deer issues, using translocation as a management strategy has the potential to cause irreversible harm to deer populations if CWD and other diseases are spread.

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