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Methods for Managing Human–Deer Conflicts in Urban, Suburban, and Exurban Areas

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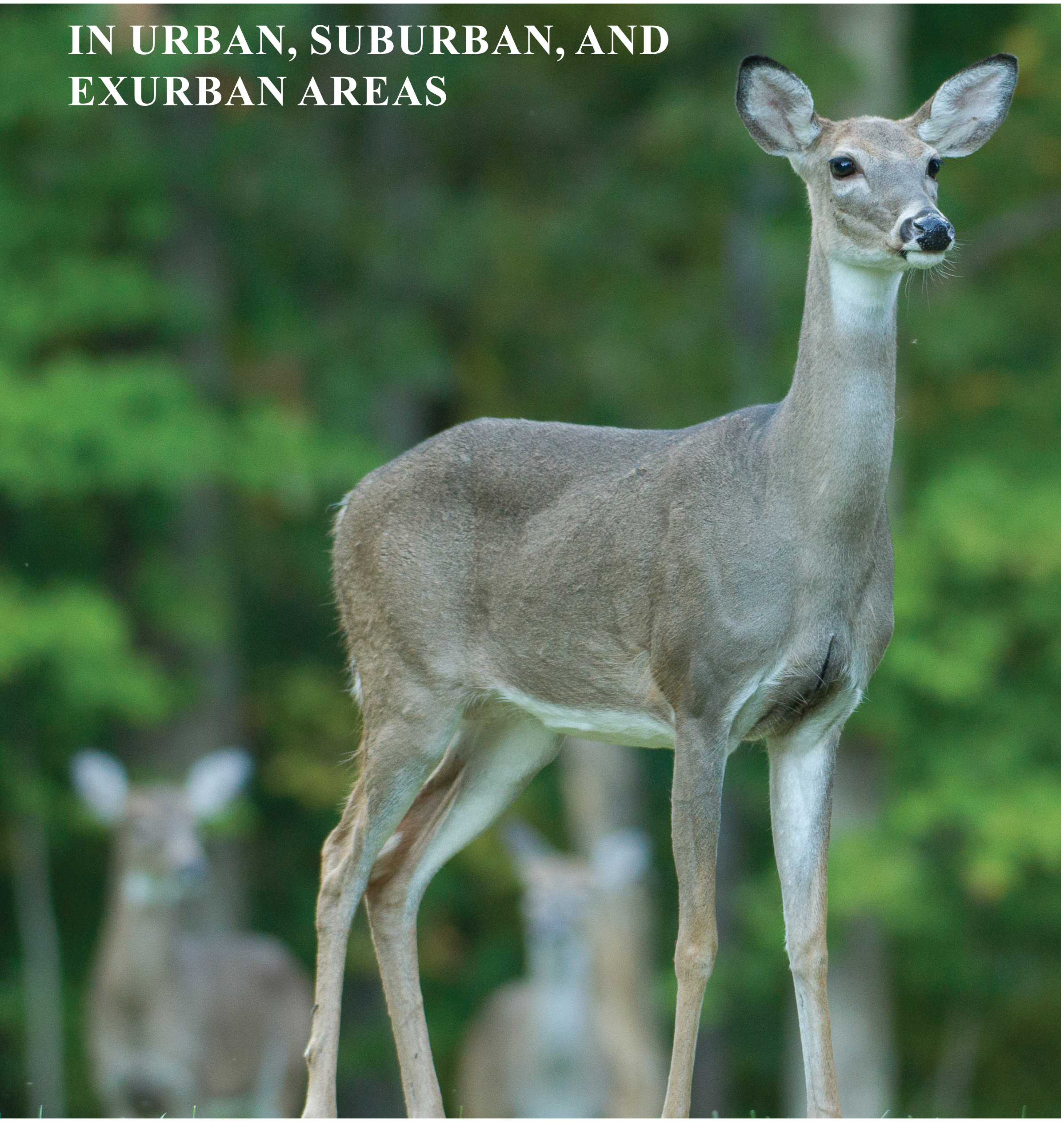
METHODS FOR MANAGING

HUMAN–DEER CONFLICTS

IN URBAN, SUBURBAN, AND EXURBAN AREAS



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While many state and provincial agencies have managed deer for over a century, managing deer in areas populated by humans poses many challenges that do not exist with wildland deer management. This document was compiled using input from leading wildlife biologists in North America who have expertise in managing deer–human conflict situations. This manuscript also drew material with permission from other publications, including those developed through the Western Association of Fish and Wildlife Agencies Mule Deer Working Groups (e.g., Keegan et al. 2011, Wakeling et al. 2015). The manuscript benefited from reviews provided by M. Boudreau, J. Fleegle, G. Jenkins, J. LaCour, B. Layton, M. O'Brien, C. Smith, J. Ver Steeg, and E. Vost. Additional support was provided by C. Stanko as well as T. Messmer, director of the Jack H. Berryman Institute at Utah State University. M. Conover and 3 anonymous referees provided comments, which greatly improved the monograph. Monograph final copyediting and layout were provided by R. Vail, *Human–Wildlife Interactions* managing editor. The monograph was published as part of the Jack H. Berryman Institute *Human–Wildlife Interactions* Monograph Series and printed by Utah State University Press. 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 AFWA.

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PREFACE

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

The Association of Fish and 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. It 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 Conflict Working Group of the Association of Fish and Wildlife Agencies formed a task force in September 2016 to document methods used to manage deer conflicts within areas of high human densities. Throughout this document, we refer to these areas as "populated" areas. Deer conflict situations arise in urban, suburban, exurban, 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. This document is not designed to endorse a specific practice over others 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). Instead, this document describes the various management practices in use, as well as the benefits and challenges associated with each practice, 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.

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ABSTRACT

Deer (*Odocoileus* spp.) pose specific management challenges when they come into conflict with humans. Although deer were once uncommon throughout North America due to unregulated take and habitat alteration, conservation efforts have restored these species to abundance. Deer now exploit urban, suburban, and exurban areas where human populations provide anthropogenic attractants, either intentionally or inadvertently, which often leads to human–deer conflicts. Although biological and ecological carrying capacity can be defined precisely, in most cases, social carrying capacity is highly dependent on the perceptions and acceptance of deer by humans on a shared landscape. Conflicts may be reduced effectively by eliminating attractants, yet eliminating attractants may not be achieved easily in many locations. Mitigating actions have varying degrees of efficacy and may not be effective or accepted in every situation. Although relocating deer may seem to be an easy solution to some public stakeholders, translocations can spread diseases like chronic wasting disease and may result in high mortality of translocated animals as finding suitable, unoccupied habitat may be difficult to impossible. Resolution to conflict requires close collaboration between wildlife management agencies and municipalities on shared jurisdictions. In this manuscript, we identify the challenges and benefits associated with many human–deer conflict mitigation actions, as well as methods to monitor the response of deer populations to management actions.

Deer, such as this white-tailed deer in Missouri, can take advantage of resources available in urban settings (courtesy of Missouri Department of Conservation).

DEER MANAGEMENT HISTORY

North America is inhabited by white-tailed (*Odocoileus virginianus*), mule deer (*O. hemionus*), and black-tailed deer (*O. h.* spp.). While species populations have fluctuated in response to anthropogenic effects, deer remain a management success story. It is estimated that the white-tailed deer population in the United States was only about 300,000 in the 1930s. Today, the population exceeds an estimated 30 million, a 1,000-fold increase in <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. Wildlife viewers value deer as well.

Prior to European settlement, white-tailed deer were common throughout most of North America, providing meat and hides to Native Americans. However, during the 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, a widespread conservation movement swept across North America, and many wildlife agencies initiated reintroduction efforts to reestablish white-tailed deer populations. These reintroduction efforts, in combination with eliminating market hunting and newly established and enforced game laws, allowed white-tailed deer populations to grow quickly. This growth continued throughout the twentieth 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 populated areas, mule deer and black-tailed deer have adapted similarly and created new challenges in portions of their range. Concomitantly, 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 municipal leaders together to address concerns regarding deer

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. However, biological carrying capacity may not be the desired management objective because a deer population at biological carrying capacity can negatively influence associated plant and animal communities. The BCC in areas with increased availability of artificial food sources may be much higher than in a wildland environment.

- **Ecological Carrying Capacity (ECC)** – The population level at which deer do not influence native plants and animals negatively is referred to as the ecological carrying capacity. Prior to the 1600s and major European settlement of North America, deer densities were likely 3–4 deer/km^2 throughout their range (McCabe and McCabe 1984, 1997). Research in the eastern half of North America suggests the ECC for white-tailed deer is normally in the range of 3–10 deer/km^2 (Healy 1997, Schmitz and Sinclair 1997). Beyond these densities, browsing deer affect the regeneration of certain plant species, which in turn affects other wildlife species that also depend on those habitats (Tilghman 1989, DeCalesta 1994).

- **Social or 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 commonly is referred to as the social or cultural carrying capacity. The SCC is related to the identification and state of negative impacts created by deer. Thus, affected local residents will determine the SCC for the deer herd and express sentiments about the desired deer population. However, because the tolerances of multiple stakeholders for deer within a particular area differ, SCC will vary by area.

OVERABUNDANT DEER: WHEN DEER POPULATIONS EXCEED SOCIAL CARRYING CAPACITY IN AREAS DOMINATED BY THE HUMAN POPULATIONS

Mule deer in urban yard, Panaca, Nevada (courtesy of B. Wakeling).

The consequences of overabundant deer (i.e., when deer exceed SCC in populated areas) in urban and suburban settings range from mild to severe. The most significant concerns of 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, Conover 2019). These collisions occur in all landscapes where deer and roads exist, but in general collisions occur more regularly in urban and suburban areas where both deer and motorists are abundant (Nielsen et al. 2003).

Deer–vehicle collisions are costly, averaging $6,717 USD per collision (Huijser et al. 2008).

Between 1990 and 2010, human fatalities from collisions with wildlife, mostly deer, increased 104% (Sullivan 2011). In addition, many deer are killed in these collisions, potentially resulting in reduced recreational opportunities and other intrinsic benefits deer provide (Huijser et al. 2008). An estimated 92% of deer involved in collisions die from the trauma (Allen and McCullough 1976). Human–deer conflicts in Princeton, New Jersey, USA increased following enactment of a no-firearms discharge law within the township in the 1970s, and a 436% increase in deer–vehicle collisions followed between 1972 and 1982 (Kuser 1995). The inability to regulate deer numbers can influence the number of conflicts and collisions.

Another major concern of the public is the risk of disease transmission from deer (Connelly et al. 1987, Curtis and Lynch 2001). As with many species of wildlife that reside in close proximity to human dwellings, deer serve as reservoirs and vectors of zoonotic diseases. Lyme disease is contracted by humans through an injection of the bacterium, *Borrelia burgdorferi*, during the bite of a deer tick (*Ixodes* spp.; Adams et al. 2006). 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). Most cases occur among states in the northeast United States, but an increasing number of 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 in urban and suburban settings can become overabundant, reaching densities of 78 deer/km^2 (Magnarelli et al. 1995). Overabundant deer browse heavily on forest understories and alter the vegetation composition of plant communities (Adams et al. 2006). This in turn may influence the distribution and abundance of species at multiple trophic levels that depend on those plant communities. It also modifies the relative abundance of species that compete with deer (Waller and Alverson 1997). This type of intensive herbivory is not confined to forests.

Urban and suburban households experience damage to gardens, yards, and ornamental plants from deer herbivory that averages $73 USD per household (Conover 2001*a*). Although rare, deer may be aggressive toward humans in areas of high human density where deer are habituated to humans and 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 believed to involve female deer (i.e., does) protecting fawns. Other attacks on humans have included male deer (i.e., bucks) during the breeding season, likely in mistaken bouts for dominance (Conover 2001*a*).

CHALLENGES WITH OVERABUNDANT DEER AND MUNICIPALITIES

In many parts of the United States and Canada, deer populations have increased in urban environments. City officials often are asked and expected to solve urban deer-related issues, but many challenges 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 for deer in municipalities varies, with some residents viewing deer as beneficial and others viewing deer as a detriment. This lack of consensus among residents is a source of controversy for elected officials, as polarized constituents may propose fundamentally different solutions to address deer-related challenges. Residents in favor of having deer within populated areas promote the philosophy that local citizens need to learn to live and coexist with wildlife. Those opposed to urban deer often call for strategies to decrease deer densities to reduce deer–vehicle collisions, address zoonotic disease risks to humans, alleviate 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. Management authority of deer generally rests with the state or provincial wildlife management agency. Municipal officials must work with state or provincial agencies to establish and achieve defined objectives. Where city leaders believe urban deer are a wildlife agency's problem and not a shared responsibility, little progress will be made in reducing conflicts. Coordination and collaboration are critical.

Wildlife management agencies primarily manage deer population size through regulated public hunting. Cities usually have ordinances and other laws that prohibit the discharge of firearms within city limits due to safety concerns 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 consider utilitarian views of hunting acceptable (Manfredo et al. 2018). Yet, in some areas, the public is becoming increasingly accepting of hunting as a management tool and a means to obtain locally grown, organic protein (i.e., locavores). Exacerbating the problem, many municipalities lack ordinances that prohibit the feeding of deer, creating a refuge for deer and increasing their abundance.

Jurisdictions with the most pronounced deer problems generally are those with high deer abundance and restricted hunting regulations (Conover 2001*b*). These regulations may apply to an entire state or province (such as restrictions in the state of New York, USA 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 to houses, making discharge of weapons unsafe under normal conditions. Changes to regulations (e.g., allowances for harvest) may take years to enact, and communities even may be reluctant to approve hunting methods with limited range and noise, such as archery hunts. Consequently, communities struggle to find acceptable solutions while the deer population and human conflicts with deer continue to increase (Messmer et al. 1997).

In 6 different New England communities during the late 1980s, human–deer conflicts began to emerge as a threat to human safety from increased vehicle collisions, an increase in detected cases of Lyme disease, and increased nuisance complaints due to deer browsing in local gardens (Northeast Deer Technical Committee 2009). 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. Even the creation of local deer management committees and a comprehensive consultation process failed to achieve consensus in the 2 largest communities; in these communities, resolution was delayed for >10 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 a 1-year immunocontraceptive study followed by bait-and-shoot operations (Northeast Deer Technical Committee 2009).

In many situations, solutions to deer conflict issues require the joint coordination of multiple jurisdictions. In Cook County, Illinois, USA, the legal custodian of wildlife is the Illinois Department of Conservation; the legal custodian of the habitat is the Cook County Forest Preserve District (Jones and Witham 1995). A successful urban deer management program requires the cooperation of all levels of government, with funding, staffing, and communication distributed in ways that promote shared responsibility (Messmer et al. 1997).

CHALLENGES FOR WILDLIFE AGENCIES IN MANAGING DEER IN POPULATED AREAS

State and provincial wildlife agencies face constraints when attempting to solve urban deer issues. Similar to most cities, a wildlife agency's operational funds (generated primarily through license sales) are limited, and many do not have a dedicated budget to address urban deer issues. Limitations imposed on the use of federal funds raised through excise taxes (i.e., Wildlife Restoration Funds) for nuisance wildlife management also hamper the agency's capacity to respond. Historically, wildlife agencies were slow to hire staff in urban settings at the same rate at which urban deer problems 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

In desert landscapes, cultivated agriculture can be appealing to mule deer (courtesy of B. Wakeling).

municipalities to help and allocating resources may be difficult.

Community leaders often call upon wildlife agencies to remove urban deer, but each technique has specific limitations (Messmer et al. 1997). Lethal removal by sharpshooters with firearms may not be viable in many instances, but even in situations where it may be feasible, having properly trained staff and the necessary equipment may be problematic. Trap and cull measures may be perceived as safer, but substantial expense, equipment, and expertise are required. Culling efforts should target removal of resident deer, as deer that migrate through urban areas may cause few problems. In addition, relying primarily on removing deer provides only temporary relief if other attractants are not removed.

In many cases, lethal removal is unacceptable socially, and wildlife agencies are asked to translocate urban deer (Messmer et al. 1997). Aside from mortality from capture-related stress (e.g., capture myopathy), moving urban deer can be expensive, may be prohibited by legal statute, is logistically challenging, and may spread wildlife diseases to healthy deer herds where the animals are released. Cost–benefit analyses should be conducted prior to translocation efforts, and disease histories and risks should be factored into the decision-making processes (Western Association of Fish and Wildlife Agencies [WAFWA] 2014). Wildlife agencies should do all they can to prevent the spread of disease, particularly chronic wasting disease (CWD). Translocating deer involves a great amount of risk and could have negative biological impacts on deer populations or economic consequences for commercial interests (e.g., livestock) if disease is spread from 1 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).

Black-tailed bucks sparring in Washington (courtesy of O. Duvuvuei).

WORKING TOGETHER TO MANAGE DEER IN POPULATED AREAS

State wildlife management agencies and municipalities must work collaboratively to effectively manage deer in populated areas. Deer management is not simply finding a way to harvest deer in situations where conflicts arise. Developing a plan to eliminate, mitigate, or reduce conflicts is essential. Many of wildlife management's greatest challenges arise at the intersection of issues with poorly defined, tenuously understood, or sometimes competing management authorities. The findings of biological science and the decisions of experts traditionally relied upon to make management decisions must integrate the varying desires of the public, especially when managing urban wildlife (Decker et al. 1996, Mangel et al. 1996, Organ and Ellingwood 2000, Riley et al. 2002).

DEFINING SUCCESS WHEN MANAGING DEER IN POPULATED AREAS

Identifying the challenges of both populated areas and wildlife agencies is an important first step in addressing urban deer conflict issues. Urban deer management has 3 main components: (1) determining where we are, (2) identifying where we want to be, and (3) bridging the gap between the 2 places. Determining where we are involves understanding the densities and growth rates of deer in a given area, the number of deer–vehicle collisions, the amount of property damage that is occurring, and the social tolerance of citizens toward deer. Identifying where we want to be involves determining what success looks like for a given municipality. Wildlife agencies should work with municipalities to define goals and objectives in some form of management or action plan and clearly lay out what results need to be achieved. Examples of defining success can involve working toward reaching a socially acceptable deer density (number/area), reducing deer–vehicle collisions (number/time period or number/km of roadway) and property damage (e.g., deer eating flowers or plants in gardens [yards depredated/time period]), and surveying the public to obtain their opinions (public satisfaction). Estimating the actual number of deer in a community is nearly impossible to determine (DeNicola et al. 2000).

When defining success, wildlife agencies should work directly with elected officials 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 2 places involves selecting a strategy to achieve the defined management goals and objectives. Each strategy has benefits and drawbacks, and each must be evaluated critically before being implemented. If communities and wildlife agencies are going to make progress toward 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 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, whereas 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 different habitat types, such as golf courses, lawns, and ornamental shrub rows. With human development, anthropogenic food sources (e.g., wildlife feeders, gardens, ornamental plants) are introduced to the landscape, and deer modify their behavior and movements to exploit these artificial food sources. For example, suburban deer in Connecticut, USA browsed heavily near houses because of the anthropogenic food sources found near the human dwellings (Swihart et al. 1995).

In general, size of deer home range decreases 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 (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 populated areas may be able to exploit higher concentrations of food and other resources, which allows them to decrease home range size while still meeting annual needs (Tufto et al. 1996, Kie et al. 2002, Saïd and Servanty 2005).

Similar to that observed among 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 and summer; Storm et al. 2007). As food becomes more scarce during the non-growing season, deer increase their movements. Additionally, deer in populated areas tend to shift their movements toward dwellings in the winter (Kilpatrick and Spohr 2000, Grund et al. 2002, Storm et al. 2007), where supplemental food sources exist and radiant heat and wind breaks are provided by buildings (Swihart et al. 1995, Grund et al. 2002).

BIOLOGICAL ADAPTATIONS

Deer can become overpopulated in urban areas due to many variables, some of which include a lack of natural predators, reduced hunting pressure, increased recruitment, and favorable habitat conditions. Due to anthropogenic food sources, resources often are less limiting for deer in populated areas, and individuals retain good health despite high population densities (Etter et al. 2002, DeNicola et al. 2008). Urban landscaping often provides a consistent source of food for the deer in urban areas, and deer remain in good health when at medium-low densities.

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 generally higher than survival rates in rural landscapes due to lack of hunting and natural predators (Etter et al. 2002, Bateman and Fleming 2012). This difference in survival is greater for male than female deer because, outside the exurban environment, male deer are more frequently harvested in regulated hunting seasons.

As nutrition improves, wildlife reproductive rates increase. When coupled with higher offspring survival, the result ultimately is higher densities (Robbins 1993). Because of the favorable conditions, deer may experience higher reproduction in urban settings than in rural populations (Etter et al. 2002), as the artificially abundant food sources allow females to reproduce without the density-dependent effects experienced by deer in non-urban landscapes.

Anthropogenic influences can limit deer abundance in some areas. 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. Anthropogenic factors such as deer–vehicle collisions, entanglement in lawn structures, drowning in pools, and attacks by domestic dogs represent potential mortality threats for urban deer (Harveson et al. 2007).

Deer–vehicle collisions are the principle cause of mortality for deer in areas where deer and humans coexist (Etter et al. 2002, Wakeling et al. 2015). As road density increases, 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 their increased movements associated with breeding (Olson et al. 2014, Wakeling et al. 2015).

Although natural predator densities may be lower in human-dominated areas than in rural habitats, domestic pets can prey on wildlife at rates similar to natural predators (Ditchkoff et al. 2006). Additionally, Ditchkoff et al. (2006) found that coyote (*Canis latrans*) predation on white-tailed deer neonates in urban areas exceeds rates found in rural areas. As deer populations approach and exceed carrying capacity, suitable hiding cover for neonates may become scarce, thus increasing predation risks and resulting in lower fawn survival (Piccolo et al. 2010). For fawns in 1 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 western United States, human development has encroached on deer winter range where deer congregate seasonally. Human development restricts the available habitat in these seasonal areas with high deer densities and further concentrates deer into smaller areas. Local factors such as home gardens, palatable ornamental shrubs, and supplemental feeding around residences can concentrate deer at a few locations on the landscape and result in smaller home ranges (Peterson and Messmer 2011). 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).

Prevalence of CWD was almost twice as high in developed areas than in undeveloped landscapes (Farnsworth et al. 2005), but variations in prevalence occur. Because development tends to reduce hunting pressure and increase survival, adult deer, particularly adult males, tend to live longer in human-developed areas, allowing disease pathogens more time to infect others. 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 (Farnsworth et al. 2005).

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, USA (Schmitt et al. 1997). The unnatural concentrations and close contact that results from human development and baiting provides ideal conditions for the transmission of bovine TB through inhalation of infectious aerosols and ingestion of contaminated feed (Whipple and Palmer 2000).

THE ROLE OF WILDLIFE AGENCIES IN MANAGING DEER

The basis of North American wildlife law is the Public Trust Doctrine. This doctrine recognizes that, although natural resources like wildlife belong to the public, government is entrusted with the conservation of wildlife for the benefit of current and future generations. A state's fish and wildlife resources are generally conserved by an elected or appointed board or commission that sets laws and regulations to manage deer as trustees according to this doctrine and employs experts who collect data and provide recommendations pertinent to each state's deer population as trust managers (Smith 2011). 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 a deer overabundance issue exists, 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 hunting, capture and tagging, culling, contraception, sterilization, and

Deer damage on Arborvitae (courtesy of G. Westerfield).

The Northeast Section of The Wildlife Society, in their position statement titled ***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.

translocation. The public is entitled to hold trustees responsible for managing wildlife and may redress management actions through judicial venues or subsequent elections.

Many states have specialized programs or regulations for managing overabundant deer where hunting is not practical or desirable. They also offer a wealth of technical information on options for addressing deer from a homeowner and a community perspective. Most wildlife agencies will make 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, the community and its leadership generally determine SCC for wildlife (Messmer et al. 1997). 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 often are 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 identification of objective indices to monitor deer populations or human–deer conflict. No single deer population index will be acceptable in all situations, and indices of conflict may be more suitable to measure and manage, including metrics such as levels of deer–vehicle collisions, property damage, environmental degradation, incidence of disease, and tolerance levels of residents.

Generally, communities require a substantial amount of time to reach the point of majority consensus and plan development. Implementation actions to address overabundant deer could take time to develop. Meanwhile, deer populations, which can double every other year, can continue to expand, and conflicts may increase commensurately. The amount of human resource investment depends on the selected management activity; some programs can rely primarily on volunteers, whereas other tasks may require municipal employees or contractors. Each community should assist in selecting the best option from among those with scientific integrity for their situation. Deer population management requires annual maintenance because deer populations can grow even after management objectives are reached. Any deer management program should be evaluated annually for progress toward the objective, revised to improve efficiency, and adapted to current biological and social conditions.

SURVEYS AND MONITORING

We describe specific methods below that are often used by state wildlife agencies to estimate deer populations. Some methods are less appropriate than others for use in the varying landscapes of urban, suburban, and exurban areas. However, our goal was to describe all methods that could potentially be useful. Investigators involved in individual projects, whether they be agencies or community leaders, will need to make decisions as to what is most appropriate in terms of the field methods employed and the analysis of information gathered.

Random observations that are not collected in a structured fashion can be misleading or widely inaccurate. A statistically valid design is important to ensure that data are comparable and measures are repeatable so that valid comparisons regarding treatment and effects can be inferred. A statistical euphemism states, the plural of anecdote is not data.

Population trend is the directional movement in relative abundance or other key parameters through time (*sensu* Skalski et al. 2005), which is discussed with great detail as applied to deer monitoring in Keegan et al. (2011). Trend indices are measures that correlate with population abundance (or other parameters); thus, trend indices indicate whether a population has increased, declined, or remained stable over time. Trend indices sometimes are used to infer magnitude of annual changes and, if collected over multiple years, they can 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

Mule deer can cause substantial damage by feeding and bedding in alfalfa fields (courtesy of B. Wakeling).

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 the usefulness of these indices (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 often is low. Consequently, changes in population size 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 little study (Skalski et al. 2005). Despite these questions, trend indices are used frequently, primarily because of cost-efficient application over large geographic areas.

Trend indices are used most frequently to index changes in population abundance, although they may be used to index trends in age structure, adult sex ratios, or productivity or recruitment ratios. Although 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 that the relationship between the index and abundance has not been determined. Despite this, trend indices are 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 should be used to determine if a relative (as opposed to absolute) change in abundance has occurred. A second important problem among trend indices is difficulty in meeting statistical sampling 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 deer trend indices, the relationship between index and deer abundance is not only unknown, but 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, survey type). A variety of techniques are used to deal with this variation. First, sampling strategies frequently are systematic (i.e., focused on a particular arrangement or number of samples) or stratified random (i.e., divides a sample into groups by some defining characteristic) as opposed to purely random, because these techniques reduce sampling error versus purely random sampling. These standardized sampling strategies attempt to account for vegetation type or other environmental attributes that vary among survey areas or times. By accounting for these differences when designing a survey, the overall index should better represent the entire population.

Systematic or stratified random surveys are easier to implement than completely randomized designs, especially when surveys are associated with roads or trails that are not located randomly across the landscape. A potential negative effect of systematic sampling is the possibility of not capturing all of the environmental variation across the landscape because the sampling is not random.

This problem can be overcome by ensuring that stratification (blocking) includes all relevant variables in the stratification (e.g., all habitats likely to be used by deer). A second way to deal with environmental variables that may affect the relationship between abundance and the index includes standardization of survey methodology, which can 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 frequently are accomplished through helicopter or fixed-wing airplane surveys; however, several other techniques (e.g., ground counts, spotlight counts) also yield minimum counts. Counts are standardized to effort, such as numbers seen per hour of flight time or kilometers of survey route.

Advantages

- Sample sizes obtained from aircraft usually are greater than ground-based methods because of increased visibility.
- Helicopter counts provide more accurate counts and better sex and age classification than do ground-based counts because of 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 vegetative cover substantially obscures aerial observation of deer or allows only glimpses of deer.
- A segment of the public strongly favors census and minimum counts over sample-based population estimation. Sample-based estimates frequently are called into question and dismissed by the public if they do not mirror perceptions.
- An absolute minimum population estimate that is clear 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 a deer census is possible. Radio-marking 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 and generally would be prohibitive except for small, confined areas.
- Although presumed to be more accurate than ground-based methods, validation may be lacking in specific urban environments, particularly for fixed-wing aircraft.
- It is significantly more hazardous for biologists than ground-based methods.

- Minimum counts frequently are smaller than annual harvests, causing the public to question survey data and permit allocations.

- Motion sickness or pilots with insufficient survey experience 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 is 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 are collected across time, a consistent proportion of the population is counted.

- Sex and age classes are identified correctly if population components are separated.

- Detectability is similar across sex and age classes or counts are conducted during biological periods where free intermixing occurs between sex and age classes (Samuel et al. 1987, Bender 2006).

Techniques

Both population censuses and minimum counts are conducted from either helicopter or fixed-wing aircraft, with flight protocols (such as airspeed, altitude above ground level [AGL], 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 include use of aerial photographs to count concentrations of individuals or thermal imaging. However, remote methods seem to have limited applicability, particularly with respect to classification. 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 are being explored as a means to decrease risks to biologists (K. Williams, U.S. Geological Survey, personal communication).

Minimum aerial counts are the most commonly used trend index for deer. Minimum counts are 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 standardized 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,

Deer may seek urban, suburban, or exurban landscapes to raise their young as a means to avoid predators and exploit higher quality forage (courtesy of Missouri Department of Conservation).

similar to those required for abundance estimators such as sightability models. Despite this, as with sightability models and similar methods, estimates always will be biased negatively because topography and other visual barriers 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 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, occasionally are used to extrapolate minimum counts to abundance estimates.

Advantages

- They are easy to conduct, inexpensive compared to aerial surveys, and can cover large geographic areas.
- Fawn-to-doe ratios are produced, 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 are likely biased because of poorer sighting conditions and behavior of bucks as compared to helicopter surveys.
- Detection probabilities vary with habitat conditions, weather, observers, and disturbance.
- Amount of traffic along trails or roads can affect proximity of deer.
- Sample sizes are usually low compared to aerial surveys.
- Low light capability of optics influences results.
- They may generate disturbance to adjacent human residents.

Assumptions

- Sample is representative of the population.
- Index reflects changes in population size rather than changes in deer distribution or detectability.
- Roadsides or trails are 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 are consistent among years and groups counted without error.
- Sex and age classes are 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 among observation points. Surveyors move along a standard route, traveling from 1 location to another that provides a good vantage point for searching for deer. If using specific observation points, 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/km traveled, or used as inputs into distance sampling models to estimate abundance.

Spotlight surveys are conducted in habitats that are representative of the area being surveyed and 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(s) shines a spotlight along the side of the route and records all deer seen and classifies deer by sex and age. Typically, number of deer seen/km of route serves as an index to deer abundance, and sex and age composition provides trend information on population demographics. Data may be 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 should be 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 the 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

- Collecting effort data through harvest surveys is relatively easy and inexpensive.
- It is presumably more accurate than harvest uncorrected for effort.
- There is a strong empirical background in fisheries management.

Disadvantages

- The method is subject to response distortion biases present in social surveys.
- It is vulnerable to changes in hunter behavior.
- Changes in deer vulnerability are influences (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 influence the relationship between HPUE and deer density.

Assumptions

- Harvest and effort data are accurate and unbiased.
- The population is closed during hunting season except for harvest removals.
- Probability of harvest is 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, electronic or phone check-in of game, or check stations where deer are physically presented. The HPUE index, such as 0.05 deer harvested/hunter-day, is 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 influence harvest. Hence, use of running averages across multiple years reduces the effects of annual variation in these factors. Comparisons among management units differing substantially in vegetation associations is a problem because HPUE reflects both abundance and vulnerability of deer, and vulnerability can change with variations in hiding 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 hunter harvest (i.e., total number of deer taken by hunters). This index assumes encounters between hunters and deer, and thus harvest, increase as deer abundance increases and decline as abundance declines.

Advantages

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

Disadvantages

- Annual variation in harvest estimates can be high and thus provides limited inference for population trend.
- Vulnerability to harvest changes occurs with changes in hunter behavior (e.g., regulation changes, equipment changes).
- Vulnerability to harvest changes occurs 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) may occur in hunter questionnaires, which are frequently not accounted for.
- Often there are no estimates of variance, thus providing no basis for statistical inference.
- Often accuracy is unknown or poor.
- Generally, these are 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.
- The deer population is closed during hunting season except for known harvest removals (e.g., no in-season migratory movements).

Techniques

Harvest data most often are 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 used as a trend index within management units. Total harvest should not be used as an index among dissimilar management units because of the substantial influence of habitat on deer vulnerability. Value of harvest as an index declines as limitations on harvest increase relative to deer abundance (e.g., reducing hunter numbers through limited entry). Harvest indices are based on buck harvest because female harvest often is more limited. 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, 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 1 way to reduce double counting (McCaffery 1976). Surveys are conducted following clearing of roads or trails of old track sets by dragging or following snowfall that covers previous tracks. Data are used as a relative index or minimum count but can be used to calculate densities (Overton 1969).

Advantages

- The method is simple to conduct, relatively inexpensive, and cover a large geographic area.
- It may be used for preliminary sampling to implement a more robust method.

Disadvantages

- The method is not statistically rigorous.
- There is difficulty in distinguishing among individuals or species if several ungulate species are present.
- It is dependent on activity levels and movement patterns.
- It is dependent on proper weather or substrate conditions for accurate counts.
- Multiple counts of the same individuals are very likely.
- Mild or severe weather conditions that influence use of seasonal ranges in some years may result in unreliable data.
- The number of individuals may be indiscernible when deer travel in groups.

Assumptions

- Methods are consistent among years and groups of deer are 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 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 weekly, assuming no disturbance to survey substrate [e.g., rain that washes away tracks]). The index is presented as number of track sets/km 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 perpendicular to travel routes between winter and spring ranges and counted periodically after the start of migration to spring ranges (Wyoming Game and Fish Department 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 presents the minimum number of individuals counted or number of tracks/km 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 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 conducted most frequently on winter ranges. Because habitats are not uniform and pellet group distribution depends on relative habitat use, pellet group transects are 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

- The method is easy to conduct, little equipment is needed, and it can cover a large geographic area.
- It has been correlated with other trend indices including aerial counts and hunter observations (Härkönen and Heikkilä 1999).
- It can provide data on relative use of habitats (Leopold et al. 1984).

Disadvantages

- Power to detect trends is 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 is associated with inclusion or exclusion of groups lying along plot boundaries.
- It is difficult to distinguish species in the field if several species of ungulate are present.
- It is 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 (Coleoptera).
- For abundance estimation, there is little validation of most commonly used daily defecation rates, which vary with season and diet.
- It is labor-intensive to conduct over large area.
- There is potential for observer bias in aging pellet groups if transects are not cleared after each counting.

- It does not account for deer that defecate in the plot only once before leaving the survey area.

Assumptions

- Methods are consistent among years and groups are 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 often are used on winter ranges at the end of winter. Pellet group counts are converted to densities by dividing by the estimated number of times a deer defecates/day and number of days plots were exposed. For example, if assuming a deer defecates 10 times/day, and 700 pellet groups/acre are found after 10 days, 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 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.

Suburban archery deer hunt (courtesy of Missouri Department of Conservation).

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 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

- A tremendous number of person-days of effort are obtained with little cost to agencies.

- In some cases, large sample sizes are provided.

- It has been correlated with other trend indices and with aerial survey data (for other species).
- The hunting public is provided with a sense of ownership of population data.
- Little agency time is required to corroborate other trend indices.

Disadvantages

- The method is sensitive to responses and biases of hunters.
- Untrained observers may not count or classify deer accurately.
- Independence of observations is 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 observation index and abundance vary among areas.
- Precision of estimates is low or undefined.

Assumptions

- Numbers of deer are observed and recorded without bias.
- Sex and age classification are correctly identified and reported.
- Number of hunter-days is consistent or observations are standardized per hunter day.
- Hunters are 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 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 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 usable index for 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 desired to empirically manage deer populations. Because 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 deer numbers on the scale of most management units. Cover and terrain can make deer inconspicuous; therefore, methods used to estimate abundance must account for incomplete detectability of deer in the sampling areas. Based on studies with radio-marked deer and counts of known numbers of deer in large enclosures, detectability is considerably <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 made during winter when deer are more concentrated and more visible against snow cover. Estimates of deer abundance and density are further complicated because numbers are dynamic, and populations are seldom geographically discrete. Deer are born, die, immigrate, emigrate, and 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 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).

Young deer in urban setting (courtesy of G. Westerfield).

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). Population size can be extrapolated from numbers of deer in a sample of line transects or plots stratified by deer density or habitat. Distance sampling for ungulates occurs 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 biased estimates.

Advantages

- A robust method provides relatively few constraining assumptions compared to other methods.
- The method 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.
- It can be relatively inexpensive if used in open and flat areas where use of fixed-wing aircraft is practical.
- It is easy to design and conduct using geographic information system (GIS) software and global positioning system (GPS) units.
- The method can be applied to ground mortality transects as well as aerial population surveys.

Disadvantages

- It is only realistic in open areas with little terrain relief where deer close to the line of travel are almost 100% detectable. However, this can be addressed using modified survey and statistical methods. For deer, this method should be limited to habitats such as upland plains, open agricultural areas, or perhaps some sagebrush (*Artemisia* spp.)-steppe winter ranges. Even in these habitats, a helicopter would 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 among transects within a stratum.
- It is 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 be problematic, especially with high densities of deer.
- Observer fatigue can become an issue during prolonged surveys.
- It can be expensive if a helicopter is used.

Assumptions

- All deer on the line of travel are detected or accurately estimated.
- Distances are measured accurately, 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 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. Assigning individual deer or clusters of deer concurrently to fixed-width bands that delineate specific distance intervals away from and perpendicular to the line of travel.

Transects usually are 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 much more practical (Guenzel 1997). Fortunately, little bias 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 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 measured using a digital radar altimeter or a laser rangefinder mounted on the belly of the aircraft. For each observation, AGL should be saved automatically 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). Typically, 4 or 5 distance intervals are used to estimate an adequate detection function.

Program DISTANCE was designed specifically 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 on the line of travel is not certain, simultaneous double counts using 2 independent observers or a sample of radio-marked deer can be used to correct for incomplete detectability (Kissling and Garton 2006). Cluster size bias can occur using distance sampling because as distance from the line increases, deer in large groups (i.e., clusters) are detected more easily 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 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 then can 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

- Transect sampling can 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.
- The method provides a probabilistic estimate of the number of detectable deer that can be adjusted using detection probabilities.

Disadvantages

- Detection probabilities should be determined using a sample of radio-marked deer, and this can 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.
- It is 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 be determined accurately and deer can be identified correctly 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.
- Marked deer have the same probability of being sighted as unmarked deer.
- Detection rate estimates are unbiased and accurately represent actual detection rates.

Techniques

Transect counts for deer usually are 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 run parallel, are spaced evenly 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 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 (often square) and, prior to GPS technology, 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 and 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

- The method provides a probabilistic estimate of number of detectable deer.
- The design is fairly straightforward and can be laid out with GIS (prior knowledge of deer distribution is very helpful) and flown using GPS.
- Handling and marking of deer are not required.

Disadvantages

- It is relatively expensive because a helicopter is 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.
- It 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.
- Quadrat methods for estimating mule deer numbers can require considerable helicopter time: 20–40 hours are typical for management units in Colorado, USA [Kufeld et al. 1980]).
- Extensive amounts of flying can cause observer fatigue and result in prolonged surveys because of weather and conflicting work assignments.

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 use sampling polygons with small areas (0.65–2.6 km^2) 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 based on cadastral section lines, but GIS and GPS units have increased design flexibility. Use of GPS units also makes quadrat sampling more practical because quadrats can be flown accurately without landmarks. Stratification is 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 on a quadrat by quadrat basis is better than by geographical area.

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 then is 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 radio-marked 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 radio-marked deer in similar habitats have been used to adjust quadrat population estimates. In Colorado, a sightability factor of 0.67 is used for quadrats in pinyon-juniper winter range and 0.75 is used for sagebrush-steppe (Bartmann et al. 1986; Colorado Division of Wildlife, 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 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 (Samuel et al. 1987, Ackerman 1988, 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 radio-collared 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

- The method 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 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.

Deer, like this white-tailed deer in Missouri, can prove difficult to enumerate and monitor in urban, suburban, and exurban landscapes (courtesy of Missouri Department of Conservation).

Disadvantages

- Initial costs to develop sightability models are high. Radio-marked deer must be used to develop different sightability functions for a wide variety of habitats and conditions.

- Ongoing costs are high 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 are 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 may not be random, but drawing sampling units under stratified random sampling produces unbiased estimates.

Assumptions

- Probability of detecting deer is relatively high and can be accurately 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 the 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 defined based on geographical features instead of constant-sized quadrats. Similar to quadrat and transect methods, precision of population estimates using sightability models can 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 are used as sample units, they 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 counted accurately to avoid underestimating population size (Cogan and Diefenbach 1998). Sightability survey techniques were described in detail by Unsworth et al. (1994, 1999).

MARK-RESIGHT AND MARK-RECAPTURE

Mark-recapture methods use the ratio of marked (i.e., individually 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 usually cannot be met in field situations. To address the need for more practical assumptions, a variety of more complex and flexible mark-recapture models have been developed that require computer-assisted solutions (i.e., no closed form estimator is available). The programs MARK and NOREMARK have been developed specifically for this purpose (White 1996, White and Burnham 1999).

More traditional mark-recapture methods are 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 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 deer (McClintock et al. 2009*a*, *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 enough 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 eliminate the need for marking deer (Magnusson et al. 1978, Potvin and Breton 2005). Infrared-triggered cameras (IRCs) have been used to assist in sighting efforts and proven to provide accurate estimates of population size when coupled with the correct statistical methods (Curtis et al. 2009, Hamrick et al. 2013). Curtis et al. (2009) concluded that using program NOREMARK or the Jacobson buck:doe ratio method provided the most reliable estimates when using IRCs.

Advantages

- It is considered one of the most reliable methods for estimating abundance of wildlife populations when sample sizes are adequate and assumptions are not 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. 2009*a*, *b*).

- The method provides a probabilistic estimate of population size and, with some more advanced models, allows some demographic parameters to be estimated.

- It 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

- Achieving an adequate sample of marked deer, ensuring marks are available for resighting, and conducting resighting surveys can be expensive and labor-intensive.

- It is 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% of point estimate) for practical applications.

- The method is dependent on a variety of assumptions, which, 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 estimated reliably.

- 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 estimated reliably.

- 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 identified correctly as being marked or unmarked when sighted.

Techniques

Most mark-resight population estimates of deer use radio-marked animals. Radio-marking has the advantage of allowing confirmation of the number of marked deer available for resighting within the area of interest and identification of individual deer. Radio-marks have some disadvantages (e.g., deer need to be captured to have radios attached, equipment is expensive, radios can fail). In lieu of radio-marking, 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 net-gunning 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 will improve the accuracy of some models.

Collection of DNA samples from scat or hair has become popular 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 noninvasive 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 considered critically before beginning mark-resight surveys because different models are based on different assumptions. Commonly used mark-resight models 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 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. 2009*b*) when sampling is done without replacement and the number of marks is known, and (2) the Poisson-log normal model (McClintock et al. 2009*a*) 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). Program NOREMARK was 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. 2009*b*) and the Poisson-log normal (McClintock et al. 2009*a*) 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 sample-based 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 marked deer counted to number of duplicated sightings (resighted deer) using independent observers (Magnusson et al. 1978, Potvin and Breton 2005). For ungulates, simultaneous double-counting is done from a helicopter or fixed-wing aircraft and 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 detectable and observers are independent. Both assumptions are questionable, and there is inherent bias toward 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 more appropriately are 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 deer numbers under the right conditions, they often fail to show much advantage over standard counting methods because of highly variable detection rates (Wakeling et al. 1999, Haroldson et al. 2003, Potvin and Breton 2005).

Advantages

- A visual record is created that can be reviewed, analyzed, and archived.
- The methods do not rely on real-time observations that could be in error.

Disadvantages

- There is a potential inability to (1) detect deer under cover, (2) differentiate deer from the background, and (3) differentiate deer from other species.
- Highly variable results can be influenced by a wide variety of factors.
- Relatively expensive equipment and flight costs are required 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.
- 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 forward looking infrared (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 (*Cervus elaphus*), white-tailed deer, pronghorn, and bighorn sheep (*Ovis* spp.).

Assumptions

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

Techniques

Thermal imaging uses a wide-angle FLIR system mounted on a helicopter or airplane. Random or systematic transects are 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. Although FLIR surveys assume detection probabilities approaching 1, actual detection rates can be highly variable (Wakeling et al. 1999, Haroldson et al. 2003, Potvin and Breton 2005). Therefore, FLIR surveys can have little advantage over visual counts because both methods 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 identified reliably (Colorado Division of Wildlife, unpublished data). Recent investigations indicate that this technology may be effective at enumerating fawns associated with radio-marked does under some conditions (P. Jackson, Nevada Department of Wildlife, personal communication).

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 be estimated at a scale that seldom would 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 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 seldom are known, cumulative models rely on easily estimated parameters that allow population gain and loss to be calculated. These parameters include harvest and wounding loss, post-hunt sex and age ratios, natural survival rates, and, in some cases, immigration and emigration rates. However, in practice, field estimates of some of these parameters are not available and, even when they are measured, they contain sampling error as well as process variance (White and Lubow 2002, Lukacs et al. 2009). Therefore, it is 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 buck-to-doe 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 high. All models are dependent on the quantity and quality of data used. The public and some wildlife professionals can be skeptical of modeled population estimates for deer (Freddy et al. 2004). Although there can be legitimate reasons for this skepticism, this often focuses 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 are useful for predicting outcomes of different management actions, evaluating density-dependent effects, and understanding effects of stochastic events on population dynamics.

METHODS FOR MANAGING HUMAN–DEER INTERACTIONS

The goal of managing human–deer interactions is to reduce conflicts to a level of acceptable tolerance by the public. Two fundamentally different approaches may be used to address overabundant deer that are creating conflicts: damage prevention and population management. Damage prevention deals with the management of the damage inflicted by overabundant deer. These methods might include making habitat adjustments, modifying human behavior, or incorporating methods like exclusion, repellents, deterrents, or a similar technique. Population management deals with methods to reduce the numbers of overabundant deer. Many techniques and strategies are available to manage human–deer conflicts resulting from high deer densities in urban situations. In most cases, using multiple methods will increase success. For deer management in urban settings to be successful, using an integrated approach that employs both damage prevention and population management is best. At times, public support may be greater for damage prevention than for population reduction, but both approaches can help achieve clearly defined objectives more quickly (Pierce and Wiggers 1997).

Double-braided poly electric fence (courtesy of Missouri Department of Conservation).

DAMAGE PREVENTION OPTIONS TO REDUCE CONFLICTS

FENCING

Fencing may be constructed to create a physical barrier that excludes deer from accessing areas where they can cause damage or where they are not wanted. When properly constructed and maintained to assure efficacy, fencing can be an extremely effective damage control technique (Conover 2001*a*). Fencing may be constructed along a roadway to reduce deer vehicular accidents, but 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 generally do 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 (see Curtis et al. 2017). Attention to detail in fence construction and maintenance is critical for fencing to be an effective deterrent to deer damage.

Non-electric fencing

Fencing that is not electrified can create an effective physical barrier to deer when constructed properly. Numerous material and construction options exist, including woven-wire, chain-link, barbed wire, larger diameter high-tensile smooth wire, or heavy plastic mesh (Northeast Deer Technical Committee 2009). Common exclusion fencing should not have spikes or spears on posts. Deer can become impaled or tangled on these fences. Non-electric fencing may not be appropriate for areas of medium or high deer densities unless it is tall enough (at least 3 m) to prevent deer from jumping over. It also must make solid contact with the ground so deer cannot crawl under and should be constructed such that the strands are close enough together (20–25 cm apart) and taut enough (>90 kg of tension) so that deer cannot slide between them (DeNicola et al. 2000). An area of cleared ground about 1.8–3 m wide around the periphery of the fence must be maintained so deer 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 1.2 m high, as long as the area enclosed is not large enough for a deer to jump into, the fence is far enough away from the tree to prevent browsing, and it is supported with stout posts to prevent it from being pushed inward (Northeast Deer Technical Committee 2009). 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.
- Heavy plastic mesh deer fencing is economical and effective.

Disadvantages

- Initial costs of some fencing material and construction are high.
- Some types of fencing may be prohibited in certain municipalities by local ordinance or by homeowner associations due to not being aesthetically pleasing.
- Professionals typically are needed to install this type of fencing.

Electric fencing

Electric fences can provide cost-effective protection for many gardens (DeNicola et al. 2000). They are easy to construct and/or remove, 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 "grounded" deer touches the fence, which then conditions deer to avoid the fence. The major cost associated with temporary electric fencing is the fence charger. Such fences require frequent inspection and maintenance because they may be damaged by wildlife or falling vegetation.

The peanut butter fence (Figure 1) has been shown to be an effective and inexpensive fence design in several field conditions (Northeast Deer Technical Committee 2009). It is best used for gardens, nurseries, and yards that are subject to low

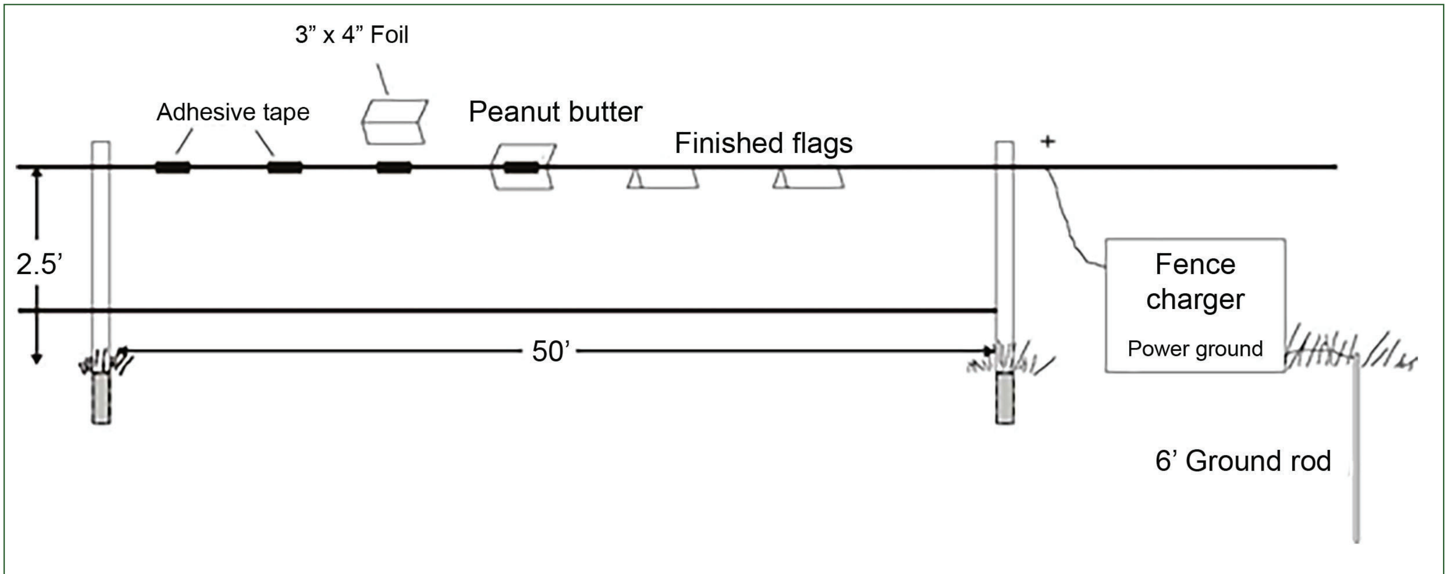


Figure 1. Schematic diagram of a modified electric fence, using peanut butter bait as an attractant (sometimes referred to as a peanut butter fence), which has proven effective at limiting deer access to vegetation, but requires maintenance to retain its efficacy.

to moderate deer pressure. Check the fence weekly to ensure proper voltage is being carried around the entire perimeter, examine for and repair damage, and remove vegetation that has grown into and may short out the fence.

A single strand of 17-gauge wire is suspended about 75 cm above the ground by 1.2-m fiberglass rods at 9–18 m intervals. Wood corner posts provide support. Aluminum foil "flags" (foil squares 10 × 10 cm folded over the wire) are attached to the wire at 6–15-m 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 2–4 weeks, depending on weather conditions (in warm, humid conditions, fences should be rebaited frequently because peanut butter will turn rancid more quickly). As deer learn to avoid the shock of the fence, bait can be reduced or eliminated.

The effectiveness of the original peanut butter fence design was 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 5–7 years.

Polywire or polytape fencing can be effective at deterring deer (DeNicola et al. 2000). Polywire is composed of 3, 6, or 9 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 it is also more expensive. Although both polywire and polytape come in a wide variety of colors, 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 or polytape can be a problem. Purchase materials with the least electrical resistance for these applications.

In its simplest application, an electrified single strand of polywire is suspended about 75 cm above the ground by 1.2-m fiberglass rods at 6–15-m intervals and baited in the same way as the original peanut butter fence. This basic design can be enhanced by adding a second wire to increase effectiveness: 1 wire placed 45 cm from the ground and the top wire at 90 cm above the ground. This prevents fawns from walking under the fence and also increases the chance that 1 wire will remain electrified if deer should physically encounter the fence. 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 smaller mammals. 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 a 1.2-m metal T-post with a bottom plate that provides stability when it is pushed into the ground. A piece of thin-walled 2.5-cm 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. Wooden posts with plastic insulators will also work well.

Although single or multiple strands of electric fencing may be somewhat effective (baited or unbaited), electric fencing constructed with an offset or a double-fence design (with a taller 2-strand fence on the outside and a shorter 1-strand fence about 100 cm to the inside) provides enhanced deterrence, but at higher cost. This type of electric fence creates a 3-dimensional barrier that is both physical and psychological and may discourage deer from jumping over or crawling under to avoid electric shock. 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 3,000 volts (or up to 4,000–6,000 volts has been used as long as it is of short duration and low impedance) 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 1.8–3 m so that deer may see the fence before making contact.

Tree tube protector (courtesy of G. Westerfield).

The use of electric fences in and around home sites can cause concern for children and visitors or may be prohibited by local ordinance. Where permitted, an option to reduce risk to humans 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 day. Electric fences should display warnings placards to alert unsuspecting people.

Advantages

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

Disadvantages

- Electric fencing is more expensive to maintain than non-electrified fencing.

- Vegetation management 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.
- 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 2.54 × 2.54-cm 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 7–10 years, and wooden posts will rot away sooner. A 1.2-m shelter is common and will prevent deer from browsing on tree seedlings until the sapling grows out of the tube. At that point, foliage from the emerging leader will appear right at nose level of a deer and may be subject to browsing and deformation. A 1.5-m shelter may be needed in areas with excessive browsing or snowfall.

REPELLENTS

Repellents may help reduce deer damage to gardens and ornamental plants (DeNicola et al. 2000, Northeast Deer Technical Committee 2009). Repellents are most valuable when integrated into a damage-abatement program that includes several repellents, fencing, scare devices, and herd management.

There are 3 kinds of repellents: contact repellents, area repellents, and those that incorporate both approaches. Apply contact repellents directly to plants; their unpleasant texture and/or taste repels deer. They are most effective on dormant trees and shrubs. Contact repellents may reduce the palatability of garden plants but should not be used on plants or fruits destined for human consumption.

Area repellents deter deer by odor and should be applied near plants needing protection. Border applications of area repellents protect larger areas at relatively low cost. Because such repellents are not applied directly to plants, they may be suitable for use on home garden crops grown for human consumption; check product labels for any restrictions or cautions on use before application.

People who use repellents should understand several basic principles:

- Repellents do not eliminate browsing; they only reduce it. Repellent success should be measured by the reduction, not elimination, of damage. If minimal damage is intolerable, 2.4-m fencing is the best option.
- Rainfall will wash off many repellents, so they will need to be reapplied. Some repellents weather better than others.
- Repellents reduce antler rubbing only to the extent that they help keep deer out of an area.
- Deer density and the availability of other, more palatable deer food dictate the effectiveness of repellents. When food is scarce or deer density in an area is high, competition increases for available resources. Deer may ignore both taste and odor repellents. In addition, deer may become habituated to certain repellents over time, reducing their effectiveness.
- If you use repellents, do not overlook new preparations, products, or creative ways to use old ones. New products frequently appear 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 1 area may not work elsewhere, even for similar crops and conditions.

Application of commercial repellents

Application methods for commercial repellents range from machine sprayers to manual backpack sprayers. Remember that 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 (1.8 m above the deepest snow). New growth that appears after treatment is unprotected.

As a preventive measure, the first repellent application should take place within 2 weeks of bud break. During the growing season, repellents should be applied as necessary to protect new growth, usually every 3–4 weeks (DeNicola et al. 2000). For dormant season protection, mid-fall and early winter applications are recommended. Fall applications may reduce 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 (DeNicola et al. 2000).

Available commercial repellents

The following list 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 precisely to achieve maximum success and remain compliant with pesticide regulations (DeNicola et al. 2000).

- **Putrescent egg solid:** This contact repellent smells and tastes like rotten eggs. Apply it to all susceptible new growth and leaders. Applications weather well and are effective for up to1–3 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 2–4 weeks but varies because of weather and application technique. Reapplication may be necessary after heavy rains.

- **Thiram (11–42% tetramethylthiuram disulfide):** Thiram is a fungicide that acts as a contact (taste) deer repellent. It is sold under several trade names and is used most often 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 fruit-bearing plants after fruit set. Vegetable crops also can be protected if sprayed before the development of edible parts.

- **Benzyl diethyl (2,6 xylylcarbomoyl) methyl, ammonium saccharide (0.065%), thymol (0.035%):** This repellant has an extremely bitter taste that repels deer. 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.

Non-commercial repellents

All non-commercial repellents are odor-based repellents that are applied to trees, shrubs, and vines. When using non-commercial 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.

Deer damage on daylilly (courtesy of G. Westerfield).

To deter deer in an urban or suburban environment, use scents that naturally do not occur in the area. Examples of non-commercial repellents are human hair and bar soap. All are odor-based repellents. However, as the density of human occupation increases in an area, effectiveness of scents typically associated with humans (e.g., soaps, shampoos, hair) rapidly lose effectiveness because deer encounter these odors regularly as they move through the urbanized environment and become habituated to them.

- **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 repellents 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 2 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 0.9 m between bags. For larger areas, hang several bags, 0.9 m 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 may 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 (DeNicola et al. 2000). Damage can vary regionally and with 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 of landscaping planted
- Deer density in the area
- Types of plants used in landscaping
- Level of deer resistance to the plants used
- 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 are not generated from scientific research, but rather on anecdotal information or by simply copying plants from another existing list. Three lists have been developed using scientific research into plant resistance of deer damage (Northeast Deer Technical Committee 2009).

Fencing can provide protection for young vegetation sprouts, such as this chestnut sprout, from deer browsing until it reaches a height at which it can sustain limited browsing (courtesy of G. Westerfield).

A 3-year study in Wildwood, Missouri, USA led to a list of native plants resistant to deer. Cornell University, New York, 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 in Ohio, USA conducted a survey of >400 nurserymen, educators, naturalists, and garden enthusiasts of deer-resistant plants that commonly appeared on >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 are preferred over non-native plants because native plants evolved in the presence of deer and persist despite sustained deer damage. However, the selection of available native plants at standard nurseries is limited and can make locating native plants challenging. Efforts should be made to plant species that are native to the area and avoid invasive species.

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 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 and bioacoustic frightening 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. Incorporation of bioacoustic frightening devices (alarm or distress calls) into an auditory stimulus system offers another option. 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 even deter deer from crossing highways, but further testing is needed.

Advantages

- Devices that frighten deer are generally inexpensive.

Disadvantages

- Loud noises are a nuisance to humans as well, and as such, may not be allowed within city limits.
- Efficacy is often short-term (with noise-making devices), as deer quickly habituate to noises that do not harm them. Bioacoustic frightening devices may have more long-term effect.

Guard dogs

Guard dogs (*Canis familiaris*) 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 will 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 (unless the dog is tied up or restricted in its access).

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 feeding (i.e., intentionally placing food for use by wildlife) or diversionary feeding (intentionally placing food for use by wildlife to reduce unwanted behaviors) of deer often is promoted as a method to draw deer away from areas where they are not wanted. However, this practice actually exacerbates existing problems or creates new ones (The Wildlife Society 2007, Peterson and Messmer 2011). Increasing access to anthropogenic foods will attract more deer to an area where an overabundant population already exists, thus increasing conflicts (DeNicola et al. 2000). Likewise, concern for the spread of diseases should be paramount, as concentrating many deer at 1 feeding area can exacerbate and promote disease transmission.

Even with supplemental feeding, deer continue to browse on natural vegetation, with increased damage near feeding sites. Deer become reliant on supplemental food and are more likely to become conditioned 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 (Huijser et al. 2009).

Permanent signs provide an early form of motorist warning to reduce wildlife–vehicle collisions. On many roads, departments of transportation have placed signs with silhouettes of wildlife to forewarn motorists of potential for collisions with wildlife. Little research has been conducted on effectiveness of permanent signs; however, the general consensus is that they are ineffective for long-term mitigation of deer–vehicle collisions because motorists largely ignore them. If permanent signs are used, placement should focus on high deer–vehicle collision areas to reduce motorist complacency (Pojar et al. 1975, Knapp and Yi 2004, Found and Boyce 2011b). 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 Interstate 90 in Montana, USA.

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 study 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, USA on animal-activated systems that include technologically advanced software that acquires and identifies specific targets before signaling their presence have had fewer incorrect classifications; electromagnetic sensors are 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 spots. Crosswalks have been tested only minimally, though Lehnert and Bissonette (1997) reported moderate effectiveness of crosswalks along 2- and 4-lane highways in Utah, USA. 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 7 km/hour (4 mph) reduction in speeds with the animal activated motorist warning signs along U.S. Highway 30 in Wyoming, USA. When a deer decoy was visible to approaching motorists in combination with the flashing lights, speeds decreased by up to 19 km/hour (12 mph). Gagnon et al. (2010) documented a 97% decrease in elk–vehicle collisions and a nearly 16 km/hour (10 mph) reduction in motorist speeds at a crosswalk with an 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, as animals frightened by passing vehicles may flee and attempt to cross at unsafe spots, increasing the potential for collisions with vehicles (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 the risk of 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 collisions. 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 system failures that lead to excessive false positives, 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 collisions, 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 (Wakeling et al. 2015). The actual expenses for these types of systems may cost $50,000–$200,000 USD depending on complexity and design. Costs for the regular maintenance of the warning system include 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 14 km/hour (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, the scientists experimentally tested various treatments involving the sign, the lights, and the presence of a deer decoy (full-body taxidermy mount of a female mule deer). Motorists traveling in the day failed to reduce speeds substantially in response to the activated system; however, speeds

Reflector sign (courtesy of New Jersey Division of Wildlife).

at night were reduced an average of 7 km/hour. Speeds were reduced an average of 20 km/hour 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 USD. Simulated decoys are available for substantially less. The potential for accidents and injuries place a substantial liability on any agency that uses them.

Auditory stimuli

Several auditory devices have been developed to stimulate 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. 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 responses. Valitzski et al. (2009) tested vehicle-mounted devices that produced pure tones, similar to sounds produced by deer whistles, at 5 different frequencies. The scientists found deer responses were not adequate to reduce collisions and concluded deer did 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.

Benefits and challenges

Primary benefits of auditory stimulus systems are their relative simplicity and low cost. If appropriate sounds could be produced that 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 and $100 USD. 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.

Visual stimuli

Various wildlife warning devices have been developed to frighten deer away from roadways through a visual stimulus in an effort to reduce deer–vehicle collisions. These devices are typically illuminated by motorist headlights and consist of reflectors or mirrors mounted on a series of posts alongside the roadway that reflect light to the roadway and roadsides in a moving pattern. The goal is that approaching deer (or other wildlife) will notice the reflected light and flee away from the road or halt on the roadside until the vehicle has passed. The reflectors are hardly noticeable to drivers.

Despite numerous studies on these devices, their effectiveness remains a point of debate. Brieger et al. (2016) has done perhaps the most comprehensive study of the various devices available and concluded that they do not significantly reduce deer–vehicle collisions. More recently, Riginos et al. (2018) found that reflectors covered with a white canvas bag were effective at reducing collisions. They found that in areas where reflectors were covered with white canvas bags versus areas where reflectors were not covered, carcass rates were 33% less, deer stopped before entering the road 20% more often, ran into the road from the right-of-way 11% less often, and fled from the road 12% more often. These are promising results, though more research in this area is needed.

Benefits and challenges

Although many studies have found that reflectors do not reduce collision rates (when measured in terms of carcass counts; Woodard et al. 1973, Waring et al. 1991, Armstrong 1992, Ford and Villa 1993, Reeve and Anderson 1993), other studies conclude that reflectors reduce collision rates from 19–90% (Gladfelter 1984, Schafer and Penland 1985, Pafko and Kovach 1996, Gulen et al. 2006). Obviously, more study in this area is needed. As with auditory stimuli, the benefits of visual stimuli are that they are simple to deploy and may offer some positive benefits in keeping deer off roadways and reducing collisions.

Financial assessments

The use of visual stimuli in the form of reflectors is likely cost prohibitive for large-scale use, though there may be instances where the value may be worth the cost (e.g., where high incidences of deer–vehicle collisions occur in a small, well defined area). Total cost of installation with reflectors, posts, equipment, and labor by 1 company that produces reflectors was estimated to be $4,000–$6,000 per km. The average life of reflectors is up to 12.5 years. Costs amount to $169–$199 per km per year. Maintenance cost per mile per year is $500 ($300 per km per year; Strieter-Lite, Strieter Corp., Rock Island, Illinois, http://www.strieter-lite.com/). In an experiment using reflectors in British Columbia, reflectors cost $10,000 per km to install along both sides of a highway, and maintenance costs ranged from $500–$1,000 per km annually (Sielecki 2004).

ROADWAY DESIGN

Wildlife crossings

Wildlife crossings (underpasses and overpasses), when combined with funnel-fencing, are an 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. 2007a, b; Dodd and Gagnon 2011). The numbers of wildlife crossings throughout North America are numerous and continue to increase in number (Bissonette and Cramer 2008).

Underpasses provide 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 larger and used to bridge larger areas like rivers and canyons, whereas culverts generally comprise smaller precast concrete or metal pipes 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 effective for deer passage, but recommendations on optimal size are an ongoing and heavily debated topic, particularly given cost constraints placed on construction projects. Openness ratio ([width × height]/length) is used to describe 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 (Reed et al. 1975, Foster and Humphrey 1995, Jacobson et al. 1997, Schwender 2013), but width seems more important than height (Foster and Humphrey 1995, Clevenger and Waltho 2000, Cramer 2013), and length is more important than width (Clevenger and Waltho 2000, Cramer 2013). Most studies on mule deer use of underpasses indicate that 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 2.4–3 m in height and a minimum of 6 m in width (Gordon and Anderson 2004, Cramer 2013),

Deer overpass (courtesy of New Jersey Division of Wildlife).

while length should not exceed 35 m if possible (Cramer 2013). In areas where underpasses exceed 35 m, 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 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 also reduces 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 erosion, but a natural soil pathway must be available for wildlife to navigate through the structure. Another method being implemented in Nevada, USA is placing a rip-rap layer under several cm 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.

Overpasses are not constructed as frequently as underpasses because of their cost. 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. The first wildlife overpass in North America was constructed in Utah along Interstate 15 and is only 6.4 m wide. Recent studies show that this 30-year-old overpass successfully facilitates mule deer movement (Cramer 2013). In British Columbia, the 5.8-m-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 bears (*Ursus arctos*) 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 overpasses that were 50 m wide (Clevenger and Waltho 2005).

Mule deer will use both overpasses and underpasses and will increase their use over time. Recently, studies to evaluate mule deer use of overpasses along U.S. Highway 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 U.S. Highway 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, West Inc., personal communication).

Proper placement of wildlife crossings (underpasses and overpasses) is essential to ensure 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 deer to encounter them within a reasonable distance. Bissonette and Adair (2008) recommended that wildlife crossings be placed about 1.6 km apart for mule deer in areas where deer regularly cross roads. Coe et al. (2015) noted that crossings could be placed more irregularly based on actual 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 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 toward crossing structures. In most cases, mule deer will not use crossing structures immediately, and a learning period will be required (Gagnon et al. 2011, Sawyer et al. 2012). For example, along U.S. Highway 30 in Wyoming, mule deer took about 3 years to adapt fully 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.

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).

Benefits and challenges

Properly designed and located wildlife crossings with funnel fencing will provide an effective method for reducing collisions with mule deer and other wildlife species. 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 deer collisions and connectivity in areas where there are elk present, designs for elk should be considered that will allow effective use by both species. Another consideration is smaller wildlife that inhabit the area. Although recommendations for deer provide for about 1.6-km 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 an expensive solution, but they are effective. Culverts are less expensive and can be installed for about $200,000 USD, whereas overpasses and bridges can cost $2–$10 million USD. 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 that is prohibitively expensive. Underpasses are 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 designed solely for wildlife are expensive and may be harder to justify. In general, overpasses are 4–6 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 provide less 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 there were ≤2 reported collisions per year (Simpson 2012). Additionally, an analysis of expenses on the same set of crossing structures showed a financial cost:benefit (Attah 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 have more time to detect, identify, and react to obstacles in their path than when traveling at greater speeds (Sullivan et al. 2004). 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–vehicle collisions regardless of posted speed limit (Bashore et al. 1985, Finder et al. 1999, Farrell and Tappe 2007, Found and Boyce 2011a, 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 collisions may provide positive results. Providing a message identifying short distances to watch for deer can increase driver attention span for those distances (Hardy et al. 2006). Deer generally increase movements during dusk and dawn, and mule deer often migrate seasonally; reducing speed limits at times of the day or year when deer are most active may reduce the probability of deer–vehicle collisions. Regardless, given that increased vehicular speeds correlate with increased accident severity and property damage, strategically placed signs both temporally and spatially may save human lives and reduce deer–vehicle collisions.

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 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 U.S. 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 U.S. Highway 191 keeps vehicles from exceeding about 55 km/hour, whereas other nearby sections can be traversed at 90 km/hour, yet 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.

Colorado experienced the confounding effects of implementing reduced speed zones to amend motorist behavior along a 160-km 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, the Colorado Department of Transportation removed the signage (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 highway 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 cost \$50,000–\$200,000 USD depending on complexity and design. Temporary flashing portable signs that are used seasonally are less expensive but still

Top: Suburban archery deer hunt (courtesy of Missouri Department of Conservation). Bottom right: Urban archery deer hunt (courtesy of J. Sumners).

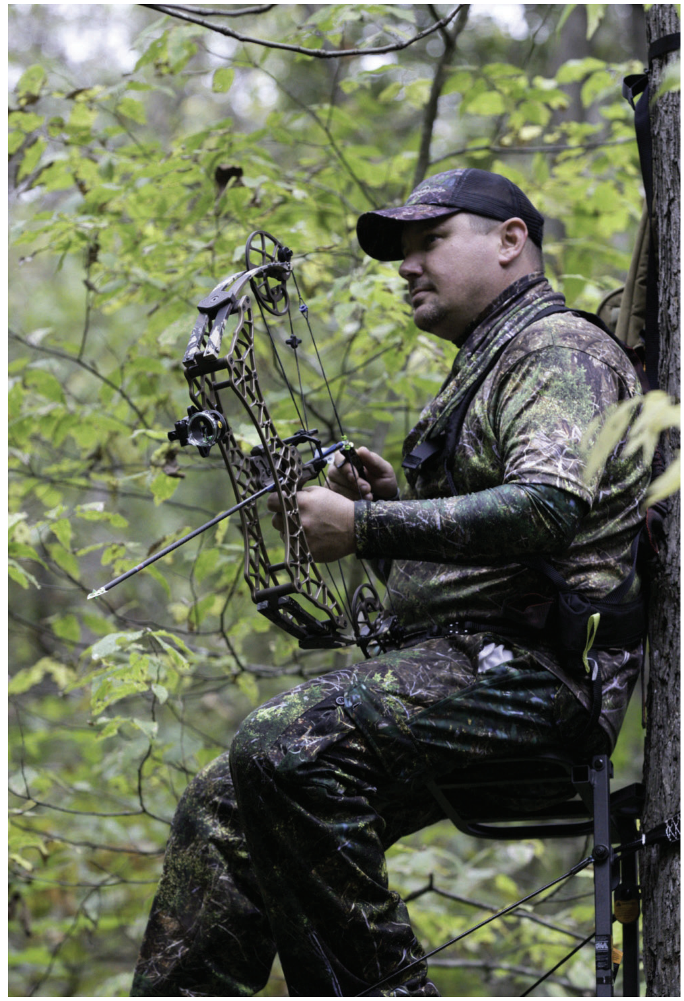
cost $10,000 USD or more to implement. Simply changing static speed-limit signs are inexpensive yet ineffective in reducing deer–vehicle collisions.

POPULATION MANAGEMENT OPTIONS TO REDUCE CONFLICTS

Agencies obviously must consider and evaluate viable, yet publicly acceptable, methods to reduce an overabundant deer population. When city leaders are determining the best option to mitigate deer issues in their community, they often look for 1 specific solution to address their situation. However, the best solution is to implement an integrated approach using multiple mitigation options, rather than rely on a single method (Conover 2001*a*). Regarding population management strategies, authorities must weigh the positives and negatives of allowing each technique within their city limits. This section will help identify the application and limitations of available population management techniques. Although these techniques are divided into broad categories, options exist for tailoring a program to a community's needs, residents' tolerances, and the landscape constraints imposed within a particular city. Any deer management program must have public support, but, to achieve that, well-defined objectives and expected outcomes for the management program must be articulated to the public.

REGULATED PUBLIC HUNTING

The use of regulated public hunting is supported by the tenants of the North American Model of Wildlife Conservation In addition, regulated public hunting is the most economical option for managing deer populations and is the primary tool used for deer management by state or provincial wildlife agencies throughout North America (Conover 2001*b*). However, its use in urban areas needs critical evaluation and unique design to ensure efficiency, safety, and to garner public acceptance. To improve the efficiency of these hunts, careful design, including the use of computer modeling, should be considered (Hubbard and Nielsen 2011). Hunting allows localized management by 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).



Suburban archery deer hunt (courtesy of Missouri Department of Conservation).

A few examples of how agencies have used managed hunts are as follows: Cuyahoga Falls, Ohio, uses regulated hunting to address deer conflict issues in the annexed portion of the city (acquisition of an adjacent township) where the prior township's allowance for hunting remained intact following annexation (Ohio Department of Natural Resources, unpublished report). Another option is to conduct a managed hunt within the city limits, similar to that in Princeton, New Jersey (New Jersey Division of Fish and Wildlife, unpublished report), municipalities of St. Louis County, Missouri (Hansen and Beringer 1997), and as was done in Connecticut (Kilpatrick et al. 2002). In New Jersey, the city defines *a priori* the number of hunters allowed to hunt within its boundaries and the locations (often city owned or managed properties) where those hunters can hunt. The city then advertises the opportunity for hunters to enter a drawing (lottery). Hunters drawn from that pool then can hunt within city limits. So long as provisions remain within the framework of the agency's regulations, a city can set specific rules for the hunt. In Columbia, Missouri, hunters 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 and 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 (A. Hildreth, Missouri Department of Conservation, personal communication). Officials in Independence, Ohio require a hunter to take an archery proficiency test before the hunters are allowed to hunt in the city limits (Ohio Department of Natural Resources, unpublished report). Hunting within city limits should be designed so that harvest objectives are met, such as creating a requirement to remove a certain number of does before a buck may be harvested. This strategy is used in Hidden Valley, Indiana (Indiana Department of Natural Resources, unpublished report). Cities can work with their game/wildlife agency to establish a deer management zone. For example, officials in Silver City, New Mexico worked with the state game agency to designate an urban management unit to allow additional deer harvest in accordance with state deer regulations. While the program does not address deer specifically within the city limits, it addresses emigration of deer into the city (New Mexico Department of Game and Fish, unpublished report). Where legal to do so, jurisdictions may seek authorization to allow baiting as a means of increasing the harvest and more efficiently reducing the deer population. For example, when Connecticut permitted baiting of deer, hunter success increased by 17%.

If the initial deer density in an urban area is high (>12 deer/km^2), 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 annual 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 via the open recreational approach will decrease. Any restrictions imposed on hunters, such as weapon type, use of baiting, and permit acquisition, will affect participation and successful attainment of desired management outcomes. Ensuring that hunters have access to enough land to hunt so that harvest objectives can be reached also is critical.

Deer are charismatic and some citizens will oppose deer hunting vehemently; others will be highly supportive (Messmer et al. 1997). Agencies and municipalities should clearly articulate the objectives and expected outcomes of hunting as a management action to all citizens. Some citizens may oppose hunting because of safety concerns, believing that they may be endangered from the discharged weapons. Authorities should address these fears by creating regulations that ensure public safety, such as limiting how close to buildings hunters may discharge a weapon and restricting hunting to public areas or private properties by permission only.

Cities may need to review and, where necessary, modify local ordinances and/or city rules to allow hunting. Periodic changes to imposed policies may be needed to address the number of hunters as a result of changing deer numbers or the inclusion/exclusion of hunting areas.

SHARPSHOOTING

Sharpshooting is a method of using trained personnel to systematically remove deer (Stradtmann et al. 1995). Sharpshooting can be effective in areas where other hunting options are limited. Because sharpshooting is highly controlled, its efficacy can be high if the appropriate number of deer can be removed over a short time frame, and there is access to private properties. Managers should be aware that not all property owners will be willing to participate in lethal removal. Typically, at least 40–60% of the deer must be removed annually to curb population growth, with the majority being female deer. In DuPage County, Illinois, deer densities were estimated at 68 deer/km^2 before 4 consecutive years of sharpshooting (1997– 2000) reduced the population to the desired density of 15–20 deer/km^2 (Etter et al. 1999).

There are personnel requirements to consider when planning a sharpshooting operation: shooters, baiters, security, processors, and logistics personnel who will handle the deer and day-to-day planning of the operation. Although 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, highly trained personnel usually are needed. One option is to use police personnel to shoot deer, as was done in Mentor, Oh (City of Mentor, Ohio, unpublished reports). Another option is to contract with U.S. Department of Agriculture (USDA)-Wildlife Services, as was done in Ann Arbor, Michigan (City of Ann Arbor 2016). This agency uses highly trained federal staff to shoot deer. Another option is to use nonprofit or private organizations permitted by the wildlife agency to control deer, such as White Buffalo, Inc. The cities of Iowa City, Iowa; Princeton, New Jersey and Solon, Ohio contracted with private sharpshooters to harvest deer annually to effectively reduce their deer populations (DeNicola and Williams 2008).

Sharpshooting can be costly, especially when 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 human resources for the typical duties of the personnel assigned. To be most effective, staff operating on a sharpshooting operation, including non-law enforcement personnel, need to be dedicated to this program and their normal duties assigned to other city personnel. If the community does not own or manage a substantial amount of land, they must gain access to private property as well. Sharpshooting requires a high level of city planning. In many cases, deer are processed for food pantries, but identifying a processor who will work within the time frame, as well as being able to handle the volume of deer, can be challenging. However, demonstrating a commitment to use any resource generated from any culling operation (i.e., venison) is essential to gaining public buy-in and support; few communities will tolerate wanton waste of the resource.

Long-term population reduction can be achieved through sharpshooting programs. In some areas, a sharpshooting program produces a rapid reduction in deer numbers, which may be followed with regulated hunting to maintain the reduced population.

Regulatory considerations

Depending on which options are used and timing, state/provincial regulations may require special permitting for the city to conduct a sharpshooting program. In addition, weapons may require a federal Bureau of Alcohol, Tobacco, Firearms, and Explosives permit, and this can take several months to obtain.

LIVE-CAPTURE TECHNIQUES

Various techniques are available to safely and humanely capture live deer. However, before considering capture strategies, communities must ascertain whether the agency will allow this approach and what the final disposition of captured animals is to be. Capture with intent to relocate and release is illegal in many areas and serves only to transfer habituated or potentially diseased animals to another area.

With all of these techniques, deer may be injured during capture or die from capture myopathy once they are released. 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, human safety is also a critical concern. With all captures, injury or death to some animals may occur. The terrain of the capture location, cost effectiveness, and safety concerns may dictate which technique is best used in a given situation.

People 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 sharpshooting (Messmer et al. 1997). However, numerous studies have shown that as a population-reduction method, live capture is more expensive and relatively inefficient. It also does not significantly extend the lifespan of individual animals that are relocated (Ishmael and Rongstad 1984, O'Bryan and McCollough 1985, Witham and Jones 1990). In certain situations, live capture may be the only or most desirable option.

If captured deer are not to be euthanized, a location that can handle the volume of deer to be relocated must be identified, and equipment to transport the deer is needed. 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. Intrastate movement of animals may also be illegal and poses the risk of spreading diseases (e.g., CWD, TB). In the east, there are few places in a given state or province where having more deer is desirable and relocated deer may move to urban areas where they resume crop depredation behaviors (Ishmael et al. 1995).

Chronic wasting disease is of substantive management concern and is virtually impossible to eliminate. The Association of Fish and Wildlife Agencies has endorsed specific recommendations regarding managing this specific disease of cervid species (Gillin and Mawdsley 2018). For instance, live animal movement is considered the greatest risk for CWD spread to unaffected areas (see Appendix A).

Trapping

Examples of live-capture methods suitable for deer include 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 are discussed at length by VerCauteren et al. (1999), and they reported only 4% of captured deer sustained injuries during trapping. Drop nets have been used successfully to capture 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 et al. 2003). Net guns fired from helicopters offer yet another option to successfully capture deer (Ballard et al. 1998, Webb et al. 2008).

Some traps are designed to capture only 1 deer at a time, whereas other techniques (e.g., drop nets, rocket nets) may capture multiple animals at once. Because the number of animals that may be captured within a single event is limited, trapping can be less efficient than other mitigation methods. To increase capture rates, traps should be placed in areas with considerable deer use. Traps should be placed away from roads or areas where they can be seen by the public to increase efficacy and to reduce stress on captured deer.

There are 2 primary trap types used for capturing deer: the Stephenson box trap or Clover trap. The Stephenson box trap is like a cage trap used for capturing raccoons (*Procyon lotor*), or groundhogs (*Marmota monax*), except that it is much larger. Box traps used for deer capture are made of plywood sheets attached to an angle iron frame that is 1.2 × 1.2 × 1.8 m in size. The trap is sprung by a trip wire. The trap can be baited, set, and left unattended. Pre-baiting of traps is required before traps are set to allow deer to habituate to the trap's presence. 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, USA (Ishmael et al. 1995).

Clover traps or netted cage traps are similar in size to box traps. They are made of mesh netting or, in the case of clover traps, sometimes chain-link fencing material, covering a metal frame. These traps have only 1 door, whereas box traps sometimes have 2 doors. Bait 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 (New Mexico Department of Game and Fish, unpublished data) and in many other places.

Traps do not target specific deer cohorts, and any deer (buck, doe, or fawn) is likely to be caught in the trap. Other forms of capture (e.g., drop nets, rocket nets, net guns, dart guns) are 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. Firearms have been used to euthanize deer in urban settings, but their use should only be considered when the landscape allows for discharge of a firearm, such as was the case in the Village of North Oaks, Minnesota, USA (Jordan et al. 1995). Euthanizing trapped deer may be less desirable to some members of the public, 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 implemented as a technique to help address local urban deer problems (Howard 2018).

Trapping usually requires some type of bait (e.g., corn, apples) to entice the deer into the trap or area to be trapped. Pre-baiting traps is 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 natural food resources are less available (VerCauteren et al. 1999).

The use of traps will require a state or provincial game/wildlife agency permit. Traps 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. City, state, or provincial regulations may dictate whether baiting can be used; where allowed, pre-baiting and baiting throughout the capture period will be required.

Cannon or rocket nets

Cannon and rocket netting have been used to capture deer safely and effectively (Hawkins et al. 1968, Dill 1969). Multiple deer may be captured at the same time using these techniques, but it is recommended that <3 deer be captured at once (Beringer et al. 1996). For a thorough discussion and instructions on the use of rocket or cannon netting, see Wildlife Materials International Inc. (n.d.a). The use of rocket or cannon netting employs nylon mesh netting, electrical wire (for firing the charges), launchers, powder charges, and weights (attached to the nets). After the netting is set, wiring connected, and launchers charged, deer are lured into position, typically with bait. Pre-baiting an area for 1–2 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 2.4–3 m in front of the rolled-up netting and launchers. When deer are in position, captors may select the time to fire the nets based on the desired number, sex, or age of deer to capture. The capture event itself, compounded by noise of the cannons or rockets and presence of numerous human handlers, is stressful for deer, so handling time should be minimized. Deer should be restrained with hobbles (all 4 legs tied) and positioned with brisket down, instead of left lying on their sides, to reduce bloating. Deer should be blindfolded immediately

Deer netting may be used to exclude deer from specific areas if the height is adequate to preclude deer from jumping over the top (courtesy of G. Westerfield).

after capture (a simple cut off sweatshirt sleeve is effective for this) to reduce stress.

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 because 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. The availability of charges for the rockets is becoming an increasing challenge to their use. Air cannons (Net Blaster®), which require no explosives to fire the net, may be used and are considered safer than those that use explosives. Nets may need to be repaired and have debris removed after each firing. Rocket threads should be greased occasionally to prevent them from rusting shut and making it impossible to insert charges. Rockets and cannons must be cleaned after firing. Pre-baiting and baiting should be considered to condition deer to come to the trap site. Permitting by the state or provincial game agency is required for the use of this technique.

Drop nets

Drop nets are suspended on posts above the ground in open areas where deer have been lured with bait. Deer are captured by dropping the net over them, when they are feeding beneath the nets. This technique has been used to capture 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 et al. 2003) and may be better suited for urban areas compared with cannon or rocket nets that involve the use of a projectile fired into the air.

Drop nets require personnel to be on hand to spring the trap and 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 drop the net. In addition, multiple deer can be trapped at once if enough personnel are available.

For a thorough discussion and instructions on the use of drop netting, see Wildlife Materials International Inc. (n.d.b). The use of this technique requires a large drop net (often 15 × 15 m or larger), tall poles (usually 2.4 m for deer), which are placed at each corner to hold up the net, electrical wire, blasting caps, and a ground blind. A block and tackle, come-along, or other device for stretching the nets is 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 1–2 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 groups. The capture event itself, compounded by noise of the cannons or 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 hobbles (all 4 legs tied) and positioned with brisket down, instead of left lying on their sides, to reduce bloating. Deer should be blindfolded immediately after capture (a simple cut off sweatshirt sleeve is effective for this) to reduce stress.

As with other live-capture techniques, there is always the possibility of injury to deer or personnel during the use of these devices. Safety of personnel and deer is always a concern with the use of blasting caps, and safety protocols for wiring should be rigorously followed. Public safety is always a concern. The use of loud charges in residential areas may be undesirable. Nets may need to be repaired and have debris removed after each drop. Pre-baiting and baiting are required to condition deer to come to the trap site. Permitting by the state or provincial game agency is required for the use of this technique.

Net guns

Net guns fired from helicopters offer another technique that has been successfully and safely used to live capture deer (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, situations might arise where it is desirable.

The use of this technique requires skilled personnel. Helicopters are typically used to locate and then chase deer until a single deer is within range of the net gun operator who then fires the net over the deer. Following this, another person typically exits the helicopter to restrain the deer. The net gun itself is loaded with a blank charge, often .308 caliber, which fires the net. Nets are typically about 4.6 × 4.6 m square with 15-cm mesh. This technique is selective as operators choose which animal to pursue and capture.

This technique can be used in a variety of habitat types and at various animal densities. However, areas must be open so that the helicopter can maneuver safely. However, Webb et al. (2008) reported only 1% capture myopathy and a 0.6% direct mortality during capture; only 1.6% of deer sustained injury during capture where total capture was 3,350 white-tailed deer. Nets may need occasional repair. Helicopters require maintenance per number of hours used. Agency permitting and Federal Aviation Administration regulations apply to this form of live capture.

Darting guns

Several capture approaches require the administration of chemicals or drugs to restrain, immobilize, or sedate wildlife. Because deer are considered food animals, anytime a tranquilizer, anesthetic, antibiotic, or other chemical substance is injected into the animal, a physical tag must be affixed to the animal to give notice to the public about concerns regarding drug withdrawals and human consumption of that animal. The ear tag should tell the public not to eat the animal without checking on drug withdrawal time. The drug withdrawal time is the time necessary for the drugs to be excreted or metabolized by the body, rendering the meat free of drug residues and safe to eat. The tag should have a phone number for the agency that injected the drug and the appropriate drug withdrawal information. Agencies can contact the Food Animal Residue Avoidance Databank for specific drug withdrawal times for human consumption.

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 used to capture 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 typically is ≤40 m. 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 from a helicopter to capture deer. Radio-telemetry darts should always be used in urban and suburban areas. These are used not only to aid in tracking darted deer, but also to recover darts that miss the target or fall out. A charged dart containing a controlled or dangerous substance that is unrecovered in the landscape where a child or other person could find it and become injured by the dart and its contents should always be considered unacceptable.

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. Chemically immobilized deer require the monitoring of vital signs, especially respiration and body temperature, if deer are to be released.

The use of chemical immobilization techniques requires training and certification. The correct type of drug (immobilizing agent and antagonist) for the deer, and the correct dosage for the deer's 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) used as an antagonist if needed. However, other drug combinations may be effective as well (Kreeger 2012). Deer should also be blindfolded, placed on their brisket, and not allowed to lay on their side while immobilized. In addition, a tube for the release of gas from the deer's digestive system may need to be inserted into the deer's mouth. Darting guns should be cleaned so guns accurately fire. Recertification for the use of chemical immobilization is required periodically.

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. Some drugs may only be purchased by a licensed veterinarian and used in the presence of certified personnel. For certain drugs, biologists may be able to obtain adequate training and certification through the U.S. Drug Enforcement Agency and state pharmaceutical boards so that the biologists can purchase, administer, and store drugs without a veterinarian on staff.

FERTILITY CONTROL

Unless coupled with other management options, fertility control will not have an immediate impact on deer densities. Because of the limitations associated with contraception, it is not an efficient means to reduce overabundant deer populations. In addition, the use of fertility control can increase the longevity of deer, further hampering short-term efficacy (Swihart and DeNicola 1995, Warren et al. 1995, Boulanger et al. 2012). Most research has identified the need for >85–90% of the female deer within the population to be rendered permanently infertile for this method to be effective (Boulanger et al. 2012).

There are 2 general categories of fertility control: contraceptives and sterilization. Surgical sterilization has been studied as a means of controlling white-tailed deer populations with varying results (MacLean et al. 2006, Merrill et al. 2006, Boulanger et al. 2009, Gilman et al. 2010, Boulanger et al. 2012). In Town and County, Missouri, the city funded the trap and sterilization of 130 does over 2 years in conjunction with a culling program. The sterilization (ovariectomy and tubal ligation) procedure was successful in that it eliminated reproduction for treated female deer. However, because deer were placed back on the landscape, there was no population decline (Beringer et al. 2002). After 2 years, the city abandoned the sterilization effort due to the high cost ($1,300 USD per treated doe) and currently culls deer annually to maintain lower deer densities. Another sterilization project was conducted on State Island, New York by White Buffalo Inc. This project focused exclusively on sterilizing (via vasectomy) male deer. The 3-year project was estimated to cost $3.3 million USD (Wolfe 2017). After 3 years, the project ultimately cost $4.1 million USD and sterilized 1,577 male deer at a cost of $12,975 each (Linge 2019). The population was reduced by 15% during the 3-year period. Also, experts disagree on whether the effort will decrease deer–vehicle collisions, incidence of Lyme disease, and reduce other damage caused by deer. The use of contraceptive vaccines have been used experimentally to control white-tailed deer populations (Fagerstone et al. 2010, Rutberg et al. 2013). There are 2 contraceptives developed for deer as of this writing: Porcine Zona Pellucida (PZP), and GonaCon®. The contraceptive PZP is often referred to by the trade-name SpayVac® or Zonastat-D®. It has been used in research studies at the National Aeronautical and Space Agency's Lyndon B. Johnson Space Center in Houston, Texas, USA (Locke et al. 2007). GonaCon® has been used in New Jersey and Maryland (Miller et al. 2008; Gionfriddo et al. 2009, 2011). Only GonaCon is approved for use at this time by the Environmental Protection Agency. Porcine Zona Pellucida creates antibodies that block the fertilization of the egg by sperm and is only applicable to female deer. GonaCon, developed by the National Wildlife Research Center, the research arm of the USDA-Animal and Plant Health Inspection Service, 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 (Miller et al. 2008). Label use is only for adult females. With GonaCon, female deer do not go into estrus. Sterilization can be done either in males or females (as in Fairfax City, Virginia, USA). To reduce production in a polygamous species, the females of a population need to be treated. Because of this, any sterilization of males is required in conjunction with a control technique on females. Cornell University in Ithaca, New York used a combination of archery hunting and sterilization through 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 surgery 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 5 years the number of deer on campus remained the same.

Reductions in populations may not be apparent for 5–10 years or longer, depending on percentage of the population that remains vaccinated, and this time frame may be too long for those communities dealing with current human–deer conflicts. Deer populations that are controlled through any of the methods of fertility control generally will endure less physiological stress associated with pregnancy and parturition (although females may still be pursued by bucks during the breeding season) and may have increased lifespans. A metropolitan park district in Columbus, Ohio, had a deer live >20 years that was treated with PZP.

In most cases, there is no barrier, such as a fence, that hinders deer movement into and out of the city. When contraceptives are used, periodic boosters are needed, which requires repeated capture of individuals. Over time, deer become incrementally more difficult to capture and treat. Deer also are susceptible to stress when being captured and/or sterilized, which may lead to their death. Because of limitations and low efficacy in most situations, fertility control is considered to be experimental and not a viable population control technique. Porcine Zona Pellucida currently is not registered for use in the United States as a management tool because treated deer are unfit for human consumption. Because PZP only works on the egg, it is only applicable for female deer. In addition, it can induce multiple estrus cycles that lengthen 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 injections. 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 its efficacy rate in adult does, and because up to 40% of fawns breed in highly productive areas, using GonaCon will result in up to a 29% increase in the deer population, without factoring in immigration and mortality sources. This is what occurred in New Jersey (Gionfriddo et al. 2009). Angel Island, California, USA attempted to use chemo-sterilization by capturing 80–90% of the female deer population with no success. This was in part because it was more difficult to capture the remaining deer as the number of previously captured deer increased. Ultimately, this project was abandoned with only 15 adult does receiving the treatment (Botti 1985).

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 required to ensure that at least 90% of the population has been treated. Additionally, the female fawns born of non-contracepted adult does and last year's fawns will need to be trapped and treated every year. The use of any fertility control will require a permit from at least the state wildlife agency.

RELOCATION OF DEER

Survival of translocated deer is low compared to resident deer in the release area. In addition, site fidelity to the release area may be low for 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 3 unaccounted for. 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 21,999-ha recreation area. In an effort to monitor the effectiveness of this translocation, 15 deer were fitted with radio-collars and monitored during the following 6 months. Subsequent surveillance determined that only 2 of the relocated deer survived the entire year. This high mortality rate was attributed to poor physical condition due to the stress of being in a new environment, and a failure to recognize new 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. Mortality rates (96%) of translocated radio-collared deer were more than twice that reported for ear-tagged deer (45%) during the same period.

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 chronic wasting disease, as well as the low survival rates of relocated deer.

The Utah Division of Wildlife Resources (UDWR) used a helicopter and net gun in 2013 to capture 102 deer in Parowan, 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). 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. New Mexico Department of Game and Fish also captured mule deer using various trapping methods and translocated them during this same time period. No deer died during the capture efforts, and survival rates and trends of translocated deer were similar to those reported by UDWR. However, site fidelity of the translocated deer was variable. At some release sites, translocated deer displayed high site fidelity, but at another release area, site fidelity was low, with many of the deer leaving the release site (O. Duvuvuei, New Mexico Department of Game and Fish, personal communication).

Another limitation of translocating deer is cost. In Utah, UDWR has worked with a limited number of 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 have never tested positive for CWD). The costs associated with capturing, radio-collaring, disease testing, and translocating each urban deer exceeded $1,000 USD per animal (Howard 2018). Cities generally have personnel committed to help set and bait traps. These cities pay $200 USD per deer (20% of total cost). The UDWR also employs 3 full-time employees and works with many volunteers to help cities address urban deer issues using a variety of strategies. 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 states also do not have adequate habitat to release translocated deer. Additionally, trap and relocation efforts will have little benefit if deer populations can quickly reestablish within the trapping area.

If translocation is used as a management strategy, an adequate number of deer would need to be moved to reduce deer densities. This effort needs 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.

Most governments recognize that relocations, although possibly of value for experimental research or repopulation, are not an appropriate management tool for overpopulated deer communities. Relocation involves the transport of an entire biological package, including parasites and disease, which inadvertently could be introduced to another population by human efforts. Any relocation would require approval from the state/provincial wildlife agency and/or the 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.

Chronic wasting disease is of substantive concern in any movement of deer. The disease is essentially impossible to eliminate once spread to a new location. The Association of Fish and Wildlife Agencies has endorsed specific recommendations regarding managing this specific disease of cervid species (Gillin and Mawdsley 2018). Live animal movement is considered the greatest risk for CWD spread to unaffected areas, and the short-term benefits of moving deer from urban areas do not outweigh the long-term, negative consequences of spreading the disease to a new area (see Appendix A: AFWA best management practices for prevention, surveillance, and management of chronic wasting disease). As a result, some states that have translocated deer in the past are eliminating translocation as a management strategy.

SUMMARY

Conflicts among wildlife and humans typically arise from anthropogenic attractants in an area populated by humans. This may be mitigated to varying degrees depending on the species in conflict (e.g., Wilson et al. 2017, Lackey et al. 2018), but deer pose unique challenges due to their ability to habituate to humans, consume agricultural and landscape vegetation, serve as a human food source and watchable wildlife, and because of the risk of debilitating disease transmission. Surveys and monitoring must be conducted to determine the level of conflict, the effect of mitigation, and demonstrate efficacy of various approaches. Management options differ depending on the situation and specific conflict, yet eliminating attractants may be the most efficacious technique available (Messmer et al. 1997). The challenge is that eliminating attractants can be difficult, and mitigation measures are necessary to reduce conflicts. Further challenging the process of mitigation is that many measures themselves are controversial or difficult to implement. The desire to simply relocate animals can be strong but should be resisted because rarely is unoccupied, suitable habitat in which animals can be placed readily available, and the potential risk of spreading CWD or other diseases is ever-present. Wildlife and municipal managers must work together to seek methods to reduce attractants, mitigate conflicts, and perpetuate the conservation of wildlife species that adds to the appreciation of nature in our lives.

Garden fence for deer (top) and fencing to prevent deer access (bottom; courtesy of G. Westerfield).

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APPENDIX A

Approved September 12, 2018, by the Association of Fish and Wildlife Agencies

AFWA Best Management Practices for Prevention, Surveillance, and Management of Chronic Wasting Disease

INTRODUCTION

The Association of Fish and Wildlife Agencies (AFWA) Best Management Practices (BMPs) for the Prevention, Surveillance, and Management of Chronic Wasting Disease (CWD) were developed to provide guidance to fish and wildlife agencies as they address the growing threat of CWD to free-ranging cervid populations. The BMPs are based on the best available peer-reviewed science and field-tested methods, and represent the contributions of more than 30 wildlife health specialists, veterinarians, and agency leaders actively engaged in CWD issues across North America. The BMPs are intended to be adaptable as new information becomes available. They are not meant to be prescriptive or to mandate programs at the state, federal, tribal, or territorial level; they should be regarded as a set of recommendations for agencies to consider as they develop or revise their CWD programs.

The BMPs are arranged under the general headings of Prevention, Surveillance, Management, and Supporting Activities. A best practice is provided for each topic, where appropriate, as are alternative methods that do not mitigate risks as well as the best practice. Many practices fit into more than one of the above headings. Expanded information, additional practices, background, justification, and reviewed literature are available in the accompanying Technical Report.

PREVENTION of CWD Introduction and Establishment

A. **Live animal movement** is regarded as the greatest risk for CWD introduction to unaffected areas.

1. Prohibit all human-assisted live cervid movements
2. Alternatives:
    a) Prohibit importation of all live cervids from CWD-positive states and provinces.

    b) Allow movement/importation of cervids from herds that have been monitored for an extended period without detection of CWD or links to herds that have been affected or exposed.

    c) Allow importation of captive cervids from herds certified as low risk for CWD by the USDA CWD Herd Certification Program (see below for more on captive cervids).

B. **Carcass movement** poses a risk for CWD introduction if unused parts from potentially infected carcasses are imported and disposed of improperly.

1. Prohibit importation from all states of intact cervid carcasses or carcass parts except boned out meat, clean hide with no head attached, clean skull plate with antlers attached, clean antlers, finished taxidermy specimens, and clean upper canine teeth.
2. Alternatives:
    a) Allow importation of quartered carcasses with no spinal column, head, or central nervous system tissue in addition to the permitted items above.

    b) Prohibit importation, with certain standard exceptions, of intact or whole carcasses from states that have detected CWD in captive and/or free-ranging cervids.

    c) Prohibit importation from specific zones in states where CWD has been detected.

C. **Products of cervid origin** may pose a risk for CWD introduction as well as an attractant that may congregate normally dispersed animals facilitating CWD transmission and/or establishment.

1. Natural products of cervid origin: Prohibit sales and use of products that include natural urine, feces, scrape material, deer pen soil or other items of cervid origin.
2. Reproductive tissues and material: Prohibit importation of cervid origin reproductive tissues, semen, embryos, germplasm.
3. Alternate practices: Allow sales and use of synthetic scent products; allow importation of products and reproductive materials only from facilities that are certified as low risk for CWD.

D. **Unnatural Concentration of Cervids** facilitates CWD transmission and establishment if the CWD agent is present.

1. Prohibit baiting and feeding of wild cervids; prohibit placement of minerals, granules, blocks, or other supplements for wild cervids; provide hay and other feed for domestic animals in a manner that does not congregate wild cervids; prohibit sales and use of other cervid attractants such as synthetic scent lures, foods, flavors, scents, pour-ons, sprays, etc.
2. Alternate practices include restrictions on amounts of bait or feed as well as restrictions on baiting and feeding on a temporal and/or spatial basis.

SURVEILLANCE

A. **CWD Testing for Cervids**.

1. Use only USDA-approved laboratories and methods for CWD testing.
2. Test obex and medial retropharyngeal lymph nodes (MRPLN) collected from dead animals; positive and suspect results should be confirmed by the USDA's National Veterinary Services Laboratories. Minimally test MRPLN for deer and both obex and MRPLN for elk.
    a) Antemortem testing may be useful in whole-herd screening of captive cervids or for sequential testing of individual free-ranging and/or research animals. Current antemortem tests are not adequate to detect CWD on an individual animal basis.
    b) All suspect positive ELISA test and Western blot results should be confirmed with IHC (The Gold Standard test).

B. **Surveillance for initial detection of CWD** should be an ongoing activity. Early detection is critical to managing CWD effectively and especially for eliminating it when/if possible.

1. Surveillance efficiency may be enhanced by:
    a) Targeting animals more likely to have CWD: clinically affected animals; road- or predator killed animals; mature animals, particularly males.
    b) Spatial targeting via risk assessments based on proximity to affected cervids, unmonitored populations, captive cervids, or other risk factors.
2. Surveillance (and monitoring) should be undertaken at biologically relevant spatial scales and inferences drawn only in the appropriate spatial context in view of the highly patchy distribution of CWD in wild cervids. Consequently, agencies should refrain from drawing statistical conclusions such as "there is 95% certainty that CWD would have been detected if present at 2% prevalence or greater."
3. See https://pubs.usgs.gov/of/2012/1036/pdf/ofr2012_1036.pdf for "*Enhanced Surveillance Strategies for Detecting and Monitoring CWD.*"

C. Surveillance to "monitor" CWD in an affected population

1. Random sampling of harvested animals provides relatively unbiased estimates of infection rates and is the most efficient active sampling method for estimating prevalence or incidence in CWD enzootic populations. Comparisons over time or between locations should be based on a common denominator (e.g., harvested males aged 2 years or older) to assure that reliable inferences are drawn. Consider including vehicle-killed animal surveillance and looking for expansion of current disease foci as well as new disease foci.

2. Practices should include defining biologically relevant spatial units for data collection and evaluation; determining meaningful sample sizes for interpretation; identifying surveillance goals to guide sampling strategies over time; and working within existing management frameworks to maximize opportunities for sample collection while minimizing additional personnel and financial costs to the agency.

MANAGEMENT

A. CWD Response Plans should be developed before CWD is detected and implemented at the first report of CWD within the jurisdiction or within a previously defined distance from its borders, such as in a neighboring state. Plans should include the immediate response to detection as well as long-term management of the disease if it cannot be eliminated. An Incident Command System or other central coordinating group may facilitate the initial response.

1. Essential elements of the response plan should include action plans for each of the following sections: Communications, diagnostics, surveillance, disease management, and research.

B. Initial Response to the First Detection should include:

1. A communications strategy should be designed to build support for response actions.

2. Sufficient testing capacity should be identified to support surveillance/monitoring activities.

3. Surveillance strategies should be implemented through consultation with epidemiologists to determine disease prevalence and geographic distribution of the affected area.

   a) Actions may include special hunts by the public with mandatory CWD testing, culling by sharpshooters and other methods.

4. Disease management activities should begin with recognition that they may be necessary on a long-term basis.

   a) CWD Management Zones should be established on the basis of the location of affected animals and natural history of local populations.

   b) Management activities likely will occur in concert with surveillance actions to define the affected area.

5. Surveillance and management of captive cervids should be in place as part of planning efforts and include fencing design, mandatory testing, inspections, animal ID, quarantine and decontamination protocols, among others (see Captive Cervid section below).

C. Managing CWD Prevalence should include utilizing harvest, sharpshooters or other removal mechanisms combined with statistically appropriate sampling and testing to monitor changes in prevalence. Strategies may include:

1. Targeting the portion of the population most likely to have CWD.

2. Targeting animals in known CWD hotspots.

3. Adjusting timing to most effectively remove infected animals.

4. Reducing cervid density in CWD-positive areas with high animal density.

5. Eliminating practices that promote artificial cervid concentrations to minimize environmental contamination.

6. Utilizing a coordinated, adaptive management approach that allows evaluation of experimental CWD suppression strategies whereby the data gathered from these efforts would be used to develop improved strategies.

7. Restricting or prohibiting intact carcass and high risk material transport out of CWD management zones.

D. Rehabilitation of Deer and other Cervids may result in translocation and/or release of infected animals.

1. Prohibit cervid rehabilitation activities, including animal transport, either statewide or in designated CWD management zones or in other geographic areas where CWD has been detected in wild or captive cervid populations.

2. Alternative practices: In areas where CWD is suspected but not yet reported, restrict rehabilitation activities to facilities that observe all recommended biosecurity protocols for the safe handling, disposal, and decontamination of prions and prion-infected tissues, materials, and equipment.

E. Carcass Disposal is critical to prevent exposure of wildlife to the CWD agent.

1. Incinerate carcasses in an Environmental Protection Agency-approved conventional incinerator, air curtain incinerator, or cement kiln.

2. Treat carcasses with high-pressure alkaline hydrolysis followed by burial of the treated material in an active, licensed landfill.

3. Alternate practices: Composting; centralized sites for disposal of CWD-positive or high risk carcasses. Landfills often are used: although burial does not eliminate infectious prion, carcass parts should be inaccessible to cervids and other animals.

F. Decontamination and Disinfection Methods for Equipment require special techniques because of the resistance of the CWD agent to standard disinfectants and sterilization methods.

1. Effective products and methods include 2% sodium hypochlorite (bleach) solution, autoclaving under specific conditions, or the use of Environ LpH se Phenolic disinfectant.

SUPPORTING ACTIVITIES

A. Internal and Public Communications are critical to build support within agencies and among the general public for CWD prevention, surveillance, and management policies, regulations, and activities. Development of an integrated communications strategy and CWD communications plan is recommended. Messages should be developed with thorough understanding of the importance of the human dimensions of wildlife disease management.

1. Communications should be open between agency administrators and field employees.

2. Agencies should maintain accurate, up-to-date websites that contain general information about CWD, jurisdiction-specific CWD information, surveillance and response activities, relevant regulations, public health concerns, recommendations for hunters and information indicating how they can help, reporting procedures for sick or dead ungulates, and test result reporting.

3. Social science surveys may be conducted to inform management decisions and increase positive stakeholder engagement.

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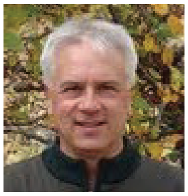

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Thomas A. Decker is a certified wildlife biologist and works for the U.S. Fish and Wildlife Service in the Wildlife and Sport Fish Restoration Program. Previously, he has worked for Vermont Fish and Wildlife and for Massachusetts Division of Fisheries and Wildlife, holding several positions including furbearer biologist, director of wildlife, and director of operations. He is a life member of the American Society of Mammologists. He has been a member of The Wildlife Society since 1988 and is a TWS Fellow and NCLI Fellow. He has served on TWS Governing Council and recently finished serving as chair of the Editorial Advisory Board of The Wildlife Professional. He has been active nationally with the Association of Fish and Wildlife Agencies Furbearer Resources Task Force. He has been part of a U.S. Technical Work Group addressing national and international policy, research, and management programs related to the sustainable management of furbearers in the United Sates. He has B.S. and M.S. degrees in fisheries and wildlife biology from the University of Massachusetts at Amherst and a bachelor's degree in geography from Worcester State University.

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Brian F. Wakeling received his bachelor's and master's degrees from Arizona State University in 1985 and 1989, respectively. He currently serves as the administrator for the Game Division at the Nevada Department of Wildlife, a position he has held since September 2014. Prior to his service with Nevada, he enjoyed a 26-year career with the Arizona Game and Fish Department, where he spent 12 years conducting research (on turkeys, elk, bighorn sheep, bison, mule deer, mountain lions, bears, and urban lizards) and 14 years in game management, concluding his career with Arizona as the chief of game management. He is a certified wildlife biologist and a certified public manager. He is currently the chair of the Association of Fish and Wildlife Agencies Human–Wildlife Conflict Working Group.

H. Bryant White

H. Bryant White is the program manager of furbearer research and trapping policy for the Association of Fish and Wildlife Agencies. He earned a degree in history from the University of Memphis (B.A.), theology from Harding University (M. Div.), and wildlife and fisheries science from Tennessee Technological University (B.S. and M.S). He currently works to develop best management practices for trapping in the United States and on issues related to the sustainable use of wildlife and human–wildlife conflict resolution.

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