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chapter seventeen

Managing deer impacts on oak forests

David deCalesta, Roger Latham, and Kip Adams

Contents

White-tailed deer benefit from the food and cover oaks provide. However, deer can be a detriment to a sustainable and healthy oak forest. Deer consume vast quantities of acorns, and they eat leaves and twigs of oak seedlings and saplings, acquiring fats, carbohydrates, and proteins for growth and body maintenance. At low or moderate deer densities, deer foraging is not an issue. However, too many deer can consume too many acorns and oak seedlings and may damage too many oak saplings, resulting in the elimination of or severe reduction in oak regeneration.

Deer have the potential to double their population size every 2 years. Like all wildlife, deer abundance is controlled by outside forces—food supply, weather extremes, predation, parasites, and diseases. Mortality factors can cause profound effects on deer density, which impact oak forests.

Deer in the eastern oak forests prior to and soon after European settlement

Prior to the arrival of European settlers, there was a full complement of predators—mountain lions, bobcats, red and gray wolves, and bears. These predators and the Native Americans hunted deer every day of the year. There were no seasons or bag limits, and deer of all ages and sexes were killed and eaten. Generally, predation (including hunting) cancelled out recruitment and tended to maintain a fairly constant and relatively low deer density. Tree seedlings germinated and proliferated where the forest overstory was opened by fire, wind, or ice, which occurred sporadically and randomly over the landscape. Relatively low deer density and natural disturbances helped maintain healthy oak ecosystems.

As Europeans settled in North America, drastic changes occurred in the landscape. Native Americans were nearly eliminated by European diseases, forced relocation, and warfare, while wolves and mountain lions were extirpated in most of Eastern North America to protect domestic livestock. European development of North America opened vast tracts of intact forestlands, providing increased browse and other foods as crops were planted following clearing. Deer abundance should have skyrocketed.

However, during this period, deer were nearly exterminated by market hunting in many areas of North America where oaks were part of the ecosystem. Resultant public outcries against the excesses of market hunting and the emergence of the conservation movement at the end of the nineteenth century spawned state and federal wildlife agencies and ensuing restrictions on deer hunting. The alignment in the early 1900s of heavy restrictions on deer harvest (bag limits, shortened hunting seasons, "buck only" laws), near elimination of predators, and habitat changes (timber harvest, land clearing and burning, followed by agriculture) created vast amounts of deer food, producing an explosion in deer numbers during the 1920s and 1930s across the East and Upper Great Lakes regions, including areas dominated by oak forests.

Rapid increases in deer density during the decades following predator removal resulted in the elimination of many of the plants, which deer preferred as forage from the understory, including seedlings, shrubs, and herbaceous plants. Forest understory species have notoriously short-lived seeds and many disperse only at short distances. Where deer numbers have been high for decades, the seeds bank (viable seeds in the soil) no longer contains these species. Plants with seeds dispersed by birds and wind recolonize, but it takes a considerable amount of time. Plants that have undergone regional declines, such as the American yew, hobblebush, native honeysuckle, blue-bead lily, and speckled wood lily, may take many decades to recover on their own. Recolonization or reintroduction is not possible if the deer density remains high.

From 1905 to 1950, the chestnut blight removed the American chestnut as a major source of hard mast for deer and other wildlife throughout much of the Eastern United States, including areas with a high proportion of oaks. At the same time, the forest overstory closed following decades of heavy harvest in many areas and reversion of failed farms to forestlands in others. Over time and across a broad area, food resources for deer in forests declined. Shade-tolerant plants that are not preferred as deer forage, such as hay-scented, New York, and bracken ferns, and a few other species resistant to deer browsing (more recently including nonnative plants such as Japanese stiltgrass and garlic mustard), proliferated and dominated the understory in many forests.

Understanding density and carrying capacity

Deer density fluctuated across the Eastern United States from the late 1800s through the 1960s in response to land use practices. It is important to realize that the deer density responded and differed markedly in various areas of the Eastern United States during this time as a result of different land use practices and habitat quality. However, by the mid- to late twentieth century across the white-tail deer range, a common experience which hunters became accustomed to was an increasingly high deer abundance while remaining largely ignorant of its impact on forest ecosystems. They believed high deer densities were natural and demanded that wildlife agencies adopt management practices, such as reduced or no antlerless deer harvest, to sustain high deer densities.

By the 1990s, scientists determined that deer density could be maintained at different abundance levels (carrying capacities), with differing levels of impact on a forest ecosystem (Figure 17.1). To maintain deer density at a given carrying capacity, mortality factors (deer harvest, predation, starvation, disease, parasites) must offset recruitment (number of fawns surviving in a given year), immigration (deer moving into an area from some other location), and food supply.

The relationships among density, recruitment, forest management, and carrying capacity are not known precisely except in a very few well-researched sites. These relationships differ depending on conditions. Those depicted on the graph in Figure 17.1, should not be applied

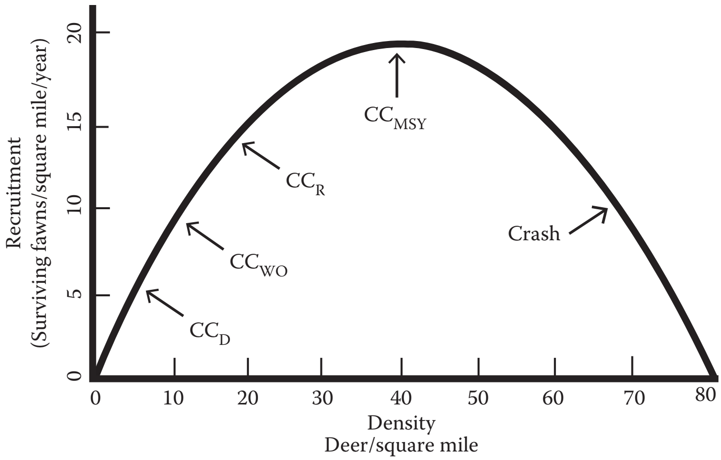

Figure 17.1 Carrying capacities of white-tailed deer in forests. CC_D, carrying capacity for (wildlife and vegetation) diversity; CC_{WO}, carrying capacity for regeneration of oak species in the white oak group; CC_R, carrying capacity for regeneration of most other tree species, including oaks in the red oak group; CC_{MSY}, carrying capacity with the maximum sustainable yield of deer for harvest; crash, density where unsustainable deer density exceeds forage, resulting in massive winter die-off in some regions. Carrying capacities vary geographically and over time; numerical values in a particular area may not match those in this graph, which illustrates the general pattern of deer density in relation to food supply (see text) using research in the Northern Hardwoods Region. The difference between deer carrying capacities for white oaks and for hardwoods in general is large in much of the northeastern part of the white-tailed deer's range and gets smaller or vanishes southward and westward. (Adapted from deCalesta, D.S. and Stout, S.L., *Wildl. Soc. Bull.*, 25, 252, 1997.)

indiscriminately. Deer density interacts with a host of factors that vary from one location to another and from year to year, all working in tandem to affect forest response. The deer density associated with different carrying capacities is affected by such factors as the amount of light that reaches the forest floor, forest type, understory species composition, landscape context, soil conditions, length of growing season, alternative food sources, patterns of seasonal movement by deer, and legacy effects of prolonged high deer numbers. In forests managed for sustained timber production, there is a limit to the proportion of a forested area that can be harvested annually. Generally referred to as the *annual allowable cut*, this upper limit to harvest also represents an upper limit of forage creation for deer, with a corresponding upper limit of carrying capacity for deer.

Several tools and methods are used to estimate deer density, including infrared-triggered cameras, aerial flights with infrared videography, counting and analyzing deer pellet groups, and various computer modeling techniques. However, it is important to realize that there is no measure of accuracy with any method unless a marked segment of the deer herd is being monitored. Thus, it is most important to follow the trends of density estimates over time and monitor the effects of deer density on sites (e.g., quantifying browsing pressure, plant species diversity, etc.).

Carrying capacity for diversity

Deer populations were sustained at a carrying capacity for diversity (CC_D) prior to the European colonization of North America when there was a larger complement of predators and forage production was sporadic and geographically limited, created by infrequent and variably sized disturbance factors, such as tornadoes, tropical storms, ice storms, and fire—either natural or set by Native Americans. Deer density was low (because of constant pressure by the predator community), allowing a vast and diverse assemblage of seedlings, shrubs, and herbs to proliferate. The wildlife community, which increases in diversity with plants and complexity of vegetation structure, is highly diverse at CC_D because of the variety and abundance of ecological niches.

Carrying capacity for tree regeneration

Restrictions on hunting in the early 1900s, coupled with vast amounts of forage created by regrowth following timber harvest and an abundance of agricultural crops, resulted in great increases in carrying capacity, which when combined with restrictions on deer harvest, resulted in exponential increases in deer density. Deer greatly reduced seedlings, shrubs, and herbs in order of their feeding preferences, nearly eliminating many highly preferred species, which may differ by region. Less-preferred species were sufficiently abundant for successful regeneration of a limited diversity of trees and herbs following timber harvest or other disturbances that allowed sunlight to reach the forest floor. This deer carrying capacity is labeled carrying capacity for tree regeneration (CC_R), a carrying capacity that permits regeneration of some tree species. At this level of deer density, there is noticeable reduction in diversity and abundance of plants in the understory, especially herbs and shrubs. Deer prefer various oaks over others. Generally, various species in the white oak group are selected over those in the red oak group. However, once seedlings of preferred species are greatly reduced or eliminated by browsing, deer turn to less-preferred species, including other oak species. Therefore, red oaks should be lumped into CC_R, and depending on regional preferences, white oaks may be associated with a lower deer density, CC_{WO}.

Carrying capacity for maximum sustained yield of deer

Even at and above CC_R, there is still much forage available for deer. In the absence of adequate predation and hunting mortality, carrying capacity reaches the highest sustainable density—carrying capacity for maximum sustained yield of deer (CC_{MSY}). This level of deer abundance, called the *maximum sustained yield* or *nutritional carrying capacity*, is the point where recruitment is highest in terms of absolute numbers. However, continued recruitment at this level is dependent on continued regeneration of forage and/or deer removal. High deer densities at CC_{MSY} and relatively high deer harvests (primarily antlered deer—hunters were ingrained with the philosophy of protecting does to retain high reproduction) framed the hunter experience in various regions from the 1930s to the 1990s. Many hunters came to believe this was a sustainable and desirable situation, representing good deer management. However, continued browsing pressure by abundant deer herds began to reduce forage availability, which was increasingly dominated by plant species less preferred by deer and lower in nutritional value as the best foods were depleted. Vegetation dynamics in the understory changed, and the formerly diverse herbaceous and woody plant community in some regions was compressed into a community dominated by mat-forming ferns, grasses, and tree seedlings resistant to deer browsing. At this point, deer populations exceeded CC_{MSY}.

Quality of deer (body weight and antler characteristics) declines as deer are unable to ingest enough energy for growth or to store adequate fat because of reduced food quality and quantity. Decades of harvesting primarily yearling bucks prevents bucks from reaching older age classes and thus producing relatively large racks. As forage availability increases following timber harvest or other disturbances, CC_{MSY} (and deer quality) may increase. However, higher densities of deer permitted by the additional forage can intensify impacts on tree seedlings and other understory vegetation as well as reduce height and diversity of understory vegetation. Deer and the associated habitat should be managed for CC_{MSY} only when the primary objective is for hunters to harvest a maximum number of deer.

Crash

As forage quality and quantity decline in the face of increasingly and unsustainably high deer abundance, severe winters (in northern latitudes) and increased transmission of parasites and disease can result in massive deer die-offs, or crashes. Because of the poor condition of deer, reproduction and recruitment are low when deer herds crash. It takes several years before deer herds can again build up. In the past, such crashes were followed by hunter demands to close or greatly reduce deer hunting season. When such actions were followed by increases in tree harvest as forests matured to harvest age, deer populations again rapidly increased with increased forage.

The balance between mortality and recruitment of white-tailed deer must be addressed annually by adjusting mortality (primarily by hunting) to prevent deer from exceeding the carrying capacity selected as a goal. If this is not done, deer abundance will exceed the desired carrying capacity, resulting in an unacceptable impact on forest ecosystems, and finally on the deer herd itself.

In many states, hunters remember when deer density was high. They saw many deer during hunting season, and they killed mostly yearling bucks with scrawny antlers. They think such deer abundance is natural, and they are resistant to aggressive harvest regulations favoring an increased doe harvest. On the other hand, foresters and ecologists are aware of the loss of plant diversity, wildlife community diversity, and successful tree regeneration when deer density exceeds carrying capacity for regeneration, especially those species deer consistently prefer. Agencies responsible for managing deer often find themselves between hunters who want deer managed at or above CC_{MSY} and foresters, ecologists, and wildlife management professionals who are aware of the effect of artificially high deer populations and want deer managed at CC_D, CC_{WO}, or CC_R.

Hunters of other species, such as ruffed grouse, often are unaware that for them deer should be managed at CC_D instead of CC_{MSY}. CC_{MSY} can negatively affect habitats to the point where some game and nongame species decline in abundance and others may be unable to persist because cover for them is decimated (e.g., nesting and feeding structures for shrub layer–dependent birds, such as black-throated blue warblers and mourning warblers).

Is there a problem?

To determine whether you need to manage deer to conform to a desired carrying capacity, you must first compare it to the existing carrying capacity. Such an assessment requires an evaluation of the extent and intensity of their impact on understory vegetation. Usually, these measurements are collected from plots placed along transects that are systematically located throughout the forestland (see Pierson and deCalesta 2015 for an example technique). Characteristics of understory vegetation representative of the five carrying-capacity situations (diversity, oak regeneration, some tree regeneration, maximum sustained yield, and deer population crash) are described in Table 17.1.

Table 17.1 Characteristics of forest understory vegetation (forest health indicators) at five deer carrying capacities

Carrying capacity	Vegetation characteristics (forest health indicators)
Diversity (CC_D)	Understory dominance by full complement of native herb, shrub, and seedling species; existence of groundcover (less than 3-feet tall) and shrub cover (3- to 10-feet tall)
Oak regeneration (CC_{WO})	Acceptable stocking levels[a] of seedlings and saplings of white oak species; limited presence of mat-forming ferns,[b] nonnative, invasive species, and other plants that interfere with the development of seedlings; herbs and shrubs preferred by deer possibly sparse or absent; open understory with sparse shrub layer
Some tree regeneration (CC_R)	Acceptable stocking levels[a] of seedlings and saplings of desired tree species other than white oaks; limited presence of mat-forming ferns,[b] nonnative, invasive species, and other plants that interfere with the development of seedlings; herbs and shrubs preferred by deer sparse or absent; open understory with sparse shrub layer
Maximum sustained yield (CC_{MSY})	Acceptable seedling stocking only of tree species resistant to deer browsing; extremely sparse or absent shrub layer; lack of preferred shrubs and herbs; groundcover either very sparse or consisting mainly of mat-forming ferns[b] or nonnative, invasive species; development of a browse line[c]
Population crash	Well-defined browse line[c]; no vegetation in ground and shrub layers except mat-forming ferns,[b] nonnative, invasive species, and other plants seldom eaten by deer

[a] Number of seedlings counted in plots representative of sufficient numbers to regenerate desired tree species following tree harvest.

[b] Mainly hay-scented fern, but sometimes also New York or bracken ferns, which carpet the ground with single fronds rather than growing in tufts or rosettes like most ferns.

[c] Heavy browsing by deer eliminates vegetation from the ground up to 6 feet, the effective browsing height of deer, discerned as a distinctive line of vegetation with a clearly demarked edge below which there is little or no vegetation.

Is it deer?

In the deciduous forests of the Eastern United States, if there is excessive browsing damage to seedlings, it is almost always caused by deer. Mice, voles, rabbits, hares, and turkeys feed on tree seedlings and soft and hard mast (including acorns), but their numbers are most controlled by predators, including snakes, hawks, owls, shrews, weasels, foxes, coyotes, and bobcats. However, in places where there are sufficient numbers of grazing or browsing mammals, such as cattle, horses, goats, swine, and sheep, seedling regeneration or acorn survival to germination may be reduced significantly and levels of impact characteristic of CC_{WO} and higher may be reached.

Browsing by deer is characterized by a shredded or torn appearance of twigs. Deer have no upper incisors, so they browse off twigs by stripping them between their lower incisor teeth and a tough pad on the upper jaw. Browsing by sheep and goats is similar to that of deer, but they are rarely found in interior forests. In small, isolated woodlots surrounded by pastures, intensity of goat and sheep browsing may be sufficient to reduce or eliminate woody regeneration. Damage by swine (feral hogs) is restricted to rooting for and eliminating acorns, and uprooting of regeneration. Cattle and horses severely impact grasses and herbaceous plants, and also shrubs and regenerating trees. Browsing by rabbits and hares is characterized by a sharp, 45° cut where twigs are clipped off. Browsing by mice and voles is characterized by the shredding of bark low on the seedling near the ground.

On the other hand, if there is scarcity or a total lack of seedlings, it may be caused by the lack of stimulus for germination and growth. The only way to stimulate germination and seedling growth is to open the forest canopy, allowing additional sunlight to reach the forest floor. The disturbance may occur naturally or by humans.

The level of browsing on seedlings should be evaluated to verify whether browsing is causing a lack of adequate seedling regeneration (Figure 17.2). If seedlings of all species are not browsed or are lightly to moderately browsed, enough will survive to produce mature trees. This condition represents CC_D. If seedlings are heavily to severely browsed, they may not survive to produce mature trees. CC_R and CC_{WO} are represented by seedlings of desired species at low to moderate browsing levels. CC_{MSY} is represented by light to moderate browsing of seedlings of resistant species, but the level of browsing on the desired seedling species will be heavy to severe. If seedlings of all species are browsed heavily or severely, the deer herd may crash if steps are not taken to reduce deer density or to exclude deer.

Simplified plant species composition is another more subtle effect of prolonged deer density higher than CC_D. Mat-forming ferns (hay-scented,

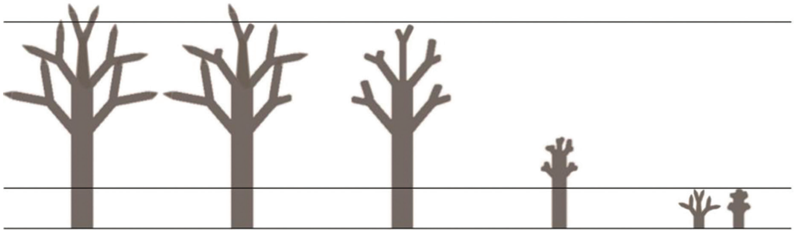

Figure 17.2 Appearance of seedlings at different intensity levels of browsing.

New York, or bracken) or nonnative species, such as stiltgrass or garlic mustard, often dominate the ground layer, and native forbs may be missing entirely. The shrub layer, if it has not been eliminated, is reduced to the least palatable species, such as the striped maple in the northern part of the white-tail deer range, spicebush in the center, pawpaw toward the South, and nonnative shrubs—Japanese barberry, ornamental-escaped honeysuckle, and many others—throughout the range.

Managing deer impact

There are two management approaches for reducing and stabilizing deer impact on forest ecosystems: (1) reduce deer density or (2) protect understory vegetation from excessive deer browsing using exclusion devices or repellents.

In situations where deer density has been high for a long time—15 years to as many as 75 years in some areas—long-lasting, chronic effects of overbrowsing can cause prolonged delays in forest recovery unless the vegetation is managed. Legacy effects of prolonged high deer numbers include inadequate seed availability and dominance by vegetation that interferes with regeneration of native trees, shrubs, and herbaceous understory plants.

Reducing deer density

Hunter harvest: Regulated hunting is the most effective strategy to reduce deer density to the desired levels. Harvesting adequate numbers of antlerless deer is a proven way to increase overall deer harvest and reduce population density. Because many hunters primarily hunt for antlered deer, they must be motivated to harvest additional antlerless deer, which is essential for reducing deer density and maintaining it at desired levels. Deer management by recreational hunting requires managing hunters.

For optimum effectiveness in achieving CC_D, CC_{WO}, or CC_R, managing deer impact with regulated hunting requires several steps:

- Characterize the status of appropriate indicators of forest health for the chosen deer carrying capacity (see Table 17.1).
- Determine whether deer abundance is just right, too high, or too low, depending on the condition of forest health indicators (presence/absence of various plant species) for the chosen deer carrying capacity.
- Experiment with adjusting hunting pressure on antlerless deer if the condition of indicators and deer abundance does not match the desired level of forest health and deer carrying capacity.
- Provide and maintain good access for hunters.
- Establish a trusting and effective relationship with hunters, including two-way communication that provides hunters with information they want and need (deer density and health) and signals that their input is genuinely considered in deer management decisions.
- Deer management strategies must be transparent and supported by science.
- Promote the benefits to hunters when deer density is reduced (healthier deer, better opportunities to hunt other game species, active participation in science-based management to sustain good hunting over the long term).

Deer culling by sharpshooters: Sometimes it is not possible, for safety or other reasons, to allow public hunting to reduce deer density. It is not uncommon that increased deer harvest by hunters proves ineffective to reach management goals for tree regeneration or recovery of other plant species or forest ecosystem functions. Professional marksmen can remove deer, usually at night over bait with rifles fitted with silencers, with minimal disturbance or risk to nearby homeowners. The carcasses are removed, and the meat is usually distributed to charitable food banks. The cost of hiring marksmen is high and a real consideration for townships or other agencies trying to reduce deer density. Permits must be obtained from the state wildlife management agency to allow sharpshooting. Not all agencies will issue such permits, and those that do will issue permits only if a convincing case can be made that the local conditions prevent regulated hunting from lowering deer density sufficiently to meet ecological goals. For these reasons, sharpshooting is generally restricted to urban and suburban parks and nature preserves. Even so, local hunters often complain this activity diminishes hunting opportunities. Sharpshooting can reduce deer density much faster than hunting. Some managers contract for one or a few years of sharpshooting in hopes that after the deer population has been drastically reduced, switching to managed hunting will be sufficient to keep the population at the lower level.

Predation by "natural" predators: A suite of large predators, including bears, wolves, mountain lions, coyotes, bobcats, and Native Americans, maintained a much lower deer density than those we see across much of the species' range today. Black bears, coyotes, and bobcats are the only "natural" predators remaining in the Eastern United States. The effect of predation is not usually sufficient to offset recruitment in many areas because of a lack of predators. However, in some areas of the Eastern United States, predators have an impact on deer density and recruitment.

Trapping and transplanting: Theoretically, deer may be trapped and transplanted to other places, but the "other places" then may experience problems caused by too many deer. In most states, trapping and transplanting have been phased out in recent years. Willing recipients are limited, the procedure is costly, and it must be repeated continually to be effective. Because the practice also increases the risk of disease transmission, state wildlife regulations typically ban trapping and transplanting except in rare instances in which the capture of small numbers may be approved for research.

Chemosterilants: Chemosterilants are an attractive concept for those who do not want deer populations reduced by hunting but prefer the idea of birth control. Unfortunately, technology is not at the stage where its use is effective or feasible in most deer populations. Many state wildlife agencies prohibit the use of chemosterilants on wild populations except on a small scale in approved research. In methods currently undergoing research and testing, female deer are injected with a chemical that prevents reproduction. Some of the chemicals may be placed in syringes fired from a dart gun, with an effective delivery range of about 100 feet. Other chemosterilants must be injected by hand, requiring deer be captured and restrained prior to injection. Average cost ranges from $100 to $500 per deer per injection. For some of the chemosterilants, does must receive additional "booster" injections to remain infertile in subsequent years. A majority of does in a herd must be injected to effect meaningful reduction in reproduction and recruitment.

Chemosterilants do not result in instant reduction in deer herds; rather, they result in a slowing of reproduction and recruitment. The logistics of injecting enough does to reduce reproduction and recruitment significantly render chemosterilants potentially useful only on small (less than 500 acres) islands or landscapes that are fenced to preclude immigration of unsterilized does. For a chemosterilant to be an effective method for reducing deer density, it must be developed that only deer (and no other wildlife species) are rendered infertile, and that it is effective when ingested, so that it can be administered over large areas via bait stations. The United States Department of Agriculture Wildlife Services, the federal agency charged with research on methods of reducing animal-caused damages, states chemosterilants are not a replacement for lethal methods in managing deer populations.

Protecting understory vegetation

Increasing deer forage: Thinning or other timber harvest methods can be used to increase deer forage availability. The increase in forage typically persists for 5–7 years before tree seedlings grow beyond the reach of deer. Forest management should be spread out, both spatially and temporally, to maintain forage availability across time and space. It may be necessary to treat 10–40 acres to temporarily overwhelm deer and allow more susceptible seedlings and herbaceous plants to establish. Deer may respond to increasing levels of forage following timber harvest with higher recruitment rates, necessitating increased mortality rates from hunting to prevent an increase in deer density. If the increased forage production cannot be maintained through sustainable forest management or deer density is allowed to increase, the result will be additional severe impacts on forest understory, other wildlife and their habitat, and the health of the deer herd itself. Thus, any forage increases must be sustained and coupled with an appropriate deer harvest to prevent deer density and impacts from increasing to unacceptable levels.

Other methods of increasing deer forage, such as developing and maintaining food plots planted to forage species such as clover, brassica, and chicory, are used by managers to offset deer-foraging pressure on the forest understory, while efforts are under way to reduce deer density and improve plant diversity. Various habitat management practices are promoted by the quality deer management philosophy that focuses on balancing deer density with improved habitat. In addition to harvesting an appropriate number of antlerless deer annually and restricting buck harvest to older deer, the approach emphasizes managing habitat (judicious use of timber harvest, prescribed fire, selective herbicides, and supplemental plantings) to improve available nutrition and increase deer quality (increased body weights, improved antler characteristics). The Quality Deer Management Association recommends maintaining deer density at or below CC_{MSY}.

Fencing: Fencing may exclude deer from forested areas recently regenerated. Ten-foot high woven wire or livestock fencing works much better than electric fencing, which requires more maintenance. Also, deer can easily penetrate electric fences and are difficult to remove from fenced areas. Woven wire fences, which are designed to last for 5–10 years generally cost at least $2 per linear foot to build, plus annual maintenance costs. More durable fencing, typically designed to last 25 years or more, may also exclude deer, but initial construction and annual maintenance costs are very high. Falling limbs and trees can knock down woven wire fencing, so trees along both sides of the fence should be cut back a sufficient distance. The cleared zones can double as firebreaks where the forest is managed with prescribed fire, and to allow passage of all-terrain vehicles for fence monitoring and repair. Deer impact on understory vegetation within fenced areas must be monitored to detect whether deer have penetrated the fence and have begun to impact plant diversity.

Tubing: Oak seedlings can be grown in nurseries and planted inside protective, degradable plastic tubes (generally 4 feet tall and staked to the ground), which prevent deer from browsing on the seedlings until they develop enough height and diameter growth to escape deer browsing and also withstand wind and antler rubbing. Tubes and nursery-grown seedling stock are relatively expensive. Also, saplings grown inside tubes often are spindly and may be susceptible to wind damage, resulting in regeneration failures after the tubes decompose or are removed. Additionally, the only resources protected are oak seedlings planted inside the tubes, as deer are free to eat all other understory vegetation.

Repellents: In areas where regeneration is achieved by planting nursery stock (most often of coniferous trees), both taste and area repellents have provided some protection. Taste repellents are applied to the tree foliage. However, precipitation washes off repellents, which then must be reapplied. Additionally, the repellent value diminishes over time as deer become accustomed to the taste or odor.

Counteracting effects of prolonged high deer density on understory vegetation

Inadequate seed availability: After reducing the deer population and establishing a program to maintain it at that level, intervention may be needed to hasten the return of missing understory shrub and herb species. Planting nursery stock is the quickest way to reestablish plant populations of desired species whose seeds are unlikely to be present or returned by natural means.

Interfering vegetation: Dense cover of mat-forming ferns or other undesirable plants that proliferate where deer have eliminated their competitors can be an impenetrable barrier against establishment of new trees, shrubs, or herbaceous plants. Dense shade and root competition suppress germination and overwhelm the few seedlings that manage to emerge. Application of herbicides (see Chapter 10) combined with partial overstory removal, such as shelterwood harvest or thinning (see Chapters 7 and 11), allows for germination and growth of tree seedlings if deer density is at or below CC_R.

Selecting a management strategy

Managing deer impact on oak regeneration requires consideration of management goals, forestland size, and the composition of the surrounding landscape, along with appropriate management tools. Table 17.2 is a guide for the selection of appropriate management strategies.

There are three alternative forest management goals that relate to deer carrying capacity: (1) managing to optimize diversity and abundance of all forest resources, including deer health (CC_D); (2) managing to sustain timber harvest (CC_R or CC_{WO}) for a suite of commercially desirable tree species and coincidentally improve habitat for a limited suite of plant and wildlife species, including white-tailed deer; and (3) managing to optimize deer harvest quantity or quality (CC_{MSY}).

Table 17.2 Guide for selecting a management strategy to achieve desired carrying capacity and deer impact level

Carrying capacity	Landscape context	Management strategy
CC_D, CC_{WO}, CC_R	Urban/suburban[a]	Fencing plants and sensitive areas; sharpshooting; strictly regulated hunting
CC_{MSY}	Urban/suburban	None—too much public conflict and hazard
CC_D, CC_{WO}, CC_R	Agriculture and forest (small woodlots[b])	Regulated hunting; forest management; food plots; fencing plants and small openings
CC_{MSY}	Agriculture and forest (small woodlots)	Regulated hunting (however, CC_{MSY} generally not a goal because of conflicts with agriculture); forest management; food plots
CC_D, CC_{WO}, CC_R	Forestlands	Regulated hunting; forest management; food plots; fencing regeneration sites
CC_{MSY}	Forestlands	Regulated hunting; forest management; food plots

[a] For hunting within urban/suburban landscapes, including parks, hunters must be intensely supervised to ensure no adverse hunter–general public interaction, such as trespassing, shots fired across residences, dragging deer carcasses across residential properties, etc.

[b] Most agriculture and small forest areas are owned by persons practicing small-scale farming with isolated, small woodlots wherein little timber management occurs and trees are harvested occasionally to produce cash for emergencies.

There are three landscape categories wherein deer and forests are managed: (1) contiguous blocks of forestland comprising hundreds to thousands of acres; (2) isolated blocks of forestland interspersed within a larger agricultural landscape; and (3) isolated blocks of forestland surrounded by urban/suburban landscapes.

Monitoring: Have you solved the problem?

Monitoring the impact of deer foraging on the forest understory over time is essential to determine if the management practices used were successful. If the program employed was not successful, examine your strategy, determine the problem, and make appropriate adjustments.

Effective management is adaptive. Learn from experience and modify behavior as a result of that experience. Think of it as a series of feedback loops where current knowledge is applied to solve a problem, and the results are monitored to rate success. Adaptive management employs incremental steps (monitor, adjust, monitor) until success is achieved and maintained.

Further suggested reading

Beaver, J.T., C.A. Harper, R.E. Kissell, Jr., L.I. Muller, P.S. Basinger, M.J. Goode, F.T. van Manen, W. Winton, and M.L. Kennedy. 2014. Aerial vertical-looking infrared imagery to evaluate bias of distance sampling techniques for white-tailed deer. *Wildlife Society Bulletin* 38(2):419–427.

Curtis, P.D., B. Boldgiv, P.M. Mattison, and J.R. Boulanteger. 2009. Estimating deer abundance in suburban areas with infrared-triggered cameras. *Human-Wildlife Interactions* 3:116–128.

deCalesta, D.S. 1997. Deer and ecosystem management. In W.J. McShea, H.B. Underwood, and J.H. Rappole (eds.), *The Science of Overabundance: Deer Ecology and Population Management*. Smithsonian Institution Press, Washington, DC, pp. 267–279.

deCalesta, D.S. 2013. Reliability and precision of pellet-group counts for estimating landscape-level deer density. *Human-Wildlife Interactions* 7:60–68.

deCalesta, D.S. and S.L. Stout. 1997. Relative deer density and sustainability: A conceptual framework for integrating deer management with ecosystem management. *Wildlife Society Bulletin* 25:252–258.

Goode, M.J., J.T. Beaver, L.I. Muller, J.D. Clark, F.T. van Manen, C.A. Harper, and P.S. Basinger. 2014. Capture-recapture of white-tailed deer using DNA from fecal pellet groups. *Wildlife Biology* 20(5):270–278.

Halls, L.K. (ed.). 1984. *White-tailed Deer: Ecology and Management*. Stackpole Books, Harrisburg, PA, 870 pp.

Hewitt, D.G. 2011. *Biology and Management of White-tailed Deer*. CRC Press, Taylor & Francis Group, Boca Raton, FL.

Lashley, M.A., C.A. Harper, G.E. Bates, and P.D. Keyser. 2011. Forage availability for white-tailed deer following silvicultural treatments. *Journal of Wildlife Management* 75:1467–1476.

Latham, R.E. (ed.), J. Beyea, M. Benner, C.A. Dunn, M.A. Fajvan, R.R. Freed, M. Grund, S.B. Horsley, A.F. Rhoads, and B.P. Shissler. 2005. Managing white-tailed deer in forest habitat from an ecosystem perspective: Pennsylvania case study. Audubon Pennsylvania and Pennsylvania Habitat Alliance, Harrisburg, PA, 340 pp.

McShea, W.J., H.B. Underwood, and J.H. Rappole (eds.). 1997. *The Science of Overabundance, Deer Ecology and Population Management*. Smithsonian Books, Washington, DC, 394 pp.

Miller, K.V. and R.L. Marchinton (eds.). 1995. *Quality Whitetails: The Why and How of Quality Deer Management*. Stackpole Books, Pittsburgh, PA, 320 pp.

Minnesota Department of Natural Resources. (No date.) *Fencing Handbook for 10′ Woven Wire Deer Exclusion Fence*. Minnesota Department of Natural Resources, Wildlife Damage Management Program, Brainerd, MN, 22 pp.

Pierson, T.G., and D.S. deCalesta. 2015. Methodology for estimating deer browsing impact. *Human-Wildlife Interactions* 9:67–77.

Potvin, F. and L. Breton. 2005. Testing two aerial survey techniques on deer in fenced enclosures: Visual double-counts and thermal infrared sensing. *Wildlife Society Bulletin* 33:317–325.

Quality Deer Management Association. 2010. Living with white-tailed deer: A community guide to urban deer management. Quality Deer Management Association, Bogart, GA, 54 pp.

Stolzenburg, W. 2008. *Where the Wild Things Were: Life, Death and Ecological Wreckage in a Land of Vanishing Predators*. Bloomsbury, New York, 291 pp.