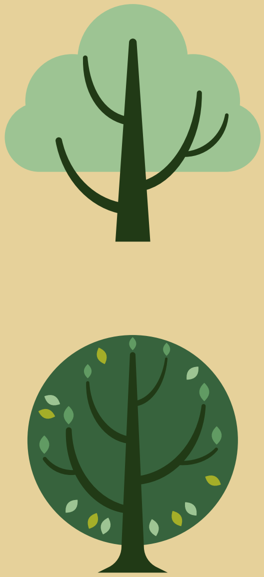
Applied Nucleation for Forest Recovery in the Mid-Atlantic



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The Delaware Center for the Inland Bays is a nonprofit organization and a National Estuary Program. It was created to promote the wise use and enhancement of the Inland Bays watershed by conducting science-based education and outreach, developing and implementing restoration projects, encouraging scientific inquiry and sponsoring needed research, and establishing a long-term process for the protection and preservation of the Inland Bays watershed.

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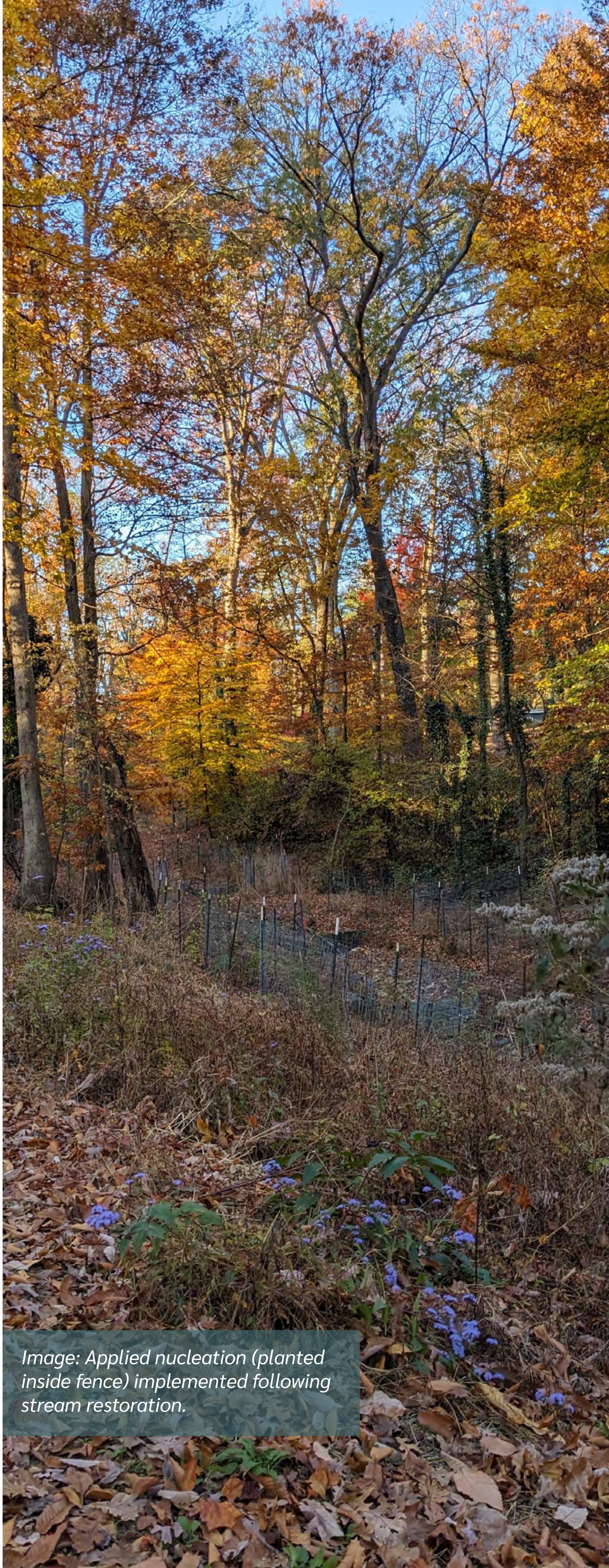
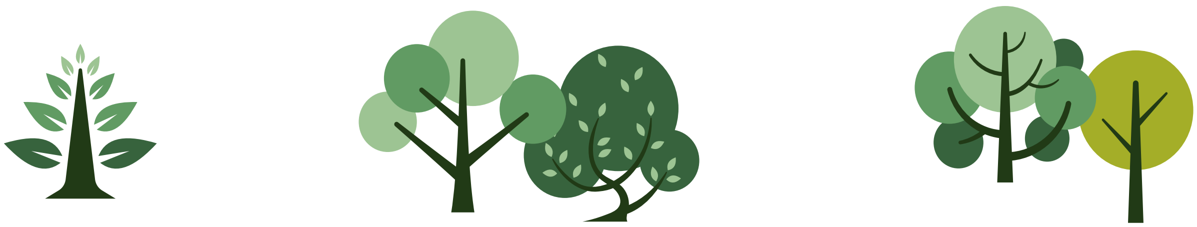


Image: Applied nucleation (planted inside fence) implemented following stream restoration.



“The superficial appearance of vegetation restoration should be avoided.” SCHIRONE ET AL. 2011.

This resource guide is in two parts, first a “how to” implement applied nucleation, and second, how to measure if a high-quality forest has been restored.

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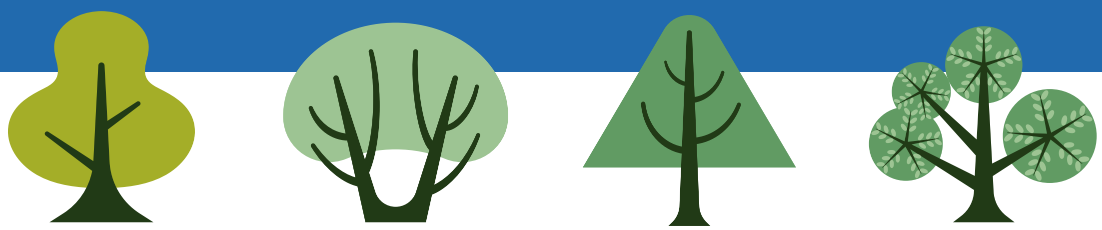

Practice Description: Establishment of forest in areas previously forested (reforestation) or areas having an alternate, tree-less, land use (afforestation).

Purpose: This practice may be applied to achieve, improve, and maintain forest function in upland or riparian conditions for the benefit of water quality, tree canopy cover, wildlife habitat value, or other benefits.

Goal Setting: Given the long lag time between management action (planting trees) and restoration goal (functional forest), shortening recovery of forest function is a desirable secondary goal. Applied nucleation (AN) can create a higher quality forest with the desired vegetation community, more quickly, while meeting habitat needs of target species and land use goals. AN may also lead to fewer number of trees planted. See Appendix A and Conservation International's Applied Nucleation Restoration Guide for Tropical Forests (Figure 12) for additional considerations in selecting the AN approach for a restoration site.

Description: Based on observed forest patterns, exemplified by the pocket-forests created by Akira Miyawaki, and a modification to the approach known as applied nucleation, the **AN approach in the Mid-Atlantic plants more individuals of more species, more closely together, after site-specific land preparation.** Variations of this method have been used throughout the world: Japan, India, Costa Rica, Honduras, Italy, Brazil, France, and in the US from Florida to New England, Missouri, Delaware, Iowa and Virginia. The oldest AN-style reforestations are in Japan and Costa Rica, sub- or tropical areas of humid, high rainfall, low herbivory and year-round favorable growing conditions. European efforts in semi-arid Mediterranean climates have found satisfactory improvements over traditional methods. Plantings in Fairfax County, Virginia, a temperate climate in the Piedmont, are now five-years old and provide a test case of AN in the Mid-Atlantic. This document summarizes the techniques and nuances during this implementation and provides supporting evidence that AN returns forest function quickly.

Regulatory Setting: Specifications for reforestation in local ordinances vary, however, they may range from the minimum requirement of 200 trees per acre, to requirements for more stems, canopy closure, initial size, size after 2-years, and diversity requirements for overstory, understory, and shrub. Sometimes, there is guidance that plants should be distributed over the entire area, but no guidance says they must be evenly/equally distributed over the entire area. One of the first documents for Chesapeake Bay reforestation includes an AN approach, here referenced as a cluster.

Figure 1. *Landscape Architect depiction of implementation of applied nucleation in the Mid-Atlantic, starting with bare roots at time zero, image below, top) and showing forest development through five years (below, bottom) and at ten years (next page). (Karen Steenhoudt, LA)*

Figure 1. - *continued*

Guides for selecting appropriate plant species:

- Chesapeake Bay Trust Native Plant Species Selection Guides
- Native Plants for Wildlife Habitat and Conservation Landscaping: Chesapeake Bay Watershed
- Classification of Vegetation Communities of Maryland (Maryland.gov)
- Virginia Guide to Natural Communities
- User Friendly Planting Guidelines Based on Natural Communities
- Guide to Delaware Vegetation Communities
- A Guide for Establishing and Maintaining Riparian Forest Buffers

Plant Material

Material includes species and size.

Species should be selected to be native to the region and tolerant of expected site conditions. As the effects of climate change begin to be understood, more information is available about native species that can tolerate expected changes in climate, which ones are unlikely to tolerate changes, and which species might be introduced to tolerate the new conditions. How the practitioner defines the native region can be broad (East Coast) or hyperlocal (within 50 miles of the restoration site). However, a hyperlocal focus may affect the reforestation's tolerance to long-term climate change and/or species availability.

Consideration should also be given to resultant plant communities. For instance, river birch and willow oak co-occur in a native plant community; however, you are unlikely to find river birch and red hickory in the same community. The planting palette should limit the creation of novel plant communities. However, we followed the rules of succession, introducing species from multiple stages in the succession continuum. Some research has experimented with priority effects – or planting different species at different times, whereas ours planted species from multiple succession stages at the same time. This constraint follows most reforestations which have a limited window of time in which to plant, usually one or two years.

Test plots were planted with ¾" caliper saplings and three-gallon shrubs.

Container plants ready to be planted.

Figure 2. *Layout of an oval "homeowner" friendly Fairfax County superclump, this one includes ferns in the understory.*

Layout

Fairfax County has experimented with multiple AN layouts including oval (Figure 2), circular, and triangular. Most test plots were oval, although Churchill was circular. For an oval layout, the smaller axis is between 18 and 20 feet and the larger axis is up to 40 feet, with a circumference of 98 feet. The approximate area is 630 square feet, requiring 3.5 cubic yards of mulch per nucleation. Each fence (if used) will need between eight and 10 five-foot stakes to secure. Install stakes six-12 inches in the ground (Table 1).

Layout should match the shape of the area to be restored, shrub/understory/canopy species ratios should match the desired forest and should not be restricted to the layouts tested. There was no difference in forest metrics between trialed layout shapes.

Species groups and density– Fairfax County's test of Applied Nucleations

Species were grouped into four categories: shrubs, understory, fast-growing overstory, and climax overstory. Categorizing the species by their desired traits streamlined meeting regulatory planting ratios and contracting specifications. This categorization was also helpful when designing with non-professionals, who had different priorities. Although each planting palette maximized the number of species, usually between 12 and 16, it was more useful to ensure the species were spread across the four categories. Other AN approaches do not focus on ratios among these categories.

At three test sites, initial planting included 28 shrubs, 12 understory, 13 fast-growing overstory, and 12 climax overstory per 400 square foot nucleation (1.75 stems/meter2; a "superclump"). At one site, there were eight shrub, four understory, five fast-growing and four climax overstory plants per 175 square feet (1.3 stems/meter2; a "clump"). Distance between individual plants ranged from two and a half to four feet (0.75-1.25m). Test sites were compared with unplanted and plantation replicates. Plantation style planting includes one or two tree saplings and up to four shrubs in 400 square feet (0.16 stems/meter^2), on ten to 12-foot (3-3.5 m) centers for trees and five-foot (1.5 m) centers for shrubs.

Installed, but not measured densities of up to 50 bare root seedlings in 200 square feet (2.5 seedlings/meter^2), and as few as 33 sapling tree, shrub, and fern stems in an area of 400 square feet (~1 stem/meter^2) have also been planted. Differential planting oversight, survivorship and clonal spread mean each replicate has a different density after five years, however anecdotally, few nucleations have not achieved desired forest function.

Species used in Fairfax County, VA plantings

For Fairfax County, the oak-hickory community was the target for most plantings. However, site conditions varied, and species were modified based on nuances in site hydrology, naturally occurring forest, availability of material from the nursery, as well as plant trials (species we had not previously used in restoration to evaluate their tolerance of restoration) (Table 2).

Planting during the establishment at Churchill Road park, following an oval AN layout, 2021.

Table 1. *Unit Cost – Non-plant supplies. Cost per nucleation averages ~ $500/ planting plus the cost of plants. Plantation style plantings can be more expensive, if every tree is sheltered.*

	Approximate cost (2024)	8-stake oak (low cost)	10-stake metal (high cost)	Typical AN density - 37 trees and 28 shrubs	Plantation (rate 65 stems/a 0.1 acre)
4', 14-gauge Welded Wire Mesh Fence	$1.26/foot	$126	$126		
Stake (5'-6' Oak)	$2.50 each	$20			
Stake (U-Channel Metal)	$7.00 each		$70		
Stake/Fence Fasteners (+2 for the gate)	$0.10 each to $0.25 each	$1.80	$5.50		
Tree Shelters	$8-15 each			$425	$718.75
Mulch (3.5 cubic yard)	%100/ cubic yard	$350	$350	$350	
Total		$497.80	$551.50	$775	$ 718.75

Fencing

Deer and small mammal herbivory is present on most Mid-Atlantic reforestation sites and may cause slower growth or mortality of planted stems. Traditional approaches to management of deer include physical and chemical barriers. AN has a multi-layer deer protection strategy. First, the density of the planted stems is such that stems are too close together for deer to walk through. Second, the species planted towards the outside of the nucleations are deer resistant, either through physical traits like thorns on black locust or smell like the pawpaw or beautyberry (secondary chemicals). Finally, plantings either had individual tree protection (shelters) or a single layer of fence around the nucleation. In the test sites, there was no difference in the forest outcome metrics, except there were nearly twice as many shrubs in nucleations that were fenced as compared to nucleations with individual shelters. A single fence of four-foot, 14-gauge welded wire mesh on metal posts is recommended. Welded wire mesh fences use the least amount of plastic, encourage the survival of natural-form shrubs and lower branching of trees, and the fence material is reusable.

Bulk order of welded-wire mesh fence arrives via trailer in Delaware trial (2023).

Table 2. *Species included in applied nucleations and considerations for use.*

Common Name	Species	Group	Number of Trial Sites	Notes on re-use
American beautyberry	*Callicarpa americana*	Shrub/Deer resistant	3	Not native to Fairfax County, did not thrive in shade
Black cherry	*Prunus serotina*	Understory/ Fast Growing Overstory	1	Use again, fastest grower
Black gum	*Nyssa sylvatica*	Climax Overstory	1	Very slow growing
Black haw	*Viburnum prunifolium*	Shrub/Understory	2	Reliable
Black locust	*Robinia pseudoacacia*	Fast Growing Overstory/Deer Resistant	3	Excellent survival and growth and producing quick shade, and leaf-litter
Buttonbush	*Cephalanthus occidentalis*	Shrub	2	Needs sun and moisture
Elderberry	*Sambucus canadensis ssp. nigra*	Shrub	2	Generally, deer intolerant, would be site-specific
Hackberry	*Celtis occidentalis*	Climax Overstory	1	Became nutrient deficient in first year, recovered second year without intervention
Nine-bark	*Physocarpus opulifolius*	Shrub	1	Site-specific, did well in planting
Pawpaw	*Asimina triloba*	Understory/Deer resistant	2	Native range is narrow
Persimmon	*Diospyros virginiana*	Climax Overstory	1	Unremarkable
Pin oak	*Quercus palustris*	Climax Overstory	1	Climate susceptible
Short-leaf Pine	*Pinus echinata*	Climax Overstory	1	Died due to beaver browse
Red cedar	*Juniperus virginiana*	Understory	1	Slow growing, not with serviceberry
Red chokeberry	*Aronia melanocarpa*	Shrub	1	Heavy deer browse when unprotected
Red maple	*Acer rubrum*	Fast Growing Overstory	2	Heavy seed rain
River birch	*Betula nigra*	Fast Growing Overstory	1	Performed well
Serviceberry	*Amelanchier canadensis*	Understory	1	Performed well, not with red cedar
Spicebush	*Lindera benzoin*	Shrub/Deer resistant	1	Failed to thrive
Sumac	*Rhus copallinum*	Understory	3	Inconsistent, either dies or first species to spread from original planting
Sycamore	*Platanus occidentalis*	Fast Growing Overstory	2	Reliable, fast, will need moisture to thrive past 10-years
Tulip tree	*Liriodendron tulipifera*	Fast Growing Overstory	1	May suffer transplant shock
White oak	*Quercus alba*	Climax Overstory	1	Performed well
Swamp white oak	*Quercus bicolor*	Climax Overstory	2	Performed above average
Willow oak	*Quercus phellos*	Fast Growing Overstory /Climax Overstory	2	Reliable, fast

Second year sycamore growth at Rock Hill, person in HI-VIS is about five feet, 2019.

Land/site preparation

Land preparation for AN is no different than land preparation for any planting method and is entirely site-specific. Land preparation includes non-native invasive species control, decompaction, or fertilization. These should be implemented based on understanding the needs of the site, available time, and budget. The AN trials include one stream restoration (Dead Run) and three upland restorations with significant non-native invasive plant cover. Fairfax County AN are typically implemented following stream restoration, which minimizes soil disturbance through prevention (construction road matting, low impact equipment, mulching, seeding with a grass/flower mixture, and tree saves).

Miyawaki forests are often implemented on highly compacted industrial sites, therefore site preparation, usually a combination of decompaction and fertilization, is a key step. Other implementation trials have been in recently abandoned agricultural fields and turf lawns – each requires specific knowledge to ensure proper site preparation.

Non-native species in Fairfax County are treated with herbicide and or mechanical control (Fecon bush hog) prior to planting. Additionally, a slow-release fertilizer tablet was added at the time of planting. Mechanical tilling or decompaction should be used when warranted but may trigger weed-seed germination and/or damage existing root systems. The process of AN requires generating many planting holes, causing decompaction and disturbance. Caution should be made where tree saves are present to limit further disturbance near standing trees.

Mulch is a useful tool to help regulate soil moisture in the Mid-Atlantic and to help suppress weeds. Hardwood mulch may even promote the growth of hardwood trees in a restoration setting (Larry Weaner Landscape Associates, pers. comm.) Mulch also provides a more kept appearance when applying this technique closer to residences or public spaces, therefore increasing social acceptance. Where mulch was not used in a turf grass area, weeding turf grass was significantly more effort, although it did not seem to cause a decrease in survivorship (this site is less than three years old). An additional application of mulch at one year after growth appeared to further reduce need for weed control.

Applied Nucleation as a Best Management Practice

In practice, the reforestation goal of a functional forest has become almost secondary to the logistics of planting large multi-acre tracts. Commercial and state forestry teams of forest planters can plant tens of thousands of stems in a single day when following a simple plant palette and the plantation style of planting. With the global need for reforestation increasing, and budgets failing to keep up, it is difficult to step back and evaluate if there may be better techniques to reach the goal of forest, as opposed to trees in the ground.

There will likely always need to be large-scale plantation forests, but in smaller areas (<10 acres), urban or suburban areas where land value may be higher, AN-style plantings may achieve better results, more quickly.

Frequently Asked Questions

(1) Does the land need to be prepared? Tilling versus herbicide?
Reforestation following construction or removal of impervious surface should consider mechanical soil decompaction based on bulk density test results. However, most sites will not require mechanical disturbance (where this was tested in Fairfax County there was no effect on the plants after one year).

For areas with aggressive grasses or other non-native invasive species, such as porcelain-berry *(Ampelopsis brevipedunculata)*, pre-treatment with herbicides is the preferred route. Herbicide applications allow for control of undesirable vegetation without triggering germination from the seedbank and should be considered over mechanical disturbance. Solarization may be used in smaller areas. Herbicide may brown vegetation for several months, however a cover crop can be planted to increase social acceptance.

Compost and fertilizers should be used if soil tests indicate deficiency. An excessive amount of compost/fertilizer can lead to weed issues.

(2) What is the preferred timeline?
If the site needs non-native invasive species control, control of undesirable

Frequently Asked Questions (continued)

vegetation should occur at least six-months to one-year before planting. Forest planting should occur during plant dormancy; the preferred growing season for Fairfax County, Virginia, is between 3/15-4/15 and 10/15-12/15.

(3) How many nucleations? What size?
Other applications use dense planting over the entire site, which may be appropriate up to 0.5 acres (2023 square meters). More or larger nucleations will mean a faster coverage of the entire site. The Fairfax County application resulted in 5-8 630 feet^2 nucleations per acre, although due to slow expansion, 10-14 nucleations/acre is recommended. Individual nucleations were between 175 and 630 feet^2.

(4) Do the trees need mulch? Any special care? What is the watering schedule?
In the Mid-Atlantic, mulch is an ally in reforestation. Mulch will reduce weed competition, trap soil moisture during droughts, and add organic matter, and make the site look neater. Mulch is recommended. Fairfax County found the best results in reapplying mulch one year after the initial planting. Forest establishment may be delayed without mulch.

A green mulch seed mix could also be a viable technique; however this was not tested. Grasses should be avoided in the green mulch seed mix as they've been shown to decrease woody plant establishment and growth.

Other AN have used straw mulch, following land preparation that included decompaction. Some type of mulch is desired to reduce runoff from rain events, however straw mulch will decompose quickly in the Mid-Atlantic and may need to be reapplied more than once if not accompanied by seeding with a green mulch.

No Fairfax County reforestation plantings are watered or irrigated.

(5) What is the height of the fence that would encircle the planting? Will it be high enough to deter deer?
Unlike a typical deer-exclosure fence of eight to ten feet tall, a perimeter, four-foot fence is a cost-effective and efficient approach. Taller fences, although effective, require frequent maintenance and are generally used in Fairfax County on reforestations greater than an acre. Trials with double fences set at 1-meter apart proved to be unnecessary (pers. observ.) The 4-foot fences excluded deer (although deer can easily jump a four-foot barrier, the deer did not enter likely because of the perceived lack of landing/take-off space and the smaller sizes of the exclosures). The shorter height was less expensive, less unwieldy, and after two weeks was breached only twice out of the 42 test nucleations, a few additional breaches after two weeks were noted in 172 additional nucleations. The first two weeks did have

Frequently Asked Questions (continued)

the highest amount of deer damage and the fence did need to be adjusted. This fence is temporary and will be removed when the forest is out of danger from deer herbivory (typically three years with the ¾” starting stock). The most efficient fence is 14-gauge weld wire mesh attached to metal posts.

Individual stem protection shelters were also successful in deterring deer browse and rub, however, individual shelters have some drawbacks – instead of one fence, 30 or more shelters needed to be added and removed; lower branches of trees and shrub form were compromised, plastic was introduced into the system, and although attempts were made to reuse and recycle the shelters, many were only used once.

(6) Is there one desired layout?
Nucleations should be placed on a site-specific layout. Consideration should be made based on the preferred maintenance. One landowner asked that there be sufficient distance between each nucleation to allow for mechanical control of vegetation if needed. It is recommended that nucleations have the long axis oriented in multiple directions, that neighboring properties are respected (viewsheds maintained and/or buffers added) and that nucleations are not placed in such a way to encourage runoff or erosion. Maximum size of a nucleation should account for maintenance and potential deer herbivory.

(7) What to expect about non-native invasive plants and/or aggressive natives?
Planting in rows with regular spacing is perceived to be superior as it allows for mechanically-assisted means of management. However, with all stems protected by fencing, spaces between nucleations are easily managed by a mower. Non-native species and aggressive native species appear to be universal across Mid-Atlantic plantings, although our data suggest that there are slight reductions of non-native species interior to a nucleation. Vining invasive species on fences may be an additional treatment over traditional reforestation practices.

(8) When you planted mini forests in urban or suburban areas did you have any pushback on the issue of public safety? Did these create places for criminals to hide?
Successful restorations provide culturally acceptable solutions, if clear sight lines are the top value for the community, a planting approach that is more open, more widely spaced, and less ‘forest-like’ should be implemented. However, nucleations are planted very densely, making it difficult to navigate between the stems. It may be too difficult for someone to move quickly if hiding in one of them, and especially if species with thorns are used, it discourages use by deer and humans.

Image: From the center of a planted applied nucleation. Dense layers of foliage are present in applied nucleations that are not visible in plantation-style plantings.

In kind donations from the USGS, EPA National Estuarine Program, Fairfax County, Fairfax County Park Authority, Northern Virginia Soil and Water Conservation District, Vanessa Beauchamp, and Sarah Roth; this work was funded by a Cheseapeake Bay Trust Pooled Monitoring Grant by the program funding partners: the Maryland Department of Natural Resources, Anne Arundel County, Baltimore City, and the Chesapeake Bay Trust.

Maryland Department of Natural Resources

Anne Arundel County Maryland

DPW Baltimore City Department of Public Works

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Image: Scientists explore a soil sample from a plantation style plot, the paired applied nucleation plot in the background.