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Slash Walls: Concepts and Applications for the Control of Deer Impacts to Forest Vegetation

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The first slash wall completed in 2017 known as the "Gas Line" harvest (74 acres) is the left (western) third of this Google Earth image. In 2019 the eastern two-thirds "North Gate" slash wall harvest (160 acres) shared a common boundary to create a mile-long impasse on the northern and southern sides.

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Contents

A downloadable pdf of this publication is available at www.slashwall.info and www.ForestConnect.info

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Overview

This document is a best practices guide for the use of slash walls to exclude deer that impact forest vegetation through selective browsing of desired seedlings. Typically, deer browsing reduces the abundance of desired tree and herbaceous species, and increases the abundance of undesired and interfering vegetation. The shift in species composition is further complicated when unsustainable harvesting removes desired species and the seed source without ensuring a new forest is established. These, and potentially other factors, can force forests towards reduced diversity and productivity. These circumstances are widespread, and cumulatively threatening to the broader health of the dominant landscape in the northeastern United States.

Slash walls were first used at the Cornell University Arnot Forest in western New York. Significant prior effort with standard forestry practices resulted in harvested areas that did not successfully regenerate with sufficient numbers of stems of desired species. Other factors were evaluated to determine what caused the failure. Ultimately, selective browsing by deer, coupled with the resulting competition for sunlight by undesired woody species were identified. Given insufficient personnel and financial

Figure 1A: Slash walls and afforestation areas established in 2021/22 as part of the Climate and Applied Forest Research Institute, in partnership with the State University of New York - College of Environmental Science and Forestry. Picture courtesy of Katie Sims, 2022.

Figure 1B: A recent slash wall in New England illustrates the ability to integrate sustainable regeneration harvesting in a forested landscape while protecting water quality. The harvested area outside the wall serves as a control for research. Photo courtesy of A. Hubbard

Should I consider using a slash wall?

1. Do I expect to regenerate woody or herbaceous plants that are palatable to deer?
2. Do legitimate field survey methods verify the extent of deer impact?
3. Can I successfully regenerate without protection from deer?
4. Will a slash wall be the most cost-effective and efficient approach after considering installation, maintenance and removal of alternatives?
5. Is there sufficient slash to build an effective wall?
6. Are there local contractors that can be trained and incentivized to build a slash wall?
7. Are there external factors such as high fire risk or regulatory restrictions that would preclude building a slash wall?
8. What other treatments are necessary for a successful outcome such as interfering vegetation control, preparatory harvests to establish regeneration prior to building a slash wall, or enrichment planting?

Figure 2: Slash walls are deliberately constructed with pole sized (5 - 11" diameter) stems as a foundation and coarse branching above.

resources to install, maintain and remove mesh and woven wire fence, an alternative was needed. The first contract for a slash wall was written in 2016, and the first slash wall completed in 2017.

Slash walls are one tool that can contribute to the successful regeneration and restoration of forests. Slash walls are typically installed as part of a regeneration harvest, although they could enclose an area of unharvested forest or afforestation site. This guide is intended to help foresters, loggers, and landowners implement successful slash wall projects.

This guide does not cover silvicultural prescriptions that are essential when initiating a regeneration harvest, the inventory for silvicultural decisions, or implementation of the final harvest. However, our preliminary observations are that conventional silvicultural prescriptions and vegetative responses may behave differently in the absence of deer. Landowners should work with a competent forester and logger to address these and related needs.

During the development of the first few versions of this guide, slash walls were created by landowners, foresters and loggers in RI, NY, NH, MA, and CT. Each new slash wall expands the collective knowledge of how to effectively use slash walls. We appreciate the willingness of these individuals to help us learn. We will share their experiences, and others that follow, at www.slashwall.info . Slash wall work continues at the Arnot Forest, and slash walls are increasingly apparent from aerial and satellite perspectives (Figure 1A and 1B).

Figure 3: More than 1000 foresters, loggers, owners, agency staff and other practitioners have participated in educational events throughout the Northeast to explain the role of slash walls.

Intended Audiences

The role of slash walls is to prevent the impact of deer and their related effects on desirable vegetation following a regeneration harvest or restoration treatment (Figure 2). Woodland owners, foresters, loggers and some public agencies will be part of these discussions as each of their roles are important (Figure 3).

Woodland owners are increasingly perceptive about the impacts that deer have on their property. Woodland owners include people and organizations who have an enduring and deliberate responsibility for and connection to a property, or the outcome of properties. Many owners see the increase of interfering vegetation and understand that selective browsing by deer reduces the abundance of desirable species while favoring the growth of undesirable species. Interfering and invasive vegetation are typically a result of deer, thus deer impacts need be controlled before addressing vegetation concerns. Woodland owners look to their forester to suggest cost-sensitive and effective tools that can resolve the problems caused by decades of deer impact and an understory that excludes desired species.

Foresters can explain to woodland owners whether the timing is appropriate for a regeneration harvest (Figure 4). As part of the regeneration prescription, foresters or other natural resource professionals will assess the impacts of deer on desired vegetation. If a problem exists, the forester and owner must select a strategy to limit deer impacts. A forester can estimate the revenue expected from a harvest and assess if that is sufficient to offset the cost of a slash wall. In some cases, state and federal cost-share programs may further offset the cost of building a slash wall because of the natural resource concerns created by deer browsing. When a forester considers slash walls, the silvicultural prescription and harvest plan should include several key components. The forester should address the abundance of low-grade volume, availability of loggers with the appropriate harvesting equipment and attitude, public sentiment, and oversight of the harvest.

Loggers are key to the success of the slash walls. Their commitment to sustainable forest practices will ensure that slash walls are built to contracted specifications. Many different equipment configurations have produced slash walls, but some are more efficient than others. Loggers will know if their equipment is appropriate to build a slash wall. This bulletin and other resources are available to help loggers understand what is necessary to build a successful slash wall. There are slash walls in several northeastern states that are accessible to visit and observe.

By the end of 2022, slash walls have been physically seen by more than 1000 foresters, loggers, owners, NGO staff, conservation scientists, and agency staff. The response has been overwhelming favorable.

Figure 4: Because of the volume of low value and low-grade wood necessary to build a slash wall, their use is most efficient during regeneration harvests. A forester should determine if a regeneration harvest is silviculturally prudent.

Impacts of Deer on Forest Vegetation

Changes in forests are inevitable because of stressors, disturbances and other natural events. Large and small-scale events increase sunlight on the forest floor and start the regeneration process (Lutz 1928, Webster et al. 2018). When the components of the ecosystem are in balance, the regeneration of the forest succeeds. Lack of balance can lead to failure, and significant negative consequences (Holm et al. 2013, McWilliams et al. 2018, Miller and McGill 2019). The impact of browsing by white-tailed deer (*Odocoileus virginianus*) is cumulative (Figure 5). Previously inconsequential canopy disturbances may now result in a significant shift in what services and values the forest will provide because of selective browsing by deer (Waller and Alverson 1997, Bradsaw and Waller 2016, McWilliams et al. 2018).

Figure 5: Deer browse some species more frequently and intensely than they browse other species, and often intensively browse stump sprouts. Repeated browsing will at least distort the growth, or as shown kill the plant.

The activity of deer as selective browsers changes the key attributes of many eastern forests (Nuttle et al. 2015, Ward et al. 2017, deCalesta 2019). Through an unknown twist of fate, deer preferentially browse woody and herbaceous species that are valued and beneficial to humans and other fauna. For example, deer tend to favor tree species of high economic value, attractive and unusual wildflowers, and plant species utilized by other wildlife, such as members of the oak genus. Plant species of lesser "value" are largely ignored by deer. Chronic and selective deer browsing reduces the survivorship of these desired forest species (White 2012) and causes broad ecosystem impacts (Horsley et al. 2003, deCalesta 2019, Miller and McGill 2019).

Selective browsing alone would be sufficient to alter the development of the forest and its benefits (Kain et al. 2011, Frerker et al. 2014). However, the same selective browsing also enhances the survival and growth of the non-palatable, native and non-native species that exclude desired plant species through competition for sunlight (Curtis and Rushmore 1958, Dávalos et al. 2015, Dávalos et al. 2015, Ward et al. 2018). These non-palatable species subsequently form highly stable (Egler 1954, Stromayer and Warren 1997, Nuttle et al. 2015) but less diverse, less productive, and less valuable forests (Waller and Alverson 1997, Horsley et al. 2003, Owings et al. 2017, Bose et al. 2018, McWilliams et al. 2018, Ward et al. 2018, Webster et al. 2018, Dey et al. 2019, Miller and McGill 2019, Sabo et al. 2019).

Despite the historic recognition of the need to reduce deer impacts (Leopold et al. 1947, Curtis and Rushmore 1958, Warren 1997, Webster et al. 2018), deer populations and deer impacts to vegetation continue to increase in many eastern states (deCalesta 2019). The historic strategy has emphasized a reduction in deer impacts through population control by hunting (Severinghaus and Brown 1956, deCalesta 2019) to remove excess numbers of deer above carrying capacity, and maintain a maximum sustained yield of the deer population. This practice is commonly advocated among most, if not all, state's natural resource agencies, but has more recently been challenged (Boulanger et al. 2014, Baumer and Pomeranz 2017, Curtis et al. 2019, Williams et al. 2013). An alternative to deer population reduction is the exclusion of deer from forests at pivotal times in their development. Exclusion provides a realistic strategy to ensure the productivity, diversity and health of the forest (Curtis and Rushmore 1958, Kelty and Nyland 1981, Horsley et al. 2003, Nuzzo et al. 2017, deCalesta 2019, Smallidge and Chedzoy 2019, Smallidge et al. 2021).

Several factors determine the type and potential for deer exclusion: financial resources, the scale of the project, the number of stems per acre that need protection, the density of deer relative to food supply, time and money to maintain exclusion structures, and the effectiveness of population control efforts. Examples of exclusion techniques include tree cages or tubes (Ward et al. 2000), scattered or aggregated slash at seedlings (Fredericksen et al. 1998), small-scale low-height fences (Smallidge et al. 2017), large-area high fences (Vercauteren et al. 2006), and most recently slash walls (Smallidge et al. 2021). Often, recommendations for a particular exclusion strategy fail to consider maintenance or removal costs, probable success in establishing full stocking of seedlings, longevity (either too much or too little) of the structure, habitat impacts, visual impacts, or other associated costs and benefits.

In summary:

i. Deer selectively browse plant species that are often desirable for production and plant diversity goals,

ii. Selective browsing often results in dominance by interfering plant species,

iii. Deer browsing can prevent forests from developing a regeneration layer of diverse species with an adequate number of stems per acre, and

iv. The lack of practical solutions for stand-level forest management treatments results in lost economic and ecological benefits from forests.

Slash Wall Effectiveness – Deer and Interfering Vegetation

As previously described, selective browsing by deer can create an abundance of undesired vegetation that interferes with efforts at regeneration or restoration. Simply removing deer impacts does not resolve the interference by vegetation. The slash wall system needs to address deer impacts, establish desired tree species in adequate abundance and disrupt dominating interfering vegetation.

Effective slash walls exclude deer, and slash walls are effective if they exclude deer. Knowing that deer are absent is often easier said than proven. If regeneration efforts are less than successful, knowing the slash wall was effective at excluding deer will help determine what didn't work. Knowing that deer are absent can be accomplished by showing an absence of deer impacts, or by trying to "prove a negative" that no deer were inside the slash wall.

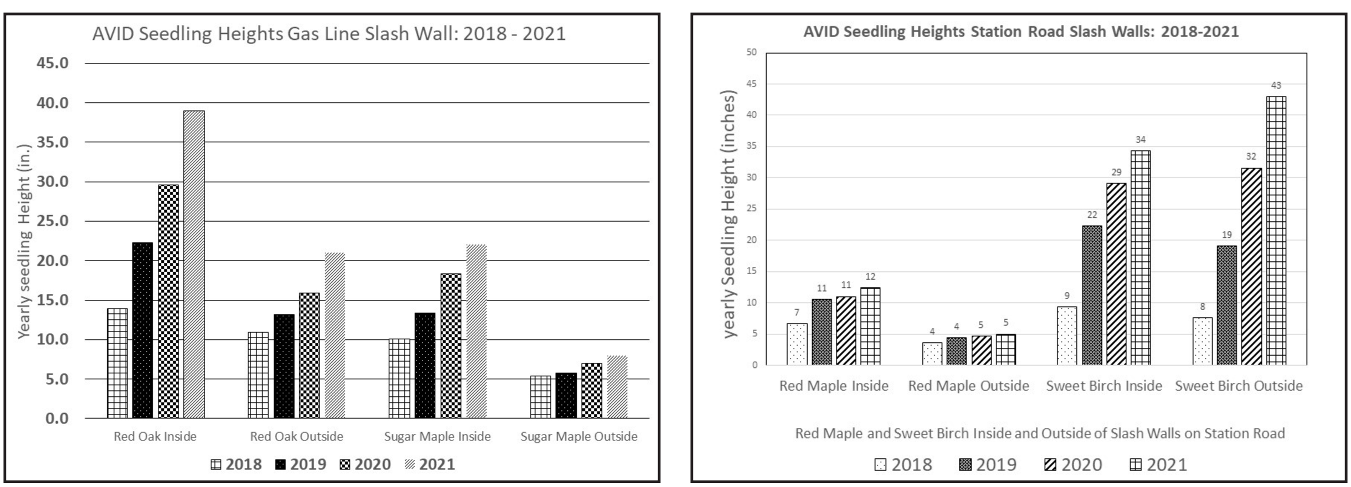

Figure 6A (Left) and 6B (Right): Data from AVID plots in the Gas Line and Station Road slash walls illustrate that seedling height growth rate inside the slash wall is greater than outside the slash wall. Seedling height growth inside fences inside the slash wall (data not shown) was similar to unfenced seedlings inside the slash wall (Smallidge, Curtis, Chedzoy, Ashdown, unpublished data 2021).

Because the goal of the slash walls is to grow desired vegetation, an index of the absence of deer is the absence of browsing on desired vegetation that allows those desired stems to grow as tall as protected stems under the same conditions. A sampling protocol known as AVID – Assessing the Vegetation Impacts of Deer (Sullivan et al. 2020, Curtis et al. 2021) uses an array of fenced and unfenced plots with tagged seedling to assess height growth. Plots are located inside and outside the slash wall. On harvests larger than a few acres, regrowth of vegetation will become dense and grow above the height of deer within two or three growing seasons. Examples of the types of data available via AVID, for seedlings protected and unprotected by slash walls, help verify the effectiveness of slash walls (Figure 6A and 6B). Note that some species of moderate palatibility, such as sweet birch, may not show strong differences in growth between protected and unprotected sites (Figure 6B).

The primary utility of the slash wall is to exclude deer to allow for natural regeneration processes or enrichment plantings to occur. Other pre- and post-harvest factors may warrant attention. In woodlands with a history of deer impacts, a legacy effect may have created a stable layer of interfering and undesired vegetation. Woodland owners will most likely need to work with their forester and either the logger or a vegetation management specialist to correct any interfering vegetation concerns. Some native and non-native plant species can be uncommon before the harvest, but emerge and dominate after the harvest. A pre-harvest inventory and a post-harvest assessment can help the owner anticipate and respond to situations that need attention. Other sections of this bulletin discuss related activities important to the owner, such as access and roads.

Design Considerations for Slash Walls

Design Considerations

Slash wall design should account for the competing considerations of cost vs. effectiveness. The goal is to build a slash wall that will effectively protect regeneration until desired species can grow beyond the browse height of deer for the least cost per acre. Effectiveness is more important than cost because an insufficient slash wall will result in a wasted investment. Our experience is that slash walls are both the lowest cost and most effective method for protecting regenerating young stands.

Factors Influencing Effectiveness

Slash walls are physical barriers intended to exclude deer from climbing, jumping over or tunneling under or through for as long as is necessary to grow sufficient quantities of desirable seedlings beyond the reach of deer. Effectiveness will depend on a combination of slash wall dimensions and slash wall density over time, and topographical advantage. Season may also influence success in areas where snow or ice might temporarily bridge a slash wall.

The following recommendations will help ensure slash wall effectiveness in excluding deer:

Dimensions

Slash walls at the Arnot Forest are currently built to a minimum height of ten feet to a two-inch diameter stem. Overall height of freshly built slash walls are typically a few feet taller if measured to the smallest branch. Achieving this height typically results in slash walls that average a little over twenty feet wide at the base. Slumping, the settling of the wall, averages 8-14% per year or up to 15 inches. Slumping rate will depend on the density of the slash wall and the type of slash being used. Fine diameter, non-durable rot-prone material will slump more than coarse and durable slash. A slash wall that has slumped well below its original height should remain effective if the base is sufficiently dense and wide to discourage deer from attempting to jump or climb over.

Density

The slash wall's foundation within the first few feet of the ground should be dense to prevent tunneling. Slash walls built at the Arnot Forest have achieved this by laying pole-sized (5-10" diameter and larger) stem material at the base, and then adding more porous and irregular material like tops and limbs to reach the target height. Avoid situations where the large diameter limbs and coarse tops are placed directly on the ground as deer may probe into these spots once the foliage and fine branches are gone.

Topography

Deer are more likely to attempt to jump over a slash wall if they can see into it from an uphill location. Where possible, locate slash walls so that deer approach from a level or downhill perspective to improve effectiveness.

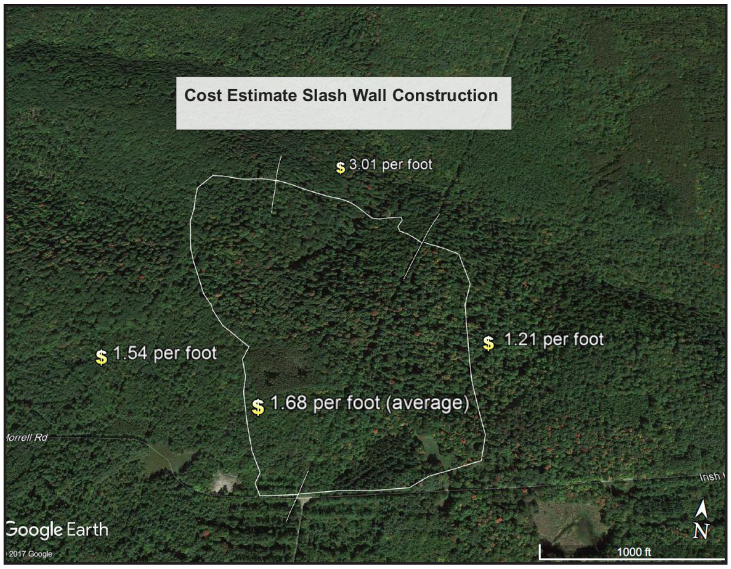

Figure 7: The Gasline Harvest had varied topography which illustrated how the time for construction varied with percent slope.

Costs

Operator variables like experience and equipment, site variables like terrain, timber volume and type, and ground conditions will all affect slash wall construction costs. Additionally, harvest size and shape will have an important influence on the per-acre cost. Consequently, managers must be attentive to these factors during the design and layout of harvests utilizing slash walls.

The following recommendations will help managers reduce slash wall construction costs:

Operator Variables

- Skilled operators will quickly develop proficiency in slash wall building. Inexperienced operators can shorten their learning curve by consulting experienced operators.
- Successfully completed projects around the Northeast have shown that a variety of logging equipment can be used to build slash walls. However, some equipment such as feller-bunchers may allow for the construction of larger slash walls at a lower cost per foot, despite their typically higher cost per operating hour.

Site Variables

- Terrain and ground conditions interact to significantly influence slash wall costs. Some equipment such as a tracked feller-buncher may be able to successfully build slash walls on slopes approaching 40% or more for short distances and only if ground conditions are stable due to dryness or freeze. Nonetheless, the ability of any machine to cut and carry stems to the slash wall will be limited on sites with excessive slope. Control points such as streams, springs, exposed bedrock and gullies will also increase slash wall costs to build, may add costs for maintenance, and may reduce slash wall effectiveness. Thus, these control points should be avoided whenever possible. One of the most prominent cost variables is terrain (Figure 7).

- Stand type, stocking, and utilization will influence slash wall costs. To the extent possible, layout should be concentrated in areas with abundant low-value trees that can be committed to the slash wall. It may be necessary to change the harvest boundary location to ensure sufficient volume to build the slash wall. Species such as beech, hemlock and spruce often have abundant branches and work particularly well, but slash walls can be built from any species.

- The characteristics of slash wall harvests at Arnot Forest from 2017 through 2020 illustrate the range of costs (Table 1). Noteworthy considerations are the proportion of land area under the wall in small harvests, and the cost per acre reductions as harvest area increases.

For some owners, a series of adjacent harvests can be planned to allow future slash walls to utilize a section of a previously built slash wall.

Arnot Forest - Perimeter and Area Summary
of Slash Walls and Mesh Fence Exclosures
P.J. Smallidge and B.J. Chedzoy, revised 4/29/2020
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www.slashwall.info

Harvest Name	Year	Harvest Area (acres)	Harvest Area Perimeter (ft)	Slash Wall Perimeter (ft)	Area Under Wall (acres)	Percentage of Harvest Area Under Wall (%)	Harvest Perimeter per Acre (ft/acre)	Cost per acre of wall at $1.50/ft	Average Biomass in Slash Wall (tons/ac)
Red Pine (RP)	2017	13	3122	3122	1.6	10.8	240	353	48
Gas Line (GL)	2017	74	7452	7452	3.8	4.8	101	148	20
North Gate	2019	160	11025	8588	4.3	2.6	69	79	14
Station Rd. 5-14 (Wedge)	2017	11	2653	2653	1.3	10.9	241	355	48
Station Rd. 5-13 (Boot)	2017	16	3775	3775	1.9	10.6	236	347	47
Recknagel North	2020	6.4	2198	2198	1.1	14.8	343	505	69
Recknagel South	2020	31	5486	5486	2.8	8.2	177	260	35
Patch 1 (experimental)	2019	1	740	740	0.4	27.2	740	1088	148
Patch 2 (experimental)	2019	1	740	740	0.4	27.2	740	1088	148
Patch 3 (experimental)	2019	1	740	740	0.4	27.2	740	1088	148
Camp Ridge	2019*	128	9619	9619	4.9	3.7	75	110	15
Sugarbush - mesh fence	2018	34	4658	4658		0.0	137		
Decker Road	2020	25	5092	5092	2.6	9.3	204	299	41
Slash Wall Total (avg of commercial walls)		467		50,205	(2.7)	(8.5)	(312)	($283)	
All Enclosures Total		501		54,863					

Table 1: Summary of slash wall attributes for commercial and experimental slash walls constructed in 2017 and 2019/2020 at Cornell's Arnot Teaching and Research Forest.

Shape, Size, and Location

- Locate slash walls in stands with adequate volumes of low-grade stocking. One slash wall in a mature stand at the Arnot Forest used an estimated 30 tons of slash greater than 2" in diameter per 100 feet of slash wall. Approximately two-thirds, or 20 tons, of this volume was greater than 6" in diameter (Table 2). A pre-harvest inventory around the prospective boundary can assess the volume available for slash wall building. Note that because of the priority need for a secure slash wall, utilization of material for the slash wall is more important than utilization for other low-value products like firewood, pulpwood and possibly even scragg and low-value sawlogs.
- Avoid acute angles in the slash wall whenever possible, especially where material for the slash wall is less abundant. Circular and square-shaped (with rounded corners) slash walls will be the most efficient designs in terms of linear footage and cost of slash wall per acre.
- Minimize the number of residual trees that are left in close proximity to the wall to reduce obstacles that have to be navigated by the contractor. At the Arnot Forest, we rarely leave residual trees within 50 feet of the wall corridor unless the tree has unique attributes.
- As the area within the slash wall increases, the cost per acre is reduced.
- Utilizing slash walls in a modular fashion for subsequent harvests can significantly decrease costs.

Wood Volume and Weight Estimates for Slash Walls
(note - calculations were based on data from slash walls that were built to specifications of ten feet tall to the smallest branch. Current specifications are for walls that are 10 ft to a 2 inch diameter stem.)

Feet per minute - build time	2.3
Tons per 100 Feet	
tons total hdwd / 100 ft	21.8
tons total conifer / 100 ft	9.5
Tons/100 ft (total)	31.3
tons hdwd >6" / 100 ft	12.4
tons conifer > 6" / 100 ft	9.2
Total Tons/100 ft (hdwd + conifer, >6")	20.6
Cords per 100 Feet (2.5 tons per cord)	
HDWD Cords/100 ft (=2.5 tons per cord, >6")	5.0
Conifer Cords/100 ft (=2.5 tons per cord, >6")	3.7
TOTAL Cords/100 ft (=2.5 tons per cord, >6")	8.2
Cubic Feet (49.5 lbs/cu. ft hardwood, 43 lbs/cu ft conifer)	
Total cubic feet hardwood /100 feet	881.6
Total cubic feet conifer /100 feet	443.2
Cubic feet hardwood > 6" /100 feet	500.9
Cubic feet conifer >6" /100 feet	329.9

Table 2: Estimates of the amount of slash and low-grade wood that were used in wall construction allow for comparison to wood volume estimated by pre-harvest inventory. Table values based on slash walls made to specifications of 10 ft to the highest branch. Note that these values are smaller than current recommendations for slash walls of 10 ft to a 2 inch diameter branch.

Loggers Make the Slash Wall Happen

Logging contractors that have the right skills and equipment – as well as the right mindset - are key partners in successful projects. Slash walls are only effective when they are 100.0% built to specifications. Deer will find and penetrate the weak spots in walls, even though they are a small percentage of the overall length of the slash wall. The best and most practical people for ensuring slash wall effectiveness are the ones doing the work.

Slash wall construction and integrated treatments like understory removal are significant expenditures that deserve to be fairly compensated. Early slash wall efforts at the Arnot Forest were compensated by mutually estimating the required time and deducting it from the sale lump sum. As contractors became more experienced, they were compensated on a flat rate basis using rates developed from both their cost estimates and internal evaluations.

Negotiating and executing a fair deal starts with clear, achievable and enforceable standards that minimize the need for expensive measurements and oversight.

The following recommendations will help managers and contractors meet slash wall construction objectives:

Define minimum acceptable slash wall dimensions and assessment criteria in the contract.

As an example, current slash wall specifications at the Arnot Forest are a minimum of ten feet to a two-inch diameter branch and a minimum of twenty feet wide at the base (Figure 8 & 9). Additionally, the slash wall must be deemed by the forest manager (the seller's agent) to be "sufficiently dense to exclude deer" - meaning that, for example, a few large oak tops loosely thrown together would by themselves be insufficient. Measuring slash wall height during the construction process can be difficult, so marking the target height on adjacent residual trees would reduce judgmental errors (Figure 8).

Figure 8: Private consulting forester Kellen Murphy illustrates his strategy to use his paint gun to place a mark at 10 ft to assist logging contractors in knowing the expected height of the slash wall.

Plan for an adequate slash wall supply zone (WSZ).

The WSZ is the corridor from which material will be sourced to build the slash wall. The main variables that influence WSZ width are the volume ("quantity") and type ("quality") of material that is designated for wall construction. An inadequate WSZ will result in an inadequate slash wall – that is, greater efforts and costs by the contractor to transport material longer distances to the slash wall. As an alternative to using slash from only the WSZ, some contractors have back-hauled tops with a grapple skidder or moved slash from throughout the harvest with a forwarder.

Tools are still in development to estimate WSZ based on readily measurable variables like basal area per acre. A rule-of-thumb currently being used in central hardwood/northern hardwood stands at Cornell University's Arnot Forest to predict the slash wall supply zone is: **WSZ (ft.) = 150 – utilized basal area (sq. ft./ac.)** The basal area of trees with grade sawlogs is excluded from this calculation.

Figure 9: Following on the example given by Kellen Murphy, at the Arnot Forest we used a paint roller and telescoping handle to position marks indicating wall height. In this example, the logger removed the upper portion of the beech trees for use in building the slash wall.

To illustrate a range of examples:

(basal area in sq. ft./ac. dedicated to wall construction)	(estimated wall supply zone width in feet)
25	125
50	100
75	75
100	50

This formula estimates the WSZ, and variation should be expected. Significant variables that influence the accuracy of this simple formula are: stems per acre, crown volume and type (large, flexible branches that bend and remain intact versus rigid branches that may shatter when piled), and the degree of utilization of stem portions of trees (basal area) otherwise designated for the wall.

- An alternative to the WSZ calculations is to use estimates of wall volume as cords, tons or cubic feet and compare to values provided through per harvest inventory (Table 2).
- The slash wall location and length may shift slightly during the project from that originally planned, so compensation should be based on completed results. Contractors should be required to build sections of the slash wall prior to or concurrent with the harvest to reduce risk of costly uncompleted work. Anticipate requests to deviate from the agreed plan due to equipment breakdowns, ground conditions, etc. and be prepared to offer flexible alternatives that ensure adequate outcomes.

- The buyer or general contractor is often not the crew that shows up to do the work. Require that all involved parties meet before the project begins to discuss expectations and agree to corrective protocols. Some foresters have required that prospective bidders watch example videos available at www.slashwall.info to assure they know the expectations of building a slash wall. Deficiencies in slash wall construction should be identified and addressed as quickly as possible to reduce costs to the contractor for moving machinery. If weak spots in the slash wall need additional work, clearly flag the location of the deficiency and specify the necessary corrections.

- For situations that require a competitive bid process to sell the timber, consider dividing slash wall construction from the harvest into separate contracts. This will reduce the risk of discouraging bidders, while allowing for greater control over choosing contractors for slash wall construction. If slash walls are required as part of a lump sum vs. a percentage (mill tally) sale, clearly delineate what timber was sold vs. what should be dedicated to slash wall construction to reduce concerns from the buyer that "their" wood is going in to "your" slash wall.

- At some locations, slash wall construction was included in the harvest prospectus, and bidders were instructed to reduce their bid accordingly. At the Arnot Forest we have directly compensated based on length of wall and acreage of brushing. Slash wall construction rates of 2.2 feet per minute and brushing estimates of 30 minutes per acre were used to estimate payments of services. A cost of $1.50 per linear foot for wall construction and up to $100 per acre for understory for cutting all understory vegetation to ground level are the rates used until January 2022 at the Arnot Forest, though these rates will be adjusted accordingly for inflation for future projects.

- Most loggers generally report no or minimal loss of profit because of the low opportunity cost of the material used to build the walls. Slash wall material is generally of low value or of insufficient value to justify skidding to the landing.

Access, Monitoring and Maintenance

Access

Slash walls should have at least one access point for reasons not limited to future overwood removal and monitoring. The most practical location for openings is usually at the landing and head of the skid road system. Openings are potential weak points in the slash wall and should be gated in a way that preserves access while minimizing risk of failure. Due to the interlaced nature of slash walls, it is easier to incorporate future access openings for equipment during slash wall construction than afterwards.

For future access of logging equipment, leave an opening wide enough for equipment. A method that has worked well on the Arnot Forest slash walls is to stack the butt ends of slash against low-value but sturdy residual trees that are spaced widely enough for the desired opening. The opening can be secured with either sturdy gate material or our current protocol is to plug the opening with slash when the harvest is completed.

For foot traffic by hunters or to assess regeneration response, use a "V-gate" with a lateral total expanse of about 6 feet (Figure 10). The V-gate, similar in concept to a minnow trap, can be integral with the mesh equipment gate, or separate from the equipment gate. At slash walls with only a foot traffic gate, it may be less time consuming to cut the opening with a chainsaw after the harvest rather than by precisely stacking butt ends against two trees. A small wire panel in front of the V-gate reduces the chances of a curious fawn inadvertently wandering inside.

To date, most gates at the Arnot Forest have been made from plastic mesh. They have been surprisingly effective, despite the potential for damage by motivated deer, bear and other wildlife. Regular inspection of access points is important. Tarps, off-set “scare wires”, and brush have been used experimentally to reinforce the mesh, but it is unclear if these additions have improved gate effectiveness. More recently slash is used to plug the equipment access trail after the harvest.

In cases of persistent wildlife damage to gates, more robust and expensive designs and materials could be used, such as welded cattle panels and steel gates. Also, if topography positions deer at a higher elevation than the gate, taller materials will be necessary.

Another situation where openings would be left in the slash wall is at larger stream crossings – especially ones prone to flooding. In the single situation of a slash wall crossing a stream at the Arnot Forest, crossings were chosen that would minimize the opening width while keeping the slash wall above the floodplain. The openings were then gated with a special design intended to allow floodwaters to pass through the lower portion of the gate without damaging the main structure. After significant floods, the gates should be inspected and repaired where needed. These flood gates have proven unreliable, difficult to maintain, and require regular attention. Future slash walls at the Arnot Forest will likely avoid crossing streams with the assumption that the cost to build additional wall is less than inspection and maintenance, plus the potential for access by deer.

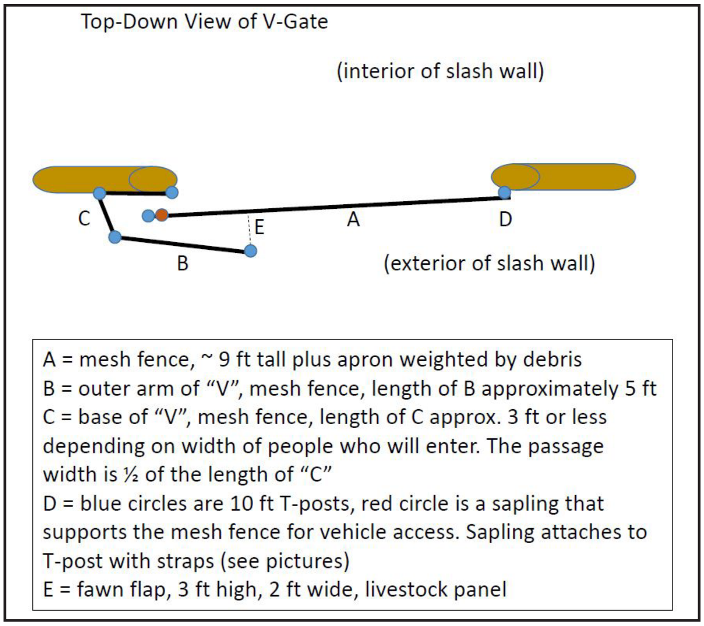

Figure 10: These pictures illustrate the features of access into slash walls. The “V-gate” takes a few hours to install, but allows easy access and no expectation of need to lock the gate. The Arnot Forest has discontinued use of mesh equipment openings, rather plugs with slash which the equipment can remove prior to the next treatment.

Deer Monitoring and Management

Upon completing and closing slash walls around larger harvests, some deer will likely remain trapped inside and should be removed as soon as possible. Deer may also breach the slash wall through undetected weak spots over time. It is important to be alert to potential breaches in the slash wall.

One approach that seems to be effective in minimizing the number of trapped deer is to complete the slash wall prior to or well after fawning season. From late fall to early spring, deer are more likely to seek cover outside of the slash wall during daylight hours.

After the slash wall is closed, practical methods to monitor for the presence of deer are to look for tracks in soft soil along the main skid trails or in fresh tracking snow. Take advantage of the first fresh tracking snow after closing the slash wall to determine if deer remain inside – and if so, determine if they escaped through weak points that can then be reinforced with slash or plastic mesh fence.

If deer need to be removed outside of hunting season, state wildlife managers should be able to issue special permits for that purpose. If this approach is anticipated, start the conversation with the wildlife officials as early as possible to reduce delays in obtaining permission. The longer that trapped deer linger inside, the greater the potential for damage and attracting other deer to breach the slash wall through weak spots like the gates.

To date, no evidence has been observed of deer breaching slash walls that intersect habitual trails. However, for locations where larger exclosures may disrupt heavily used trails, it would be prudent to build a more robust slash wall along those sections.

Some owners, state natural resource agencies, or cost-share sponsors may encourage data collection to verify the effectiveness of the wall. A simple approach is a field method that tags seedlings of the same species inside and outside the slash wall and the owner or forester annually measures seedling height. Approximately 30 seedlings inside and another 30 outside the slash wall are needed for each species. Details of this method, called AVID: Assessing Vegetation Impacts of Deer are available online at http://AVIDdeer.com. Android and iPhone apps simplify data collection.

Figure 11: In some situations, steep topographic features allow for slash walls that exaggerate their height when approached from the downhill side. These designs might allow for a reduction of slash wall height specifications, though testing is ongoing.

Unknown Aspects of Slash Walls

New Applications and Designs for Slash Walls

The initial slash walls at the Arnot Forest were designed and built to a wall height of 10 feet to the highest branch. Because of the rate of slumping observed in the 2017 walls, we have increased our slash wall height to 10 feet to a branch diameter of 2 inches. Free-standing walls that are 10 feet high have averaged 20 feet wide at the base. One of the four slash walls built in 2017 was below our specifications due to having less slash for construction. This harvest now shows evidence of deer presence inside the wall. Motion sensitive cameras suggest that deer continually travel the edges of slash walls and would take advantage of weak sections or tunnels.

Since 2017, a few slash walls were intentionally built to lesser height and width dimensions. These slash walls have not been as effective in excluding deer, though breach points appear to be limited to a few weak spots in the slash walls. Those weak points have since been reinforced with deer netting, and on-going monitoring will determine if these smaller slash walls coupled with some minimal repairs will adequately protect regeneration.

A number of wall design alternatives might be effective, but testing continues. A project done during the winter of 2021-22 at the Arnot Forest will assess slash wall heights x width, harvest area, and residual overstory and understory stocking.

Future testing might assess several potential design considerations that include:

- Lower, wider slash walls. This design may be justified when machinery limitations prevent stacking and piling slash, but where slump-resistant slash can be pushed or dragged into a sufficiently dense windrow. Keys to success: use sufficiently coarse material such as oak and hemlock tops that will retain sufficient height for up to ten years before deer can walk over the top – especially in deep, crusted snow conditions. Compensate for lower height by adding greater width. This may require the same amount of slash and cost.

- Narrower, taller slash walls. A narrower base may result in accelerated slumping. This design may be practical when slash can be more carefully stacked against low-value “support trees” on the perimeter with a negative topographic slope (Figure 11). Specialized equipment such as an excavator with a thumb or a forwarder may be more agile and cost-effective than using a feller-buncher. Keys to success: use poles and finely-branched material that will stack well, and designate an adequate number of support trees to build a stable slash wall. Collapsed sections of slash walls will be costly to repair, so neatness counts.

- Smaller slash walls. These may be effective on small-acreage harvests or where deer pressure is relatively low. This approach may also be sufficient when regenerating fast growing vegetative sprouts (e.g., aspen, black locust) or where well-established advanced regeneration may only require a few years of protection. Keys to success: when in doubt, build a larger slash wall. Down-scaling slash walls to cut costs will be tempting. However, spending a little more to have a slash wall that is successful in establishing regeneration is better than spending a little less on a slash wall that is ineffective.

- Smaller slash walls reinforced by topography. In February 2020, approximately 2,000 feet of six to eight feet tall slash wall was built on the crest of steep slope so that deer would approach the slash wall from the downhill side (Figure 1). The harvest area retained 80 sq. ft. of basal area/acre making little available for the slash wall. In February 2021, two deer breached a weak point that was low and sparse enough for the deer to walk through, as determined by the evidence of fresh tracks. The weak spot was repaired, but deer have found other points of entry. This approach may be justified where topography can be used advantageously, but the slash wall still needs to be sufficient to deter hungry deer. Keys to success: if contractors are allowed to build smaller slash walls in areas where deer seem likely to challenge it, clearly delineate those sections and ensure that slash wall size is adjusted accordingly where not supported by topography.

- Periodically refreshed slash walls. Some pilot projects tested reinforcing slash walls during adjacent subsequent harvests. In these cases, the original slash walls were already at least two years old. Piling new slash on top of previous slash walls appeared to crush the brittle older slash and was deemed counterproductive. Although it remains to be tested, it may be more practical to place new slash adjacent to instead of on top of the existing slash wall for reinforcement. Consider options to harvest in a modular fashion to utilize existing slash walls when still early in their expected life span.

- Slash walls built from non-adjacent slash. Construction costs increase as slash is moved greater distances to the slash wall. However, our experience and estimates from foresters is that slash wall costs are about one-quarter to one-third the installation costs of conventional deer exclusion fences. This margin may allow for slash to be moved greater distances and still be comparatively cost effective.

Other Site-Specific Variables That Determine Slash Wall Success

The bottom-line goal of slash walls is to regenerate a future forest that will have species composition, stem quality, and stocking equal or better than the current stand. Success will require limiting deer impacts and managing interfering vegetation. At the Arnot Forest, we achieve this by excluding deer through the regeneration phase (preparatory treatments, slash walls and eventually sapling release) and controlling interfering vegetation in the understory (brushing). The following list of considerations must also be taken into account for project success:

Figure 12: In the 2017 "Wedge" harvest, this stand was not previously harvested. Accumulated pin cherry seeds germinated and dominated the regeneration. Currently, desired maple seedlings are overtopped, and additional treatments (such as herbicide release) will be necessary before the slash wall slumps to a point of being ineffective.

Timber Markets

The strength of low-grade timber markets can help or hurt slash wall projects. Good markets increase the viability of predominately low-grade harvests and the revenues will help to offset the investments made in slash walls and site preparation. On the other hand, markets that are too strong could create conflict with the contractor who may feel that "too much good wood" is being wasted in the slash wall, especially if the contractor is struggling to meet supply contract obligations. Structure the sale contract so that the slash remains the property of the owner to be used at the owner's discretion in building the slash wall.

Figure 13: In the Recknagel South harvest, logging in November 2019-January 2020 coincided with an abundant acorn crop.

Appropriate Silviculture

In addition to choosing a regeneration system that is both compatible with the management objectives and conducive to slash walls, additional treatments and considerations are likely necessary beyond the usual "good forestry". A common example is removal of understory interference either as an integrated or complimentary operation. Integrated mechanical removal of mostly beech, striped maple and eastern hophornbeam understories by brushing with the feller-buncher hot saw has been an effective approach within Arnot slash walls. The Arnot is fortunate to have few areas with a heavy component of ferns, invasive herbaceous plants like garlic mustard and swallowwort, or invasive shrubs like honeysuckle and buckthorn. Each of these plants present unique challenges and mechanical control may not be sufficient. We have created a matrix to guide the selection of vegetation management tactics (https://bit.ly/2ZuHB4r-FVM-Matrix).

Figure 14: Essentially no advance regeneration was observed during the pre-harvest inventory. Red oak seedlings developed, likely as a result of a mast crop that benefited from soil scarification.

Other prescription-related variables that should be evaluated and addressed include:

- Possible preparatory treatments to establish seedlings prior to initiation of the regeneration harvest and to possibly flush a problematic seed bank before overstory stocking is significantly reduced. An example from the Arnot Forest is pin cherry in areas that were undisturbed for decades prior to harvest (Figure 12).
- Coincidence of harvest with a seed crop - If little desirable regeneration is evident on the ground, then wait until a good seed crop of target species is anticipated. Timing harvests for such events may sound challenging, but droughts may be a trigger event for seed production of

sugar maple in the growing season following the drought. Also, eastern white pine and northern red oak have fruits that mature over two years and allow anticipation of seed crops. The Arnot Forest experienced a severe drought in 2020, and 2021 sugar maple flower production was generally high throughout the region. However, a late frost and severe defoliation by Spongy Moth appeared to significantly reduce seed production.

- Soil scarification - If waiting for a seed rain, germination will be dependent on good seed-soil contact, as well as adequate moisture and temperature for germination. Regeneration sampling efforts will continue to compare "heavy" scarification areas near slash walls to lower scarification sites in the interior of slash walls. However, most mechanical harvesting in the absence of snow packs has the potential to beneficially scarify soil and encourage germination. In a 2019/20 harvest, the winter logging followed an abundant red oak seed crop (Figure 13). Little snow cover was present during harvest, and deer were excluded before they were able to consume an appreciable amount of the acorn crop. High numbers of oak seedlings were present throughout the harvest in subsequent growing seasons (Figure 14).
- Judicious enrichment plantings the first or second spring after completing the harvest and wall construction if pre-harvest inventory suggests that desirable regeneration will be inadequate. Waiting beyond the first growing season may complicate planting and reduce seedling survival.

Summary: Building a Slash Wall

1. Landowners, loggers and foresters need to be committed to building a slash wall that is 100% effective.
2. Assess the impacts of deer on forest vegetation using a proven technique such as AVID (http://AVIDdeer.com) or a plot inventory to monitor browse damage to seedlings of desired species. The absence of seedlings of desired species may suggest a deer impact problem.
3. Look for other factors that might limit successful forest regeneration such as the lack of seedlings of desirable species, poorly drained or infertile soils, or excessive interfering vegetation.
4. Verify that the selected silvicultural treatment is appropriate based on inventory, expert judgement, and decision-making frameworks like "SILVAH" (https://www.nrs.fs.usda.gov/sustaining_forests/conserve_enhance/timber/silvah/)
5. Consider adjoining stands that might be used for slash that could augment slash availability, or that might become isolated by the presence of slash wall and thus best to include in the treatment.
6. Evaluate topography of the harvest boundary. Avoid or minimize the need to cross streams and steep topography.
7. Inventory the stand to determine the volume of low-grade wood and basal area per acre for use in building the slash wall. If insufficient, consider repositioning the harvest boundary for easier access to slash.
8. Mark slash wall position and mark adjacent trees at desired wall height as a visual guide during construction.
9. Develop a contract that clearly identifies slash wall construction standards, the sequence of operations, compensations, and other requirements for the successful outcome of slash wall construction.

Future Research Objectives for Slash Walls

In addition to continued research of the alternatives and questions discussed in the previous two sections, the following are other aspects of slash walls that should be investigated in the future:

1. Succession on the footprints of old slash walls.
2. Differential sequestration of carbon and carbon life cycle analysis inside different types of exclusionary structures (e.g., slash walls, mesh fence, metal wire fence, tree tubes), including the cost per ton of carbon based on installation, maintenance and removal costs.
3. Wildlife use of slash walls as habitat, and habitat quality differences in early successional forest established in the presence and absence of deer. Slash walls are essentially brush piles, but their long, linear pattern may influence wildlife movements, prey patterns and predator patterns.
4. Using slash walls in conjunction with traditional vs. atypical silvicultural harvesting systems (e.g., expanding gap shelterwood, femelschlag, and uneven-aged systems): timing, scale, economics, and construction methods to prolong the effective life span of slash walls. In CT and MA, new slash walls have been built by contractors who intentionally compacted the slash of mostly decay-resistant oak. These walls are expected to have a longer effective life span and will help to deter deer and moose.
5. Modification of silvicultural prescriptions and forest management strategies to facilitate future slash walls and reduce the need for preparatory treatments. More work is needed to develop optimal balances between slash wall construction costs, growth of overstory "crop" trees, and management of understory vegetation. Crown thinning that retains lower crown classes during intermediate treatments may be more beneficial than thinning from below to preserve higher volumes of future slash wall-building material while also reducing the need for costly control of interfering vegetation. Thinning prescriptions might vary with location in the stand based on the anticipated location of the future slash wall.
6. Use of slash walls, or "brush walls" built as a by-product of site preparation to afforest invasive shrublands.

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