

List of potential carbon practices for the Family Forest Carbon Program

Draft list for first stakeholder workshop, February 2020

1. **Avoiding forest conversion**

Actions that reduce the risk of forest conversion, including payment for due diligence costs for land conservation, estate planning (both formal/binding and informal), assistance in enrolling in current use tax programs or registries, and more.

2. **Creating regeneration with complexity**

When forests are undergoing harvests, retention of a minimum number of large-diameter live trees, snags (see NEFF's Exemplary Forestry standards), and live-but-dying trees (future snags), enhancement of coarse woody debris, and limiting gap creation to 15% to no more than 20% of the parcel.

3. **Retaining more carbon in thinnings**

Increased retention of live trees and slash during thinning practices, resulting in greater post-harvest stocking. Retain trees of a diversity of species.

4. **Protecting forest regeneration from herbivory**

Actions to reduce over-browsing and protect regeneration from animal damage. These can include dense slash to protect regeneration following thinning (see "Retaining more carbon in thinnings practice) or gap creation (see "Creating regeneration with complexity" practice). Practices may include use of tree shelters, exclusion fencing, bud capping, or repellent sprays to reduce herbivore damage to desirable regeneration or planted stock.

5. **Extending rotations**

Expanding from one 10-year management plan to two consecutive plans, and delaying planned harvests until the second 10-year plan. Increases post-harvest stocking and enhances recovery from recent poorly planned or carried out management (or disturbance) by allowing for 10 years of additional growth before harvest.

6. **Avoiding salvage logging**

Leaving dead or dying trees following or preceding forest pest outbreaks associated with high tree mortality. For example, leaving hemlock or ash to add carbon to soil and downed wood carbon pools. Also, avoiding salvage logging following severe natural disturbances, (e.g. hurricanes, tornadoes, ice storms).

7. **Establishing reserves**

No harvesting over a 20-year period with intent to continue beyond 20 years (with exceptions for invasive removals or novel outbreaks of forest pests and pathogens). Preference given to sites with high carbon density (may include: soil organic carbon threshold; old growth characteristics — such as all-aged conditions, abundant CWD, large diameter trees) and low vulnerability sites with high species diversity

or species composition with high proportion of future-adapted species. Reserves can cover an entire parcel, or can occur on part of a parcel.

8. Removing competing vegetation

Removal of heavy infestations of invasives that compete with regeneration, either pre- or post-harvest, or both. May include treatments designed to prevent the establishment of invasives (e.g. herbiciding).

9. Adding trees

Tree planting using climate-informed species. May include:

- a. underplanting on understocked sites,
- b. reforestation planting on sites with <25% stocking, including suburban and urban sites
- c. planting in areas severely affected by pests to increase diversity,
- d. afforestation on marginal ag and suitable non-agricultural lands,
- e. Implementing agroforestry practices, with standards for species or planting density/ spacing requirements from above to allow for continued agricultural practices.

10. Maintaining healthy soils

A collection of various practices that aims to reduce soil erosion, maintain or restore soil health, and retain soil moisture and nutrients. Potential practices include:

- a. Winter-only harvests, or use of mats/ timber bridges to protect wet soils
- b. Use of soil amendments during tree planting on nutrient-poor soils, particularly carbon-rich amendments such as biochar, compost, etc.
- c. Minimize logging roads/ landing sites. Locate on stable soils
- d. Retain adequate amounts of slash (following recommendations of Forest Guild Biomass Working Group, 2010)
- e. Chipping woody debris and spreading on-site to accelerate decomposition and soil nutrient availability

11. Reduced-impact logging

Almost always done in concert with maintaining healthy soils practices, this practice refers to lessening collateral damage to residual trees. Reduce collateral damage to trees, directional felling, cut-to-length logging, and potentially practices that reduce damage to saplings and other advance regeneration.

[A 1.5-page background document for each practice is below.](#)

PRACTICE: *Avoiding forest conversion*

Description

Actions that reduce or eliminate the risk of conversion from forest to other land use (especially development). These may include payment for due diligence costs for land conservation, estate planning (both formal/binding and informal), assistance in enrolling in current use tax programs or registries, and more.

What are we paying for?

Payment is designed to change the behavior of the landowner in a way that (either for the 20-year contract period, or permanently) prevents forest loss. This practice requires more discussion and careful thinking from stakeholders. Payment could be for a portion of the economic value that could have been realized through conversion of forest land to another use. Or, in many cases, a landowner does not need to realize the full dollar value they would get from development, but rather needs to cover their conservation costs, and/or realize a portion of the land value.

Key eligibility criteria

- Landowner must have sole ownership of their land, or be able to get written agreement from co-owners that they intend to keep their forest as forest.
- Preference given to land where there is an entity, whether a state or local government, land trust or other non-profit, trust, etc., willing to verify each year that the land remains in forest, and to defend against encroachment or development of the land.

Anticipated Carbon Pool Responses

Carbon benefits from this practice include securing the ability of the land to sequester additional carbon each year, and avoidance of loss of much of the carbon stock currently on the land. Avoided conversion does not, by itself, maintain the entire existing carbon stock within a 20-year time frame, as depending on management, stocks could remain the same, be reduced by harvest or natural disaster or other factors, or increase. Size of the carbon benefit will vary based on forest type, stocking, and age. Soil carbon pools are the least impacted by development, so aboveground live and dead, coarse woody debris, and leaf litter pools are likely to show the biggest increases compared to carbon pools on land that is partially or entirely developed.

Factor	Description and Details
Carbon benefit in 20 years	<i>Maintain all or a portion of carbon stock and add to it every year. All carbon pools expected to increase compared to a development scenario, with smallest increases to soil pools.</i>
Timing of carbon benefit	<i>If land is at imminent risk of development, carbon benefit is immediate. If not, carbon benefit may occur later in the 20-year timeframe.</i>
Risk of failure	<i>Most likely failure is due to development during or after the contract period. Other risks include catastrophic disturbance (especially fire), though carbon stocks can recover after disturbance as long as the response to disturbance is not forest conversion.</i>

Co-benefits	<i>Avoided forest conversion maintains all of the forest benefits: carbon, wildlife habitat, water quantity and quality benefits, economic and recreation benefits, wood products, and more.</i>
Program fit	<i>This is a challenging strategy to consider in the context of the Family Forest Carbon Program. However, since the carbon benefits for this practice likely outweigh those from others, it seems important to include this as an option, and to think creatively about how a financial incentive might change landowner behavior and result in avoided or delayed forest conversion. Can we incent smart growth or cluster development? Better communication of intent to family members? What additional research or analysis could be done to help define this practice?</i>

Approach(es)

NIACS forest carbon management menu: 1.1 Avoid forest conversion to nonforest land uses

Sources:

Analyses of carbon losses from forest conversion are available from Harvard Forest (New England Landscape Futures project, www.newenglandlandscapes.org), The Nature Conservancy and other authors (carbon opportunities from avoided deforestation, in Fargione et al. 2018. Natural Climate Solutions for the United States. <https://advances.sciencemag.org/content/4/11/eaat1869>), Forest Carbon: An essential natural solution for climate change from UMass Amherst and The University of Vermont (<https://masswoods.org/caring-your-land/forest-carbon>) and many other sources.

PRACTICE: *Creating regeneration with complexity*

Description

This practice produces carbon benefits through reduced harvested area with a greater retention of biomass in snags, downed wood, and large diameter trees in harvested gaps. For forests undergoing regeneration harvests, this practice sets guidelines for a) limiting harvested areas to gaps or patches that total no more than 20% of the harvestable area of the parcel, b) within harvested areas, the retention of a minimum number of large-diameter live trees (>18 inches, or greater than mean tree diameter), all snags, and a minimum number of live-but-dying trees that represent future snags (see NEFF’s *Exemplary Forestry in the Acadian Forest* standards), and c) the enhancement of coarse woody debris through the retention of slash, treetops, and other non-merchantable wood, and leaving a portion of low-quality merchantable timber on site, (e.g. chop-and-drop).

What are we paying for?

Payment is to change the behavior of the landowner and forester to retain otherwise merchantable timber. Payment is for a portion of the economic value that could have been realized through more intensive harvesting, including cutting a greater area and more intensive harvesting of both high-value sawlogs and low-value timber. Payment should be made to landowner following confirmation of adequate retention (*would it be appropriate to direct a portion of the payment to the forester and/or harvester to represent lost income?*).

Key eligibility criteria

- Preference for landowner payments is given to sites with high species diversity of retained live trees, particularly of future-adapted species.
- On sites with high invasives establishment potential, this practice must be paired with invasives treatment.
- Eligible forest type is predominantly hardwood forest with conifer component representing <50% of basal area [i.e. want to avoid increasing fuel loads in a fire-adapted system].

Anticipated Carbon Pool Responses

Carbon benefits from this practice include maintaining a greater proportion of carbon following a regeneration harvest from a) limiting the harvested area, and b) the retention of large-diameter trees and the enhancement of dead wood carbon pools from retaining slash, all snags, and a proportion of low-quality trees as either future snags or CWD. Collectively, these actions help to maintain larger carbon stocks on-site compared to their removal, and contribute to long-term storage in soil carbon pools. For unharvested areas, increases in live tree carbon in the system follows patterns of tree growth of regeneration as well as retained or mature stems, and is maintained at a greater level through reduced harvest intensity. Standard growth tables for regeneration and retained trees suggests that harvesting up to 20% of the area of a parcel area, recovery of total live tree carbon stocks to pre-harvest levels across the entire property will likely occur within 20-25 years, depending on forest type and the age of the stand (assuming 80-100 year old stands).

Factor	Description and Details
Carbon benefit in 20 years	<i>Primarily from maintaining greater carbon stocks through reducing harvest area, while retaining a higher proportion of carbon in harvested areas through large-diameter tree</i>

	<i>and coarse woody debris retention; secondary carbon benefits from live tree growth from regeneration.</i>
Timing of carbon benefit	<i>Immediate benefit with reduced harvest area and retention of snags, slash, and legacy trees following harvest. Carbon gains from regrowth in harvested areas will take 15 or more years to be significant.</i>
Risk of failure	<i>Largest risk of failure is from failure of tree regeneration due to herbivory, competing vegetation, or drought impacts to seedlings. Additionally, risk of reversal is possible for natural disturbances or pest and pathogen outbreaks impacting retained trees.</i>
Co-benefits	<i>In many southern New England forests, the CWD carbon pool is comparatively small, and this practice adds significant CWD and retains large diameter trees to create additional structural complexity. Soil moisture and erosion prevention benefits in some cases. Some wildlife benefits for species that regenerate on downed wood, use logs as refugia, or require complex vertical structure that would be expected to develop with a range of downed and dying trees. Preservation of genetic diversity and partially-resistant individuals to given pests/pathogens through live tree retention.</i>
Program fit	<i>There may be some complexity to implementation as there are a number of silvicultural practices that could be implemented under this practice, including but not limited to irregular shelterwoods, selection methods, two-aged variants of clearcutting and seed-tree methods, variable-retention harvesting systems, and variable-density thinning.</i>

Approach(es)

NIACS forest carbon management menu: Approach 6.1-Increase structural complexity through retention of biological legacies in living and dead wood; 6.6-Promote species and structural diversity to enhance carbon capture and storage efficiency;

Sources:

- D'Amato, A.W., Bradford, J.B., Fraver, S., Palik, B.J. 2011. Forest management for mitigation and adaptation to climate change: insights from long-term silviculture experiments. *Forest Ecology and Management* 262:803-816.
- Gunn, J. S., M. J. Ducey, and A. A. Whitman. 2014. Late-successional and old-growth forest carbon temporal dynamics in the Northern Forest (Northeastern USA). *Forest Ecology and Management* 312:40–46.
- Ford, S.E. and W.S. Keeton. 2017. Enhanced carbon storage through management for old-growth characteristics in northern hardwoods. *Ecosphere* 8:1-20.
- Nunery, J.S., Keeton, W.S. 2010. Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management* 259:1363-1375.
- Puhlick, J.J., Weiskittel, A.R., Fernandez, I.J., Fraver, S., Kenefic, L.S., Seymour, R.S., Kolka, R.K., Rustad, L.E., Brisette, J.C. 2016. Long-term influence of alternative forest management treatments on total ecosystem and wood product carbon storage. *Canadian Journal of Forest Research* 46:1404-1412.
- Russel-Roy, E.T., Keeton, W.S., Pontius, J.A., Kerchner, C.D. 2014. Rehabilitation forestry and carbon market access on high-graded northern hardwood forests. *Canadian Journal of Forest Research* 44:614-627.

PRACTICE: *Retaining more carbon in thinnings*

Description

This practice produces carbon benefits through increased retention of live trees and slash during thinning harvests. This practice sets guidelines for maintaining greater post-harvest stocking by a) employing no more than one harvest during the 20-year contract period, and b) retaining 70% or more of pre-harvest basal area (high-grading practices prohibited – no thinning from above), and c) retention all woody debris. Practice guidelines will emphasize the importance of diversity of species in retained trees, particularly those that are future-adapted. This practice applies to forests subject to mid-rotation thinnings.

What are we paying for?

Payment is to change the behavior of the landowner/forester to retain additional basal area and is for the lost economic value from reduced harvest intensity of higher-value timber (Business-as-usual scenario is characterized as thinning from above to ~60% BA). Payment should be made to landowner following confirmation of adequate BA retention and meeting the required levels of diversity of retained trees. (*Would it be appropriate to direct a portion of the payment to the forester and/or harvester to represent lost income?*)

Key eligibility criteria

- Property has a forest management/stewardship plan
- Eligible forest type: predominantly hardwood forest with conifer component representing <50% of basal area [e.g., don't increase fuel loads in a fire-adapted system]

Anticipated Carbon Pool Responses

Retaining most of the basal area in the largest diameter trees maintains a greater proportion of carbon in tree biomass relative to BAU, which will continue to accrue throughout the duration of the contract. Thinning reduces competition in overstory trees, providing benefits for enhancement of forest productivity and greater rates of sequestration of carbon in live tree biomass.

Factor	Description and Details
Carbon benefit in 20 years	<i>AFF/ TNC provided extensive modelling of this practice for the Central App region showing that the combination of thinning from below and higher BA retention provides a strong enhancement of carbon over a BAU scenario. Higher rates of retention provide stronger carbon benefits.</i>
Timing of carbon benefit	<i>Continuous over the 20 years compared to BAU.</i>
Risk of failure	<i>Risk of reversal is primarily from development of unprotected land or a return to BAU forestry practices after program ends</i>
Co-benefits	<i>Late seral structure is a rare or missing feature in many parts of the landscape; this practice should build resilience by retaining most species present, with an emphasis on future-adapted species, as well as allowing for the development of older, larger trees most resistant to drought impacts.</i>
Program fit	<i>Being used in central apps</i>

Approach(es)

NIACS forest carbon management menu: 6.1-Increase structural complexity through retention of biological legacies in living and dead wood; 6.2-Increase stocking on well-stocked or understocked forest lands; 6.6-Promote species and structural diversity to enhance carbon capture and storage efficiency

Sources:

- D'Amato, A.W., Bradford, J.B., Fraver, S., Palik, B.J. 2011. Forest management for mitigation and adaptation to climate change: insights from long-term silviculture experiments. *Forest Ecology and Management* 262:803-816.
- Evans, A.M., Perschel, R. 2009. A review of forestry mitigation and adaptation strategies in the Northeast U.S. *Climatic Change* 96(1-2):167-183.
- Hoover, C.M., Stout, S. 2007. The carbon consequences of thinning techniques: stand structure makes a difference. *Journal of Forestry* July/August: 266-270.
- Mika, A.M., Keeton, W.S. 2015. Net carbon fluxes at stand and landscape scales from wood bioenergy harvests in the US Northeast. *Global Change Biology Bioenergy* 7:438-454.
- Nunery, J.S., Keeton, W.S. 2010. Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management* 259:1363-1375.
- Puhlick, J.J., Weiskittel, A.R., Fernandez, I.J., Fraver, S., Kenefic, L.S., Seymour, R.S., Kolka, R.K., Rustad, L.E., Brisette, J.C. 2016. Long-term influence of alternative forest management treatments on total ecosystem and wood product carbon storage. *Canadian Journal of Forest Research* 46:1404-1412.

PRACTICE: *Protecting forest regeneration from herbivory*

Description

This practice produces carbon benefits through improved forest productivity from enhanced regeneration in stands impacted by herbivory from deer and/or moose. Actions under this practice aim to reduce over-browsing and protection of regeneration from herbivore damage. Future-adapted tree species should be targeted for protection. These actions can include:

- a. utilizing dense slash to protect regeneration following thinning (see “Retaining more carbon in thinnings practice) or gap creation (see “Creating regeneration with complexity” practice)
- b. fencing, either perimeter fencing or small-scale (<50m²) exclusions¹ that protect a minimum of 100 trees per acre (fencing is also necessary when high canopy cover produces low-light condition as shelters will not provide adequate sunlight for seedling growth)
- c. use of tree shelters unless occurring on less than 5 acres or greater than 400 trees per acre² (barriers must be maintained, including sealing removable shelters and tree tubes to the ground, for a minimum of three (*preferably five?*) growing seasons, with mesh netting placed over tree tubes to prevent entrapment of songbirds, and to reduce wasp and bee nests from forming (eventual removal of mesh to prevent damage to the emerging terminal leader will be necessary))
- d. use of bud capping, or other physical barriers used to reduce herbivore damage to either desirable regeneration or planted stock until trees are above the browse line

What are we paying for?

Payment is to change forester and/or harvester behavior to actively protect advance regeneration from deer or moose browse. Payment offsets a portion of the costs associated with purchasing materials needed for seedling protection and the labor involved in the installation and maintenance of tree protection. Protection from herbivory increases stand-level forest carbon stocks through the enhancement of survival of desired tree regeneration of planted stock and natural regeneration.

Key eligibility criteria

Practices necessary for protecting forest regeneration from herbivory may apply across a variety of forest conditions, and eligibility requirements will differ accordingly.

- Preference for landowner payments is given to sites with high species diversity of regeneration, particularly of future-adapted species.
- Highly invaded forests (*e.g.* dominated by invasives) may not be appropriate for payments without additional treatment to remove invasives that further limit forest regeneration and tree growth.

Anticipated Carbon Pool Responses

Carbon pool responses will depend on forest conditions. When slash is retained following harvest, there is an immediate transfer of carbon from live trees to coarse woody debris, which will maintain greater carbon on-site compared to removal of slash. For both harvested and unharvested sites, carbon gains in the system follow patterns of tree growth of regeneration and/or planted stock as well as retained or mature stems. Significant growth of regeneration and/or planted stock may take 15 or more years in order to contribute to measurable carbon benefits at the site.

Factor	Description and Details
Carbon benefit in 20 years	<i>Primarily live tree from enhanced regeneration, with potential to retain some carbon following harvest through coarse woody debris retention.</i>
Timing of carbon benefit	<i>Immediate benefit if slash is retained following harvest. Carbon gains from growth of regeneration will take 15 or more years.</i>
Risk of failure	<i>Largest risk of failure is from failure of tree protection, e.g. from animal damage to shelters, inability of slash to reduce herbivory. Additional factors that could result in less carbon gain than anticipated, includes pest and pathogen outbreaks, competing vegetation, or drought impacts to seedlings.</i>
Co-benefits	<i>This practice allows for enhancement of CWD and structural complexity through additional age cohorts. Wildlife benefits for species that regenerate on downed wood or use logs as refugia.</i>
Program fit	<i>This practice addresses a widespread and significant issue affecting many forests in the region: a marked deficit of regeneration where deer and moose densities are highest. Protection of advanced regeneration is relatively expensive practice and thus is not widely practiced, providing payments to landowners to implement may be expected to be easy to implement but economic analysis may be necessary to determine a price that may elicit behavior change given that payments will not likely be able to cover all costs. Additional modeling analyses may be needed to determine minimum density of trees (TPA) needed to affect carbon stocks over the 20 year time frame.</i>

Approach(es)

NIACS forest carbon management menu: Approach 4.3-Protect future-adapted seedlings and saplings.

Footnotes:

¹Martin, K. 2006. Can small deer exclosures work? Woodland Management [<http://www.deerandforests.org/resources/Can%20small%20deer%20enclosures%20work.pdf>]

²Jacobson, M. 2006. Fencing for Forest Regeneration: Does it Pay? Penn State Extension [<https://extension.psu.edu/forest-finance-2-fencing-for-forest-regeneration-does-it-pay>]

Sources:

Walck, J.L.; Hidayati, S.N.; Dixon, K.W.; Thompson, K.; Poschlod, P. 2011 . Climate change and plant regeneration from seed. *Global Change Biology*. 17: 2145-2161.

Tanentzap, A.J., Coomes, D.A. 2011. Carbon storage in terrestrial ecosystems: do browsing and grazing herbivores matter? *Biological Reviews* 87:72-94.

PRACTICE: *Extending rotations*

Description

This practice increases carbon in all pools by delaying a planned harvest and allowing for at least 10 years of additional growth. Practice involves employing two consecutive 10-year forest management plans that allow for one harvest in the second 10-year period. Harvest may be any of the other practices within the Family Forest Carbon Program. Landowners must be able to show that a harvest was originally planned (referenced in their management plan or other documents) within the first 10 years of the contract period. Preference might be given to forests that have undergone a recent (last 20 years) poorly planned or overly aggressive harvest (e.g. highgrade), but that are not in such poor condition that 10 years of growth won't allow for significant recovery.

What are we paying for?

Payment is to change the behavior of the landowner/forester to extend the time between harvests. Payment is for the delayed realization of economic value from harvest. Payment might be split between landowner and forester, to account for delayed income for both parties.

Key eligibility criteria

- Forest has history of logging in past 20 years (actively managed forest)
- Property has a forest management/stewardship plan that includes a planned harvest within the next 10 years
- Eligible forest type: Need more refinement here: preference in payment should likely be given to forests that would show highest carbon benefit from a period of recovery, due to recent past harvest or disturbance
- Forest is not covered by a deed restriction, conservation easement, or other encumbrance that does not allow harvesting

Anticipated Carbon Pool Responses

Delaying harvesting, by extending rotations by a number of years increases the number of large trees relative to business as usual harvesting. The live tree biomass carbon pool will increase over the life of the program/contract. For forests with a very short rotation interval, extending rotations may also allow for recovery of soil nutrients and soil carbon to some extent.

Factor	Description and Details
Carbon benefit in 20 years	<i>AFF/ TNC provided extensive modelling of this practice for the Central App region, but we need to work to separate the extended rotation from their modeling of a particular type of thinning after 10 years.</i>
Timing of carbon benefit	<i>Continuous over the 20 years, with bigger benefit if harvest was imminent and is now delayed.</i>
Risk of failure	<i>Risk of reversal is primarily from development of unprotected land or a return to BAU forestry practices after program ends.</i>
Co-benefits	<i>This practice should build resilience by allowing for the development of older, larger, trees, and for the a 10-year period of addition to the coarse woody debris pool. The 10-year</i>

	<i>delay also allows for careful thinking and planning around forests that may have heavy invasive cover or other threats that may not have been considered in the original planned harvest.</i>
Program fit	<i>Being used in central apps, though the only forestry practice allowed in years 10-20 is a thinning with significant retention of basal area. There are some questions about this practice relating to program fit. We likely need more research into how this might conflict with a 10-year planning period for current use programs, and if the carbon benefits are so varied based on the choice of eventual harvest that calculation of payment is not possible.</i>

Approach(es)

NIACS forest carbon management menu: 2.1 Reduce impacts on soils and nutrient cycling 6.2-Increase stocking on well-stocked or understocked forest lands; 6.6-Promote species and structural diversity to enhance carbon capture and storage efficiency

Sources:

Nunery, J.S., Keeton, W.S. 2010. Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management* 259:1363-1375.

Two unpublished literature pieces (thesis and white paper) provide useful modeling information and considerations:

Foley, T. 2009. Extending Forest Rotation Age for Carbon Sequestration: A Cross-Protocol Comparison of Carbon Offsets of North American Forests. (Unpublished Master's thesis), Duke University, NC. 51p.

Sohnngen, B., and Brown, S. 2006. The cost and quantity of carbon sequestration by extending the forest rotation age. AED Economics, Ohio State University, Columbus. 34p.

PRACTICE: *Avoiding salvage logging*

Description

This practice produces carbon benefits through enhancement of standing dead and coarse woody debris carbon pools associated with disturbance events of tree mortality. Leaving dead or dying trees following or preceding forest pest outbreaks associated with high tree mortality. For example, leaving hemlock or ash to add carbon to soil and downed wood carbon pools. Similarly, avoiding salvage logging following a severe natural disturbance (e.g. hurricane, tornado, ice storm).

What are we paying for?

Payment is to change the behavior of the landowner in the aftermath (or immediately before) significant tree mortality. Payment is for a portion of the economic value that could have been realized through a salvage logging operation, and is instead foregone by the landowner and their team. Payment should be made to a landowner after a documented natural disturbance or insect pest outbreak and a signed commitment to leave all downed, standing dead, and live trees of the impacted species/area. For landowners with an existing management plan that would have resulted in harvest of some of the impacted trees within 10 years of the avoided salvage logging, it may be appropriate to direct a portion of the payment to the forester and/or harvester to represent lost income.

Key eligibility criteria

- Presence of a significant forest pest and/or pathogen outbreak on the forest in question, OR in adjacent area and predicted to expand to the forest in question.
- Alternatively, a forest that has been impacted by a severe natural disturbance (wind, ice, drought) in a way that has caused or will soon cause significant mortality.
- This practice is not appropriate for novel outbreaks of pests or pathogens, where swift action and quarantine might stop the spread of the outbreak.
- For fire-dependent forest systems, forests on the urban/wildland interface may not be appropriate sites.
- Removal of trees that threaten public safety (will block roads as they fall, or damage property, e.g.) would not make a landowner ineligible for payment.

Anticipated Carbon Pool Responses

There is an almost immediate benefit to the standing dead and coarse woody debris pools, with a somewhat more delayed benefit to the soil carbon pools. Depending on the circumstances, there could also be benefits to carbon in aboveground live trees if advanced regeneration is protected from browse by significant downed wood, or if trees assumed to die instead continue to survive.

Factor	Description and Details
Carbon benefit in 20 years	<i>Standing dead, coarse woody debris, and soil carbon pools.</i>
Timing of carbon benefit	<i>Nearly immediate upon implementation of the practice after a natural disturbance, more varied when in response to a pest/pathogen outbreak.</i>
Risk of failure	<i>Risk of reversal is primarily from violation of the agreement or transfer of the land without adequate communication, that could result in a salvage logging harvest very similar to that which was avoided. Fire also represents a reversal risk. If a pest/pathogen is expected to travel to the forest in question, but never does, this also represents a risk of failure.</i>
Co-benefits	<i>In many southern New England forests, the CWD carbon pool is comparatively small, and this practice adds significant CWD and some missing late-seral structure. Soil moisture and erosion prevention benefits in some cases. Some wildlife benefits for species that regenerate on downed wood, use logs as refugia, or require complex vertical structure that would be expected to develop with a range of downed and dying trees. Preservation of genetic diversity and partially-resistant individuals to given pests/pathogens.</i>
Program fit	<i>Likely requires economic modeling to determine fit. The practice is relatively simple to implement and monitor, but there are questions about the ability of a small incentive payment to change behavior when compared to the larger economic return of salvage logging.</i>

Approach(es)

Crosswalk to NIACS forest adaptation menu: 6.1 Increase structural complexity through retention of biological legacies in living and dead wood.

Sources

Orwig, D.A. and D.B. Kittredge. 2005. Silviculture Options for Managing Hemlock Forests threatened by Hemlock Woolly Adelgid. pp.

7. https://harvardforest.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/Orwig_HWA_fact_sheet_2005.pdf

Santoro, J. A., and A. W. D'Amato. 2019. Structural, compositional, and functional responses to tornado and salvage logging disturbance in southern New England hemlock-hardwood forests. *Forest Ecology and Management* 444:138-150.

<https://www.uvm.edu/rsenr/tonydamato/pubpdfs/Santoro%20and%20D%27Amato%20FEM%202019.pdf>

PRACTICE: *Establishing reserves*

Description

This practice produces carbon benefits through increased total forest carbon stocks from eliminating biomass removal from harvest activities. No harvesting, and a commitment not to convert from forest to other land use/cover, over a 20-year period with intent to continue beyond 20 years (with exceptions for invasive removals or novel outbreaks of forest pests and pathogens). Reserves can cover an entire parcel, or can occur on part of a parcel through enhanced or wider riparian/wetland buffer strips beyond legal requirements and best management, or through foregoing management on a portion of a harvestable area.

What are we paying for?

Payment is to change the behavior of the landowner to avoid all commercial timber harvesting. Payment is for a portion of the economic value that could have been realized through timber harvest, and is instead foregone by the landowner and their team. Payment also covers some of the less visible costs of documenting and communicating the intent to establish a reserve, such as estate planning, boundary marking, or other stewardship costs.

Key eligibility criteria

- Young forest (stand age less than 20 years) is generally not eligible.
- If the reserve is over only a portion of the ownership, must include a significant amount ($>1/3$ (*?open for discussion?*) of otherwise harvestable area.
- Preference for landowner payments is given to sites with high carbon density (proxies might include above-average amounts of coarse woody debris and large-diameter trees, older forests (greater than 100 years), or fully stocked forests on prime forest soils).
- Preference for landowner payments is given to low vulnerability sites, e.g. intact, interior forests and forests with high species diversity including future-adapted species.
- Highly degraded forests (e.g. dominated by woody invasives with little to no advance regeneration, or stands where multiple rounds of highgrading has left understocked forest with key species missing) may not be appropriate sites for payments to landowners given a disconnect between assumed rates of growth and amounts of carbon accumulation (used to calculate payments) and actual growth/C accumulation.

Anticipated Carbon Pool Responses

Relatively large, relatively old trees are anticipated to add a large amount of carbon stock over 20 years of growth. Without removals from harvesting, most carbon pools would be expected to increase, especially coarse woody debris and aboveground live and dead biomass pools.

Factor	Description and Details
Carbon benefit in 20 years	<i>Most carbon pools would be expected to increase. If site includes relatively large, old trees, the aboveground live biomass and coarse woody debris pools would be expected to increase significantly.</i>
Timing of carbon benefit	<i>Constant throughout the measurement period.</i>
Risk of failure	<i>Largest risks of failure are from conversion of forest land (violating the contract), or fire. There are many other factors that could result in less carbon gain than anticipated, including natural disasters and pest and pathogen outbreaks.</i>
Co-benefits	<i>Late seral forests are missing from most parts of southern New England. This practice allows for some recovery of CWD and missing late-seral structure including large-diameter trees. Some wildlife benefits for species that regenerate on downed wood, use logs as refugia, nest/live in snags, or require complex vertical structure that would be expected to develop with a range of downed and dying trees. Water quality and quantity benefits as forests filter pollutants from water and slow the movement of water through soils.</i>
Program fit	<i>This practice is relatively easy to implement but it will be important to determine a way for landowners to declare their intent not to simply delay planned harvest or conversion and take those actions immediately after the contract ends. Will likely be challenging to determine a price for this practice. It is important, given likely much higher demand than funding, to prioritize where reserves are established. Benefits will be greater if reserves are on forests that already have at least average, and ideally higher than average, carbon density. Landscape context is also important, since many regional-scale conservation plans aim for ~25% of the landscape in either wildlands management and/or older forest age classes. A landscape in which nearly all forests were reserves could have unintended carbon consequences due to changes in supply and demand of forest products.</i>

Approach(es)

Crosswalk to NIACS forest adaptation menu: 5.2 Establish reserves on sites with high carbon density.

Sources

Anderson, M.G. 2019. *Wild Carbon: A synthesis of recent findings*. Northeast Wilderness Trust. Montpelier, VT USA. <http://www.newildernesstrust.org/wild-carbon/>

Ford, S.E. and W.S. Keeton. 2017. Enhanced carbon storage through management for old-growth characteristics in northern hardwoods. *Ecosphere* 8:1-20.

PRACTICE: Removing competing vegetation

Description

This practice increases stand-level forest carbon stocks through improved forest productivity and enhanced survival of desired tree regeneration of planted stock and natural regeneration following removal of competing vegetation. Removal of heavy infestations of invasive plants or cover of otherwise undesirable vegetation that compete with regeneration, either pre- or post-harvest, or both. May include treatments designed to prevent the establishment of invasives (e.g. herbiciding) following natural disturbances or harvests. Removal of competing vegetation

What are we paying for?

Payment is to change landowner and/or forester behavior to take deliberate actions to remove invasive plants or native plants that are over-abundant and threaten forest growth, and/or prevent an increase in the abundance and cover of those plants after harvest. Payment is for a portion of the costs associated with materials and labor associated with treatment of competing vegetation.

Key eligibility criteria

- Presence of a significant population of invasive or native competing vegetation within the forest in question, OR in adjacent area and predicted to expand to the forest in question.
- Alternatively, a forest that has been impacted by a severe natural disturbance (tornado, hurricane) in a way that has caused or will soon cause significant risk of invasion.

Anticipated Carbon Pool Responses

Carbon pool responses will depend on forest conditions. Carbon benefits could include enhanced forest productivity from reduced competition for limiting nutrients or soil water, particularly during periods of growing season drought. Enabling greater regeneration and enhancing growth of seedlings and sapling through reduced competition will increase live tree carbon pools over time.

Factor	Description and Details
Carbon benefit in 20 years	<i>Primarily from enhanced live tree growth in mature trees and increased growth from regeneration</i>
Timing of carbon benefit	<i>Little immediate benefit beyond potentially more understory carbon. Timing of carbon gains from enhanced forest productivity may be variable depending on species composition and occurrence of other stressors, however it is likely to take >5 years; benefits to live tree carbon pools from enhanced regeneration may take 15 or more years to be significant.</i>
Risk of failure	<i>Largest risk of reversal is from failure of tree regeneration due to herbivory, drought impacts, or other stressors. Additionally, risk of reversal is possible for natural disturbances or pest and pathogen outbreaks impacting mature trees.</i>
Co-benefits	<i>In many areas of southern New England, invasive plant species is a predominant factors in degraded habitat quality. Removal of invasives would benefit native plant species and increase habitat values for wildlife and pollinators. In riparian areas on slopes, restoring native plant communities can reduce soil erosion and sedimentation of stream and degradation of aquatic habitat as well.</i>

Program fit	<i>The practice is relatively simple to implement and monitor, but there are questions about the ability of a small incentive payment to impact populations of invasives, which can represent a persistent problem at both established sites as well as at new sites, if adjacent populations are present or there is persistent a source of propagules. Additionally, there may be question regarding the timing of carbon benefits.</i>
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Approach(es)

NIACS forest carbon management menu: 2.5-Reduce competition for moisture, nutrients, and light

Sources:

- Dwyer, J.M., Fensham, R., Buckley, Y.M. 2010. Restoration thinning accelerates structural development and carbon sequestration in an endangered Australian ecosystem. *Journal of Applied Ecology* 47: 681-691.
- Bottero, A., D'Amato, A.W., Palik, B.J., Bradford, J.B., Fraver, S., Battaglia, M.A., Asherin, L.A. 2017. Density-dependent vulnerability of forest ecosystems to drought. *Journal of Applied Ecology* 54:1605-1614.

PRACTICE: *Adding Trees*

Description

This practice produces carbon benefits through increasing stocking levels from planting trees using a diversity of appropriate climate-informed species. Planting activities may occur on a variety of site conditions, including reforestation, afforestation, understocked stands, as well as implementation of agroforestry practices on appropriate agricultural lands. Where appropriate, this practice would also allow for passive reforestation to occur. For example, allowing for tree and woody shrub establishment to occur through natural succession following cessation of management (*i.e.* mowing of herbaceous vegetation).

What are we paying for?

Payment is to change landowner behavior to plant trees or to stop mowing/clearing and allow natural succession. Payment is for a portion of the costs associated with the procurement of planting stock and labor associated with tree planting and follow up activities needed for effective seedling establishment. For tree plantings on marginal agricultural sites or agroforestry on existing agricultural lands, payment additionally covers the lost potential economic value when lands are taken out of production. Payments would additionally reflect cost-share potential through NRCS for accepted Conservation Practice Standards applicable to the landowner based on location. Payments to a landowner should be split over the 20 year contract period: 1) after initial tree planting activities are completed, and 2) after a period of no less than two years following planting in order to meet seedling establishment criteria.

Key eligibility criteria

- Stands that are determined to be understocked: stocking levels between 25 to 60%.
- Reforestation on sites with <25% stocking
- Sites could include those where presence of a significant forest pest and/or pathogen outbreak has occurred within <10 years, and planting is needed to restore species diversity.
- When trees are planted on agricultural lands to convert them to forest, they must be marginal lands (e.g. floodplains), not highly productive lands.
- All agricultural lands eligible for agroforestry practices such as establishment of wind breaks, riparian forest buffers, silvopasture, or alley cropping.

Anticipated Carbon Pool Responses

Carbon responses to tree planting typically follows patterns of live tree growth. For sites with recently established trees, significant additional live tree growth (not as a result of growth in pre-existing vegetation) may take 10-15 years in order to contribute to measurable carbon benefits at the site. However, with proper site preparation and post-planting maintenance, the benefits to live aboveground carbon pools may be significant by years 20. Even greater carbon benefits would be expected in the decades beyond year 20 as trees mature in not only the live tree (aboveground and belowground) carbon pool, but additionally to forest floor and coarse

woody debris pools as well. Depending on the circumstances, tree plantings on agricultural lands may additionally produce significant long-term (>20 years) carbon sequestration with mineral soil carbon pools.

Factor	Description and Details
Carbon benefit in 20 years	<i>Primarily live tree; potential for coarse woody debris and forest floor.</i>
Timing of carbon benefit	<i>Varied, will typically take ~15 years</i>
Risk of failure	<i>Primarily from seedling establishment failures. Additional measures will likely be required to reduce this risk, including protection of seedlings from herbivory and on some sites, reducing competition from herbaceous vegetation during the establishment period.</i>
Co-benefits	<i>There are significant benefits for tree planting in agricultural sites, including benefits to wildlife species that require young forest conditions, improvements to water quality and soil erosion rates in adjacent water bodies, and improvement of aquatic habitat. Depending on tree species used, there may be benefits for pollinators as well. Reforestation and underplanting in existing forests can provide additional benefits to wildlife, particularly forest bird species, through additional structural complexity and species diversity.</i>
Program fit	<i>Likely requires economic modeling to determine fit. The practice is relatively simple to implement and monitor, but there are questions about the ability of a small incentive payment to offset the relatively large costs associated with tree planting and follow up maintenance. Additional analysis would be required to determine how to best complement existing NRCS Conservation Practices Standards for certain sites (e.g. agroforestry practices).</i>

Approach(es)

Crosswalk to NIACS forest carbon management adaptation menu: 1.2-Reforest lands that have been deforested and afforest suitable lands; 1.4-Increase or implement agroforestry practices

Sources

- Smith, James E.; Heath, Linda S.; Skog, Kenneth E.; Birdsey, Richard A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. GTR NE-343. Newtown Square, PA: USDA, Forest Service, Northeastern Research Station. 216 p.
- Fargione, J.F., Bassett, S., Boucher, T., Bridgham, S.D., Conant, R.T., et al. 2018. Natural Climate Solutions for the United States. Science Advances 4 : eaat1869.
- Nave, L.E., Domke, G.M., Hofmeister, K.L., Mishra, U., Perry, C.H., Walters, B.F., Swanston, C.W. 2018. Reforestation can sequester two petagrams of carbon in US topsoils in a century. Proceedings of the National Academy of Science of the United States www.pnas.org/cgi/doi/10.1073/pnas.1719685115

PRACTICE: *Maintaining healthy soils*

Description

This practice provides carbon benefits either through protection against soil carbon losses or the enhancement of soil organic matter. This practice is a collection of various on-the-ground tactics that collectively or individually aim to reduce soil erosion, maintain or restore soil health, and retain soil moisture and nutrients. All actions that are determined to be needed to reduce risks to protecting soils during or following a scheduled harvest should be implemented. Potential actions within this practice include:

- a. Winter-only harvests, or if harvests are conducted on non-frozen ground, the use of mats/ timber bridges to protect wet soils
- b. Use of soil amendments during tree planting on nutrient-poor or drought-prone soils, particularly carbon-rich amendments such as biochar, composted manure, etc.
- c. Minimizing logging roads/ landing sites during harvests. Additionally, these should be located on stable soils when possible. Restoration (ripping to reduce compaction, seeding to stabilize soils and prevent invasion) of landing sites, temporary roads, and skid trails should occur as necessary.
- d. Retain adequate amounts of slash (following recommendations of Forest Guild Biomass Working Group, 2010)
- e. Chipping woody debris and spreading on-site to accelerate decomposition and soil nutrient availability.

What are we paying for?

Payment is to change the behavior of the harvester and forester in ways that protect and restore soil health. Payment is for offsetting a portion of the costs associated with any of the above soil protection or site restoration activities. A portion of payments may be directed to the harvester to offset lost revenue if there are additional costs associated with implementing soil protection measures.

Key eligibility criteria

Practices necessary for protecting forest soils may apply across a variety of forest conditions, and eligibility requirements will differ accordingly.

Anticipated Carbon Pool Responses

Carbon pool responses will be strongly dependent on forest conditions and specific tactic implemented. Actions taken to prevent erosion and degradation of soil quality, such as soil compaction, will primarily prevent the loss of existing soil organic carbon stocks. When slash is retained following harvest, there is an immediate transfer of carbon from live trees to coarse woody debris, which will maintain greater carbon on-site and maintain or enhance soil organic carbon pools as wood residues decompose. Soil organic carbon is a key component of maintaining soil health and provides a positive long-term (>10 years) feedback to carbon gains in other forest ecosystem carbon pools, particularly live tree growth resulting from maintaining soil nutrients and water holding capacity. Long-term carbon gains follow patterns of tree growth at the site.

Factor	Description and Details
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Carbon benefit in 20 years	<i>Primary benefits occur through the prevention of loss of soil organic carbon stocks, in addition to retaining or enhancing on-site carbon through slash retention and soil amendment applications (amendments would be expected to produce small carbon gains in the system relative to other benefits). Additional carbon benefits may occur through maintaining or enhancing forest regeneration and productivity resulting from improvements to soil quality</i>
Timing of carbon benefit	<i>Immediate benefits for actions that prevent soil degradation and subsequent carbon losses, in addition to slash and harvest residue retention. Immediate to near-term benefits would be expected from application of soil amendments. Carbon gains from enhanced forest growth and regeneration would be expected to be longer term (e.g. 15 or more years).</i>
Risk of failure	<i>Largest risk of failure is from failure of to implement practices. Many of these practices are considered BMP's for soil protection and standards have been developed for adequate implementation, thus risk is low. Increasing frequency of extreme storms with heavy precipitation could present a risk of failure of some actions to adequately protect from erosion.</i>
Co-benefits	<i>Co-benefits include maintaining or improving habitat quality for wildlife, improving water quality and aquatic habitat.</i>
Program fit	<i>This practice addresses a need for further incentivizing BMPs for soil protection, and on some sites or scenarios, a need to go beyond typical BMPs for soil protection to include tactics that are not typical for forest management plans (e.g. use of soil amendments for enhancing survivability of plants stock).</i>

Approach(es)

NIACS forest carbon management menu: 2.1-Reduce impacts to soils and nutrient cycling; 2.2-Maintain or restore hydrology; 4.1-Promptly revegetate sites following disturbance.

Sources:

Ellison, D., Morris, C.E., Locatelli, B., Sheilg, D., Cohen, J., Murdiyarso, D., et al. 2017. Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* 43:51-60.

Hoover, C.M. 2011 Management impacts on forest floor and soil organic carbon in northern temperate forests of the US. *Carbon Balance and Management* 6:17.

Johnson, D.W. 1992. Effects of forest management on soil carbon storage. *Water, Air, and Soil Pollution* 64:83-120.

Nave, L.E., Vance, E.D., Swanston, C.W., Curtis, P.S. 2010. Harvest impacts on soil carbon storage in temperate forests. *Forest Ecology and Management* 259:857-866.

Nave, L.E., DeLyser, K., Butler-Leopold, P.R., Sprague, E., Daley, J., Swanston, C.W. 2019. Effects of land use and forest management on soil carbon in the ecoregions of Maryland and adjacent eastern United States. *Forest Ecology and Management* 448: 34-47.

PRACTICE: *Reduced-impact logging*

Description

Almost always done in concert with maintaining healthy soils practices, this practice refers to lessening collateral damage to residual trees. Practices may include directional felling, cut-to-length logging, and potentially practices that reduce damage to saplings and other advance regeneration.

What are we paying for?

Payment is to incentivize harvester to spend more time (and perhaps use equipment differently) to reduce collateral damage to residual trees. Payment might be calculated as all/a portion of the extra time or increased equipment costs required by the harvester to meet the performance criteria: average area of bark removed from residual tree stems is less than X square inches per mile of skid trail, average stump height is less than X inches above the ground, minimal residual tree damage per felled tree, minimal saplings/trees killed by skidding per acre harvested, no more than X% of harvested area cleared and graded for haul roads and log yards. May require additional research to apply performance standards to New England.

Key eligibility criteria

- Done in association with a harvest that retains significant basal area (there needs to be a residual stand that is the focus of these reduced-impact logging practices).
- Nearly always combined with the maintaining healthy soils practices.
- Preference might be given to prime soils or other forests where residual trees are expected to have high rates of carbon accumulation?

Anticipated Carbon Pool Responses

Carbon benefits from this practice may require additional research and/or modeling. In other geographies, there are significant benefits to the aboveground live carbon pools from reduced mortality and avoiding injury that would slow growth. Surveys of harvesters being designed in MA may provide additional useful information.

Factor	Description and Details
Carbon benefit in 20 years	<i>Carbon benefit should be mainly to the aboveground live pools, especially residual trees and advanced regeneration. May need stricter eligibility criteria to direct this practice to forests where the largest benefit can be realized.</i>
Timing of carbon benefit	<i>Carbon benefit begins after harvest and should occur throughout the rest of the contract period.</i>
Risk of failure	<i>If residual stand damage is avoided, but some other threat results in reduction in growth or increase in mortality, these benefits might not be realized.</i>
Co-benefits	<i>This work would nearly always be paired with practices that maintain healthy soils. Collectively, they have water quality benefits and potentially some reduction in the impact of threats like deer and invasives (from better-sited and smaller roads and landings).</i>
Program fit	<i>Unclear. We can better define the metrics for reduced mortality and other damage, and determine what it will cost to avoid this damage. It is less clear how large a carbon</i>

	<i>opportunity this is in southern New England, and so the economic viability of this practice is uncertain.</i>
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Approach(es)

NIACS forest carbon management menu: 2.1 Reduce impacts on soils and nutrient cycling

Sources:

Egan, A.F. and Baumgras, J. 2003. Ground skidding and harvested stand attributes in Appalachian hardwood stands in West Virginia. *Forest Products Journal*. 53(9):59-63.

Hassler, C.C. and Grushecky, S.T. 1999. An assessment of stand damage following timber harvests in West Virginia. *North. J. Appl. For.* 16(4):191-196.