Forest Biomass Retention and Harvesting Guidelines for the Northeast

by the Forest Guild Biomass Working Group

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May 2010

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Available online at
www.forestguild.org/publications/research/2010/FG_Biomass_Guidelines_NE.pdf

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This report was prepared with support from the Northern Forest Investment Zone of the U. S. Endowment for Forestry & Communities, the Massachusetts Department of Energy Resources as part of the Manomet Center for Conservation Science's Biomass Sustainability and Carbon Policy Study, the Betterment Fund, and the Merck Family Fund.

The Forest Guild promotes ecologically, economically, and socially responsible forestry - "excellent forestry"- as a means of sustaining the integrity of forest ecosystems and the human communitites dependent upon them.

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1. Introduction and Background

Interest in removing wood with a historically low economic value from forests has increased because of rising fossil fuel costs, concerns about carbon emissions from fossil fuels, and the risk of catastrophic wildfires. Even as federal, state and regional programs encourage the utilization of forest biomass, there are concerns about its potential adverse effects on biodiversity, soil productivity, wildlife habitat, water quality, and carbon storage. At the same time, biomass removal and utilization have the potential to provide a renewable energy source, promote the growth of higher-value trees and forest products, reduce forest fire risk, support the removal of invasive species, and help to meet the economic development goals of rural communities. These guidelines are designed to encourage protection of soils, wildlife habitat, water, and other forest attributes when biomass or other forest products are harvested in the Northeastern United States.

Our Principles

1. The well-being of human society is dependent on responsible forest management that places the highest priority on the maintenance and enhancement of the entire forest ecosystem.

2. The natural forest provides a model for sustainable resource management; therefore, responsible forest management imitates nature's dynamic processes and minimizes impacts when harvesting trees and other products.

3. The forest has value in its own right, independent of human intentions and needs.

4. Human knowledge of forest ecosystems is limited. Responsible management that sustains the forest requires a humble approach and continuous learning.

5. The practice of forestry must be grounded in field observation and experience as well as in the biological sciences. This practical knowledge should be developed and shared with both traditional and non-traditional educational institutions and programs.

6. A forester's or natural resource professional's first duty is to the forest and its future. When the management directives of clients or supervisors conflict with the Mission and Principles of the Guild, and cannot be modified through dialogue and education, a forester or natural resource professional should disassociate.

The Forest Guild Guidelines

The Forest Guild guidelines are designed to augment and enhance existing Best Management Practices (BMPs) or new state-based biomass guidelines that may, in some cases, leave managers and policy makers looking for more detailed recommendations. While these guidelines were developed to address biomass harvesting, they also are intended to inform all harvests in northeastern forests. We developed these guidelines to assist several audiences: field foresters, loggers, state-based policy makers charged with developing biomass guidelines and standards, biomass facilities wishing to assure sustainability, third party certifiers, and members of the public interested sustainable forest management.

These guidelines are based on the Forest Guild's principles (see text box). Forest Guild members are concerned with reconciling biomass removals with the principles of excellent forestry—forestry that is ecologically, economically, and socially responsible. Excellent forestry exceeds minimum best management practices and places the long-term viability of the forest above all other considerations. It uses nature as a model and embraces the forest's many values and dynamic processes.

Excellent forestry maintains the functions, structures, and composition that support the health of the entire forest ecosystem. Excellent forestry is different in each ecoregion, but is guided by science, place-based experience, and continuous learning.

Forest Guild members acknowledge their social responsibilities as forest stewards to address climate change and mitigate the buildup of atmospheric carbon. In addition, we understand how renewable fuels derived from well-managed forests can provide energy security and enhance rural communities. At the same time, we have an ecological imperative to ensure that all our harvests—including biomass harvests—maintain or enhance the ecological values of the forest.

Creating the Guidelines

Our working group consisted of 21 Forest Guild members representing public and private field foresters and resource managers, academic researchers and members of major regional and national environmental organizations. The process was led by Forest Guild staff and was supported by two Forest Guild reports: *Ecology of Dead Wood in the Northeast*[4] and *An Assessment of Biomass Harvesting Guidelines.*[5] Wherever possible we base our recommendations on peer-reviewed science. However, in many cases research is inadequate to connect practices, stand level outcomes, and ecological goals. Where the science remains inconclusive, we rely on field observation and professional experience. The guidelines provide both general guidance and specific targets that can be measured and monitored. These guidelines should be revisited frequently, perhaps on a three-year cycle, and altered as new scientific information and results of field implementation of the guidelines become available.

"Sustainability" and Biomass Harvesting

Photo: Rick Morill

Using a common definition, sustainable biomass harvests would "meet the needs of the present without compromising the ability of future generations to meet their needs" (Brundtland Commission 1987). Crafting a more precise definition of sustainable forest management is inherently complex because forest ecosystems are simultaneously intricate, dynamic, and variable. Sustainable forest management must integrate elements of ecology, economics, and societal well being. These guidelines primarily pertain to issues of sustaining ecological function and productivity; they are not meant to replace a comprehensive assessment of forest sustainability.

In general, the sustainability of managed forests must be judged on timelines that span generations. Individual trees can persist for centuries and management decisions made today will have important implications well beyond the tenure of any one manger. As a result, the indigenous focus on the impact of decisions seven generations into the future may be an appropriate timescale to consider. Similarly, sustainability must be judged on scales larger than that of the individual forest stand.

For example, large mammal home ranges, water quality, and a viable forestry industry all depend on landscapes that encompass multiple stands. Due to the difficulties of defining appropriate time frames and spatial scales, the concept of forest sustainability is best thought of as an adaptive process that requires regular monitoring and recalibration. Consequently, these guidelines are presented not as static targets to be maintained at all times in all places, but rather as guideposts on a path to sustainability.

In this report, the term BIOMASS refers to the vegetation removed from the forest, usually logging slash, small-diameter trees, tops, limbs, or trees not considered merchantable in traditional markets.


Photo: Zander Evans

Definitions

Biomass

In a scientific context, the term "biomass" includes all living or dead organic matter. In common parlance, biomass usually refers to woody material that has historically had a low value and was not considered merchantable in traditional markets. Biomass harvesting can also involve the removal of dead trees, downed logs, brush, and stumps, in addition to tops and limbs. Changing markets and regional variations determine which trees are considered sawtimber or pulpwood material and which are relegated to the biomass category. This report does not discuss biomass from agricultural lands and short-rotation woody biomass plantations.

In this report, the term **biomass** refers to *vegetation removed from the forest, usually logging slash, small-diameter trees, tops, limbs, or trees not considered merchantable in traditional markets.* Similarly we use the phrase **biomass harvesting** to refer to the *removal of logging slash, small-diameter trees, tops, or limbs.*

Biomass can be removed in a number of ways. Some harvests remove only woody biomass, some combine the harvest of sawtimber or other products with biomass removal, and some remove biomass after other products have been removed. This report focuses on post-harvest forest conditions and not on the type of harvest. The goal is to ensure the forest can support wildlife, maintain biodiversity, provide clean water, sequester carbon, protect forest soil productivity, and continue to produce income after a biomass harvest or repeated harvests. In some regions, current wood utilization is such that very little woody material is available for new markets such as energy. For these high-utilization areas, application of these guidelines may result in more biomass being left in the forest.

Downed Woody Material

Woody material is sometimes divided into coarse woody material (CWM) and fine woody material (FWM). CWM has been defined as more than 6 inches in diameter at the large end and FWM

Photo: Rajen Parekh

that is less than 6 inches in diameter at the large end.[17] The USDA Forest Service defines CWM as downed dead wood with a small-end diameter of at least 3 inches and a length of at least 3 feet, and FWM as having a diameter of less than 3 inches.[25] FWM has a higher concentration of nutrients than CWM. Large downed woody material, such as logs greater than 12 inches in diameter, is particularly important for wildlife. In this report, we use the term **downed woody material (DWM)** to encompass all three of these size classes, but in some circumstances we discuss a specific size of material where the piece size is particularly important.

2. Guidelines for Biomass Retention and Harvesting for All Forest Types

The following recommendations are applicable across a range of forest types in the Northeast. However, different forest types naturally develop different densities of snags, DWM, and large downed logs. Unfortunately, even after an exhaustive review of the current science there is too much uncertainty to provide specific targets for each forest type. The recommendations in this section set minimum retention targets necessary for adequate wildlife habitat and to maintain the integrity of ecological process such as soil nutrient cycling. Wherever possible, exceed the targets as a buffer against the limitations of current research. Section 3 presents research that may help landowners and foresters interested in additional tree, snag, and DWM retention tailored to specific forest types.

Site Considerations to Protect Rare Forests and Species

- Biomass harvests in critically imperiled or imperiled forest types (i.e., globally recognized or listed as S1 or S2 in a State National Heritage Program) should be avoided unless necessary to perpetuate the type. Management of these and other rare forest types (for example, those ranked S3 by state Natural Heritage Programs) should be based on guidance from the local Natural Heritage Program and/or other local ecological experts.
- Biomass harvesting may be appropriate in sensitive sites to control invasive species, enhance critical habitat, or reduce wildfire risk. However, restoration activity should be guided by ecological goals and not designed solely to supply biomass. It is unlikely that restored sites will contribute to the long-term wood supply, because biomass removals for restoration may not be repeated at regular intervals.
- Old growth forest stands with little or no evidence of harvesting are so rare in the Northeast that they should be protected from harvesting, unless necessary to maintain their structure or ecological function. Areas with scattered old growth trees or late-successional forest characteristics should be carefully managed to ensure retention of their ecological functions. Biomass generally should not be removed from these areas.

Retention of Downed Woody Material

Though CWM represents a large pool of nutrients in some ecosystems, it likely plays a relatively small role in nutrient cycling for managed Northeastern forests. A review of scientific literature suggests that biomass harvesting is unlikely to cause nutrient problems when both sensitive sites (including low-nutrient sites) and clearcutting with whole-tree removal are avoided (see Evans and Kelty 2010 for a more detailed discussion of the relevant scientific literature). However, there is no scientific consensus on this point because of the limited range of treatments and experimental sites.

Maintenance of Soil Fertility


Photo: David Hobson

Biomass harvesting on low-nutrient sites is a particular concern. For example, Hallett and Hornbeck note that "red oak and white pine forests growing on sandy outwash sites are susceptible to nutrient losses due to inherently low-nutrient capitals and/or nutrient depletion by past activities such as farming, fire, and intensive harvesting." [9] Maine's *Woody Biomass Retention Guidelines* [1] list shallow-to-bedrock soils, coarse sandy soils, poorly drained soils, steep slopes, and other erosion-prone sites as sensitive to biomass removals. We encourage states to identify low-nutrient soil series where biomass harvesting should not occur and those soil series where biomass harvests require particular caution. Wisconsin's *Forestland Woody Biomass Harvesting Guidelines* is an excellent example.[11]

In areas that do not qualify as low-nutrient sites, where 1/3 of the basal area is being removed on a 15- to 20-year cutting cycle, it is our professional judgment that retaining 1/4 to 1/3 of tops and limbs will limit the risk of nutrient depletion and other negative impacts in most forest and soil types. Additional retention of tops and limbs may be necessary when harvests remove more trees or harvests are more frequent. Similarly where the nutrient capital is deficient or the nutrient status is unknown, increased retention of tops, branches, needles, and leaves is recommended. Conversely, if harvests remove a lower percentage of basal area, entries are less frequent, or the site is nutrient-rich, then fewer tops and limbs need to be retained on-site.

Guidelines for DWM Retention

- In general, when 1/3 of the basal area is being removed on a 15 to 20 year cycle, retain 1/4 to 1/3 of the slash, tops, and limbs from harvest (i.e., DWM).
- Three main factors influence the percentage of tops and limbs that should be left onsite:
    - o number of live trees left on-site,
    - o time between harvests, and
    - o available soil nutrients.

- As harvesting intensity increases (and the three preceding factors decrease) more slash, tops, and limbs from harvests should be left on-site.
- As harvesting intensity decreases (and the three factors increase) less slash, tops, and limbs from harvests are required to protect site productivity.
- Avoid harvesting on low-nutrient sites or adjust retention of tops, branches, needles, and leaves.
- Retain DWM of all sizes on-site including FWM, CWM and large downed logs.
- In general, leave DWM distributed across the harvest site. However, there may be cases where piles of DWM provide habitat, or redistribution of DWM collected at the landing would cause excessive damage to soil or regeneration.
- Minimize the removal of needles and/or leaves by harvesting in winter, retaining FWM on-site, or leaving felled trees on-site to allow for needle drop.

Retention of Forest Structures for Wildlife and Biodiversity

- Leave and protect litter, forest floor, roots, stumps, and large downed woody material.
- Leave and protect live cavity trees, den trees, other live decaying trees, and snags (i.e., dead standing trees >10"). Individual snags that must be felled for safety requirements should not be removed from the forest.

Table 1. General Guidelines for Retaining Forest Structures

Structure	Minimum Target (per acre)		Considerations
	Number	Basal area (ft^2)	
Live decaying Trees 12-18 inches DBH	4	4	Where suitable trees for retention in these size classes are not present or may not reach these targets due to species or site conditions, leave the largest trees possible that will contribute toward these targets.
Live decaying Trees >18 inches DBH	1	1	
Snags>10 inches DBH	5	5	Worker safety is top priority. Retain as many standing snags as possible, but if individual snags must be felled for safety reasons, leave them in the forest.

Table 1 is based on the scientific literature review in *The Ecology of Dead Wood in the Northeast* [4] as well as other biomass harvesting and retention guidelines.[5] These guidelines are not meant to be attained on every acre, at all times. Rather, they are average targets to be applied across a stand, harvest block, or potentially an ownership.

- If these forest structures do not currently exist, select and identify live trees to become these structures in the future. Retaining live decaying trees helps ensure sufficient snags in the future. Similarly, both decaying trees and snags can eventually become large downed logs.

Photo: Pieter van Loon

- If forest disturbances such as hurricanes, ice storms, and insect infestations create large areas of dead trees, leaving all snags or decaying trees may be impractical. If an area is salvage logged, leaving un-salvaged patches totaling 5% to 15% of the area will provide biological legacies important to wildlife. However, the potential for insect populations to build up in dead trees may prohibit retention of unsalvaged patches in some situations.
- Since there are differences in decay rates and wildlife utilization, retain a variety of tree species as snags, DWM, and large downed logs.
- In areas under even-aged management, leave an uncut patch within or adjacent to every 10 acres of regeneration harvest. Uncut patches, including riparian buffers or other set-asides within the management unit, should total 5% to 15% of the harvest area.
- Build retention patches around large legacy trees, den or cavity trees, large snags, and large downed logs, to maximize structural and habitat diversity.
- Marking retention trees will help ensure that sufficient numbers are retained during the current harvest, and that and they will not be removed in subsequent harvests.
- Management that maintains multiple vegetation layers, from the overstory canopy to the midstory, shrub, and ground layers will benefit wildlife and plant species diversity.

Water Quality and Riparian Zones

In general, water quality and riparian concerns do not change with the addition of biomass removals to a harvest plan. Refer to state water quality best management practices (BMPs) and habitat management guidelines for additional measures to protect streams, vernal pools, and other water bodies (see Appendix I for a list of these BMPs and habitat management guidelines).

Photo: Zander Evans

- DWM retention described above is also important for water quality, because DWM reduces overland flow and holds water.
- Leave and protect existing woody material in streams, ponds, and lakes. DWM in riparian systems provides sites for vegetation colonization, forest island growth and coalescence, and forest floodplain development.

- Leave and protect live decaying trees (e.g., cavity/den trees), snags, and large downed logs in riparian or stream management zones.
- Keep vernal pools free of slash, tops, branches, and sediment from forestry operations. If slash falls into the pool during the breeding season, it is best to leave it in place to avoid disturbing egg masses or other breeding activity that may already be occurring.
- Within 100 feet of the edge of a vernal pool, maintain a shaded forest floor to provide deep litter and woody debris around the pool. Also avoid ruts, bare soil, or sources of sediment near vernal pools.
- Extra care should be taken working in or around foreste wetlands because of their importance for wildlife and ecosystem function. Wetlands are often low-fertility sites and may support rare natural communities, so removal of DWM may be inappropriate.

Harvesting and Operations


Photo: Zander Evans

Most concerns about the operational aspects of biomass harvesting are very similar to all forestry operations. However, some key points are worth emphasizing:

- Protect forest land from conversion to non-forest use and native forest from conversion to plantations.
- Involve a professional forester (or a licensed forester in states where available) in development of a long-term management plan and supervision of harvests.
- Engage a certified logger from the Master Logger Certification Program or other similar program when harvesting.
- Follow all best management practices (BMPs) for the state or region.
- Plan and construct roads and skid trails based on professional advice and BMPs.
- Integrate biomass harvesting with other forest operations. Re-entering a site where timber was recently harvested to remove biomass can increase site impacts such as soil compaction and may harm post-harvest regeneration.
- Use low impact logging techniques such as directional felling or use of slash to protect soil from rutting and compaction from harvest machines.
- Use appropriate equipment matched to site and operations.

3. Relevant Research for Northeastern Forest Types

Although there is too much scientific uncertainty to provide specific targets for each forest type, the research described below may help landowners and foresters interested in additional tree, snag, and DWM retention tailored to specific forest types. We hope the need to better quantify decaying tree, snag, and DWM retention requirements will catalyze new research efforts and the retention target can be updated based on new science.

Photo: Zander Evans

Measurements of Downed Woody Material

Most of the scientific research measures DWM in terms of dry tons per acre rather than percentage of DWM retained after harvest. Tons per acre may not currently be a useful measurement unit for forester and loggers, but we present data in those units here because of their prevalence in scientific literature. This measurement unit may become more prevalent as biomass harvesting increases. Field practitioners typically have not paid a great deal attention to volumes of DWM. Measurement techniques are available to integrate DWM sampling into forest inventories; over time, field practitioners will develop an awareness of volumes-per-acre of DWM, similar to standing timber volumes. The Natural Fuels Photo Series illustrates various levels of DWM and can be used to assist this process (http://depts.washington.edu/nwfire/dps/).

In general, stands have the most DWM when they are young (and trees are rapidly dying from competition) or when they are old (and trees are in various states of decline). Healthy, intermediate-aged stands tend to have less DWM. The following table represents a target range for the mass of DWM left on-site after harvest (including both existing and harvest-generated DWM). The table is based on a number of studies that documented the ranges of observed DWM in managed and unmanaged stands in the Northeast (see Evans and Kelty 2010 for more details). The selected target ranges reflect measurements from unmanaged stands more than those from managed stands and take into account patterns of DWM accumulation during stand development.

Table 2. DWM Ranges by Forest Type

	Northern HW	Spruce-Fir	Oak-Hickory	White and Red Pine
Tons of DWM per acre*	8 – 16	5 – 20	6 – 18	2 – 50

** Includes existing DWM and additional material left during harvesting to meet his target measured in dry tons per acre.*

Spruce–Fir Forests

Photo: Dave Publicover

Research data on DWM in Maine's spruce-fir forest include 3.4 tons per acre10 and a range from 22 to 117 tons per acre.[20] The low estimate of 3.4 tons per acre is from a survey that includes intensively-managed lands that may not have enough DWM to maintain ecosystem processes and retain soil nutrients,[10] while the higher estimates come from unmanaged lands.[20]

The basal area of dead trees from a survey of paper birch-red spruce-balsam fir and red spruce-balsam fir stands ranged from 11 to 43 percent of stand basal area.[23] The Canadian province of Newfoundland and Labrador requires retention of 4 snags per acre, while Maine recommends retaining 3 snags and/or cavity trees greater than 14 inches DBH and one greater than 24 inches DBH.[6, 19] Smith and colleagues recommend retention and recruitment of white birch snags to ensure sufficient snag and DWM density.[19] Other guidelines recommend between 5 and 6 snags per acre greater than 8 inches DBH and an additional 4 to 6 potential cavity trees at least 10 inches DBH.[26]

Photo: Zander Evans

Northern Hardwood Forests

Measures of the DWM in northern hardwood forests are as low as 3.1 tons per acre,[18] but 16 other measurements from 6 scientific articles average 17 tons per acre, with a low of 8 tons per acre.[18, 21, 8, 14, 16, 2] Dead trees made up 3 to14 percent of the basal area in five hemlock-yellow birch stands and 5 to 34 percent of basal area in sugar maple-beech-yellow birch stands.[23] Other research suggests retention of between 5 and 17 snags per acre.[7, 15, 13] Tubbs and colleagues recommend leaving between one and ten live decaying trees per acre at least 18 inches DBH.24 Research has documented a range of 7 to 25 to cavity trees per acre in unmanaged stands.[7, 13]

Transitional Hardwood /Oak-Hickory Forests

Measures of the DWM in transitional hardwood forests, i.e., oak-hickory forests of southern New England, range from 5.8 to 18 tons per acre.[22, 12] Out of seven oak stands in Connecticut, the number of dead trees ranged from 19 to 44 per ac or 5 to15 percent of basal area.[23]

White and Red Pine Forests

Estimates of the volume of downed dead wood in white and red pine forests range from 1.6 to 50 tons per acre of DWM.[3, 10] Unmanaged red pine stands in the Great Lakes area had 30 snags per acre while a managed forest had 6.9 per acre.[3] Many of the red oak and white pine stands on sandy outwash sites are susceptible to nutrient losses because of a combination of low-nutrient capital and past nutrient depletion.[9]

Photo: Zander Evans

4. Carbon Considerations and Guidelines

To date, forestry or biomass harvesting BMPs have not included guidelines for the management of carbon. However, climate change has the potential to fundamentally change both forests and forestry over the next century. Moreover, climate change has added carbon management to the responsibilities of forest managers and landowners (Forest Guild Carbon Policy Statement 2010). Protecting forests from conversion to other land uses is the most important forest management measure to store carbon and mitigate climate change. Biomass harvests may reduce the incentive to convert forests to other uses by providing additional income to forest landowners, and maintaining the forest industry and availability of markets.

The extent to which forest biomass can serve as a low-carbon alternative to fossil fuels is currently the subject of intense debate. In 2010, the Forest Guild is engaged in a comprehensive study commissioned by the Massachusetts Department of Energy Resources and led by Manomet Center for Conservation Sciences. Together with Manomet and other partners, we are investigating the impact of various forest practices on atmospheric carbon between managed and unmanaged forests. The results of this study will be available by June 2010 and will be used to expand this section on the carbon considerations for biomass harvesting. The Manomet study will model different biomass harvest scenarios to help determine which forest practices have less of an impact on the accumulation of atmospheric carbon.

In the interim, the following sections offer suggestions based on research that is currently available. It is important to recognize that in some cases a practice that contributes to a significant reduction in atmospheric carbon may be, or may appear to be, in conflict with considerations regarding biodiversity or long-term site productivity, as outlined in previous sections of this document. For example, while utilizing logging slash for energy may prove important in a scenario designed to reduce atmospheric carbon, the retention of some logging slash post harvest may also be important for the maintenance of forest productivity. In such cases, as in many areas of forestry, divergent goals must be balanced for the specific operating unit or ownership. As discussed in previous sections, the guidelines in this report are primarily intended to support decision making about the maintenance of ecological function and value in a forest management context.

Photos: Robert Bryan

Strategies that Improve the Carbon Budget on Managed Forests

Some forest management strategies can increase carbon sequestration rates and store more carbon over time than others. Silviculture that encourages the development of structural complexity stores more carbon than silvicultural methods that create homogenous conditions. Uneven-aged management is often used to promote a structurally complex forest and can sequester more carbon than less structurally complex forests managed with even-age methods. Even-aged management systems periodically remove most of the forest carbon. When used in existing mature forests they may have a greater negative carbon impact, particularly since near-term carbon emission reductions are most important. Where even-aged management systems are appropriate, encouraging advance regeneration, or retaining residual components of the original stand, may be the fastest way to build up or maintain forest carbon. Extending rotation length will also result in an increased mean carbon stocking volume and a potential increase in carbon in harvested wood products stored offsite.

The use of logging slash for energy production has a lower carbon impact than the use of live trees for energy because logging slash will decay and emit carbon and other greenhouse gases, while live trees will continue to sequester carbon. Similarly, since trees naturally die, decay, and emit carbon, harvests that focus on suppressed trees likely to die in the near future produce fewer carbon emissions overall than the harvest of trees that are healthier, sequester carbon faster, and have long life expectancies. By using biomass harvests to remove suppressed trees with shorter life expectancies, the remaining healthier trees, "crop trees", can grow faster and larger and produce higher-value products. These more valuable products have the potential to store carbon off-site longer than products with a shorter life cycle, such as paper or shipping pallets. These products also will meet human needs while emitting less carbon than alternatives such as steel or concrete. However, the harvest of future crop trees for energy is the worst case scenario: such a harvest reduces on-site carbon, probably limits the economic productivity of the stand, and reduces the opportunity to produce higher-value products that provide long-term carbon storage and displace more carbon-intensive products.

Determining the Carbon Impact of Biomass Harvesting


Photo: Zander Evans

While the use of forest biomass for energy production can be helpful in mitigating climate change, accounting procedures for carbon mitigation programs must accurately account for all of the impacts of the proposed biomass use. The accounting should be based on a life cycle analysis that evaluates the effects of forest management and biomass removals on forest carbon. In order to determine the carbon impact of a biomass harvest, the analysis must include the following elements:

1. The amount of carbon removed from the site.
2. The amount of carbon used to grow, remove and transport the material to utilization.
3. The efficiency and carbon emissions of the use of forest biomass for energy, compared to business-as-usual (i.e., no biomass harvest) alternatives.
4. Future carbon sequestration rate for the site.
5. The impact of biomass removals on the site's capacity to grow forest products that store carbon or replace other carbon-intensive products.
6. The time required to re-sequester the carbon removed from the site and the time required to re-sequester the carbon that would have been sequestered in the business-as-usual scenario.
7. The business-as-usual scenario which includes
   a. Predicted harvest rates for the forest type and site in question
   b. Carbon emissions factors for the production, transportation, and use of the business-as-usual fuel, most likely a fossil fuel.

A full accounting that includes these elements can help answer complex questions regarding forest management and carbon impacts. For example, logging slash plays a number of functions. It is a valuable source of nutrients, provides biodiversity habitat, stores carbon on-site and is a potential source of renewable energy. Biomass retention guidelines provide targets for how much to retain for ecological reasons. But how much to remove as a renewable fuel versus how much to leave for on-site carbon storage can only be answered by comprehensive modeling of carbon flows over time.

Guidelines for Carbon Storage

- When managing for shade-tolerant and mid-tolerant species, a shift from even-aged to uneven-aged management will increase the retention of carbon on-site.
- When appropriate to the tree species, a shift to regeneration methods that encourage advanced regeneration, such as from clearcut to shelterwood, will retain carbon on-site for longer periods.
- Retain reserve trees or standards or delay their removal.
- Delay regeneration harvests or lengthen harvest cycles to grow trees for longer times and to larger sizes.
- Encourage rapid regeneration.
- Capture natural mortality as efficiently as possible while retaining adequate numbers of snags, decaying trees, and DWM.
- Use biomass harvests to concentrate growth on healthy crop trees that can be used to manufacture products that hold carbon for long periods or replace carbon-intensive products.

5. Resources and References

BMPs and Other State Guides

- Maine's Woody Biomass Retention Guidelines
  http://www.maine.gov/doc/mfs/pubs/biomass_retention_guidelines.html

- Biodiversity in the Forests of Maine: Guidelines for Land Management
  http://www.maine.gov/doc/mfs/pubs/pdf/biodiversity_forests_me.pdf

- Vernal Pool Habitat Management Guidelines (Maine)
  http://www.maine.gov/doc/mfs/pubs/pdf/vernal_pool_hmg.pdf

- Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire
  http://extension.unh.edu/resources/files/Resource000294_Rep316.pdf

- Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont http://www.vtfpr.org/watershed/documents/Amp2006.pdf

- Massachusetts Forestry Best Management Practices Manual
  http://www.mass.gov/dep/water/drinking/forstbmp.pdf

- Connecticut Best Management Practices for Water Quality while Harvesting Forest Products http://www.ct.gov/dep/cwp/view.asp?A=2697&Q=379248

- Northeast Master Logger Certification Program
  http://www.masterloggercertification.com/

- Natural Fuels Photo Series
  http://depts.washington.edu/nwfire/dps/

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  www.forestguild.org/publications/research/2010/ecology_of_deadwood.pdf

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  www.forestguild.org/publications/research/2009/biomass_guidelines.pdf

- Synthesis of Knowledge from Biomass Removal Case Studies
  www.forestguild.org/publications/research/2008/Biomass_Case_Studies_Report.pdf

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