ISSN: 1070-1508

Woody Biomass Retention Guidelines

Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine

Miscellaneous Publication 761
January 2010
Maine Agricultural and Forest Experiment Station
University of Maine

Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine

Miscellaneous Publication 761
January 2010
Maine Agricultural and Forest Experiment Station
University of Maine

Cite as: Benjamin, J.G. (Editor) 2010. Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine. University of Maine, Maine Agricultural and Forest Experiment Station. Orono, ME. Miscellaneous Publication 761. 68p.

Contents

1 ACKNOWLEDGMENTS

A collaborative effort between the Maine Forest Service, the University of Maine, and the Trust to Conserve Northeast Forestlands has been undertaken to develop woody biomass retention guidelines for Maine. Funding for this effort has been received from the Natural Resources Conservation Service, Maine Forest Service, and the University of Maine's Forest Bioproducts Research Initiative (NSF Grant No. EPS-0554545).

TECHNICAL COMMITTEE MEMBERS

Jeffrey G. Benjamin:	University of Maine, School of Forest Resources
Rob Bryan:	Forest Synthesis, LLC
Donald J. Mansius:	Maine Forest Service, Department of Conservation
Kate Albert:	The Trust to Conserve Northeast Forestlands
John Gunn:	Manomet (formerly of The Trust to Conserve Northeast Forestlands)

STEERING & STAKEHOLDER COMMITTEE MEMBERS

Susan Aygarn:	Society of American Foresters – Maine Division
Nick Bennett:	Natural Resources Council of Maine
Harold Burnett:	Association of Consulting Foresters
Jim Contino:	Maine Forest Products Council
Mike Dann:	Small Woodland Owners Association of Maine
Bob Perschel:	Forest Guild
Jim Runyan:	Forest Resources Association
Pat Sirois:	Maine Forest Products Council
Joel Swanton:	Forest Resources Association

This report represents the collective effort of many individuals with often diverse perspectives of Maine's forest industry. As such, not everyone is in agreement with all of the views expressed in this report, but the Technical Committee feels strongly that this project was greatly improved with their feedback and suggestions for improvement. In particular we would like to thank the members of the Stakeholder and Steering Committees, the Technical Reviewers for each section (Ivan Fernandez, John Peckenham, and Andrew Whitman), and University of Maine graduate students Charles Coup and Roger Ryder. Constructive comments on earlier versions of this document by Mort Moesswilde, Merle Ring, Gordon Moore, Andy Schultz, Max McCormack, and the Master Logger Executive Board in particular, were also greatly appreciated. Members of the University of Maine's Forest Bioproducts Research Initiative (including Bob Wagner, Jeremy Wilson, Rob Lilieholm, Jessica Leahy, and Hemant Pendse) provided valuable feedback on this initiative over the past two years.

Designed by University Relations, University of Maine

2 INTRODUCTION

Written by:
Jeffrey G. Benjamin, Assistant Professor of Forest Operations, University of Maine
Donald J. Mansius, Director of Forest Policy & Management, Maine Forest Service – Department of Conservation

There is intense competition for raw material within Maine's forest products industry. In addition to traditional round wood markets, bioenergy facilities that produce electricity by burning wood are common throughout the state. Some are stand-alone facilities and others are integrated within pulp and paper mills. Biomass chip harvests in Maine have increased more than 3½ times since 2000 (Figure 1) – a trend that is expected to continue given plans for new and expanded capacity in the region. Several wood pellet plants are either in operation or planned for construction. Industry analysts expect global production of wood pellets for residential and commercial heating to increase 25 to 30% annually over the next decade (Wood Resources Quarterly 2009). Research is also in progress at the University of Maine to produce a variety of forest bioproducts including ethanol.

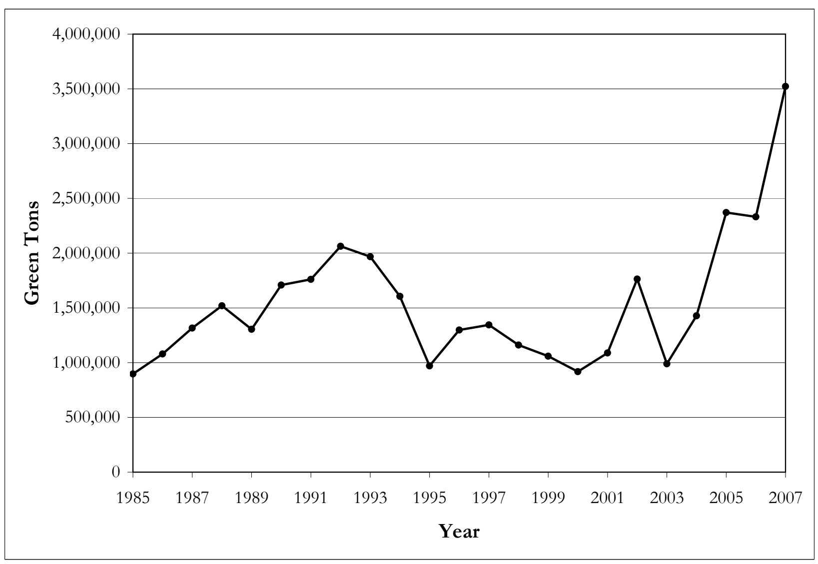


Figure 1. Historic biomass chip harvest levels in Maine (Maine Forest Service 2008).

We do not know the impact these new initiatives will have on wood supply, but it is certainly possible that competition for raw material between wood-using facilities will increase. Increased competition may impact harvest levels through shorter rotations, or increased use of small diameter and poor quality stems. This may create opportunities for timber stand improvement by combining such harvests with conventional forest management and silvicultural treatments. Regardless of the outcome, there is concern that these and other related activities will put more pressure on our forests. Wood supply is a concern for both traditional wood processing sectors and the emerging bioindustry, and the general public has raised concerns regarding long-term sustainability of biomass harvesting (Benjamin et al. 2009, Marciano et al. 2009).

Increased demand for woody biomass will generally increase the potential for conflicts among forest values. For example, a standing dead tree may provide habitat for wildlife, reduce soil compaction and erosion if used in skid trails, or provide economic value to a bioenergy facility. Logging residue can be used to maintain soil productivity, reduce erosion, or produce bioproducts. All values cannot be achieved in each case, so tradeoffs may be necessary. The forest industry in Maine has been dealing with these and other related issues for many years, but guidelines specific to woody biomass retention are missing from existing best management practices and regulations.

This report and associated guidelines focus on the amount and type of woody biomass that should be retained in the forest after a harvest operation to protect soil productivity, water quality, and site-level biodiversity. Woody biomass, defined from a forest operations perspective, is comprised of logging residues, previously un-merchantable stems, and other such woody material harvested directly from the forest typically for the purposes of energy production. In the broadest sense woody biomass is the total mass of roots, stem, branches, bark and leaves of all tree and shrub species (live and dead) in the forest. Under the broad definition all forest products could be considered as woody biomass, but in practice a forest operations perspective is more appropriate for this initiative. Harvest of woody biomass is often integrated with traditional forest operations, so it can be difficult to isolate effects of woody biomass removals at a site level. As such, it is important to consider retention of woody biomass during all harvest activities and to emphasize post-harvest site condition rather than the amount of any given product removed during harvest.

The objective of this report is to recommend guidelines for retention of woody biomass on harvest sites from a general perspective (Section 3) and with respect to soil productivity (Section 4), water quality (Section 5), and site-level biodiversity (Section 6). Background information is provided on each topic based on a review of relevant scientific literature and harvesting guidelines from other states with similar forest types and markets. Site specific guidelines are primarily based on a number of published documents, including:

- *Best Management Practices for Forestry* (Maine Forest Service 2004)
- *Site Classification Field Guide* (Briggs 1994)
- *Biodiversity in the Forests of Maine: Guidelines for Land Management* (Elliott 2008)

The guidelines are presented at the end of each section (General – page 4, Soil Productivity – page 8, Water Quality – page 22, and Forest Biodiversity – page 38) in a format that can be readily understood and applied by forest practitioners. For quick reference, a complete summary, in pamphlet format, of all guidelines identified in this report is provided in Appendix A. A glossary of commonly used terms and a listing of additional resources are provided in Sections 7 and 8 respectively.

3 GENERAL RECOMMENDATIONS

Written by:
Jeffrey G. Benjamin, Assistant Professor of Forest Operations, University of Maine
Donald J. Mansius, Director of Forest Policy & Management, Maine Forest Service – Department of Conservation

3.1 INTRODUCTION

The following section identifies general principles regarding woody biomass retention in Maine's forests for protection of soil productivity, water quality, and site-level biodiversity. Recommendations should be used in conjunction with all applicable regulations and Water Quality Best Management Practices (BMPs) and the guidelines are intended to be adapted and incorporated into site-specific silvicultural prescriptions developed by a licensed forester. Implementation of the guidelines will rely on the professional judgment, knowledge, and skill of the logger conducting the harvest operation and they are intended to inform the landowners' decision-making as they review the forester's prescription. Pre-harvest planning among all three parties is an important part of the process. The recommendations in this report are intended to be used by loggers, foresters, and landowners' in this context.

Fundamentally, logging contractors do not treat woody biomass differently than other forest products, rather it is simply another product sorted at the landing. A market for this material creates opportunities to offset management and silvicultural treatment costs in overstocked stands, including salvage operations following insect or disease outbreaks. For those opportunities to become a reality, having the right equipment and access to markets is required. Handling woody biomass presents the greatest challenge for forest operations as logging residue has both a low value and bulk density. The proportion of solids in logging residue and chips is less than 20% (Andersson et al. 2002). Compared to handling round wood, it is simply more awkward and inefficient to work with logging residue because existing logging and trucking equipment was designed to handle larger stems. Specialized equipment is very expensive and economically risky to contractors, so integration with existing harvest systems is a critical factor (Benjamin et al. 2009).

An understanding of the entire supply chain is critical to understanding the likely impact of a growing market for forest-based energy wood. As outlined by Benjamin et al. (2009), forest products generally flow to the use that offers the greatest net return (e.g., high price for veneer logs, low price for biomass). That relationship is dependent on active markets and informed buyers and sellers, and increased demand by bioenergy or bioproducts facilities may affect resource flows. In other words, the relative price that can be paid for biomass may change depending on competing uses and the cost of production. Therefore, in each situation it is critical to optimize the value of all harvested products.

3.2 Guidelines

The following guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant component of the product mix.

- Develop a site-specific harvest plan that addresses the forest values identified in this brochure. Publications and programs, such as the Water Quality BMPs, Master Logger Harvest Integrity System, and the Certified Logging Professional Program, can provide general pre-harvest planning guidance. Contact your local MFS District Forester for on-the-ground assistance. Call 1-800-367-0223, or visit www.maineforestservice.gov, for more information.
- Follow all applicable regulations and Water Quality BMPs.
- Strive to optimize utilization and value of all products removed from each site. For example, it is worth considering whether tops, limbs or other woody material has greater value on a trail to prevent erosion or on the landing as biomass chips.

4 SOIL PRODUCTIVITY

Written by:
Charles Coup, Graduate Student, University of Maine
Jeffrey G. Benjamin, Assistant Professor of Forest Operations, University of Maine

Reviewed by:
Ivan Fernandez, Professor of Soil Science, University of Maine

4.1 INTRODUCTION

Forest soils are complex biological, chemical, and physical systems. Soil productivity is directly related to nutrient availability which depends on factors such as minerals in the parent material, rates of mineral weathering, leaching losses and erosion, past land use, atmospheric deposition, vegetation composition, rotation length, rate of tree growth and harvest intensity. Nutrient amounts removed in biomass from whole-tree operations are much greater than nutrient amounts removed from conventional stem-only harvesting. This is because nutrient concentrations are much higher in branches and particularly in needles and leaves, and therefore a much larger portion of the total biomass nutrients is removed when branches and foliage are included in the harvest removal. (It is important to point out that we are referring to mineral nutrients, not all nutrients within a tree, in the above description and throughout this section.) The more fine woody material that is left on site during harvest operations, the less risk there is to long-term soil productivity.

Not all soils are created equal. Higher quality forest sites tend to have a higher natural nutrient supply and cycle nutrients more rapidly. The greater the nutrient supply, and the faster the rate of nutrient transformation into available forms, the lower the risk that harvesting will reduce soil productivity as long as there are no other limiting factors of greater importance on the site. This means that for a given level of biomass retention, the risk to soil productivity is lower on higher quality sites.

Forest soils produce excess nutrients through mineral weathering and organic matter decomposition as part of the natural function of the soil, and these excess nutrients beyond vegetation requirements are typically leached from the site. Increased nutrient removals through harvesting that are less than or equal to these excess nutrients should not alter forest site productivity. If harvesting results in nutrient removals that exceed these excesses, then forest soil nutrient availability will decline. By avoiding the intensification of biomass removals on soils with characteristics that suggest limited nutrient amounts (e.g., shallow soils) or slow rates of nutrient supply (e.g., sandy soils), we also avoid the risk of reducing site productivity through harvesting. Although it is possible to restore nutrient supply in a forest soil in some circumstances by increasing rotation length or altering species composition, short-term improvements in nutrient availability can only be achieved through the application of fertilizers, biosolids, or other soil manipulations.

In conducting research for this section, it was found that most of the studies on whole-tree harvesting utilize the method of whole-tree clearcutting. Yet, less than 5% of harvests in Maine were categorized as clearcuts or land use changes between 2002 and 2007 (Maine Forest Service 2008). This was partly in response to the public debate following a ballot initiative in 1996 to ban clearcutting in Maine (Briggs et al. 2000). Clearcutting also represents a more severe disturbance and maximizes soil nutrient loss through increased soil leaching and erosion. Therefore, the results of soil productivity studies focusing on whole-tree clearcut harvesting may suggest a more severe impact than the current silviculture systems currently employed in Maine (e.g. thinning and partial harvests). On the other hand, while clearcutting may represent a larger overall disturbance to a site, partial harvesting, in general, allows more wood to be extracted in a given period of time because partial cuts do not require buffers or separation zones (Hagan and Boone 1997). It is likely, however, that whole-tree clearcutting provides the most conservative basis with which to judge the environmental impacts of increased biomass harvesting since all merchantable vegetation is removed from the site. Therefore, while the results of these studies are severe, they are still relevant in illustrating the relationship between amounts of biomass extraction and nutrient retention.

4.2 Effect of Harvesting on Soil Productivity

The long-term maintenance of healthy and productive soils is one of the most vital aspects of sustainable biomass production in Maine. Forest soils support root anchorage, supply water and mineral nutrients for tree growth, provide habitat for numerous organisms, support hydrologic processes, provide a surface for operating harvesting machinery, and create favorable conditions for the decomposition and recycling of forest residues and wood ash (Burger 2002, Brady and Weil 2002). Forest soil productivity is the capacity of a soil to contribute to forest biomass production (Burger 2002). The base level of soil productivity is measured by the natural capacity of unaltered soils to support plant growth over a specified period (Heninger et al. 1997).

Maintaining the relative capacity of a forest to sustain a steady supply of resources in the long-term is a fundamental goal of ecologically sound forest management (Pierce et al. 1993, Helms 1998). Therefore, unless biomass extraction processes maintain long-term productivity of forest soils, then the system could lead to a decline in production. Declines in productivity may limit future biomass harvest levels. While the importance of soil productivity is well understood amongst foresters and land managers implementing non-biomass harvests, questions have been raised about the sustainability of biomass harvesting practices that remove a larger proportion of material from the site, operate on shorter rotational periods, and increase site disturbance as a result of more intensive harvesting practices (Hornbeck 1986). Of particular concern is the sustainability of the physical properties of soil, soil horizons, and complex biogeochemical cycles constantly at work within the forest system.

In order to determine the effects that increased harvesting will have on forest productivity, it is important to first look at the distribution of biomass and nutrients within forests to identify the relative quantity of biomass and nutrients that will be removed when utilizing the various components.

4.2.1 Nutrient and Biomass Distribution in Trees

There is a great deal of uncertainty in the specifications (e.g. species, quality, and dimensions) of raw material required by an emerging bioproducts market. Potentially any part of a tree could be utilized as biomass. As interest in renewable energy sources increases and as bioproduct markets mature, bioplants could potentially offer more competitive prices for their biomass fiber source. Demand for biomass feedstock may also exceed the currently utilized sources of biomass such as logging residues and unmerchantable trees. Therefore, the possibility exists that bioproduct markets could also target bolewood as its main feedstock and directly compete with pulp and sawtimber markets. Other than an increase in demand, this situation would be no different than the conventional stem-only harvesting occurring throughout the state which is accepted as a sustainable forestry practice (Boyle and Ek 1972, Likens et al. 1978, Wells and Jorgensen 1979, Hakkila 2002).

While extracting any resource from the forest will inevitably remove some nutrients in the harvested product, there has been wide concern that intensive utilization of biomass over and above conventional stem-only harvesting may result in long-term nutrient depletion. In order to examine the impact that this increase may have on forest nutrient cycles, it is important to look at the distribution of biomass in trees, where major nutrient sources lie within the above- and belowground forest biomass, and how they both relate to natural biogeochemical cycling. Individual components of forest biomass available for harvesting are numerous and include both above- and belowground material. The subsequent sections will compare biomass and nutrient components of the stump and root system, the tree stem, and foliage and branches.

4.2.1.1 STUMP AND ROOTS

The stump and root system has been identified as a potential feedstock of wood fiber from the forest (Hakkila and Parikka 2002). With some allowance for losses in the harvesting phase, the potentially available biomass from the stump and root (greater than 5 cm in diameter) wood is 25% of the stem mass (Young 1974, Hakkila 1989). In the "complete tree" harvest method, introduced by Young (1964), the entire tree including the stump and major roots is removed to the roadside for processing and utilization. Other harvesting methods return to a previously harvested site to extract the stump and root system after the initial harvest has already taken place. Although stump harvesting is increasing in Nordic countries (Laitila et al. 2008), this method never really came into general use in the United States due to low demand and high extraction costs. Stump and root extraction is used in some instances in the United States to prevent the spread of root diseases, but there is no evidence that it is widely used for woody biomass harvesting in Maine.

At this time it is safe to assume that the cost and energy required to harvest, clean, transport, and process the stump and root system far exceeds the current demand and cost structure from industries in Maine. In addition, since stump and root systems play a vital role in nutrient cycling, contribute significantly to nutrient retention, increase soil stability against erosion, and retain soil structure, the environmental and economic aspects of stump and root harvesting may preclude their present utilization. For example, root production in Loblolly pine (*Pinus taeda* L.) has been shown to be 2.8 times greater than net normal wood production (Bowen 1984 cited in Burger 2002). This is a significant, and often underappreciated, nutrient cycling process in the soil. While this potential source of woody biomass may be considered in the future as the bioenergy and bioproducts industries continue to grow, it will not be discussed further in this paper.

4.2.1.2 STEM

The stem (or bole) is the traditional fiber source of sawmills and pulpmills in Maine. In general, the stem (excluding the bark) contains the lowest concentration of mineral nutrients in the whole-tree (Young and Carpenter 1976). In a northern hardwood stand Alban et al. (1978) estimated 65% of the aboveground biomass is stemwood (Figure 2). However, they estimated that only about a fourth of the nutrients in the aboveground tree are in the bole wood. While the concentration of nutrients within the bole wood is rather low, the bark of the stem contains higher concentrations. Alban et al. (1978) indicated that approximately half of total bole nutrients are found within the stem, and the other half within the bark of the stem (Figure 3).

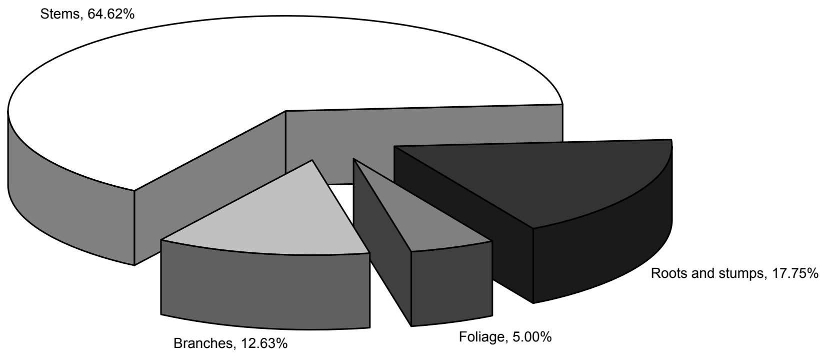


Figure 2. Average organic matter composition of above- and belowground overstory vegetation component of a 40-year-old stand in north-central Minnesota (Alban et al. 1978).

Conventional stem-only harvesting is generally accepted as a sustainable practice for most forest sites and is not considered to have any long-term detrimental effects on site nutrient pools because of the small portion of nutrients extracted and the long rotation periods that allow for nutrient replenishment (Boyle and Ek 1972, Mälkönen 1976, Likens et al. 1978, Wells and Jorgensen 1979, Jurgensen et al. 1997, Hakkila 2002).

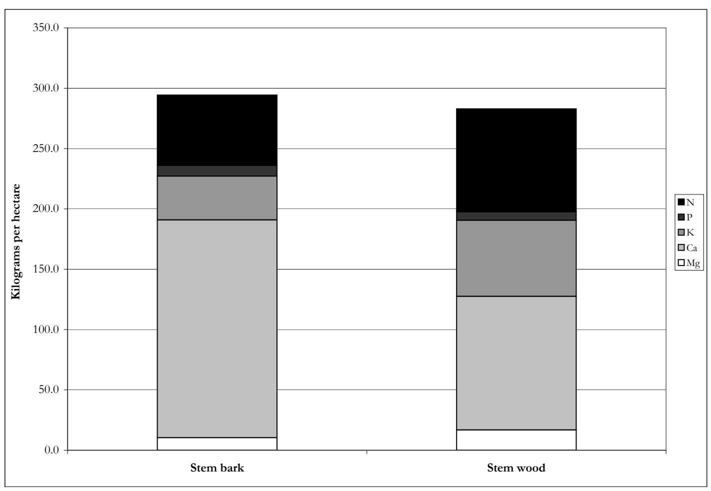


Figure 3. Comparison of average nutrient content (kg ha^{-1}) of N, P, K, Ca, and Mg in the stem bark and stem wood of tree boles based on data from Alban et al. (1978).

4.2.1.3 Foliage and Branches

Foliage and branches act as a major nutrient sink (Prescott 2002). Although foliage constitutes only a small portion of the total aboveground biomass (Figure 2) of a tree, it is the most nutrient rich component containing up to half (Figure 4) of the N, P, K, Mg, and Ca in tree biomass (Kimmins 1977, Alban et al. 1978, Wells and Jorgensen 1979, Smith et al. 1986, Hakkila 2002, Prescott 2002). Heding and Loyche (1984) indicate that only 20% of the total aboveground biomass was contained in branches and leaves of 50 year old Norway spruce (*Picea abies*) and even less for pine species. Smith et al. (1986) determined that the crown material of spruce and fir trees in Maine contained 74% of the P, 70% of the N, 62% of the Mg, 51% of the K and 49% of the

Ca in whole trees (Table 1). The crowns, however, constituted only 28% of the total aboveground biomass. Concentrations of mineral elements in foliar biomass are six to seven times as high as those in the stem (Hakkila 2002). In general, the branches of the upper stem and crown have less nutrients than foliage but approximately the same nutrient content as the roots (Young and Carpenter 1976). Table 2 summarizes the average macro-nutrient distribution in several young hardwood and softwood species in Maine.

Table 1. Pre-harvest biomass (t/ha) and nutrient (kg/ha) content in spruce-fir component (trees >14 cm dbh) of a central Maine forest (Smith et al. 1986).

Tree Component	Biomass	N	P	K	Ca	Mg
Crown	50	225	34	97	208	26
Bole	130	97	12	94	215	17
Whole-tree	180	322	46	191	423	44

Table 2. Average concentration of macro-nutrient elements in dry biomass of young softwoods and hardwoods in Maine (Young and Carpenter 1976).

Category	Tree Component	Concentration in Dry Mass, g $100g^{-1}$				
		N	P	K	Ca	Mg
Softwoods	Foliage	0.928	0.140	0.398	0.710	0.096
(5 spp.)	Branches	0.318	0.071	0.149	0.555	0.049
	Stem	0.150	0.021	0.065	0.350	0.030
	Roots	0.225	0.046	0.098	0.389	0.037
Hardwoods	Foliage	1.347	0.177	0.760	0.780	0.188
(3 spp.)	Branches	0.423	0.189	0.167	0.579	0.063
	Stem	0.251	0.101	0.103	0.409	0.034
	Roots	0.293	0.113	0.185	0.575	0.063

Annual leaf fall plays a key role in nutrient cycling as a source of litter on the forest floor (Boyle and Ek 1972). Nutrients taken up by foliage are returned to the soil through leaf fall. Hornbeck and Kropelin (1982) reported significant increases in nutrient removal when foliage was included in the harvest (Table 3). According to Hakkila (2002: 246) "as a rule of thumb, and using conventional stem-only harvesting for comparison, each percentage increase in biomass recovery represented by crown mass with foliage can be expected to incur increased nutrient losses amounting to 2-3% for pines, 3-4% for spruces and 1.5% for leafless hardwoods. In the case of Ca, the relative loss is smaller in all species."

Table 3. Biomass (oven-dry metric tons/ha) and nutrient removal (kg/ha) for three whole-tree harvests on a northern hardwood stand in New Hampshire (mean±SE) (Hornbeck and Kropelin 1982).

Harvest Type	Biomass	N	P	K	Ca
Winter, no leaves	116±5	230±10	18±1	121±1	335±24
Summer, no leaves	105±7	219±23	17±2	122±5	329±31
Summer, w/leaves	111±5	278±12*	22±2*	142±5*	368±15*
Extractable soil nutrient capital	---	---	---	150	1,140
Total soil nutrient capital	---	7,725	2,237	10,098	15,372

*Significantly greater at 0.05 level from values for other harvest situations.

It would seem logical then to assume that harvesting deciduous trees during the dormant season, or employing transpiration drying, would mitigate a majority of the nutrient loss from whole-tree biomass extraction. Transpiration drying is a method of reducing the moisture content in biomass, whereby trees are felled and left in place with the crowns intact, allowing them to dry through continued transpiration (Stokes et al. 1993). Trees could be left to dry long enough to allow the leaves or needles to fall off (Hakkila 2002). Both of these ideas have been recommended by researchers in the past for conserving foliage nutrients on site in whole-tree harvests (Boyle et al. 1973, White 1974, White and Harvey 1979, Hornbeck and Kropelin 1982, Hornbeck et al. 1990). However, the idea of conserving nutrients by leaving the leaves on the site is complicated by the uncertainty in the concentration of "nutrients in the foliage and the degree to which foliar nutrients are translocated back into other tree tissues prior to abscission" (Johnson 1983: 161). An excerpt from Hakkila (2002: 244) describes some of the variability in foliar nutrient contents:

> When leaf buds break in the spring and new foliage begins to grow, the leaf tissues have high concentrations of N, P and K. As the foliage matures and accumulates carbohydrates, the initial concentrations of these elements are diluted. On the other hand, concentrations of Ca, Mg and Fe usually increase with leaf age. After leave maturation, the content of N, P, and K remains relatively constant during the growing season until a rapid reduction takes place in the fall. Such losses are a result of active withdrawal of nutrients from foliage for reuse during the following year. Leaf nutrient content is also affected by rainfall that leaches some elements, particularly K, from the leaf surface. Leaching rates often increase as foliage undergoes senescence before abscission. Losses of nutrients by leaching follow the decreasing order K, P, N, Ca (Waring and Schlesinger 1985). The same loss pattern seems to occur after harvesting during summer storage of whole-trees and residual crown mass. This means that a proportion of the mineral element content is leached or moved from foliage to the woody components of the branches before the foliage is shed through transpiration drying.

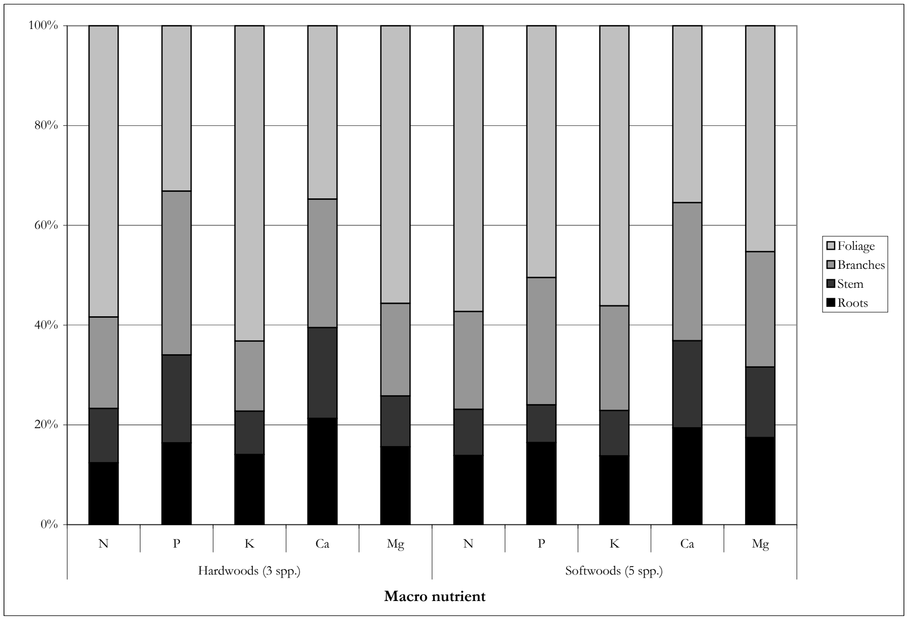


Figure 4. Average percentage macro-nutrient content of the foliage, branches, stem, and roots of three hardwood species and five softwood species of Maine (Young and Carpenter 1976).

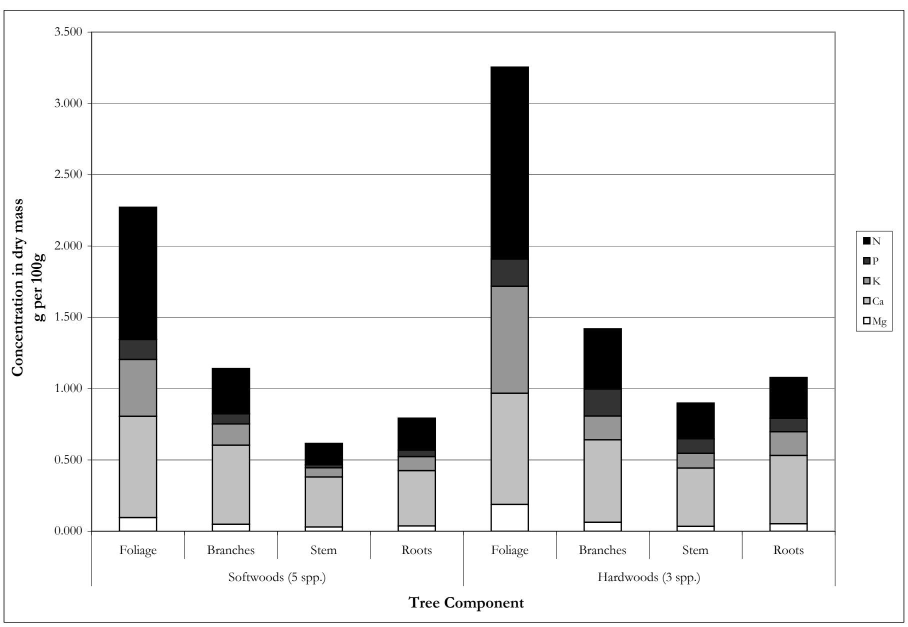


Figure 5. Average concentration of macro-nutrients in foliage, branches, stems, and roots of young hardwood and softwood species in Maine (Young and Carpenter 1976).

4.2.1.4 Generalizations

Several broad generalizations regarding nutrient distributions in biomass have been widely published and generally adopted among forest researchers. They are useful in making management decisions about various aspects of biomass harvesting. The following section reviews several of these.

- In general "the greatest concentration of plant nutrient elements occurs in the parts of the tree where essential life processes take place, i.e., foliage, cambial zone, inner-bark, and root tips" (Hakkila 2002: 244).
- The percentage (Figure 4) or concentration (Figure 5) of nutrient elements in trees "decreases from the foliage to the branches, decreases further in the stem, but increases in the roots approximately to the amount found in the branches" (Young and Carpenter 1976: 5).
- As a stand ages, the concentration of elements that can be found in the stem of trees increases, and the proportion of nutrients in the crown decreases (Kimmins 1977). In younger stands the foliage and branches compose a larger portion of the total aboveground biomass (Wells and Jorgensen 1979). Therefore, harvesting residues in younger stands will generally result in a greater effect on nutrient removal than harvesting more mature stands (Burger 2002).
- Stands with larger overall crown size or density, possibly occurring on more productive sites or associated with a specific species, would contain a larger concentration of nutrients than a site with a smaller overall crown size or foliage biomass density (Kimmins 1977).
- Foliar concentrations of nutrients in spruce and fir trees have been determined to be greater than the foliar concentrations of pines (Kimmins 1977). Wells and Jorgensen (1979) state that even in the dormant season biomass harvesting of hardwood species would remove a greater portion of nutrients than would an equal harvest of conifers. Figure 5 upholds this generalization assuming a stem only harvest.

Johnson (1983) warns that many of these generalizations do have significant exceptions that are often overlooked. Variations in species, age, position in the tree, climatic conditions, stand density, season, and site quality make it difficult to determine the exact distribution of biomass and nutrients in the various components of trees at any one time (Wells and Jorgensen 1979, Johnson 1983, Burger 2002). For most of the same reasons it is just as difficult to determine the amount of nutrients removed by harvesting. Factors such as the component of biomass, live crown ratios and the degree to which the various biomass components are utilized affect the amount of nutrients removed from a given site. Johnson (1983) indicates that while distinctions in nutrient concentrations removed from harvesting hardwoods versus conifers have been reported in the past, exceptions to these broad generalizations must be recognized. "It is generally true that, for a given climatic region, deciduous trees contain more nutrients per unit biomass than coniferous trees. It is incorrect, however, to conclude that this is always the case" (Johnson 1983: 158). He further states that generalizations of this type would be more valid and useful when comparing an individual species or genus, an argument that is also supported by White and Harvey (1979), and Alban et al. (1978). He also states that "while it is usually true that nutrients are most concentrated in younger tissues, it is not always true, and the exceptions can be important from the perspective of total nutrient removal from sites (especially in the case of Ca). It is also clear that the relative importance of foliage in total nutrient removal is so variable that broad generalizations as to the importance of foliage are hazardous" (Johnson 1983: 161).

4.2.2 WHOLE-TREE HARVESTING AND NUTRIENT DEPLETION

Whole-tree harvesting (or full-tree harvesting and in some papers total-tree harvesting) is the method of extracting the entire aboveground portion of the tree including trunk, branches, and needles or leaves to the roadside. It is the most dominant commercial harvest method currently used in Maine (Benjamin 2009). Almost as soon as whole-tree harvesting came into practice in the early 1970s, researchers began raising concerns that it would result in nutrient depletion that could lead to significant drops in site productivity (Boyle and Ek 1972, Boyle et al. 1973, White 1974, Aber et al. 1978, Wells and Jorgensen 1979, Freedman et al. 1981, Hornbeck and Kropelin 1982, Mroz et al. 1985, Hendrickson et al. 1989, Hornbeck et al. 1990). A large amount of research has focused on this issue over the years, but as noted earlier most of the studies on whole-tree harvesting utilize the method of whole-tree clearcutting.

Several complications arise in attempting to determine the effect of nutrient removal on long-term productivity from harvesting when comparing and contrasting results of several different studies. Differences in sampling protocols among studies complicate direct comparisons. Johnson and Curtis (2001) note differences in chronosequence versus real-time sampling, number of replicates, sampling depth, time of study since treatment, and intensity of study, and both Smith et al. (1986) and Aber et al. (1978) identify differences in quantitative evaluation of nutrient budgets.

The practice of whole-tree harvesting was developed as an efficient means of extracting much higher yields per unit area from forests through the removal of biomass that, under other harvesting methods, would have remained on site to decompose (Freedman et al. 1981). While the magnitude of biomass utilization depends on the silvicultural objectives for a site, whole-tree harvesting can effectively remove up to 96% of aboveground biomass, increasing biomass yields up to 46% when compared to conventional stem-only harvesting (Napier 1972, Hornbeck and Kropelin 1982, Smith et al. 1986). Currently a large portion of Maine's biomass energy wood is derived from the byproducts produced during whole-tree harvesting.

There are legitimate concerns, however, that the increase in biomass extracted from the site which results in disproportionately high rates of nutrient removal may ultimately lead to long-term declines in forest productivity (Wells and Jorgensen 1979). Past research has clearly shown that forest soils with higher levels of macro nutrients (N, P, K, Ca, Mg,) are typically associated with more productive forest stands (Mroz et al. 1985). Researchers agree that the concentration of nutrients removed in biomass from whole-tree operations are much greater than the nutrient concentrations removed from conventional stem-only harvesting because a significantly larger portion of the total biomass nutrients are located within branches and leaves (Pierce et al. 1993, Hakkila 2002).

4.2.2.1 SHORT TERM STUDIES

Freedman et al. (1981) harvested a red spruce (*Picea rubens*) - balsam fir (*Abies balsamea*) stand in central Nova Scotia yielding a 30% increase in biomass from the site as a result of whole-tree harvesting (compared to stem only harvesting) with a 99, 93, 74, 54, and 81% increase of N, P, K, Ca, and Mg, respectively. Whole-tree harvesting of a 65-year-old spruce-fir forest in central Maine removed an estimated 90% of the total aboveground biomass from the site and removed two times the Ca and K, three times the Mg and N, and four times the P that would have been removed in a bole-only harvest (Smith et al. 1986). Nutrient contents of the roadside biomass piles (i.e., unutilized crown material) were determined to contain the equivalent of 16% of the P, 61% of the K, 53% of the Ca and 12% of the Mg present in exchangeable form in the forest floor and mineral soil (Table 4). Hornbeck and

Kropelin (1982) found that on average whole-tree harvesting of northern hardwoods in New Hampshire removed the equivalent of 85% of the estimated available K and 30% of the estimated available Ca in the site's exchangeable soil nutrient pool. They also found harvesting increased the removal of N by 19%, P by 4%, K by 15%, and Ca by 12% in whole-tree harvests where leaves were also extracted (Table 3). This becomes even more important with shorter rotations. Based on the nutrient content in aboveground portions of a red spruce-balsam fir stand in St. Jovite, Quebec, Weetman and Webber (1972) estimated that whole-tree harvesting could remove the equivalent of 940, 246, 353 and 126% of the exchangeable P, K, Ca, and Mg in the soil reserves, respectively. Whole-tree harvesting of 45- to 50-year-old mixed hardwoods in Wisconsin removed the equivalent of 11% of the total soil N and 12, 58, 58, and 20% of the extractable soil P, K, Ca, and Mg, respectively; doubling the quantity of nutrients removed when compared to harvesting the boles alone (Boyle and Ek 1972). White (1974) found that whole-tree harvesting of short rotation cottonwood stands on alluvial sites in southwest Alabama could remove the equivalent of 194% of P, 44% of K, 3.3% of Ca, and 5.2% of Mg in the available soil nutrient pool.

Table 4. Percentage content of exchangeable soil macro nutrient elements in crowns, boles, and whole-trees in a spruce-fir forest in central Maine (Smith et al. 1986).

Species & Component	P	K	Ca	Mg
	Percentage of total belowground exchangeable nutrients (%)			
Spruce-Fir (>14 cm dbh)				
Crown	15.7	61.0	53.1	12.3
Bole	5.5	59.1	54.9	8.1
Whole-tree	21.2	120.1	107.9	20.9
Spruce-Fir (<14 cm dbh)				
Whole-tree	2.3	12.6	10.2	2.4
Other species (all sizes)				
Whole-tree	3.7	21.4	18.9	3.7
All species				
Above stump total	27.2	154.1	137.0	27.0

It is important to keep in mind that soil nutrients are distributed in different forms within the soil profile. Soil nutrients can be divided into "available" and "unavailable" pools. Available nutrients are the portion of any element or compound in soil that can be readily absorbed and assimilated by growing plants, and include the nutrients in soil solution and those held loosely by soil particles (Brady and Weil 2002). Unavailable nutrients are those bound up in primary and secondary minerals and undecomposed organic matter (Pierce et al. 1993). These nutrients can be slowly released over time to the available pool through biogeochemical processes. The total soil nutrient pool includes both the available and unavailable reserves. The bulk of the total nutrient elements are held in a structural framework of primary and secondary mineral elements and organic matter. Only a small fraction of the total soil nutrient pool is in a form that is readily available for plant uptake and use. Smith et al. (1986) found that the percentage of exchangeable Mg, K, Ca, and P in the total soil nutrient pool in a central Maine forest was only 0.6, 1.6, 3.7, and 7.8% respectively. Furthermore, Freedman et al. (1981)

noted that exchangeable pools of soil nutrients are ephemeral and small compared to the much larger inputs and outputs of nutrients occurring through processes such as mineralization, atmospheric deposition, biological N fixation, plant uptake, dissolved inorganic outputs to stream water, or the formation of secondary minerals.

Therefore, very different conclusions can be reached when assessing the ecological effects of nutrient removal in intensively harvested biomass stands depending on whether the results are compared to the total or available soil pools for the site (Table 5). When nutrient removals are reported as a proportion of available soil nutrient capital, the results seem much more severe than when reported as a proportion of the much larger total soil nutrient pool. Therefore, researchers have suggested that an appropriate index value for comparing nutrient removal to soil capital lies somewhere between the total and available pools (Freedman et al. 1981, Hornbeck and Kropelin 1982). Weetman and Webber (1972) conclude that forest stands seem to have the ability to extract greater quantities of nutrients beyond that of the measured extractable pool and that these values should not be considered absolute indices of soil nutrients available to trees.

Table 5. Biomass and nutrient removals by conventional and whole-tree clear-cutting of an all-aged *Picea rubens* - *Abies balsamea* stand, expressed as a percentage of the quantities in the forest floor plus exploitable mineral soil (Freedman et al. 1981).

								NH_4 N				Exchangeable	
		Total	Total	Total	Total	Total	NO_3	NH_4	+	P_2O_5			
Treatment	Compartment	N	P	K	Ca	Mg	N	N	NO_3 N	P	K	Ca	Mg
Conventional	Merchantable bole	2.1	1.3	0.7	3.1	1.0	953	256	207	15.7	127.0	164.0	43.5
Whole-tree	Merchantable bole	2.5	1.4	0.6	3.8	2.1	1166	324	253	17.5	106.0	199.0	52.3
	Tops, branches, foliage	2.5	1.3	0.4	2.1	0.9	1155	321	251	16.3	78.0	107.0	42.3
	Total whole-tree removal	5.0	2.7	1.0	5.9	3.0	2321	645	504	33.8	184.0	306.0	94.6

Regardless of how the results are reported, the underlying principle remains the same: in order to ensure the long-term productivity of a site, inputs of nutrients to available pools must be significant enough to replace the nutrients removed from the harvested site and be made available for regenerating vegetation. This principle holds true for any harvesting method. The rate at which nutrients become available for plant growth from sources such as organic matter decomposition, primary and secondary mineral weathering, and precipitation is crucial to maintaining long-term forest productivity (Pierce et al. 1993). The rate at which nutrients are replenished is highly variable, is somewhat difficult to determine, and requires detailed monitoring (Boyle and Ek 1972). However, many researchers agree that if rotation lengths are significantly shortened for biomass production, then nutrient removals through harvesting could drastically accelerate and exceed the rate at which nutrients are made available within the soil (Wells and Jorgensen 1979, White and Harvey 1979). Plants may also use up the readily available supply of a nutrient even if the total supply of that nutrient in the soil is very large (Brady and Weil 2002). Harvesting biomass on sites already identified as being deficient in one or more nutrients will also likely lead to negative effects on forest productivity. According to Smith et al. (1986: 385), long-term nutrient supplies for a site will be dictated by “harvest removals; tree growth and uptake rates; rotation length; litter and internal plant nutrient recycling rates; organic matter mineralization rates;

mineral precipitation and weathering rates; total site nutrient reserves; N fixation, nitrification, and denitrification; atmospheric deposition rates; and leaching losses in soil solution and stream water."

4.2.2.2 Effects on Soil Organic Matter

Soil organic matter (SOM) is a complex and varied mixture of organic substances that includes plant and animal residues at various stages of decomposition (Brady and Wiel 2002). SOM is a vital component of productive soils and plays a major role in soil water retention, cation exchange capacity, aeration, drainage, and nutrient supply (Jurgensen et al. 1986, Jurgensen et al. 1997, Burger 2002). There has been concern that by removing the branches and foliage that are typically left in the forest to decompose, whole-tree harvesting would alter the cycling of organic matter from forest vegetation to the soil, especially when practiced on shorter rotations (Jurgensen et al. 1986).

Timber harvesting in general usually results in a significant decrease in surface SOM for an appreciable time. This is typically attributed to increases in moisture and temperature that initiate higher levels of microbial decomposition (Jurgensen et al. 1986). Therefore, it is speculated that the extraction of woody logging residues even further removes organic materials that would typically be returned to the soil to compensate for this loss.

Using computer modeling, Aber et al. (1978) demonstrated that for a northern hardwood stand, forest floor organic matter and N availability rapidly declined for 15-30 years following whole-tree clearcutting and did not return to pre-harvest levels for 60-80 years. Predictions made by the model indicated that this type of harvest would result in lower amounts of organic matter as well as a somewhat lower N availability compared with conventional harvesting. However, they concluded that rotation length had a greater effect on the forest floor than harvesting intensity.

Burger (2002: 175) explains that "the extent to which forestry operations might result in a decrease of SOM depends on the quantity of the biomass removed, the amount of displacement and removal of the forest floor, and the degree to which substrate availability, soil moisture and soil temperature are modified. It also depends on the ratio of the amount of biomass removed to the amount recycled during the rotation." Johnson and Curtis (2001) concluded that site preparation treatments such as intense burning, mechanical disturbance, or tillage result in overall losses of SOM, but not harvesting *per se*.

4.2.2.3 Long-Term Studies

As has been shown, previous research clearly indicates that whole-tree harvesting results in significant initial changes in the nutrient pools of a site. Larger amounts of nutrients are extracted as a result of increased utilization of biomass from the site. In the extreme cases of whole-tree clearcutting, which is representative of many of these studies, nutrient leaching loss is amplified due to increased mineralization of the forest floor and the lack of nutrient uptake from vegetation. However, more recent studies have focused on reviewing the long-term effects of whole-tree harvesting on site productivity, and many seem to indicate that long-term nutrient declines and reduced site productivity may not be as great of a concern as once thought.

Along with concerns of long-term macronutrient depletion on harvested forest sites, researchers have also expressed concern with the potential long-term effects of ecosystem C balance and soil C storage (Johnson and Todd 1998). Soil C is an important factor in determining soil fertility and with recent concerns over C storage and atmospheric CO_2 concentrations soil C has become a matter of increasing interest among forest soil scientists (Brady and Wiel 2002, Johnson et al. 2002). Research seems to indicate that whole-tree harvesting effects on soil C have shown little effect in most cases (Johnson and Todd 1998). Johnson et al. (2002) compared the effects of sawlog harvesting with whole-tree harvesting on biomass recovery and soil C on four forested southeastern sites. In their report they recognized that forest harvesting appeared to have little lasting effect on soil C after 15-16 years. They concluded that whole-tree harvesting does not result in drastic long-term changes in soil or litter C.

In analyzing the intensity of harvesting forest residues on four coniferous forest sites in Sweden, Olsson et al. (1996) concluded that whole-tree harvesting did not lead to greatly reduced amounts of soil C and N after 16 years compared to conventional stem harvesting. However, in conducting a meta analysis of harvesting effects on soil C and N, Johnson and Curtis (2001) reported that whole-tree harvesting was associated with a 6% reduction of C and N in the soil A horizon whereas leaving residues on site such as in a sawlog harvest resulted in an 18% increase (in comparison to controls) in coniferous stands. Yet they concluded that on average forest harvesting had little or no effect on soil C and N.

In harvesting mixed oak forests in Tennessee, Johnson and Todd (1998) identified that nutrients (but not C) from decomposing logging residues remain on the site as the logs decay but beyond this fact do not play a significant role in the forest ecosystem. Although there are effects of residues on soil and foliar Ca, K, and Mg in some instances, there has yet been no positive effect of residues on regeneration. "If leaving residues on site has no long-term positive effect on mineral soil C, removing residues for biomass burning may be more C efficient (by offsetting fossil fuel combustion) than leaving them on site" (Johnson and Todd 1998 as cited in Johnson and Curtis 2001: 235). They also found that whole-tree harvesting on these sites did not result in reductions of exchangeable soil Ca2+ after 15 years, a nutrient that many researchers believe to be limiting in the long-term in intensively managed forests as a result of harvest removals and leaching loss (Boyle and Ek 1972, Weetman and Webber 1972, Boyle et al. 1973, Silkworth and Grigal 1982, Mann et al. 1988, Federer et al. 1989, Hornbeck et al. 1990, Likens et al. 1996). Furthermore, they found that there were no significant treatment effects resulting from whole-tree harvesting on vegetation biomass or species composition after 15 years.

In comparing whole-tree harvesting with conventional harvesting in Ontario, Canada, Hendrickson (1988) concluded that there was no evidence found indicating decreased productivity or nutrient uptake four years after the whole-tree harvest operation, but that concentrations of N, Ca, and Mg were all lower in the regeneration on the whole-tree site. In Maine, long-term studies on whole-tree harvesting have been made available through research on a pair of adjacent watersheds at Weymouth Point in north central Maine. The site consisted of a mature spruce-fir forest and was harvested using whole-tree clearcutting in 1981. Four years after the harvest in 1985 a conifer release treatment was conducted using an aerial application of triclopyr. Nutrient analysis has been conducted periodically since the time of the harvest. Briggs et al. (2000) stated that following the harvest, increases in forest floor temperature and moisture accelerated the decomposition of litter and residues which resulted in a flush of nitrate-N and Ca concentrations. Within three years nutrient concentrations returned to pre-harvest levels at Weymouth Point as vegetation reoccupied the site. McLaughlin and Phillips (2006) found that whole-tree harvesting had not depleted C, N, or base cations 17 years after the initial harvest and that the exchangeable soil Ca pool doubled, possibly as a result of whole-tree harvesting. They concluded that whole-tree harvesting at Weymouth Point could be a sustainable practice for at least one rotation.

It is important to remember that nutrients are lost not only through direct extraction of biomass but also through leaching, soil disturbance and even erosion associated with logging (Mann et al. 1988). Furthermore, while loss of soil nutrients is the major anticipated cause of declines in future forest productivity resulting from increased biomass harvesting, nutrients are not the sole driver of regeneration responses to a harvesting method. Other factors such as understory competition, soil organic matter, the physical properties of the soil and exposure of the soil to erosive forces as a result of more frequent use of heavy equipment play a major role as well (Wells and Jorgensen 1979, Johnson et al. 2002).

Starting in the 1950s, researchers in Maine have studied the effects of forest soils on site productivity, and it is now widely recognized that soil drainage class is strongly related to overall site productivity. (Eleven articles dating from 1954 to 1994 are referenced by Briggs in the Soils Classification Guidebook.) This has been particularly evident in spruce – fir forests. In 1994, Russell Briggs of the University of Maine's Cooperative Forestry Research Unit (CFRU) developed the site classification system shown in Table 6. Generally speaking, sites with poorly drained soils, or excessively drained soils, are less productive.

Table 6. The Briggs Site Classification System (Redrawn from Briggs 1994).

	Site Class							
	1		2		3	4		5
Drainage Class	Well	Somewhat Excessive		Mod. Well	Somewhat Poorly	Poorly	Excessive[a]	Very Poor
Mottling Depth[b]	>24"	--	--	16-24"	8-16"	4-8"	--	<4"
Loam Cap Thickness	--	>12"	8-12"	--	--	--	--	--

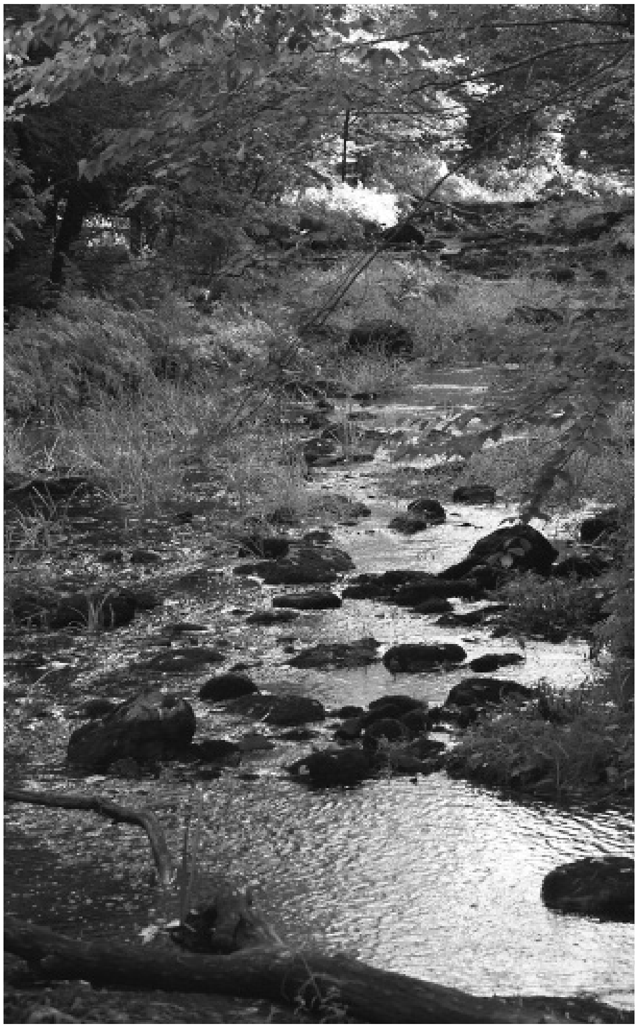
[a] Shallow depth to bedrock (<12") or coarse sand and gravel.

[b] Depth to seasonal high water table is indicated by depth to low chroma (or grey) mottles.

4.3 Guidelines

These guidelines can be adapted and included in site-specific recommendations developed by a licensed forester. They are intended to inform the landowners' decision-making as they review the forester's prescription. Most importantly, implementation of these practices on the ground depends on the professional judgment, knowledge, and skill of the logger conducting the harvest operation. These guidelines are intended to be used by loggers, foresters, and landowners in this context. The guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant part of the product mix.

- Except where scarification of the soil is important for regeneration, leave the litter layer, stumps, and roots as intact as possible. Wood decaying on the ground, especially tops and limbs, contributes nutrients that help build up the growth potential of the soil.
- Leave as many tops and branches as possible on:
  - – low-fertility sites,
  - – shallow-to-bedrock soils,
  - – coarse sandy soils,
  - – poorly drained soils,
  - – steep slopes, and
  - – other erosion-prone sites.



5 WATER QUALITY

Written by:
Jeffrey G. Benjamin, Assistant Professor of Forest Operations, University of Maine
Roger Ryder, Graduate Student, University of Maine

Reviewed by:
John Peckenham, Senior Research Scientist, Senator George Mitchell Center for Environmental and Watershed Research

5.1 INTRODUCTION

This section is intended as a reminder about several important aspects of water quality as it relates to the amount of woody biomass retained on harvesting sites, but it is not intended as a replacement of existing Water Quality BMPs. In one of the few studies directly related to the impact of woody biomass harvesting on water quality, Shepard (2006) concludes that since woody biomass is often harvested in conjunction with other round wood forest products, existing BMPs for any harvest can be followed to protect water quality. Therefore, a working knowledge of BMPs is essential to make full use of this section.

The importance of woody biomass to water quality is related to site disturbance and riparian areas. A common practice to minimize soil compaction and erosion is the placement of brush (i.e., woody biomass) in skidding and forwarding trails. Previously non-merchantable trees that support land and aquatic habitat are often located within riparian zones, so woody biomass retention in these areas warrants further discussion. As a starting point, however, the following two sections provide a summary of water quality policies in Maine and the general effects of harvesting on water quality.

5.2 POLICY

Water pollution and water quality in the United States are regulated by the US Environmental Protection Agency, primarily through the 1972 Clean Water Act (CWA) and its reauthorization in 1993. While much of the CWA deals with point source pollution, non-point source pollution is addressed in sections 404, 208 and 319. Forest harvesting is designated as a contributor to non-point source pollution, and although forestry has a silvicultural exemption from permitting, the profession still has the responsibility to protect water resources and uphold water quality standards. The USEPA (1999) defines water quality standards in terms of use and then sets criteria to protect those uses and to prevent water quality loss through anti-degradation provisions. In response to the CWA silvicultural exemption, all states have adopted their own set of forestry best management practices (BMPs) to protect water quality.

The goal of BMPs, in accordance with the CWA, is protection and enhancement of the chemical, physical, and biological attributes of our water resources. In particular, BMPs are to be used during and/or after road and landing construction, harvesting, and other forestry operations (Shepard 2006). Sections 303 and 304 of the CWA require states to also protect biological integrity as part of their water quality standards. USEPA (1999) establishes biological criteria to measure the condition of the aquatic biota, determine water quality goals and priorities, and evaluate the effectiveness of controls and management actions. Maine has utilized bioassessments, in addition to chemical and physical assessments, as part of the metrics for classification and tracking of the state's water-bodies (Davies et al. 1999).

The Maine Forest Service's Best Management Practices for Forestry is a program that focuses on education, outreach, and voluntary measures to protect water quality during timber harvesting activities (Maine Forest Service 2004). For several years the Maine Forest Service has also conducted a comprehensive monitoring program of BMP implementation and effectiveness. Briggs et al. (1998) indicated that while there was a high level of compliance with those BMPs associated with planning haul road and skid trail location and layout, the need for BMPs beyond the planning stage was not as widely appreciated in field operations. According to their report, some BMPs were inconvenient and they reduced the efficiency of wood extraction, thus adding to the harvesting cost. Compliance began to drop as BMPs required more substantial inputs beyond planning, especially when elevated costs were involved. A number of BMPs pertaining to haul roads and skid trails were used at half the sites where they should have been applied. The report also indicated that compliance levels in Maine at that time were still on par with those reported in Vermont and Minnesota.

More recently, the Maine Forest Service has adopted, and regularly implements, standard BMP monitoring protocols to determine the use and effectiveness of BMPs on timber harvesting operations within the state. The most current review indicates significant improvements in BMP use and effectiveness (Table 7). In 2000, BMPs were not used on 25% of harvests, but by 2007 compliance increased by close to 20% in total. The report indicates that BMPs use and effectiveness continue to improve.

Table 7. Comparison of BMP use from 2000 to 2007 (Maine Forest Service 2008).

Reporting Period	Sampling Units	Appropriate BMP Use (%)	Non-application of BMPs (%)
2000-2001	181	41	25
2001-2003	288	52	8
2005	102	79* (92**)	4* (6**)
2006-2007	252	77*	4* (2**)

* Crossings
** Approaches

Riparian areas represent another situation where the retention of woody biomass is critical to water quality. Riparian areas are a natural filter which require stable vegetation to function properly. In particular, mature trees provide both shade and organic matter to streams. Maine already has regulations in place for conducting timber harvesting activities in riparian areas. They are summarized as follows:

- Erosion and Sedimentation Control Law, 38 MRSA §420-C
- Mandatory Shoreland Zoning Law, 38 MRSA §435 *et seq*
- Natural Resources Protection Act, 38 MRSA §480-A *et seq*
- Land Use Regulation Commission, Land Use Districts and Standards (Chapter 10)
- Municipal-specific shoreland zoning ordinances

5.3 EFFECT OF HARVESTING ON WATER QUALITY

Throughout the United States, forested watersheds are the source of the highest quality of water (Brown and Binkley 1994). Forests act to filter moving water by inhibiting sediments and other pollutants from reaching waterways (Maine Forest Service 2004). Maine, more than other states, has an abundance of lakes, streams, rivers, and wetlands due in part to its glacial history and to a year round rainfall pattern with more precipitation than evapotranspiration (Stafford et al. 1996). As such, and with acknowledgment of a high percentage of forestland, Maine's water quality is high relative to other states. Both natural and unnatural disturbances can have deleterious effects on the quality of water systems (Brown and Binkley 1994). Natural disturbances such as wildfires and heavy rainstorms can alter water quality in a number of ways. Disturbances caused by logging operations, however, have raised concerns about increased pollutants entering Maine's waterways. Forest operations can influence the chemical, physical and biological attributes of water quality. Unlike natural events, however, anthropogenic disturbances can be minimized and controlled through planning and careful operations.

The University of Maine has been involved with water quality research for many years. In 1996, the Water Research Institute prepared a report for the Maine Department of Environmental Protection to review the effects of forest practices on water quality in Maine (Kahl 1996). That same year, the Cooperative Forestry Research Unit also completed a literature review of forestry related non-point source pollution in Maine (Stafford el al. 1996). Both Kahl (1996) and Stafford et al. (1996) closely examined the impact of forest practices in relation to water quality and also the use of best management practices to mitigate undesirable consequences. They focused primarily on regional studies that were applicable to Maine including the Hubbard Brook Experimental Forest in New Hampshire and the Weymouth Point Study Area in Maine. Both reports provide detailed descriptions of the relationships between harvest practices and many issues important to water quality including site disturbance, hydrology, nutrient cycling, stream temperature, and stream flow. Kahl (1996) in particular points out that the level of site disturbance from harvest activities is related to both harvest intensity and compliance with best management practices, but in general harvesting has the potential to reduce long-term site productivity as well as to decrease water quality. He summarizes that harvesting impacts nutrient cycling and water quality in three ways due to removal of nutrients in the harvested material, decreased uptake of nutrients and water, and changes to biogeochemical processes. The latter is linked to increased runoff of nutrients and sediment caused by soil compaction, rutting, increased stream temperature, and altered hydrology.

Following any harvest, there is potential to reduce the amount of water intercepted and transpired by vegetation. As vegetative cover above the soil decreases there is a direct correlation to increased peak runoffs, decreased transpiration, and decreased time of concentration (i.e., time a drop of water moves from one point in the watershed to another). Reduction in vegetative cover typically increases peak runoff, thereby increasing stream flow. The extent to which stream flow is increased is directly related to harvest intensity and greater peak runoff may contribute to sedimentation and stream turbidity (Patric 1978). Patric's (1976) study in West Virginia found that stream flow had returned to pre-harvest levels within three years. Pierce et al. (1993) found that stream flow increased between 10 and 88% during the first three years following whole-tree harvesting on three New England watersheds. Most of the annual increase was found to occur in the summer and early fall when streams are typically at low levels anyway. This was speculated to be favorable to stream biota and municipal watersheds. They also noted that due primarily to reductions in transpiration, soils on recently harvested sites are wetter which means stream flow tends to increase and remain elevated on whole-tree harvested sites for as long as six years with no other interventions. Since soils are expected to be near saturation in winter and early spring for both undisturbed forests and whole-tree harvest sites, stream flow is thought to be unaffected (Pierce et al. 1993). It should be noted that snowmelt from whole-tree harvest sites will likely be earlier due to increased exposure which may balance snowmelt flood peaks.

Alterations to the watershed that increase water run-off will also alter the stream channel since stream channel geometry is directly related to run-off volume and velocity. When stream dynamics are altered, the stream is placed in an unbalanced situation and therefore the stream begins self-alteration to adjust for the changes to reestablish the overall stream balance. Adjustments are typically observed in the channel cross sectional and longitudinal geometry which may have a significant impact on changes to existing stream habitats and the stream functionality to transport the watersheds water flows and natural sediment load (Leopold 1994, USACE 2004). With changes in peak flows within a watershed there is a higher probability that stream crossing structures may fail and primary transport trails may incur increased erosion (Pierce et al. 1993).

According to Maine's BMPs, water quality is affected the most by roads, skid trails, landings, and drainage systems which change the natural flow of water through a watershed (Maine Forest Service 2004). Disturbances created during harvest operations have the potential to reduce soil absorption capacity, thereby increasing surface runoff and erosion. Roads and trails can divert and concentrate water flows resulting in the creation of eroded channels through which water can carry sediments to local streams, rivers, lakes, and wetlands. Woody biomass becomes important to water quality in mitigation of site disturbance and management of the riparian areas.

5.4 Site Disturbance

No matter how carefully planned and implemented, logging practices will cause site disturbance. Martin (1988) compared soil disturbance on nine studies from the 1960s and 1970s with three watersheds in Maine, New Hampshire, and Connecticut that were whole-tree clearcut harvested in the early 1980s. He concluded the percentage of disturbance per area has increased over time with changes in equipment (i.e., tracked to wheeled machines, chain saws to harvesters) and harvest methods (i.e., partial cuts to clearcuts to whole-tree clearcuts). Turcotte et al. (1991) found that differences in soil moisture influenced the amount of site disturbance on a whole-tree clearcut site in northern Maine that used feller forwarders. Other reports indicate site disturbance levels at this site were in excess of 90% (Martin 1988, Pierce et al. 1993), but significant site disturbance, as defined by exposed mineral soil and deep tire ruts, was found on 19 and 42% of the site for moderately well drained soils and poorly drained soils respectively. Hatchell et al. (1970) studied soil disturbance from nine tree-length skidding operations in South Carolina covering a wide range in soil types, moisture regimes, and harvesting locations (e.g., trails, landings, undisturbed sites) and found that area in trails averaged 35% with four of those sites showing “above average” disturbance levels (Table 8). Although soil disturbance from ground-based skidding operations in Saskatchewan, Canada, was found to be higher on three sites harvested in the summer compared to two sites harvested in the winter, average soil disturbance was less than 15% across all sites (Block et al. 2002). Ryan et al. (1992) found that whole-tree harvesting in northern hardwood region disturbed 65% of the area including 25% exposed mineral soil. The above studies highlight that the level of site disturbance from harvesting activities is highly variable and is also dependent on harvest method, harvest system, and site conditions.

Table 8. Summary of surface soil disturbance classified by type (Hatchell et al. 1970).

Disturbance Type	Bulk Density (g/cm^3)	Soil Strength (kg/cm^2)	Infiltration Rate (in./hr)	Air Space (percent by volume)
Log Deck	1.14	3.4	2.6	26.2
Primary Skid Trail	1.08	2.8	2.7	23.1
Secondary Skid Trail	0.92	2.1	5.5	27.5
Undisturbed Soil	0.75	1.1	25.2	38.5

Comparison of site disturbance levels between studies is difficult because there is not a consistent site disturbance classification system. For example, Martin (1988) outlines a detailed line transect methodology for measuring soil disturbance on logging sites based on a 10-point visual classification system that describes level of disturbance in terms of rutting, amount of dead wood, and exposed mineral and organic soil. Hatchell et al. (1970) did not describe how disturbance levels were measured, although they were likely based on detailed measurements of bulk density, infiltration, and soil strength (Table 8). Further, many site disturbance results are reported for scientific harvesting studies using the “best” management practices based on visual estimates of erosion and sedimentation as opposed to measured biological, chemical, and physical changes to the site (Kahl 1996). As such, it is important to consider specific site disturbance impacts related to compaction and erosion.

5.4.1 Soil Compaction

5.4.1.1 Causes

Williamson and Neilsen (2000) describe many factors that determine soil susceptibility to compaction including soil moisture, organic matter content, soil type, skidding cycles, applied load (machine and timber combined), and machine characteristics. Operation of heavy machinery on roads, landings, and major trails makes these areas highly susceptible to soil compaction. The weight of the machine causes an increase in soil bulk density and a reduction in water flow through the soil (Alaoui and Helbling 2006), although soil compaction is not solely a function of machine weight as Horn et al. (2007) found that a machine with a mass of 8.7 Mg achieved higher peak stress values than a machine five times as large. Significant compaction occurs during the first pass of a machine (Grigal 2000) which has been shown to reduce infiltration capacity, increase surface runoff and erosion, and adversely affect plant growth and regeneration (Hatchell et al. 1970, Corns 1988, Martin and Hornbeck 1994, Briggs et al. 2000, Ampoorter et al. 2007). This is especially apparent when operations are conducted on wet soils (Hatchell et al. 1970, Moehring and Rawls 1970, Turcotte et al. 1991, McNabb et al. 2001, Ampoorter et al. 2007).

Many studies related to soil compaction focus on changes in soil bulk density due to logging activities. A detailed soil compaction experiment was conducted by Hatchell et al. (1970) on 47 sites in South Carolina. A crawler tractor weighing 12,500 pounds (10 psi) pulled a two-wheeled trailer loaded with water weighing 3,500 pounds (46 psi) to approximate a normal load of pulpwood. Soil bulk density subsequently increased between 22 and 52% for trails and landings, with primary trails showing twice the increase over secondary trails. Block et al. (2002) studied changes in soil bulk density on five ground-based skidding operations (combination of whole-tree and tree-length), including mechanical site preparation, in Saskatchewan, Canada and found a significant increase in bulk density of 8 to 11% at 10 cm and 20 cm depths for two sites harvested in the winter. An additional increase in bulk density of 7 to 14% was also found on two of three summer-harvested sites at a 10 cm depth. Williamson and Neilsen (2000) conducted extensive soil compaction investigations of ground-based skidding operations (presumed to be tree-length harvests) on six sites in Tasmania. Even though the sites covered a range of initial conditions (e.g., initial bulk density, soil moisture, soil type, altitude, geology, and average annual rainfall), final bulk densities were similar at an average of 0.17 g/cm^3. McNabb et al. (2001) also did not find any significant relationships between bulk density and other site and soil conditions. The number of skidding cycles or machine passes, however, has been positively related to changes in soil bulk density (Hatchell et al. 1970, Williamson and Neilsen 2000, McNabb et al. 2001, Ampoorter et al. 2007).

In general, a non-linear relationship exists between number of machine passes and increases in soil bulk density. Assuming the soil is not in a saturated state, the soil is strengthened with each subsequent pass which reduces the rate of change in bulk density (Ampoorter et al. 2007). McNabb et al. (2001) found that bulk density was most affected within the first three skidding cycles in two cut-to-length operations and twelve whole-tree operations (Figure 6) and that the increase was due in part to soil water potential at the time of operation. Hatchell et al. (1970) found that bulk density increased in surface soils at a higher rate during the first two skidding cycles compared to the final seven and in particular an average of 2.5 cycles were required to compact the soil within 10% of the maximum from nine cycles. Ampoorter et al. (2007) found that the first pass by a cut-to-length harvester increased soil bulk density by 7 to 14%, while subsequent passes resulted in limited increases of only an additional 1 to 5%. Considerable change in bulk density was also observed in the first one to three cycles of ground-based skidding operations in Tasmania (Williamson and Neilsen 2000). This observation held true when data were examined with respect to soil layer and site conditions. Sixty-two percent of soil compaction in the first 10 cm occurred after the first skidding cycle, while over 80% of soil compaction occurred at 30 cm after three cycles (Williamson and Neilsen 2000).

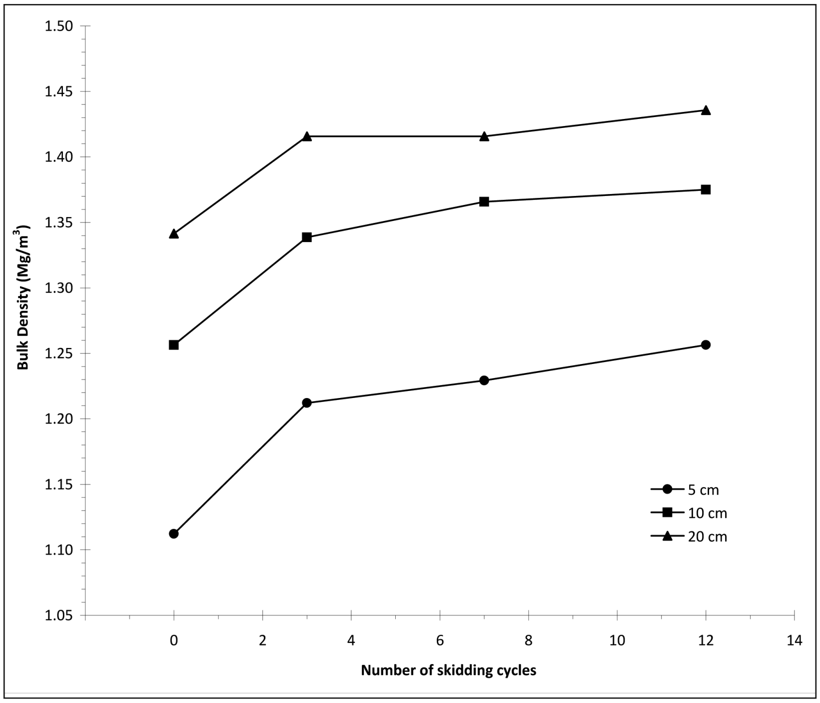


Figure 6. Effect of the number of skidding cycles by wide-tired skidders and forwarders on bulk density for medium textured boreal forest soils (McNabb et al. 2001).

Several soil properties in addition to bulk density are linked to soil compaction. Horn et al. (2007) examined the effects of current forestry equipment on various soil properties including strength, soil displacement, and air permeability. Their study of soils susceptible to compaction (e.g., low initial bulk density, low pre-compression stress, high air permeability) focused primarily on mechanized cut-to-length systems, but also included whole-tree skidding and horse logging operations. They found that although peak stresses disappeared from most operations at the conclusion of harvesting activity, soil properties were still affected at greater depths. Hatchell et al. (1970) found that tree-length skidding decreased air space in the soil which resulted in reductions of infiltration on trails and landings between 80 and 90% and a significant increase in soil strength between 90 and 210%. Ampoorter et al. (2007) found that penetration resistance was shown to significantly increase after one pass of a cut-to-length harvesting machine in the first 30 cm (73 to 122%), but considerably more resistance (an additional 70 to 150%) was measured with subsequent passes. Williamson and Neilsen (2000) found that although a sharp rise in soil strength occurred after the first cycle, it continued to rise at a lesser, but constant, rate rather than level out as in the case of bulk density.

5.4.1.2 IMPACTS

Soil compaction has been recognized as one of the primary sources of long-term soil degradation, affecting both regeneration and water quality. As summarized by Martin (1988), soil compaction resulting from forest operations (i.e., roads, landings, and skid trails) can negatively affect pore space, root growth, regeneration, infiltration, leaching, and storage of soil water. Ampoorter et al. (2007) found that it was only after subsequent passes (as many as seven) that limits for optimal root growth were exceeded. Corns (1988) found significant reductions in seedling growth due to soil compaction in a controlled experiment where lodgepole pine (*Pinus contorta* London var *latifolia*

Engelm.) and white spruce (*Picea glauca* (Moench) Voss) seedlings were grown under a range of soil bulk densities (0.7 to 1.5 Mg/m^3) common to Alberta, Canada. He further states that the effect of soil compaction on root growth is "a complex interaction between soil strength, water and nutrient availability, and aeration" (Corns 1988: 83). In a study of tree-length logging in South Carolina, soil disturbance affects loblolly pine regeneration the most when soil compaction is combined with excessive soil moisture especially on medium to fine-textured soils (Hatchell et al. 1970). Moehring and Rawls (1970) found that diameter growth of loblolly pine was reduced by 25 to 35% five years after logging where traffic intensity was located on three and four sides of each tree respectively. There was no statistical difference in growth when traffic intensity was confined to one or two sides. Gomez et al. (2002) found that soil compaction effects on ponderosa pine (*Pinus ponderosa* P. Lawson & C. Lawson) growth were also dependent on soil texture and soil moisture content.

Soil compaction has been shown to negatively influence water infiltration, conductivity, water capacity, and aeration of various soil types (Holman et al. 1978, Martin and Hornbeck 1994, Huang et al. 1996). Soil with either naturally occurring small pore spaces (e.g., clays), or small pore spaces created by compaction, will tend to increase capacity to retain water and can lead to saturation. For example, an infiltration experiment conducted by Alaoui and Helbling (2006) in Switzerland on sandy loam soils, showed that non-compacted soils experienced immediate water infiltration while compacted soils experienced puddling on the soil surface. Soil compaction can lead to development of ruts, and especially when combined with reduced infiltration, runoff potential is increased thereby accelerating erosion.

5.4.1.3 Mitigation

Although soil compaction can have lasting effects on forested sites, proper harvest planning can help mitigate those effects. In Maine, research at Weymouth Point by Martin (1988) has indicated that mechanized harvesting can cause compaction on more than 90% of a site if machine operators do not follow a controlled harvest pattern to minimize the disturbed area. Planning for season of harvest (e.g., dry conditions in summer, frozen or snow-covered conditions in winter) can greatly reduce the extent of soil compaction on skid trails (Kahl 1996). In studying the effects of mechanization on the soils of Maine's spruce-fir region, Holman et al. (1978) found that soil bulk density outside of skid trails returned to pre-harvest levels after only one over-wintering period and that soil bulk densities from skid trails of winter harvests were restored after only two over-wintering periods. They found that after three growing seasons the soil bulk density was not significantly different between the uncut control and the winter skid trail. They also found that machines compact skid trails twice as much in the summer as in the winter and that skid trails from summer harvests had not returned to normal conditions after three over-wintering periods which was the duration of the experiment. They concluded that compacted soils could be restored to their original bulk density as a result of natural cycles of freezing and thawing, wetting and drying as well as from root penetration and faunal activity.

Although two to three years is probably the minimum amount of time it takes to alleviate compaction, some studies outside of Maine estimate a longer recovery period. Froehlich et al. (1985) found that soil bulk density on skid trails in Idaho did not return to normal levels even after 23 years. Hatchell et al. (1970) estimated that it would take 18 years for soil bulk density to return to normal after tree-length skidding operations in South Carolina. Corns (1988) estimated that it could take up to 21 years for soil bulk densities to return to pre-harvest levels following a whole-tree harvest in Alberta despite annual freeze-thaw cycles. Although this conflicts with estimates by Martin (1988) and Holman (1970) for operations in New England, it does highlight that frost action alone cannot be relied upon as the sole solution to harvest-induced soil compaction.

In some instances, placement of residue on skid trails can be an important measure to alleviate soil compaction by logging machinery. Slash displaces the machine weight over a greater area, not confining it to the tires or tracks. Wood et al. (2003), found that both bulk density and strength of peatland soils on six sites in the United Kingdom were not affected by cut-to-length logging operations with the use of slash in trails. They also noted that use of brush mats has been shown to be more effective on sites where wood is carried as opposed to dragged. Ampoorter et al. (2007) found that a brush mat piled 40 cm high on a skid trail in an experiment on sandy soils reduced compaction considerably across all soil depths, but despite this reduction, the brush covered soil was still compacted significantly more than the undisturbed soil. Horn et al.'s (2007) study of sandy loam soil in Germany also found that brush placed 60 cm high on the skid trail alleviated a slight amount of the compression stress caused by the machinery, however, not nearly enough to prohibit changes in the internal soil properties. Their study also highlighted the importance of spatial arrangement of brush in trails and they advocate for the use of dedicated forwarding and harvesting trails, the spacing of which would be limited to the boom reach of forest machinery. If the latter option was implemented in this region, a significant increase in trail area would result and likely conflict with many silvicultural objectives.

The number of passes of a machine on a trail and soil moisture are still critical factors for soil compaction in trails even if a brush mat is used. McDonald and Seixas (1997) found that after one pass the slash made little difference, however, after five passes total compaction of the unprotected trail was twice that of the brush protected trail. In the same study, slash densities of 10 kg/m^2 and 20 kg/m^2 were compared on both wet and dry skid trails. On dry soils the slash had a beneficial effect, but slash density made no difference. On wetter soils, however, compaction was greater on skid trails with only 10 kg/m^2 of slash than those with 20 kg/m^2. Here, only the higher density of slash significantly reduced soil compaction. Ampoorter et al.(2007) also stress that the influence of the brush mat is proportional to its thickness.

Implementation of existing BMPs that limit rutting and compaction to well-planned skid trails will help mitigate the problems of soil compaction resulting from harvesting activities. Research seems to suggest that biomass harvesting will not contribute to or create additional physical impacts on the soil productivity as compared to conventional harvesting as long as best management practices are followed (Shepard 2006). The obvious implications of woody biomass retention from the above discussion is that forest operations should continue to use woody biomass in trails where necessary, plan trail locations, and integrate operations to reduce the frequency of entries onto a site by multiple pieces of equipment.

5.4.2 SOIL EROSION

5.4.2.1 CAUSES

Soil erosion is defined as the loss of soil through the detachment of soil particles by means of water, wind or ice. Sedimentation of waterways occurs when eroded soil is deposited into streams, rivers, lakes, or wetlands. Soil erosion is a natural geologic process with rates of 0.1 ton/ac/yr considered as normal (Patric 1978). Erosion from undisturbed or carefully managed forests occur at relatively slow rates (0.05-0.10 ton/acre/year) which, as shown in Figure 7, are at least 50% less than geological norms and at least one order of magnitude less than accepted rates for agricultural land (Patric 1976). The forests of New England in particular erode an average of 30-40 kg/ha/yr (0.01-0.02 ton/ac/yr), which is less than any other region in the country (Martin and Hornbeck 1994). Vegetative cover and the litter and debris layer blanketing the forest floor protect mineral soil from erosive forces (Patric 1978, Stafford et al. 1996). In the northeast, water infiltrates the soil faster than the rate of precipitation so that water moves down slope through subsurface porous soils resulting in very little overland flow (Patric 1978, Stafford et al.

1996). Natural erosion rates are accelerated when disturbances expose mineral soil and water movement creates defined water flows along the surface of the forest floor (Grigal 2000).

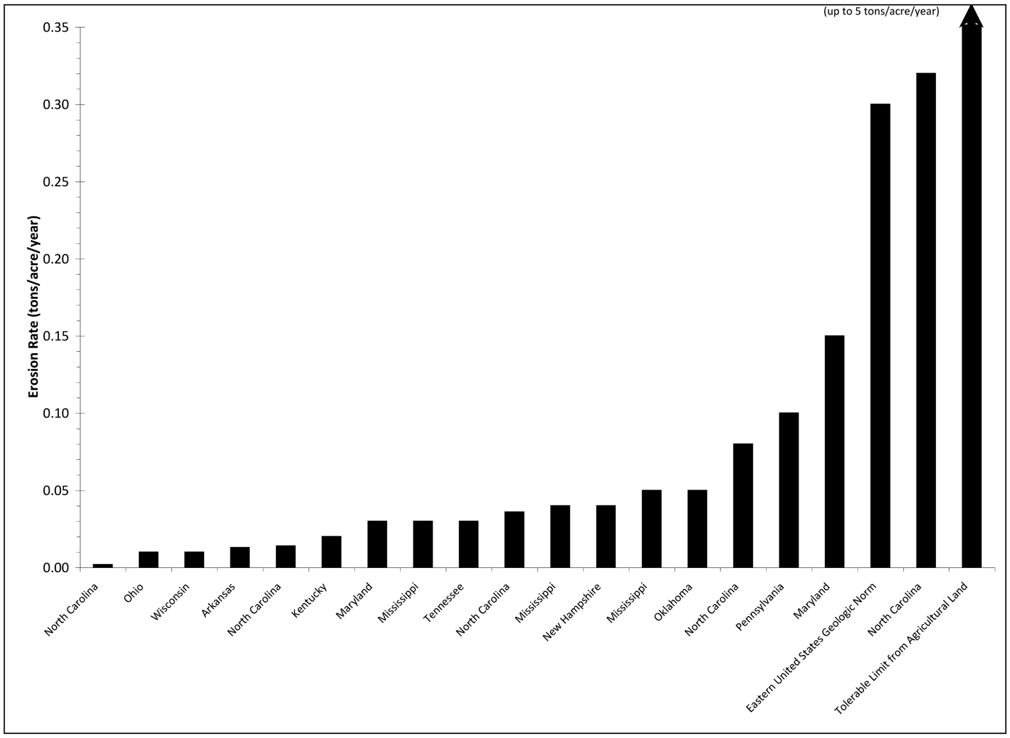


Figure 7. Erosion rates from forested plots and small watersheds in the eastern United States in comparison to tolerable limits of 1 to 5 ton/ac/yr from agricultural land (Patric 1976).

There are many factors unrelated to the method of management that increase risk of erosion. As Patric (1978) highlights, erosion hazard increases with steep slopes, wet areas, and proximity to streams. As slope increases, water velocity of overland flow increases. As volume and velocity of water flow increases, channelization of water flow begins, thus increasing sedimentation distances and increasing the erosive force of the flowing water. In Maine, slope steepness is not as influential a factor as in other portions of the country. For example, a whole-tree clearcut conducted in Maine that exposed mineral soil on 20% of the site, did not significantly increase stream turbidity because of a lack of topographic relief (Pierce et al. 1993). In a comparison of conventional and reduced impact logging in Indonesia, Hartanto et al. (2003) found that although soil loss was related to canopy cover, sapling density, litter depth and woody debris, it was rainfall that had the most influence on runoff. (Reduced impact logging for that study was defined as a practice where tractor passes were minimized, through planning and layout of skid trails, and directional felling were used to protect advanced regeneration. Both of these practices are standard in the logging industry from our region.) Martin and Hornbeck (1994) found that although there was considerable variation in annual sediment yield within three undisturbed forested watersheds in New Hampshire, average yield over a 16-year period was close to long-term average rates estimated by Patric (1984). Sediment yields in those watersheds were not correlated with precipitation (Figure 8), but they were correlated with large storm events (Martin and Hornbeck 1994).

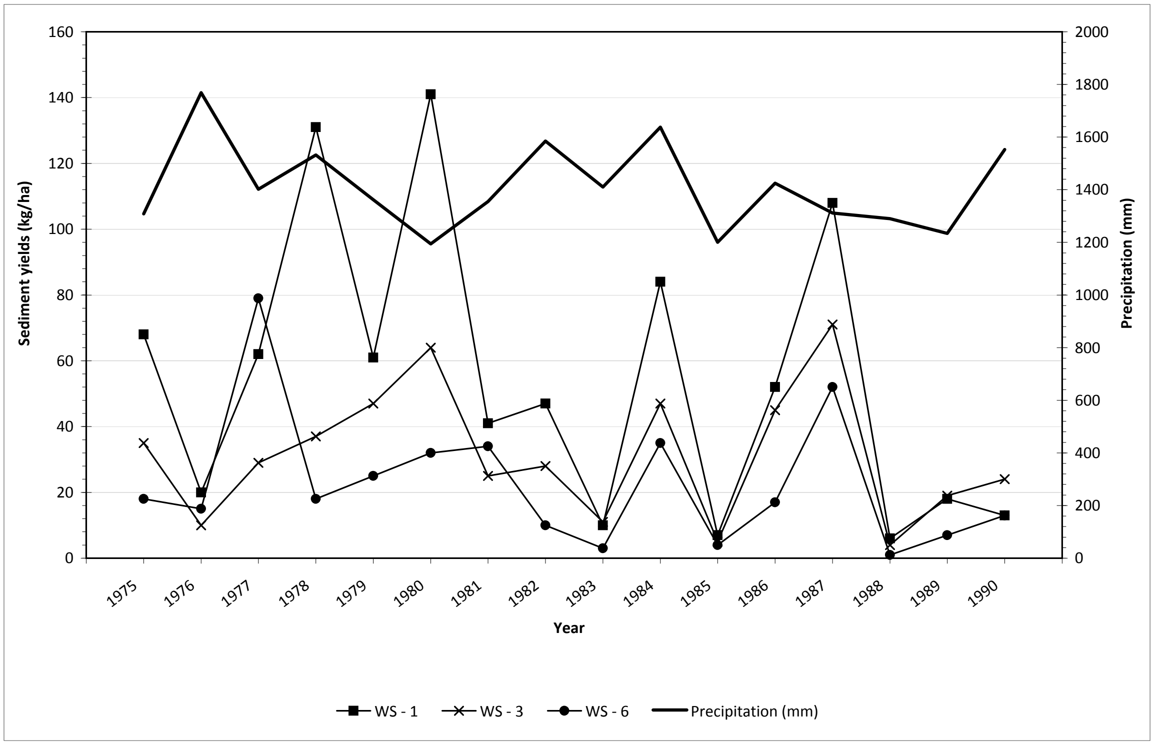


Figure 8. Sediment yields from three uncut watersheds at the Hubbard Brook Experimental Forest in New Hampshire were not found to be correlated with precipitation (Martin and Hornbeck 1994).

Generally speaking, the forested regions of Maine are not at substantial risk to erosion due to extensive forest vegetation cover, high infiltration capacities, evenly distributed precipitation regimes, and large areas of mild topography (Martin and Hornbeck 1994, McWilliams et al. 2005). Surface flow is uncommon in undisturbed forest conditions because water infiltration rates are often much higher than rainfall intensity. For example, in the eastern hardwood region infiltration rates can easily be 50 inches per hour with rainfall intensity typically less than two inches per hour (Patric 1978). Tree cutting, by itself, does accelerate surface erosion and historical research has shown that as long as the forest soil structure and organic layer is relatively undisturbed, the kind, size or density of trees being harvested has little influence on soil erosion (Likens et al. 1970, Patric 1976, Martin and Hornbeck 1994). Figure 9 shows how sediment yields from a clearcut watershed in the Hubbard Brook Experimental Forest compare to the natural variation of sediment yields from two adjacent undisturbed watersheds. Watershed 2 was clearcut in 1965, subsequently treated with herbicide for the next three years, but no wood products were removed and no skid trails or roads were constructed (Martin and Hornbeck 1994). Other than the five years after harvest and herbicide treatment, sediment yields from watershed 2 were comparable to the undisturbed watersheds. Minimal disturbance to the forest floor near water channels is critical to maintaining erosion rates at geological norms, although even with careful logging operations soil loss can still be double that of geological norms (Patric 1978).

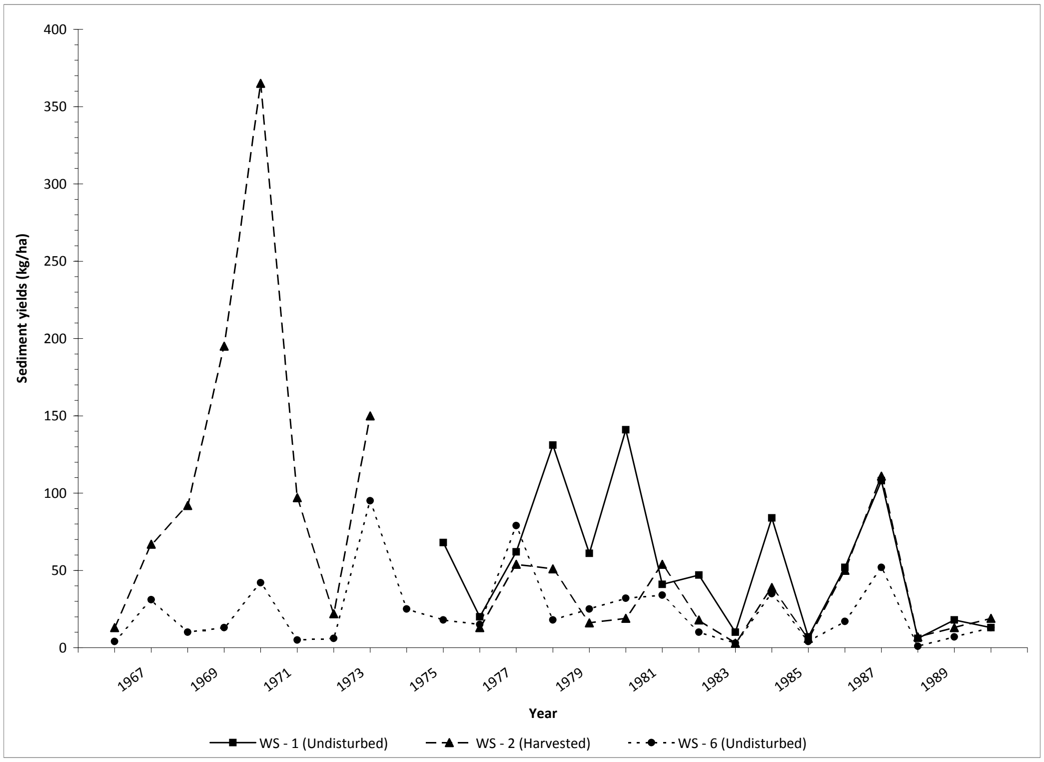


Figure 9. Comparison of sediment yields from three watersheds at the Hubbard Brook Experimental Forest in New Hampshire (Martin and Hornbeck 1994).

Erosion becomes a concern in forest operations when soils are exposed through harvest activities and transport of products to roadside. Forest operations have the ability to accelerate erosion (or increase the risk of erosion) beyond natural levels, especially when practiced carelessly (Hatchell et al. 1970, Patric 1976, 1978). Researchers are in agreement that the construction, use, and maintenance of haul roads, skid trails, and yarding areas are the principal sources of erosion and non-point source sedimentation pollution in forest harvesting operations (Rich 1961, Copeland 1965, Fredriksen 1965, Megahan and Kidd 1972, Anderson et al. 1976, Dissmeyer 1976, Patric 1976, Kochenderfer 1977, Martin and Hornbeck 1994). These areas are generally located within the harvesting operation where the mineral soil becomes exposed, thereby increasing the risk of soil erosion. Although clearcutting is often linked to increased erosion, Patric (1978) notes that frequent re-entry into areas under selection management will actually increase erosion potential on roads and trails.

While many difficulties with forest resource extraction and forest access have already been addressed, some concerns still arise with woody biomass harvests. In particular, whole-tree skidding has the ability to disrupt more of the organic cover, exposing and compacting the mineral soil beneath (Mroz et al. 1985). Another possible concern is that yard sizes may increase in area in order to accommodate both biomass and conventional products. Increasing yard area increases the risk of exposed mineral soil and potentially increases the risk of soil erosion. Yards are also the area of high density traffic which adds to the challenge of protecting the soil. As in the past when large chipping operations produced paper quality chips direct from a logging operation, planning and stabilizing yard locations becomes a critical factor for success in protecting the soil and water resources.

Whole-tree harvesting may cause increased disturbances to the forest compared to other harvest methods such as tree-length or cut-to-length (Pierce et al. 1993). Hornbeck et al. (1986) indicate that whole-tree harvesting (i.e., whole-tree clearcutting) removes close to twice the amount of biomass compared to stem only harvests and skidding cycles will likely increase as a result. Whole-tree harvesting, however, may not be as detrimental to water quality as might be expected. Martin and Hornbeck (1994) studied a watershed in New Hampshire's Hubbard Brook Experimental Forest that was whole-tree clearcut in 1984. They found that sediment yield from the clearcut area (64 kg/ha) in the year of harvest was not significantly different than precut yields over the nine years prior. Sediment yields, however, were significantly elevated in the three years following harvest, but even they were not much higher than the pre-cut maximum level (134 kg/ha). Five years after harvest sediment yields had returned to pre-harvest levels.

Patric (1980) found that harvest intensity makes a minimal difference in the amount of particulate matter reaching waterbodies. He reports the results of a soil and water study of a 31.7 ha watershed in West Virginia that underwent a series of three selection cuttings (13%, 8%, and 6% basal area removed) over a span of eleven years (1958-1968), and then was clearcut in 1969. Over ten years, the selection cut doubled particulate matter in the pond (35 kg/ha/yr) compared to a control watershed (17 mg/ha/yr), while over the seven years following the clearcut, particulate matter tripled in the pond (49 kg/ha/yr). Despite significant differences in sedimentation between treatments, none of the values indicate high levels of particulate matter. Only during large storm events were extreme turbidity measures observed, due to erosion from muddy logging roads. Three years following the harvest, measures of particulate matter in the pond had restored to precut levels. These minor disturbances to water quality, therefore, existed for only a short time period. Pierce et al. (1993) stated that "New England forest ecosystems have great amounts of both resistance to disruption of [interacting biotic and abiotic] processes (as indicated by generally small responses to severe disturbances such as whole-tree clearcutting) and resilience, as shown by rapid recovery."

5.4.2.2 IMPACTS

The impact of sedimentation on stream water quality and populations of various aquatic species is well documented. Both Kahl (1996) and Stafford et al. (1996) summarize effects of sedimentation to include reduced permeability of stream beds, loss of fish habitat, adverse effects on aquatic respiratory systems from suspended solids, degradation of lakes and reservoirs, decreased invertebrate populations, loss of fish habitat, and increased eutrophication. Sedimentation and turbidity caused by logging negatively affect water quality in this region (Martin and Hornbeck 1994). Sediments have been related to negative impacts on stream biota and roads have been identified as the largest source of sediment related to forestry (Megahan 1972, Pimentel et al. 1981, Waters 1995, Wood and Armitage 1997). Accelerated erosion can adversely impact water quality by increasing turbidity and carrying phosphates, pesticides, and other hydrocarbons into surface water and groundwater resources (Stafford et al. 1996, Brooks et al. 2003).

A common measure sedimentation in streams is turbidity. Simply stated, stream turbidity is a measure of the "suspended sediment in the water" (Kahl 1996: 6). Jackson Turbidimeter Units (JTU) measure the ability of suspended materials in water to reduce light penetration (Patric 1976). Streams from undisturbed forests typically have JTU values close to zero, with values less than 11 desirable for drinking water (Hornbeck et al. 1986, Pierce et al. 1993). The effect of harvesting on turbidity have been well documented for this region.

Pierce et al. (1993) summarized four case studies comparing whole-tree clearcut watersheds to control (i.e., non-clearcut) watersheds in three different New England forest types: spruce-fir, northern hardwood, and central hardwoods. They determined that whole-tree clearcutting did not cause a major increase in water turbidity in all four clearcut watersheds. Turbidity was measured at biweekly intervals throughout the study and during large storm events. Only two stream turbidity measures from the Maine site (12 JTU and 17 JTU) and two from the New Hampshire site (2,200 JTU and 3,300 JTU) were above the New England drinking water standard. Given the significant level of site disturbance at these sites (Martin 1988), it is surprising to find turbidity values in the normal range for drinking water. Hornbeck et al. (1986) note that control uncut areas were less than 1 JTU. A culvert failure on a skid trail caused the extremely high turbidity measures on the New Hampshire site. Pierce et al. (1993) indicate that a combination of gentle terrain at the Maine site, a 30 m buffer strip along the stream in New Hampshire, and implementation of erosion control measures in Connecticut explain the low turbidity values. With well-planned and constructed roads, these reports suggest that whole-tree clearcutting can result in minimal sedimentation. The study supports Patric's (1976) findings that it is careful planning and conducting of harvest activities, rather than harvest intensity, that impact sedimentation.

5.4.2.3 Mitigation

Foresters have known for years that erosion is rarely a problem on undisturbed forested soils and that the greatest defense against erosion is the surface accumulation of the leaves and twigs of the forest floor composing the organic layer. The forest litter layer absorbs the kinetic energy of raindrops and allows such high infiltration rates that surface runoff may be very small or even absent (Patric 1978). Because timber transportation networks have the greatest potential to influence water quality related to forestry, BMPs for water quality tend to focus on the placement and construction of skid trails (primary transportation) and haul roads (secondary transportation). Thus, the key to preventing soil erosion during a harvest is to minimize the disturbance of this valuable layer. When harvest activities do occur near a water body, there are fundamental principles and numerous practices that offer guidance for protecting water quality.

Multiple manuals and guidelines have been published over the years detailing ways to mitigate, prevent and control erosion on forest roads, trails, and landings before, during, and after harvesting (Haussman and Pruett 1960, Kochenderfer 1977, Hartung and Kress 1977, Kent 1978, Wiest 1998). Along with these resources, many states have developed best management practices (BMPs) that recommend guidelines for reducing the erosion and sedimentation effects of forest harvesting operations and road construction. Martin and Hornbeck (1994) concluded that erosion and sedimentation do not need to be major concerns in the forests of New England if BMPs, such as providing shade to streams with adequate buffer strips and minimizing addition of woody biomass in streams, are followed closely.

Logging residues applied to the forest floor, and to primary skid trails in particular, are considered standard BMPs. The residue or brush can minimize soil disturbance by improving soil bearing capacity and reducing the risk of erosion on a harvest operation by minimizing exposed mineral soil. Patric (1976) found that a dense layer of slash reduced erosion on a watershed that was clearcut in 1969 on the Fernow Experimental Forest in West Virginia. Martin (1988) recommends use of woody biomass to reduce soil disturbance on whole-tree harvests by either leaving tops and limbs on site or placing them in skid trails. Brush in trails provides protection against rain impact which can initiate erosion and increases surface roughness which reduces surface water movement below an erosive rate (Hartanto et al. 2003). Some researchers have suggested that to remediate this disturbance forwarders should be used rather than dragging the trees across the ground as in conventional skidding (Martin 1988) and Wood et al. (2003) noted that use of brush mats is more effective on sites where wood is carried as opposed to dragged. Martin and Hornbeck (1994) conclude that whole-tree harvesting with careful logging is no more of an erosion risk than conventional logging systems. In general, the research suggests that biomass harvesting will not contribute to or create additional physical impacts on soil productivity as compared to conventional harvesting as long as best management practices are followed and harvest rotations are not shortened.

5.5 RIPARIAN ZONES

Areas adjacent to water bodies are defined as riparian zones. These transitional areas between terrestrial and aquatic ecosystems are recognized for having high species diversity and are distinguished by gradients in biophysical conditions, ecological processes, and biota (Odum 1979, Gregory et al. 1991, DeGraaf et al. 1992). Management and maintenance of riparian zones are considered a critical link in protecting and enhancing biodiversity (Cummins 1980, Naiman et al. 1993, Gregory 1996). Through surface and subsurface hydrology, riparian zones connect water-bodies with their adjacent uplands. Riparian zones are adjacent to perennial, intermittent, and ephemeral streams, as well as lakes and estuarine-marine shorelines, and they vary in width based on interaction and influence (Naiman et al. 1993). They are important for water flow in soils and streams, stream temperature, organic contributions to streams, bird and mammal habitat, feed for fisheries, amphibian and reptile habitat and a wide diversity of vegetation (Troendle and Olsen 1994, Vuori and Joensuu 1996). Disturbances, whether natural or anthropogenic, have the potential for short- and long-term impact on a wide variety of aquatic and terrestrial ecosystems. As Kahl (1996) points out, the riparian zone is the most important area for stream protection as it can filter sediment and nutrients, as well as provide shade to small streams for controlling light and temperature for aquatic biota. As such, the riparian zone is critical to the functioning of stream habitat and is "essential for maintenance of water quality and the health of the biota, regardless of the overall land use of the region" (Kahl 1996: 6). In other words, a riparian area can be thought of as a primary zone of influence for water quality.

Since the riparian area is the interface between the aquatic and terrestrial ecosystems, it has influence on the ever-expanding definition of water quality under the CWA. Much of the current concern focuses on the presence and quality of aquatic and terrestrial life and their associated habitats in the area, in addition to the connectivity of riparian areas throughout a watershed (Naiman et al. 1993). Whereas water bodies and associated riparian areas are a high priority for protecting water quality, many of these areas are regulated and have numerous existing recommendations for management (e.g., LURC, MFS, DEP, CWA). Ephemeral areas above intermittent streams are areas not regulated but rely on guidelines to maintain water quality in its broadest definition.

Increased stream temperature has often been identified as a risk associated with harvesting practices and riparian zones have an important role in maintaining stream temperature. Patric (1978) noted that water temperature may increase up to 10 degrees if shading is removed, and although cooling may occur quickly downstream, the problem is easily avoided with maintenance of riparian areas. As part of a case study of clearcutting effects in New England watersheds, Pierce et al. (1993) found that stream temperature increased by 16^0C in a Connecticut whole-tree harvest site with no stream buffer compared to an uncut control watershed. This is indicative of the need for buffers and not a reflection of harvest method because the Maine and New Hampshire harvest sites averaged 2^0C higher than uncut controls. These temperature changes are expected to be negligible as small headwater streams empty into larger rivers and streams, but if temperature is a concern the use of buffer strips can be beneficial. Based on a review of forest practices and associated effects on water quality, Binkley and Brown (1993) found that adverse changes to stream temperature can be controlled with buffer strips along streams and that use of BMPs can effectively control sedimentation under normal weather conditions. As part of a commercially harvested watershed in New Hampshire's Hubbard Brook Experimental Forest, Burton and Likens (1973) showed that buffers downstream of strips harvested to the stream edge reduce stream temperatures close to conditions observed in uncut sections of the watershed.

The importance of riparian zones to water quality is highlighted by the significant attention given to maintenance and protection of filter areas as best management practices. The Maine Forest Service (2004) describes filter areas as forested areas (including associated vegetative cover, forest floor, and stream banks) adjacent to streams or other waterbodies. Although general guidance is provided for the width of filter areas, site specific interpretation is left to forest practitioners and widths are invariably dependent on site conditions, harvest methods, and regulations. In addition to filtering sediments, nutrients, and debris from runoff, and providing shade to streams, filter areas often contain many habitat elements important for forest biodiversity as described below in Section 6.3. Woody biomass harvesting is unlikely to impact these areas any more than conventional harvest practices as long as existing water quality BMPs are followed.

5.6 GUIDELINES

These guidelines can be adapted and included in site-specific recommendations developed by a licensed forester. They are intended to inform the landowner's decision-making as they review the forester's prescription. Most importantly, implementation of these practices on the ground depends on the professional judgment, knowledge, and skill of the logger conducting the harvest operation. These guidelines are intended to be used by loggers, foresters, and landowners in this context. The guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant part of the product mix.

The Water Quality BMP manual describes many fundamental approaches to protect water quality on harvest operations. These include anticipating site conditions, controlling water flow, and stabilizing exposed soil.

- In particular the Water Quality BMP manual highlights that:
  - disturbance of the forest floor should be minimized;
  - woody biomass may be used to control water flow, to prevent soil disturbance, and/or to stabilize exposed mineral soil, especially on trails and the approaches to stream crossings; and
  - woody biomass used for erosion control and soil stabilization may be left in place, if it is above the normal high water mark of streams or other water bodies.

6 FOREST BIODIVERSITY

Written by:
Jeffrey G. Benjamin, Assistant Professor of Forest Operations, University of Maine
Robert Bryan, Forest Biologist, Forest Synthesis LLC
Charles Coup, Graduate Student, University of Maine

Reviewed by:
Andrew Whitman, Natural Capital Director, Manomet

6.1 INTRODUCTION

Biodiversity has many definitions. DeLong (1996) found 85 separate definitions for biodiversity and concluded that the word is widely modified to suit the interests or needs of the discipline applying it. Hunter (1996) broadly defines biodiversity as all forms of life (gene to species to ecosystem) including all the processes that maintain each level. Although forest biodiversity refers to the diversity within forests at each of those levels (Burley 2002), many people equate forest biodiversity to species diversity (Simberloff 1999). Species diversity is certainly an important component, but Perlis (2002) raises the issue of whether a forest with 1000 species is more valuable, and better managed, than a forest with 500 species, and Jonsell (2007) highlights the inherent complexities and costs of measuring species diversity in a forest. In practice, forest biodiversity can be thought of as the sum total value of all living things in the forest ranging from mites to moose and the tallest trees to the smallest bacteria. Forest communities are generally characterized by the major tree species, often along with understory plants that serve as indicator species. An important aspect of conserving biodiversity is maintaining the natural diversity of plant and animal species that occur within these communities.

Timber harvesting can be a tool used to manage wildlife habitat values and, if carefully planned, it is compatible with most aspects of biodiversity. As with other forest resources, the potential risk to biodiversity increases with the amount and type of woody biomass removed from a site and with the frequency of such removals (Fridman and Walheim 2000, Jonsell 2007, Jönsson and Jonsson 2007, Whitman and Hagan 2007, Vaillancourt et al. 2008). Therefore, high rates of woody biomass removal can negatively affect forest biodiversity.

For this section, an emphasis was placed on studies that identified the impact of woody biomass harvesting on biodiversity. Much research has been conducted over the last 20 years in regard to forest biodiversity specific to our region, but it also covers highly diverse regions such as tropical rainforests and old growth forests (Wilson 1989, Hansen et al. 1991, Gentry 1992, Bawa and Seidler 1998, Putz et al. 2001) and recent studies of forest structure from other geographic regions like the Pacific Northwest (Dunk and Hawley 2009), Canada (Aakala et al. 2008, Vaillancourt et al. 2008), and Nordic countries (Fridman and Walheim 2000, Thorell and Götmark 2005, Jönsson et al. 2007, Jönsson and Jonsson 2007, Roberge et al. 2008). Only a small number of papers were found that attempted to postulate the impacts to biodiversity from woody biomass harvesting specifically.

As described below (Section 6.4.1), many studies are concerned that biomass harvesting will lead to agriculture-like conversions of forestlands or levels of harvesting that will extensively alter current habitat conditions. As important as those issues are, it is also important to place them in the context of Maine's existing forest industry (Section 6.4.2). Clearly, there are significant spatial and temporal challenges to overcome if forest biodiversity is to be measured and managed in a meaningful manner with or without a specific focus on woody biomass.

6.2 Measurement

The only practical approach to assessing biodiversity, and thus sustainability, is to use biological indicators. For example, the coarse woody debris profile is an important biodiversity indicator for saproxlic species (Stokland 2001, Johansson 2006), arthropods can be used as indicators of forest ecosystem integrity (Maleque et al. 2006), invertebrates can be indicators for biodiversity in plantations (Stephens and Wagner 2007), and macro-invertebrates are commonly used as biological indicators of water quality. Biological indicators give insight to the status and fluctuations of biological systems.

One of the greatest challenges of measuring biodiversity is the process of selecting useful and robust indicators. This process requires a great deal of cooperation and agreement between forest stakeholders and managers (Hagan and Whitman 2007) and a solid understanding of what a given species is meant to indicate (Lindenmayer 1999). Relationships between the indicator species and the related taxon must be thoroughly tested and understood before being set into practice (Lindenmayer 1999). Selection of wrong or inappropriate indicators could give a false impression of scientific understanding, managerial knowledge, and ecological sustainability (Lindenmayer et al. 2000, Stephens and Wagner 2007). There are several publications that describe considerations for selecting suitable biological indicators (Lindenmayer 1999, Lindenmayer et al. 2000, Hagan and Whitman 2006, Hagan and Whitman 2007) with Hagan and Whitman (2006) in particular stressing the importance of scientific merit, ecological breadth, practicality, utility, and relevance for indicator evaluation. Juutinen et al. (2006) also note that indicators should be easy to sample, widely applicable, independent of sample size, and sensitive enough to detect change.

Research into the relationships between species and their ability to act as bio-indicators is lacking. Johansson (2006) describes the importance of coarse woody material (both volume and type) to saproxylic beetles in the boreal forest of Scandinavia, and highlights a lack of knowledge regarding the amount and type of deadwood required for beetles, and regarding biological interactions of dead wood ecosystems. Lindenmayer (1999) reviewed the validity and use of the indicator species concept, and the negative consequences of selecting inappropriate species as indicators, or incorrectly identifying natural relationships. The report identified the need for long-term monitoring in validating concepts such as indicator species, and structural management strategies for maintaining biodiversity at the stand level, ecosystem level, and landscape level. Lindenmayer et al. (2000) further recommend several actions that should be adopted to enhance the likelihood that forest biodiversity will be protected including: establishing representative priority areas for biodiversity conservation, establishing structure-based indicators within production forests, sharing risks in wood production forests using multiple conservation strategies over various spatial scales, and applying adaptive management approaches to allow for testing of indicators across management practices.

6.3 HABITAT ELEMENTS OF WOODY BIOMASS

There are many habitat elements that provide multiple biodiversity benefits that can be used as indicators of forest biodiversity. Several specific elements, such as wildlife trees, reserve trees, and coarse and fine woody material on the forest floor, fall under the forest operations definition of woody biomass provided earlier in Section 2.

6.3.1 WILDLIFE TREES

There are four types of wildlife trees that should be considered for retention including decaying live trees, cavity trees, snags, and mast-producing trees (Elliot 2008). Decaying live trees provide habitat for insects and fungi, which provide food for other animals and contribute to the decay and recycling of wood. Over time, decaying live trees also contribute to other biodiversity values as they grow old and die, including cavity trees, snags, and large woody material. While decaying trees in all size classes provide biodiversity value, in general, the larger the decaying tree, the more valuable it is for biodiversity. Cavity trees provide nesting and denning habitats for birds and mammals. Most cavities are created by "primary excavators" such as woodpeckers and then used in later years by other species. Snags are dead standing trees that provide habitat for insects and other organisms not found in live trees, and when fallen they contribute to large woody material. Mast trees provide nuts such as acorns and beechnuts as well as berries and other fruit consumed by wildlife. Mast is typically high-energy food that is important to the productivity and winter survival of animals (e.g., squirrels, white-tailed deer, and bear) by allowing them to enter the winter in prime condition.

Some species have been shown to have specific requirements for wildlife trees. According to Elliot (2008), some species require large-diameter snags, such as pileated woodpeckers (at least 22"), and yellow-bellied sapsuckers (at least 12"). In a study of woodpecker abundance and tree use in northern Maine, Gunn and Hagan (2000) showed that collectively six species of woodpeckers preferred live trees and they summarized that of the 181 woodpeckers in the study, approximately 70% were found using live trees greater than 10 inches dbh. Other studies have concluded that harvesting reduces snags which play a particularly important role as denning and nesting sites (Duvall and Grigal 1999).

6.3.2 Reserve Trees

Reserve trees include scattered individuals and patches of trees and shrubs that are retained at the time a mature stand is harvested. While retention of wildlife trees should be incorporated into all harvests, the concept of reserve trees applies most appropriately to even-aged regeneration harvests. Regeneration harvests are broadly defined as those that remove approximately 40% or more of the initial stand. Helms (1998) identifies three types of even-aged regeneration harvests. A clearcut harvest is defined as "the cutting of essentially all trees, producing a fully exposed microclimate for the development of a new age class." A shelterwood harvest is defined as "the cutting of most trees, leaving those needed to produce sufficient shade to produce a new age class in a moderated microenvironment." A seed tree harvest is defined as "the cutting of all trees except for a small number of widely dispersed trees retained for seed production and to produce a new age class in fully exposed microenvironment."

Reserve trees and reserve patches provide a "biological legacy" that ensures some of the important biodiversity elements of an existing stand, such as habitat for understory plants, tree species diversity, and large decaying trees, are carried forward into the new stand. This is similar to natural disturbances such as fire, wind, or insect outbreaks where patches of undisturbed live vegetation remain after the disturbance. Habitat values are enhanced if reserve patches are adjacent to riparian management areas, as buffers around small wetlands or vernal pools, and include large decaying trees, snags, or cavity trees within the harvest unit. In a long-term study of harvest retention patches in a Norway spruce forest of northern Sweden, Jönsson et al. (2007) showed that although patches (approximately 0.15 to 2.5 acre plots [n=5]) did not maintain their desired structure, they did serve as an important source of coarse woody debris and snags until the regenerating forest resumes production of deadwood. They also found that mortality generally decreased with increasing patch size. Thorell and Götmark (2005) showed that areas adjacent to reserves with high conservation value in southern Sweden were not as heavily exploited by forestry activities as originally expected. Instead of a sharp decrease in conservation values from the reserve edge, a gradual change was observed, which means that the "buffer zones" can play an important role in further enhancement of conservation values.

6.3.3 Coarse Woody Material (CWM)

Coarse woody material (or large woody material) includes dead and down woody material such as logs greater than three to four inches in diameter at the small end, large branches, and stumps. When dead and down, CWM is sometimes referred to as coarse woody debris. CWM provides habitat for insects, fungi, microorganisms, and amphibians, and provides cover and runways for small mammals and winter den sites for bears and other wildlife (Elliot 2008). As logs and other large woody material decay, the suite of organisms finding habitat will shift. CWM is also an important component of stream ecosystems because it provides cover for fish, helps create deeper pools, and provides a substrate for stream insects and microorganisms that are important food sources in streams.

The importance and benefits of CWM to saproxylic and non-saproxylic species has been well documented (Harmon et al. 1986, Hunter 1990, Hagan and Grove 1999, Hammond et al. 2004, Sippola et al. 2004, Johansson 2006, Juutinen et al. 2006). CWM has also been linked to stage of forest development (Whitman and Hagan 2007) and both the amount and type of CWM has been studied in regard to various levels and types of forest management (Fridman and Walheim 2000, Jönsson and Jonsson 2007, Aakala et al. 2008, Mahon et al. 2008, Vaillancourt et al. 2008). For example, Jonsell (2007) raised concerns over the increased removal of harvest residues for biomass from managed forests in Scandinavia and an associated decline and in some cases regional extinctions in saproxylic species. Studies in Maine have shown that harvesting treatments can lead to increased volume and biomass extraction of small diameter non-decayed coarse woody debris (Fraver et al. 2002), but this is also related to utilization standards, harvest method and harvest equipment.

6.3.4 FINE WOODY MATERIAL (FWM)

Fine woody material (or slash) includes live or dead trees and shrubs less than three to four inches in diameter at the large end. When dead and down, FWM is sometimes referred to as fine woody debris. FWM is an important contributor to the organic layer of forest soils and it contains a high proportion of the nutrients found in woody plants when compared to the stems (Young and Carpenter 1976, Alban et al. 1978, Smith et al. 1986, Hakkila 2002). Furthermore, fine woody material protects soils from erosion, provides important energy and nutrients to stream ecosystems, and live fine woody material (i.e., saplings and shrubs) is an important understory habitat component (Elliot 2008).

6.4 FOREST MANAGEMENT

The specific habitat elements described in the previous section can easily be visualized at the site level which is the primary focus of this report. To support biodiversity, however, forest managers also need to consider how harvest activities will affect habitat for individual species that have large home ranges and specific habitat requirements, and to consider how those habitats will change over time as a result of management. As such, maintenance of biodiversity has established itself as a keystone of sustainable forest management and forest health.

The natural stand has become the benchmark by which foresters maintain biodiversity. Forest practices are modeled after natural disturbance regimes and stand development (Hansen et al. 1991, Angelstam et al. 2002). While the concept of biodiversity is relatively new (Soulé 1986, Solbrig 1991), it has already established deep roots in the field of forestry (Angelstam et al. 2002). The two most prevalent third party forest certification systems in the Northeast U.S., the Sustainable Forestry Initiative (SFI) and the Forest Stewardship Council (FSC), both require participants to have a written policy directed at protecting forest biodiversity (FSC 2001, SFI 2004).

6.4.1 GENERAL CONCERNS

The diversity of habitat in natural forests is a combination of differences in soil type, topography, climate, availability of nutrients and water, forest structure, and disturbance regimes. Biodiversity provides natural stability and resilience to a forest system (Frank and McNaughton 1991, Johnson et al. 1996) and supports essential forest processes such as the breakdown of nutrients and organic matter, seed dispersal, pollination, and pest control (Flatebo et al. 1999, Burley 2002). As a result, naturally dynamic forest habitats are usually complex systems consisting of a large number of different components, structures and processes (Angelstam et al. 2002). Concerns over the loss of biological diversity have resulted in a general increase in the demand for conservation of forests in order to prevent local or global extinction of the "original" species richness and species composition (Kuusipalo and Kangas 1994). Habitat destruction is the greatest threat to forest biodiversity followed by habitat degradation (Cook et al. 1991, Angelstam et al. 2002). One of the greatest concerns among researchers is that harvest of woody biomass will have a negative impact on species habitat by creating a market for wood fiber that holds particular biodiversity value such as the habitat elements described above in Section 6.3.

As the intensity of forest management increases, the tendency has been to reduce the overall diversity within the managed stand and place the growth on selected trees and species of commercial value. Increasingly, intensive forest management and the conversion of natural stands to dedicated energy farms are significant threats that biomass production poses to natural forest habitat (Cook et al. 1991). They also raised concerns that as the United States shifts from fossil fuel energy to wood-based energy, the country will develop an increasing dependence on biomass that could lead to intensive harvesting of natural forest ecosystems, and a substantial demand for land to grow short-rotation woody crops. Their concern is that large areas of highly diverse, complex natural forestlands will be converted to "monoculture agro-ecosystems" and forestlands that remain as natural ecosystems will be harvested at unsustainable levels, eliminating habitat for native species and destroying lands with special qualities such as wetland environments. Further environmental impacts resulting from large-scale biomass harvesting and production could come from water and air pollution, loss of soil fertility, and the spread of bioengineered organisms (Rykowski 2002, El-Lakany 2004). The impact that woody biomass production will have on forest habitat will largely be determined by the extent that these threats are realized.

Angelstam et al. (2002) points out that conventional forest management focuses on promoting a preferred collection of commercial tree species that will have good form and grow large enough to be harvested. Over time this practice naturally replaces species-rich and structurally diverse forests to stands consisting of only a few species of the same age and size. They also point out that forests are also often managed on shorter rotation periods than the time period between naturally occurring disturbances, limiting long-term processes essential to biodiversity. Shorter rotation ages do not allow stands to grow large mature trees, or develop snags and a coarse woody debris profile. They imply that if forests are managed for woody biomass, these problems could be greatly magnified.

While investigating the impact of whole-tree harvesting and subsequent planting of white pine (*Pinus strobus*) and white spruce (*Picea glauca*) on Prince Edward Island, Canada, Mahendrappa et al. (2006) found that except for a brief decrease in ground vegetation immediately after harvesting, all the species originally present on the site were re-established. Using the Shannon-Wiener biodiversity index as their metric they concluded that there were no vegetative biodiversity differences 2-3 years after harvesting. However, because of the narrow focus of the research the outcome provides little insight into enhanced forest management. Lindenmayer (1999) warns that short-term impact studies that only focus on comparisons of logged and unlogged areas are not suitable for determining logging impacts on biodiversity as they do not focus on identifying the relational and interactive changes that occur after a harvest operation. Clearly there are both spatial and temporal factors that must be considered.

According to the Food and Agriculture Organizations of the United Nations report, *State of the World's Forests 2001,* approximately 1.5 million hectares per year of natural forest cover worldwide is being converted to plantations, with the majority in tropical countries. While widespread conversion of natural forests to plantations could have detrimental effects on global biodiversity, plantations have the potential to reduce demands on natural forests and therefore may have an important role in the future (Stephens and Wagner

2007). While there are many studies that indicate plantations have lower biodiversity than natural forests, new research highlights that most plantations are established on non-forested lands and when comparisons are made between plantations and other land uses, there is often either a positive impact or no effect on biodiversity (Stephens and Wagner 2007).

6.4.2 SPECIFIC CONSIDERATIONS FOR MAINE

The previous discussion of forest management concerns related to biodiversity must be put into context with the existing forest industry in Maine. Between 2002 and 2007, over 50% of all harvests were conducted as partial harvests, and less than 5% were categorized as clearcuts or land use changes (Maine Forest Service 2008). Maine's forest industry also relies heavily on natural regeneration. An average of 40% of all harvests between 2002 and 2007 were classified as shelterwood harvests (Maine Forest Service 2008), and between 1996 and 2007 less than 2% of harvested acres were planted (Maine Forest Service 2008). Clearly Maine has not succumbed to vast agriculture-like conversions of forestland into monoculture energy plantations even with an energy wood market since the 1980s.

The amount and type of woody biomass removed from a harvest site is highly dependent on the harvest method and equipment used. Whole-tree harvesting is the dominant harvest method in Maine with over 85% of harvested areas using ground-based skidding systems in the last four years (Benjamin 2009). Although this type of harvest delivers tops and limbs of merchantable trees to roadside for processing into energy wood, the amount of timber removed from a site varies with silvicultural prescription and landowner objectives. The equipment in use today is not designed to efficiently handle and process small diameter stems, snags, or other such downed woody material which has been described earlier to hold special habitat value. Specialized woody biomass accumulation technologies are commercially available and include slash bundlers (Andersson et al. 2002, Turner 2005, Johansson et al. 2006, Jylhä and Laitila 2007, Schmidt 2009), residue compaction units (CBI 2006, Paiement 2008), and mobile chippers (Andersson et al. 2002, Turner 2005), but to date their use has not proven to be cost effective in Maine.

Notwithstanding the observations made in the previous two paragraphs, timber harvesting in Maine, and removal of woody biomass in particular, does have implications on forest biodiversity. The goal of this entire chapter is to highlight the important aspects of woody biomass as it relates to forest biodiversity and to remind practitioners to plan harvests with those features in mind. Fortunately, much work has already been completed for the forests of Maine in this regard. Woody biomass harvesting practices will have to comply with established recommendations for biodiversity as defined for non-biomass harvests.

A comprehensive manual outlining recommended guidelines for maintaining biodiversity in the forests of Maine was originally published by Flatebo et al. (1999) and many of the general recommendations in Section 6.6 were summarized from the updated version by Elliot (2008). One of the primary goals for biodiversity in Maine's managed forest is to ensure that adequate habitat is present to maintain viable populations of native plant and animal species. Recommendations are written for site-specific characteristics covering five stand characteristics and 10 special habitats and ecosystems (including riparian and stream ecosystems, vernal pools, beaver-influenced ecosystems, woodland seeps and springs, nesting areas for colonial wading birds, deer wintering areas, nesting sites for woodland raptors, old-growth and primary forests, rare plant or animal sites, and rare natural communities). Stand-level recommendations are related to vertical structure and crown closure; native species and composition; downed woody material, snags, and cavity trees; mast; and forest soils, forest floor and site productivity.

The guidelines by Elliot (2008) also address landscape-level considerations that focus on patterns, processes and linkages across landscapes and regions. They address the distribution of native forest communities, age structure of the landscape, habitat patch size, habitat connectivity, disease agents, insects, pests, and weeds. The guidelines also address two land-use issues: public access and roads, and conversion to non-forest use. The manual provides a clear definition of each element targeted for conservation, provides a rationale for its importance to biodiversity, and presents recommended practices. Both versions of Maine's biodiversity guidelines (Flatebo et al. 1999, Elliot 2008) generally focus on what is being retained in the forest after a harvest, so they are as applicable to woody biomass harvesting as they are to traditional round wood operations.

6.5 Setting Targets

It is important to note that any forest disturbance, either natural or anthropogenic, has the potential to degrade a habitat, especially when focusing on a small scale and a specific species. All timber harvesting can affect wildlife habitat, but the key concern is whether impacts are significant at the landscape level and, as noted above in Section 6.2, biological indicators are important tools for measuring forest biodiversity in this regard. Hagan and Whitman (2006) point out, however, that although science can direct selection of biological indicators, it is still weak in selecting specific target levels. As such, management of biological diversity appears to have an important social component which imparts a level of importance and value to all species, structures, and characteristics of a forest ecosystem.

There have been few studies that have quantified the amounts of woody debris needed to maintain specific populations or communities (Tolbert and Wright 1998, Brown et al. 2003, Ranius and Fahrig 2006). Gunn and Hagan (2000) hypothesized that woodpecker abundance would be lower in managed stands compared to unmanaged stands due to lower amounts of snags in managed stands. They studied seven different species of woodpeckers in combination with a variety of stand conditions (e.g., unmanaged old growth to recent shelterwood harvests) and found that 1) woodpecker abundance was higher in managed softwood stands compared to unmanaged stands, and 2) woodpecker abundance was unaffected by management type for hardwood stands. Further, they also concluded that the abundance of woodpecker habitat could not be used to predict woodpecker abundance in any stand type (managed and unmanaged, softwood and hardwood). Woodpeckers were observed using trees (live and dead) across a wide range of sizes from approximately 10 to 90 cm dbh with peak use in the 40 to 45 cm dbh classes. Although at first glance this may appear to contradict minimum size requirements for snags presented by Elliot (2008), the latter specifications are related to nesting requirements.

Roberge et al. (2008) established tentative quantitative habitat targets for two species of specialized forest insectivore woodpeckers in the Baltic region of northern Europe following an intensive landscape-level study that included 111 study areas of 100 ha each covering a wide range in management regimes and forest types. The target identified for the middle spotted woodpecker (*Dendrocopos medius*) was large diameter deciduous trees with basal area greater than 1.0 m^2/ha. This is equal to 3 stems per acre greater than 16 inches dbh, or two trees per acre greater than 20 inches dbh. The target identified for the white-backed woodpecker (*Dendrocopos leucotos*) was snags with basal area greater than 1.4 m^2/ha and size greater than 10 cm dbh. This is equal to 72 stems per acre greater than 4 inches dbh, eight stems per acre greater than 12 inches dbh, or 3 stems per acre greater than 20 inches dbh. These targets are significantly higher than recommended guidelines for our region (Elliot 2008). It should be noted that Roberge et al. (2008) stress caution should be taken before application of their targets in forest management. In particular they conclude that "our results point to the

fact that surveys performed using the same methodology may lead to different quantitative estimates of the species requirements in different areas" and that the tentative targets should be interpreted as "working hypotheses for active adaptive landscape-scale management and for further research rather than as strict guidelines" Roberge et al. (2008: 1008).

Elliot (2008) also describes significant challenges to setting specific targets at the site-level. For this region, stand-level targets for forest structure have been established based on expert opinion. For example, Elliot (2008: 31) recommends retaining "a minimum of four secure cavity trees or snags per acre, with one exceeding 24 inches dbh and three exceeding 18 inches dbh". Specific size classes for downed logs are also suggested to be "greater than 12 inches dbh and greater than 6 feet long" Elliot (2008: 31). These, and other regional targets, are qualified by statements indicating it is not always possible or appropriate to manage the habitat requirements for all species in all areas at the same time and that some management practices can conflict with each other. Stand-level application of those guidelines is left to the forest practitioner. Since there is not widespread acceptance of those guidelines within Maine's forest industry, specific targets for maintenance of site-level biodiversity are not included in Section 6.6. Instead, a summary of regional recommendations pertaining to wildlife trees and biomass harvesting are provided in Appendices B and C respectively.

6.6 GUIDELINES

As with other forest resources, the potential risk to biodiversity increases with the amount and type of woody biomass removed from a site and with the frequency of such removals. Every acre of forest cannot be managed under the same prescription and the following guidelines should not be interpreted in that manner. The guidelines address elements of forest structure related to soil, water quality and biodiversity. These elements include snags, wood of all sizes left on the forest floor, live cavity trees and mast-producing trees. The guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant part of the product mix. Wood of all sizes provides a range of habitats for other organisms that are essential to a fully productive forest. The following guidelines focus primarily on desired outcomes at the harvest site:

- Leave as much dead wood on site as possible.
  - Leave as many snags standing as safety and access will permit.
  - Leave any felled snags in place.
  - Limit disturbance to existing down logs.
  - If large woody material is lacking on the ground, consider leaving some newly cut logs scattered throughout the harvest area.
  - Large woody material can be created over time by retaining all snags possible and leaving some large trees to die.

- Leave some live wildlife trees.
  - Retain live cavity trees on site. Cavity trees are live trees with holes, open seams or hollow sections that wildlife can use.
  - Leave live trees with rot when cavity trees are not available.
- Leave some mast-producing trees.
  - Species such as oak, beech, apple, black cherry, pin cherry, hickory, and raspberry produce valuable food for many wildlife species.
- Vary the amount of snags, down logs, and wildlife trees across the harvest area.
  - Stream buffers, retention patches and other protection zones provide an opportunity to leave more large trees than may be possible in other harvest areas.
  - Leaving lightly cut or un-cut patches in heavy harvest areas yields more biodiversity benefits than widely dispersed single trees.
  - The larger the retained patch, the greater the benefit to sensitive understory species.
- Leave as much fine woody material as possible.
  - Where possible and practical (depending on harvest method and system) retain and scatter tops and branches (fine woody material) across the harvest area.
  - If trees are delimbed at roadside, haul a portion of the tops and limbs back into the woods. Leave the material along skid trails if carrying it off the trail would cause greater damage.

These guidelines address key features of forest structure that are important to biodiversity within harvest areas. Other features should be considered including: riparian habitat, forest age class structure, species diversity, travel corridors, and special habitat areas. Special management areas will not be found on all harvest sites, but when present, their values should be protected with careful management. Examples of special management areas include: riparian management zones, areas with threatened and endangered species, and late succession stands and pockets of old-growth forest. Contact the Maine Natural Areas Program (MNAP) for information on the possible presence of rare, threatened, and endangered species habitats and natural communities, and the possible presence of habitats for species of greatest conservation need and other high value plant and wildlife habitats. If MNAP indicates that any such areas exist, or if they are found during a pre-harvest site review, consult with MNAP (for plants and natural communities) or Maine Department of Inland Fisheries and Wildlife (for fish and wildlife) for management recommendations. Section 8 includes additional resources for management of biodiversity across a forest ownership and special habitats not covered by these guidelines. Whitman and Hagan (2004) can be used to identify significant late-successional or old-growth stands.

7 GLOSSARY

Biological Diversity (biodiversity): The spectrum of life forms and ecological processes that support and sustain them. Biological diversity occurs at four interacting levels: genetic, species, community, and ecosystem.

Biological Legacy: An organism, a reproductive portion of an organism, or a biologically derived structure or pattern inherited from a previous ecosystem. Biological legacies often include large trees, snags, and down logs left after harvesting to provide refugia and to structurally enrich the new stand.

Biomass, woody: Logging residues, previously un-merchantable stems, and other such woody material harvested directly from the forest typically for the purposes of energy production.

Bolewood Utilization: The utilization of trunks, tops and any limbs of trees up to a 4-inch dib (diameter inside bark).

Cavity (Den) Tree: A hollow (or partially hollow) living tree used by wildlife.

Clearcut: An area with less than 30 square feet of basal area on acceptable growing stock in trees >6 inches dbh and lacking established regeneration, as further defined by Maine's Forest Practices Act rules.

Community: An assemblage of plants and animals living together and occupying a given area (see also natural community).

Erosion Prone Sites: Sites that are rated with "severe" or "very severe" erosion hazards (off-road, off-trail) by the USDA NRCS. A site's erosion hazard rating can be viewed at: http://websoilsurvey.nrcs.usda.gov/app/

Fine Woody Material: Woody material, living or dead, less than 4 inches diameter inside bark at the large end; including fine woody debris and portions of standing living and dead shrubs and trees.

Forest: An ecosystem characterized by a more or less dense and extensive tree cover, often consisting of stands varying in characteristics such as species composition, structure, age class, and associated processes. Typically, tree cover will exceed 50% crown cover, except following a severe disturbance and during stand (re)establishment. Productive forest stands are capable of growing wood volume at an average rate of at least 20 cubic feet per acre per year.

Habitat: The environment (including food, water, cover, and climate) where an animal, plant, or population naturally or normally lives and develops.

Large woody material: Dead woody material, greater than or equal to 4 inches (dib) at the small end, on the ground in forest stands or in streams.

Logging Residue: The unused portions of trees cut during logging and left in the woods or at roadside.

Mast: Fruit and nuts consumed as food by wildlife.

Natural Community: An assemblage of plants and animals living together and occupying a given area as classified by the Maine Natural Areas Program.

Rare natural community: A natural community ranked G1, G2, G3, S1, S2, or S3 by the Maine Natural Areas Program (MNAP) as well as any exemplary representatives of common communities ranked A or B by MNAP.

Rare, threatened, and endangered species: Species listed as Special Concern, Threatened or Endangered by the State of Maine or the US Fish and Wildlife Service.

Regeneration Harvests: As used in this guideline, regeneration harvests include clearcuts, shelterwood harvests from initial entry through final overstory removal, seed tree cuts, and other harvests that remove approximately 40% or more of the initial stand.

Reserve Tree: Living trees, ≥5 inches dbh, retained after the regeneration period under even-aged or two-aged silvicultural systems.

Riparian Management Zones (RMZ): Riparian management zones include the areas adjacent to lakes and ponds, streams, wetlands, and other riparian habitats such as vernal pools. At minimum RMZs include the area protected by state and local regulations, but in practice should include wider zones necessary to provide biodiversity benefits associated with these areas, including a) habitat for aquatic species that breed in surrounding uplands (e.g., turtles, cavity-nesting ducks), b) habitat for predominantly terrestrial species that breed in adjacent aquatic habitats (includes some amphibians), c) habitat for species that use riparian areas for feeding, cover, and travel (may include birds, mammals, retiles, amphibians, and insects), d) habitat for plant species associated with riparian areas, and e) stream shading and inputs of wood and leaf litter into the adjacent aquatic ecosystem.

Slash: The residue left on the ground after logging or accumulating as a result of storm, fire, girdling, or delimbing.

Snag: Standing dead tree.

Species of Greatest Conservation Need: Species of concern identified by the Maine Department of Inland Fisheries and Wildlife in Maine's Comprehensive Wildlife Strategy.

Whole-tree Harvesting: Felling and removing an entire upper portion of a tree consisting of stem, top, limbs, and leaves (or needles).

Wildlife: All non-domesticated animal life.

8 RESOURCES

8.1 AGENCIES

MAINE NATURAL AREAS PROGRAM

157 Hospital Street
State House Station #93
Augusta, ME 04333
Phone: (207) 287-8044 • Fax: (207) 287-8040

This is the primary source of maps of known high value plant an wildlife habitats and management guidelines for rare plants and natural communities. If high value wildlife habitats are present, MNAP will refer you to the Maine Department of Inland Fisheries and Wildlife.

MAINE DEPARTMENT OF INLAND FISHERIES AND WILDLIFE

284 State Street
State House Station #41
Augusta, ME 04333
Phone: (207) 287-8000 • Fax: (207) 287-8094

Management information for wildlife habitats of management concern.

MAINE FOREST SERVICE, DEPARTMENT OF CONSERVATION

State House Station #22
Augusta, ME 04333
Phone: (207) 287-2791 • Fax: (207) 287-8422

MFS provides a wide variety of forest management information and assistance to landowners, loggers, and foresters.

8.2 Related Publications

Briggs, R.D. 1994. *Site Classification Field Guide.* CFRU Technical Note 6. MAFES Misc. Pub. 724.

Bryan, R.R. 2007. *Focus Species Forestry: A Guide to Integrating Timber and Biodiversity Management in Maine.* Maine Audubon, Falmouth, ME, in cooperation with Maine Department of Conservation, Professional Logging Contractors of Maine, and the Small Woodland Owners Association of Maine.

Calhoun, A.J.K. and P.G. deMaynadier. 2004. *Forestry Habitat Management Guidelines for Vernal Pool Wildlife.* MCA Technical Paper No. 6, Metropolitan Conservation Alliance, Wildlife Conservation Society, Bronx, New York.

DeGraaf, R.M., M. Yamasaki, W.B. Leak, and A.M. Lester. 2006. *Technical Guide to Forest Wildlife Habitat Management in New England.* University Press of New England, Lebanon, NH.

DeGraaf, R.M., M. Yamasaki, W.B. Leak, and A.M. Lester. 2005. *Landowners Guide to Wildlife Habitat: Forest Management for the New England Region.* University Press of New England, Lebanon, NH.

Elliot, C.A., editor. 2008. *Biodiversity in the Forests of Maine: Guidelines for Land Management.* UMCE Bulletin # 7147, University of Maine, Orono.

Maine Department of Inland Fisheries and Wildlife. 2005. *Maine's Comprehensive Wildlife Strategy.* http://www.maine.gov/ifw/wildlife/groups_programs/comprehensive_strategy/

Maine Forest Service. 2004. *Best Management Practices for Forestry: Protecting Maine's Water Quality.*

Maine Forest Service. 2005 *Biennial Report on the State of the Forest and Progress Report on Forest Sustainability Standards.* http://www.maine.gov/doc/mfs/pubs/pdf/2005sof_full_rpt.pdf

Whitman, A.A. and J.M.Hagan. 2004. *A Rapid-assessment Late-successional Index for Northern Hardwoods and Spruce-fir Forest.* Forest Mosaic Science Note #2004-3. Manomet Center for Conservation Sciences, Brunswick, Maine.

8.3 LIST OF FIGURES

LIST OF TABLES

9 LITERATURE CITED

Aakala, T., T. Kuuluvainen, S. Gauthier, and L. De Grandpré. 2008. Standing dead trees and their decay-class dynamics in the northeastern boreal old-growth forests of Quebec. *Forest Ecology and Management* 225:410-420.

Aber, J.D., D.B. Botkin, and J.M. Melillo. 1978. Predicting the effects of different harvesting regimes on forest floor dynamics in northern hardwoods. *Canadian Journal of Forest Research* 8:308-316.

Alaoui, A. and A. Helbling. 2006. Evaluation of soil compaction using hydrodynamic water content variation: comparison between compacted and non-compacted soil. *Geoderma* 134:97-108.

Alban, D.H., D.A. Perald, and B.E. Schlaegel. 1978. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. *Canadian Journal of Forest Research* 8:290-299.

Ampoorter, E., R. Goris, W.M. Cornelis, and K. Verheyen. 2007. Impact of mechanized logging on compaction status of sandy forest soils. *Forest Ecology and Management* 241:162-174.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. *Forests and Water: Effects of Forest Management on Floods, Sedimentation, and Water Supply.* General Tech. Report PSW018. USDA, Forest Service, Pac. South. For. and Range Exp. Sta., Berkeley, CA. 115p.

Andersson, G., A. Asikainen, R. Björheden, P.W. Hall, J.B. Hudson, R. Jirjis, D.J. Mead, J. Nurmi, and G.F. Weetman. 2002. Chapter 3.2: Integration of energy production into forest management. In: Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (Eds.). *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic, Boston. pp. 67-84.

Angelstam, P., G. Mikusinski, and M. Breuss. 2002. Chapter 5.4 Biodiversity and forest habitats. In: Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (Eds.). *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic, Boston. pp. 216-237.

Bawa, K.S. and R. Seidler. 1998. Natural forest management and conservation of biodiversity in tropical forests. *Conservation Biology* 12(1):46-55.

Benjamin, J.G. 2009. Maine's logging industry: Developing a health assessment. Presented at the New England Regional Council on Forest Engineering workshop on March 9, 2009. University of Maine, Orono, ME.

Benjamin, J., R.J. Lilieholm, and D. Damery. 2009. Challenges and opportunities for the northeastern forest bioindustry. *Journal of Forestry* 107(3):125-131.

Binkley, D. and T. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. *Journal of the American Water Resources Association* 29(5):729-740.

Block, R., K.C.J. Van Rees, and D.J. Pennock. 2002. Quantifying harvesting impacts using soil compaction and disturbance regimes at a landscape scale. *Soil Science Society of America Journal* 66:1669-1676.

Boyle, J.R. and A.R. Ek. 1972. An evaluation of some effects of bole and branch pulpwood harvesting on site macro nutrients. *Canadian Journal of Forest Research* 2:407-412.

Boyle, J.R., J.J. Phillips, and A.R. Ek. 1973. "Whole-tree" harvesting: Nutrient budget evaluation. *Journal of Forestry* 71:760-762.

Brady, N.C. and R.R. Weil (Eds.). 2002. *The Nature and Properties of Soils.* MacMillan, New York. 639 pp.

Briggs, R.D. 1994. *Site Classification Field Guide.* CFRU Technical Note 6. Maine Agriculture and Forest Experiment Station Misc. Pub. 724.

Briggs, R.D., J. Cormier, and A. Kimball. 1998. Compliance with forestry best management practices in Maine. *Northern Journal of Applied Forestry* 15:57-68.

Briggs, R.D., J.W. Hornbeck, C.T. Smith, R.C. Lemin, and M.L. McCormack. 2000. Long-term effects of forest management on nutrient cycling in spruce-fir forests. *Forest Ecology and Management* 138:285-299.

Brooks, K.N., P.F. Ffolliott, H.M. Gregorsen, and L.F. DeBano. 2003. *Hydrology and the Management of Watersheds,* 3rd edition. Iowa State University Press, Ames, IA. 574p.

Brown, J.K., E.D. Reinhardt, and K.A. Kramer. 2003. *Coarse Woody Debris: Managing Benefits and Fire Hazard in the Recovering Forest.* Gen. Tech. Rep. RMRSGTR105. USDA, Forest Service, Rocky Mountain Research Station, Ogden, UT. 16p.

Brown, T.C. and D. Binkley. 1994. *Effect of Management on Water Quality in North American Forests.* USDA For. Serv. Gen. Tech. Rep. RM248, RM For. and Range Exp. Sta. 28p.

Burger, J.A. 2002. Chapter 5.2: Soil and long-term site productivity values. In: Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (Eds.). *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic, Boston. pp. 165-185.

Burley, J. 2002. Forest biodiversity: an overview. *Unasylva* 53:3-9.

Burton, T.M. and G.E. Likens. 1973. The effect of strip-cutting on temperatures in the Hubbard Brook Experimental Forest, New Hampshire. *Bioscience* 23(7):433-435.

CBI. 2006. Brush Transport System. Accessed 06/17/09. http://www.cbi-inc.com/library/pdfs/CBI_BTS_Data_Sheet.pdf

Cook, J.H., J. Beyea, and K.H. Keeler. 1991. Potential impact of biomass production in the United States on biological diversity. *Annual Review of Energy and the Environment* 16:401-31.

Copeland Jr., O.L. 1965. Land use and ecological factors in relation to sediment yields. In *Proc. Fed. Inter-Agency Sedimentation Conf.* 1963. USDA, Misc. Publ. 970. pp. 72-84.

Corns, I.G. 1988. Compaction by forestry equipment and effects on coniferous seedling growth on four soils in the Alberta Foothills. *Canadian Journal of Forest Research* 18:75-84.

Cummins, K. 1980. The multiple linkages of forests to streams. In Waring, R.H. (Ed.). *Forests, fresh Perspectives from Ecosystem Analysis.* Oregon State University Press, Corvallis, OR. pp. 191-198.

Davies, S.P., L. Tsomides, J.L. DiFranco, and D.L. Courtemanch. 1999. *Biomonitoring Retrospective: Fifteen Year Summary for Maine Rivers and Streams.* Division of Environmental Assessment Bureau of Land and Water Quality. DEPLW1999-26.

DeGraaf, R., W. Yamasaki, W. Leak, and J. Lanier. 1992. *New England Wildlife: Management of Forested Habitats.* Gen. Tech. Rep. 144. USDA For. Service, Northeast For. Exp. Sta. Radnor, PA.

DeLong Jr., D.C. 1996. Defining biodiversity. *Wildlife Society Bulletin* 24(4):738-749.

Dissmeyer, G.E. 1976. Erosion and sediment from forest land uses, management practices and disturbances in the southeastern United States. In: *Proc. Third Inter-Agency Sedimentation Conf. [Denver, Colo, March 22–25, 1976.] Symp. 1. Sediment Yield and Sources.* Water Resources Council. pp. 140-148.

Dunk, J.R. and J.J.V.G. Hawley. 2009. Red-tree vole habitat suitability modeling: Implications for conservation and management. *Forest Ecology and Management* 258:626-634.

Duvall, M.D. and D.F. Grigal. 1999. Effects of timber harvesting on coarse woody debris in red pine forests across the Great Lakes states, U.S.A.. *Canadian Journal of Forest Research* 29:1926-1934.

El-¬Lakany, M.H. 2004. Are genetically modified trees a threat to forests? *Unasylva* 55:45-47.

Elliot, C.A. (Ed.). 2008. *Biodiversity in the Forests of Maine: Guidelines for Land Management* (2008 edition). University of Maine Cooperative Extension Bulletin 7174, Orono, ME. 166p.

Federer, C.W., J.W. Hornbeck, L.M. Trittion, C.W. Martin, R.S. Pierce, and C.T. Smith Jr. 1989. Long-term depletion of calcium and other nutrients in eastern US forests. *Environmental Management* 13:593-601.

Flatebo, G., C.R. Foss, and S.K. Pelletier. 1999. *Biodiversity in the Forests of Maine: Guidelines for Land Management.* University of Maine Cooperative Extension, Orono, ME. 167p.

Forest Stewardship Council (FSC) US Standards Committee. 2001. *National Indicators for Forest Stewardship.* FSC US Standards Committee, Atlanta, GA. 42p.

Frank, D.A. and S.J. McNaughton. 1991. Stability increases with diversity in plant communities: Empirical evidence from the 1988 Yellowstone drought. *Oikos* 62:360-362.

Fraver, S., R.G. Wagner, and M. Day. 2002. Dynamics of coarse woody debris following gap harvesting in the Acadian forest of central Maine, U.S.A. *Canadian Journal of Forest Research* 32:2094-2105.

Fredriksen, R.L. 1965. Sedimentation after logging road construction in a small western Oregon watershed. In: *Proc. Fed. Inter-Agency Sediment. Conf.,* 1963. USDA, Misc. Publ. 970. pp. 56-59.

Freedman, B., R. Morash, and A.J. Hansen. 1981. Biomass and nutrient removals by conventional and whole-tree clearcutting of a red spruce-balsam fir stand in Nova Scotia. *Canadian Journal of Forest Research* 11:249-257.

Fridman, J. and M. Walheim. 2000. Amount, structure, and dynamics of dead wood on managed forestland in Sweden. *Forest Ecology and Management* 131:23-26.

Froehlich, H.A., D.W.R. Miles, and R.W. Robbins. 1985. Soil bulk density recovery on compacted skid trails in central Idaho. *Soil Science Society of America Journal* 49:1015-1017.

Gentry, A.H. 1992. Tropical forest biodiversity: Distributional patterns and their conservational significance. *Oikos* 63:19-28.

Gomez, A., R.F. Powers, M.J. Singer, and W.R. Howath. 2002. Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. *Soil Science Society of America Journal* 66:1334-1343.

Gregory, S. 1996. Riparian management in the 21st century. In: Kohm, K.A. and J.F. Franklin (Eds.). *Creating a Forest for the 21st Century: The Science of Ecosystem Management.* Island Press, Washington, DC. pp. 69-86.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41(8):540-551.

Grigal, D.F. 2000. Effects of extensive forest management on soil productivity. *Forest Ecology and Management* 138:167-185.

Gunn, J.S. and J.M. Hagan. 2000. Woodpecker abundance and tree use in even-aged managed, and unmanaged, forest in northern Maine. *Forest Ecology and Management* 126:1-12.

Hagan, J.M. and R.B. Boone. 1997. *Harvest Rate, Harvest Configuration, and Forest Fragmentation: A Simulation of the 1989 Maine Forest Practices Act.* Manomet Center for Conservation Sciences, Manomet, MA. 17p.

Hagan, J.M. and S.L. Grove. 1999. Coarse woody debris. *Journal of Forestry* 97(1):6-11.

Hagan, J.M. and A.A. Whitman. 2006. Biodiversity indicators for sustainable forestry: simplifying complexity. *Journal of Forestry.* 104(4):203-210.

Hagan, J.M. and A.A. Whitman. 2007. *Considerations in the Selection and Use of Indicators for Sustaining Forests.* National Commission on Science for Sustainable Forestry Report. August, 2007. On-line: www.manometmaine.org

Hakkila, P. 1989. *Utilization of Residual Forest Biomass.* Springer Series in Wood Science. Springer, New York. 586p.

Hakkila, P. 2002. Chapter 5.5: Operations with reduced environmental impact. In: Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (Eds.). *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic, Boston. pp. 244-261.

Hakkila, P. and M. Parikka. 2002. Chapter 2: Fuel resources from the forest. In: Richardson, J., R. Björheden, P. Hakkila, A.T. Lowe, and C.T. Smith (Eds.). *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic, Boston. p. 19-48.

Hammond, H.E.J., D.W. Langor, and J.R. Spence. 2004. Saproxylic beetles (Coleoptera) using Populus in boreal aspen stands of western Canada: spatiotemporal variation and conservation of assemblages. *Canadian Journal of Forest Resources* 34:1-19.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J.L. Ohmann. 1991. Conserving biodiversity in managed forests lessons from natural forests. *Bioscience* 41(6):382-392.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research.* Department of Forest Science, Oregon State University, Corvallis, OR. Vol 15, pp. 133-302.

Hartanto, H., R. Prabhu, A.S.E. Widayat, and C. Asdak. 2003. Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management. *Forest Ecology and Management* 180:361-374.

Hartung, R.E. and J.M. Kress. 1977. *Woodlands of the Northeast Erosion & Sediment Control Guides.* USDA SCS Northeast Tech. Serv. Cent. and For. Serv. Northeast. Area State and Priv. For., Upper Darby, PA. 26p.

Hatchell, G.E., C.W. Ralson, and R.R. Foil. 1970. Soil disturbance in logging. *Journal of Forestry* 68:772-775.

Haussman, R.F. and E.W. Pruett. 1960. *Permanent Logging Roads for Better Woodlot Management.* USDA For. Serv., Div. State and Private For., Upper Darby, PA. 38p.

Heding, N. and M. Loyche. 1984. *Volume and Nutrient Content of Norway spruce Needles.* Dansk Skovforenings Tidsskrift. Zhefte, August. Dansk Skovforening, Kobenhavn.

Helms, J.A. (Ed.). 1998. *The Dictionary of Forestry.* The Society of American Foresters, Bethesda, MD.

Hendrickson, O.Q. 1988. Biomass and nutrient in regenerating woody vegetation following whole-tree and conventional harvest in a northern mixed forest. *Canadian Journal of Forest Research* 18(11):1427-1436.

Hendrickson, O.Q., L. Chatarpaul, and D. Burgess. 1989. Nutrient cycling following whole-tree and conventional harvest in northern mixed forest. *Canadian Journal of Forest Research* 19:725-735.

Heninger, R.L., T.A. Terry, A. Dobkowski, and W. Scott. 1997. Managing for sustainable site productivity: Weyerhaeuser's forestry perspective. *Biomass and Bioenergy* 13(4/5):255-267.

Holman, G.T., F.B. Knight, and R.A. Stuchtemeyer. 1978. *The Effects of Mechanized Harvesting on Soil Conditions in the Spruce-Fir Region of North-Central Maine.* Univ. Maine Life Sci. and Agric. Exp. Stn. Bull. 751.

Horn, R., J. Vossbrink, S. Peth, and S. Becker. 2007. Impact of modern forest vehicles on soil physical properties. *Forest Ecology and Management* 248:56-63.

Hornbeck, J.W. 1986. Nutrient cycles and Productivity. In: *Proc. 1986 Symposium on the Productivity of Northern Forests Following Biomass Harvesting.* USDA For. Serv. Gen. Tech. Rep. NE-115, NE. Forest Exp. Sta. pp. 23-27.

Hornbeck, J.W. and W. Kropelin. 1982. Nutrient removal and leaching from a whole-tree harvest of northern hardwoods. *Journal of Environmental Quality* 11(2):309-316.

Hornbeck, J.W., C.T. Smith, C.W. Martin, L.M. Trittion, and R.S. Pierce. 1990. Effects of intensive harvesting on nutrient capitals of three forest types in New England. *Forest Ecology and Management* 30:55-64.

Huang, J., S.T. Lacey, and P.J. Ryan. 1996. Impact of forest harvesting on the hydraulic properties of surface soil. *Soil Science* 161(2):79-86.

Hunter, M. 1996. *Fundamentals of Conservation Biology.* Blackwell Science, Inc., Cambridge, MA. 482p.

Hunter Jr., M.L. 1990. *Wildlife, Forests, and Forestry: Principles for Managing Forests for Biological Diversity.* Prentice Hall, Englewood Cliffs, NJ.

Johansson, J., J.E. Liss, T. Gullberg, and R. Björheden. 2006. Transport and handling of forest energy bundles – Advantages and problems. *Biomass and Bioenergy* 30:334-341.

Johansson, T. 2006. The conservation of saproxylic beetles in boreal forest: Importance of forest management and dead wood characteristics. Doctoral thesis, Swedish University of Agricultural Sciences Faculty of Forest Sciences. 34p.

Johnson, D.W. 1983. The effects of harvesting intensity on nutrient depletion in forests. In: Ballard, R. and S.P. Gessel (Eds.). *IUFRO Symposium on Forest Site and Continuous Productivity.* USDA Forest Service General Technical Report PNW163. pp. 157-166.

Johnson, D.W. and P.S. Curtis. 2001. Effects of forest management on soil C and N storage: A meta analysis. *Forest Ecology and Management* 140:227-238.

Johnson, D.W., J.D. Knoepp, W.T. Swank, J. Shan, L.A. Morris, D.H. Van Lear, and P.R. Kapeluck. 2002. Effects of forest management on soil carbon: Results of some long-term resampling studies. *Environmental Pollution* 116:S201-S208.

Johnson, D.W., and D.E. Todd. 1998. The effects of harvesting on long term changes in nutrient pools in a mixed oak forest. *Soil Science Society of America Journal* 62:1725-1735.

Johnson, K.H., K.A. Vogt, H.J. Clark, O.J. Schmitz, and D.J. Vogt. 1996. Biodiversity and the productivity and stability of ecosystems. *Trends in Ecology and Evolution* 11(9):372-377.

Jonsell, M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. *Biomass and Bioenergy* 31:726-732.

Jönsson, M.T., S. Fraver, B.G. Jonsson, M. Dynesius, M. Rydgard, and P.A. Esseen. 2007. Eighteen years of tree mortality and structural change in an experimentally fragmented Norway spruce forest. *Forest Ecology and Management* 242:306-313.

Jönsson, M.T. and B.G. Jonsson. 2007. Assessing coarse woody debris in Swedish woodland key habitats: Implications for conservation and management. *Forest Ecology and Management* 242:363-373.

Jurgensen, M.F., A.E. Harvey, R.T. Grahm, D.S. Page Dumroese, J.R. Tonn, M.J. Larson, and T.B. Jain. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of inland northwest forests. *Forest Science* 43(2):234-251.

Jurgensen, M.F., M.J. Larsen, G.D. Mroz, and A.E. Harvey. 1986. *Timber Harvesting, Soil Organic Matter, and Site Productivity.* in Smith, C.T., C.W. Martin, and L.M. Trittion. (Eds.). *Proc. 1986 Symposium on the Productivity of Northern Forests Following Biomass Harvesting.* USDA For. Serv. Gen. Tech. Report NE-115. pp. 43-52

Juutinen, A., M. Mönkkönen, and A.L. Sippola. 2006. Cost-efficiency of decaying wood as a surrogate for overall species richness in boreal forests. *Conservation Biology* 20(1):74-84.

Jylhä, P. and J. Laitila. 2007. Energy wood and pulpwood harvesting from young stands using a prototype whole¬tree bundler. *Silva Fennica* 41:763-779.

Kahl, S. 1996. *A Review of the Effects of Forest Practices on Water Quality in Maine.* A report to the Maine Department of Environmental Protection – Bureau of Land and Water Control. 52p.

Kent, B. 1978. *The Land Use Handbook Section 6: Erosion Control on Logging Jobs.* Maine Department of Conservation. Land Use Regulation Commission. 28p.

Kimmins, J.P. 1977. Evaluation of the consequences for future tree productivity of the loss of nutrients in whole-tree harvesting. *Forest Ecology and Management* 1:169-183.

Kochenderfer, J.N. 1977. Area in skidroads, truck roads, and landings in the central Appalachians. *Journal of Forestry* 75:507-508.

Kuusipalo, J. and J. Kangas. 1994. Managing biodiversity in a forestry environment. *Conservation Biology* 8(2):450-460.

Laitila, J., T. Ranta, and A. Asikainen. 2008. Productivity of stump harvesting for fuel. *International Journal of Forest Engineering* 19(2):37-47.

Leopold, L.B. 1994. *A View of the River.* Harvard University Press Cambridge, MA.

Likens, G.E., F.H. Bormann, N.W. Johnson, D.W. Fisher, and R.S. Pierce. 1970. Effects of cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed-ecosystem. *Ecological Monographs* 40:23-47.

Likens, G.E., F.H. Bormann, N.W. Johnson, D.W. Fisher, and R.S. Pierce. 1978. Recovery of a deforested ecosystem. *Science* 199:492-496.

Likens, G.E., C.T. Driscoll, and D.C. Busco. 1996. Long-term effects of acid rain: Response and recovery of a forest ecosystem. *Science* 272:244-246.

Lindenmayer, D.B. 1999. Future directions for biodiversity conservation in managed forests: Indicator species, impact studies and monitoring programs. *Forest Ecology and Management* 115:277-287.

Lindenmayer, D.B., C.R. Margules, and D.B. Botkin. 2000. Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology* 14(4):941-950.

Mahendrappa, M.K., C.M. Pitt, D.G.O. Kingston, and T. Morehouse. 2006. Environmental impacts of harvesting white spruce on Prince Edward Island. *Biomass and Bioenergy* 30:363-369.

Maine Forest Service. 2004. *Best Management Practices for Forestry: Protecting Maine's Water Quality.* Maine Forest Service, Augusta, ME. 93p.

Maine Forest Service. 2008. Annual publications. Available online at: http://www.maine.gov/doc/mfs/pubs/annpubs.htm.

Mahon, C.L., J.D. Steventon, and K. Martin. 2008. Cavity and bark nesting bird response to partial cutting in northern conifer forests. *Forest Ecology and Management* 256:2145-2153.

Maleque, M.A., H.T. Ishii, and K. Maeto. 2006. The use of arthropods as indicators of ecosystem integrity in forest management. *Journal of Forestry* 104(3):113-117.

Mälkönen, E. 1976. Effect of whole-tree harvesting on soil fertility. *Silva Fennica* 10:157-164.

Mann, L.K., D.W. Johnson, D.C. West, D.W. Cole, J.W. Hornbeck, C.S. Martin, H. Reikerk, C.T. Smith, W.T. Swank, L.M. Tritton, and D.H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on post-harvest hydrologic losses, nutrient capital, and regrowth. *Forest Science* 42:412-428.

Marciano, J.A., R.J. Lilieholm, J.E. Leahy, and TL. Porter. 2009. *Preliminary Findings of the Maine Forest and Forest Products Survey.* A Report to the Forest Bioproducts Research Initiative, University of Maine, Orono, ME. 54p.

Martin, C.W. 1988. Soil disturbance by logging in New England–Review and management recommendations. *Northern Journal of Applied Forestry* 5:30-34.

Martin, C.W., and J.W. Hornbeck. 1994. Logging in New England need not cause sedimentation of streams. *Northern Journal of Applied Forestry* 11(1):17-23.

McDonald, T.P. and F. Seixas. 1997. Effect of slash on forwarder soil compaction. *Journal of Forest Engineering* 8(2):15-26.

McLaughlin, J.W. and S.A. Phillips. 2006. Soil carbon, nitrogen, and base cation cycling 17 years after whole-tree harvesting in a low-elevation red spruce *(Picea rubens)*-balsam fir *(Abies balsamea)* forested watershed in central Maine, USA. *Forest Ecology and Management* 222:234-253.

McNabb, D.H., A.D. Startsev, and H. Nguyen. 2001. Soil wetness and traffic level effects on bulk density and air-filled porosity of compacted Boreal forest soils. *Soil Science Society of America Journal* 65:1238-1247.

McWilliams, W.H., B.J. Butler, L.E. Caldwell, D.M. Griffith, M.L. Hoppus, K.M. Laustsen, A.J. Lister, T.W. Lister, J.W. Metzler, R.S. Morin, S.A. Sader, L.B. Stewart, J.R. Steinman, J.A. Westfall, D.A. Williams, A. Whitman, and C.W. Woodall. 2005. *The Forests of Maine: 2003.* Resource Bull. NE164. USDA, Forest Service, Northeastern Research Station, Newtown Square, PA. 188p.

Megahan, W.F. 1972. Logging, erosion, sedimentation–Are they dirty words? *Journal of Forestry* 70(7).

Megahan, W.F. and W.J. Kidd. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. *Journal of Forestry* 7:136-141.

Moehring, D.M. and I. Rawls. 1970. Detrimental effects of wet weather logging. *Journal of Forestry* 68(3):166-167.

Mroz, G.D., M.F. Jurgensen, and D.J. Frederick. 1985. Soil nutrient changes following whole-tree harvesting on three northern hardwood sites. *Soil Science Society of America Journal* 49:1552-1557.

Naiman, R., H. Decamps, and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3:209-212.

Napier, D.A. 1972. Total tree harvesting doubles fiber tonnage from aspen stand. *Journal of Forestry* 70(6):343-344.

Odum, E. 1979. Ecological importance of the riparian zone. *Proc. Natural Symposium. Strategies for Protection and Management of Flood Plain Wetlands and Other Riparian Ecosystems.* USDA For. Ser. Gen. Tech. Rep WO12.

Olsson, B.A., H. Staff, H. Lundkvist, J. Bengtsson, and K. Rosen. 1996. Carbon and nitrogen in coniferous forest soils after clear-felling and harvests of different intensity. *Forest Ecology and Management* 82:19-32

Paiement, P. 2008. Personal communications, Gestion Cyclofor Inc., Toronto, Ontario.

Patric, J.H. 1976. Soil erosion in the eastern forest. *Journal of Forestry* 74:671-677.

Patric, J.H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. *Southern Journal of Applied Forestry* 2:66-73.

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality* 9:73-80.

Patric, J.H. 1984. Summary of sediment yield data from forested land in the United States. *Journal of Forestry* 82:101-104.

Perlis, A. 2002. Forest biological diversity. Editorial. *Unasylva* 53:2.

Pierce, R.S., J.W. Hornbeck, C.W. Martin, L.M. Tritton, C.T. Smith, A.C. Federer, and H.W. Yawney. 1993. *Whole-tree Clearcutting in New England: Manager's Guide to Impacts on Soils, Streams, and Regeneration.* Gen. Tech. Rep. NE-172. USDA, Forest Service, Northeastern Forest Experiment Station, Radnor, PA. 23p.

Pimentel, D., M.A. Moran, S. Fast, G. Weber, R. Bukantis, L. Balliett, P. Boveng, C. Clevelend, S. Hindman, and M. Young. 1981. Biomass energy from crop and forest residues. *Science* 212:1110-1115.

Prescott, C.E. 2002. The influence of the forest canopy on nutrient cycling. *Tree Physiology* 22:1193-1200.

Putz, F.E., G.M. Blate, K.H. Redford, R. Fimbel, and J. Robinson. 2001. Tropical forest management and conservation of biodiversity: An overview. *Conservation Biology* 15(1):7-20.

Ranius, T. and L. Fahrig. 2006. Targets for maintenance of dead wood for biodiversity conservation based on extinction thresholds. *Scandinavian Journal of Forest Research* 21:201-208.

Rich, L.R. 1961. *Surface Runoff and Erosion in the Lower Chaparral Zone–Arizona.* USDA Forest Serv., Rocky Mt. Forest and Range Exp. Stn. Pap. 66. 35p.

Roberge, J.M., P. Angelstam, and M.A. Villard. 2008. Specialised woodpeckers and naturalness in hemiboreal forests – Deriving quantitative targets for conservation planning. *Biological Conservation* 141:997-1012.

Ryan, D.F., T.G. Huntington, and C.W. Martin. 1992. Redistribution of soil nitrogen, carbon, and organic matter by mechanical disturbance during whole-tree harvesting in northern hardwoods. *Forest Ecology and Management* 49(1-2):87-99.

Rykowski, K. 2002. Forest biological diversity conservation as an element of sustainable forest management – Policy and practice in Poland. *Unasylva* 53:16-24.

Schmidt, M. 2009. Forest Resources Industrial Forum: Forestry equipment update – The latest and greatest in wood energy production. January 8. Brewer, ME.

Shepard, J.P. 2006. Water quality protection in bioenergy production: The US system of forestry Best Management Practices. *Biomass and Bioenergy* 30:378-384.

Silkworth, D.R. and D.F. Grigal. 1982. Determining and evaluating nutrient losses following whole-tree harvesting of aspen. *Soil Science Society of America Journal* 46:626-631.

Simberloff, D. 1999. The role of science in the preservation of forest biodiversity. *Forest Ecology and Management.* 115:101-111.

Sippoloa, A.L., M. Similä, M. Mönkkönen, and J. Jokimäki. 2004. Diversity of polyporous fungi (Polyporaceae) in northern boreal forests: Effects of forest site type and logging intensity. *Scandinavian Journal of Forest Research* 19:152-163.

Smith Jr., C.T., M.L. McCormack Jr., J.W. Hornbeck, and C.W. Martin. 1986. Nutrient removal from a red spruce-balsam fir whole-tree harvest. *Canadian Journal of Forest Research* 16:381-388.

Solbrig, O.T. 1991. The origin and function of biodiversity. *Environment* 33:16-20, 34-38.

Soule, M.E. (Ed.). 1986. *Conservation Biology: The Science of Scarcity and Diversity.* Sinauer Associates, Sunderland, MA. 584p.

Stafford, C., M. Leathers, and R. Briggs. 1996. *Forestry-Related Nonpoint Source Pollution in Maine: A Literature Review.* CFRU Information Report 38. University of Maine, Orono, Maine. 18p.

Stephens, S.S. and M.R. Wagner. 2007. Forest plantations and biodiversity: A fresh perspective. *Journal of Forestry* 105(6):307-313.

Stokes, B. J., T.P. McDonald, and T. Kelley. 1993. Transpirational drying and costs for transporting woody biomass—A preliminary review. In: *Proc IEA/BA Task IX, Activity 6: Transport and Handling; 1994 May 16-25; New Brunswick, Canada.* Aberdeen University, Aberdeen, UK. pp.76–91.

Stokland, J.N. 2001. The coarse woody debris profile: An archive of recent forest history and an important biodiversity indicator. *Ecological Bulletins* 49:71-83.

Sustainable Forestry Initiative (SFI). 2004. *Sustainable Forestry Initiative: 2005-2009 Standard.* Sustainable Forestry Initiative, Sustainable Forestry Board, and the American Forest & Paper Association, Washington, DC. 26p.

Thorell, M. and F. Götmark. 2005. Reinforcement capacity of potential buffer zones: Forest structure and conservation values around forest reserves in southern Sweden. *Forest Ecology and Management* 212:333-345.

Tolbert, V.R. and L.L. Wright. 1998. Environmental enhancement of U.S. biomass crop technologies: Research results to date. Biomass and Bioenergy 15(1):93-100.

Troendle, C. and W. Olsen. 1994. *Potential effects of timber harvest and water management on stream flow dynamics and sediment transport. Sustainable ecological systems. Implementing an ecological approach to land management.* USDA For. Ser. Gen. Tech. Rep. RM-247.

Turcotte, D.E., C.T. Smith, and C.A. Federer. 1991. Soil disturbance following whole-tree harvesting in north-central Maine. *Northern Journal of Applied Forestry* 8(2):68-72.

Turner, D. 2005. Harvesting and bioenergy. *Atlantic Forestry Review,* pp. 40-43.

U.S. Army Corps of Engineers (USACE) 2004. Physical Stream Assessment: A Review of Selected Protocols for Use in the Clean Water Act Section 404.

U.S. EPA. 1999. Rapid Bioassessment Protocols EPA 841B99002 for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. 2nd edition.

Vaillancourt, M.A., P. Drapeau, S. Gauthier, and M. Robert. 2008. Availability of standing trees for large cavity¬nesting birds in the eastern boreal forest of Quebec, Canada. *Forest Ecology and Management* 255:2272-2285.

Vuori, K. and I. Joensuu. 1996. Impact of Forest Drainage on the macroinvertebrates of a small boreal headwater stream: Do buffer zones protect lotic diversity? *Biological Conservation* 77:87-95.

Waring, R.H. and W.H. Schlesinger. 1985. *Forest Ecosystems: Concepts and Management.* Academic Press, London.

Waters, T.F. 1995. *Sediment in Streams: Sources, Biological Effects and Control.* American Fisheries Society Monograph 7. Bethesda, MD.

Weetman, G.L. and B. Webber. 1972. The influence of wood harvesting on the nutrient status of two spruce stands. *Canadian Journal of Forest Research* 2:351-369.

Wells, C.G. and J.R. Jorgensen. 1979. Effects of intensive harvesting on nutrient supply and sustained productivity. In: *Proceedings of the Impact of Intensive Harvesting on Forest Nutrient Cycling*. SUNY, College of Environmental Science and Forestry, Syracuse, NY. pp. 212-230.

White, E.H. 1974. Whole-tree harvesting depletes soil nutrients. *Canadian Journal of Forest Research* 4:530-535.

White, E.H. and A.E. Harvey. 1979. Modification of intensive management practices to protect forest nutrient cycles. In: *Proceedings of Impact of Intensive Harvesting on Forest Nutrient Cycling*. SUNY, College of Environmental Science and Forestry, Syracuse, NY. Pp. 264-278.

Whitman, A.A. and J.M. Hagan. 2004. A Rapid-assessment Late-successional Index for Northern Hardwoods and Spruce-fir Forest. *Forest Mosaic Science Note* #2004-3. Manomet Center for Conservation Sciences, Brunswick, ME.

Whitman, A.A. and J.M. Hagan. 2007. An index to identify late-successional forest in temperate and boreal zones. *Forest Ecology and Management* 246:144-154.

Wiest, R.L. 1998. *A Landowner`s Guide to Building Forest Access Roads*. Technical Publication NA-06-98. USDA, Forest Service, Northern Area State and Private For., Radnor, PA.

Williamson, J.R. and W.A. Neilsen. 2000. The influence on forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground-based harvesting. *Canadian Journal of Forest Research* 30:1196-1205.

Wilson, E.O. 1989. Threats to biodiversity. Scientific American 261(3):108-116.

Wood, M.J., P.A. Carling, and A.J. Moffat. 2003. Reduced ground disturbance during mechanized forest harvesting on sensitive forest soils in the UK. *Forestry* 76(3):345-361.

Wood, P. J. and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21:203-217.

Wood Resources Quarterly. 2009. Wood pellet producers are increasingly competing with pulp manufacturers for wood fiber. *Wood Resources Quarterly*, February 2009 press release. 2p.

Young, H.E. 1964. The complete tree concept—A challenge and an oppportunity. In: *Proc. Soc. Am. For. Nat'l. Meeting [Denver, CO]*. Soc. Am. For., Washington, DC. pp. 231-233

Young, H.E. 1974. Complete-tree concept: 1964–1974. *Forest Products Journal* 24(12):13-16.

Young, H.E. and P.M. Carpenter. 1976. *Weight, Nutrient Element and Productivity Studies of Seedlings and Saplings of Eight Tree Species in Natural Ecosystems*. Maine Agric. Exper. Station Tech. Bull. 28. University of Maine, Orono, ME.

APPENDIX A
SUMMARY OF SITE-SPECIFIC GUIDELINES

TIMBER HARVESTING always involves a trade-off between what is removed from the forest and what is left behind. Along with applicable regulations and Water Quality Best Management Practices (BMPs), these guidelines are intended for use by loggers, foresters, and landowners to protect soil, water quality and biodiversity on timber harvesting sites in Maine.

These guidelines can be adapted and included in site-specific recommendations developed by a licensed forester. They are intended to inform the landowners' decision-making as they review the forester's prescription. Most importantly, implementation of these practices on the ground depends on the professional judgment, knowledge, and skill of the logger conducting the harvest operation. These guidelines are intended to be used by loggers, foresters, and landowners in this context.

Every acre of forest cannot be managed the same way and these guidelines should not be interpreted in that manner. The guidelines address elements of forest structure related to soil, water quality and biodiversity. These elements include snags, wood of all sizes left on the forest floor, live cavity trees and mast-producing trees. The guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant part of the product mix.

GENERAL RECOMMENDATIONS

Develop a site-specific harvest plan that addresses the forest values identified in this brochure. Publications and programs, such as the Water Quality BMPs, Master Logger Harvest Integrity System, and the Certified Logging Professional Program, can provide general pre-harvest planning guidance. Contact your local MFS District Forester for on-the-ground assistance. Call 1-800-367-0223, or visit www.maineforestservice.gov, for more information.

- Follow all applicable regulations and Water Quality BMPs.
- Strive to optimize utilization and value of all products removed from each site. For example, it is worth considering whether tops, limbs or other woody material has greater value on a trail to prevent erosion or on the landing as biomass chips.

SOIL PRODUCTIVITY

Except where scarification of the soil is important for regeneration, leave the litter layer, stumps, and roots as intact as possible. Wood decaying on the ground, especially tops and limbs, contributes nutrients that help build up the growth potential of the soil.

- Leave as many tops and branches as possible on:
  - low-fertility sites,
  - shallow-to-bedrock soils,
  - coarse sandy soils,
  - poorly drained soils,
  - steep slopes, and
  - other erosion-prone sites.

Water Quality

The Water Quality BMP manual describes many fundamental approaches to protect water quality on harvest operations. These include anticipating site conditions, controlling water flow, and stabilizing exposed soil.

- In particular the Water Quality BMP manual highlights that:
  - disturbance of the forest floor should be minimized;
  - woody biomass may be used to control water flow, to prevent soil disturbance, and/or to stabilize exposed mineral soil, especially on trails and the approaches to stream crossings; and
  - woody biomass used for erosion control and soil stabilization may be left in place, if it is above the normal high water mark of streams or other water bodies.

Forest Structure

Wood of all sizes provides a range of habitats for other organisms that are essential to a fully productive forest.

- Leave as much dead wood on site as possible.
  - Leave as many snags standing as safety and access will permit.
  - Leave any felled snags in place.
  - Limit disturbance to existing down logs.
  - If large woody material is lacking on the ground, consider leaving some newly-cut logs scattered throughout the harvest area.
  - Large woody material can be created over time by retaining all snags possible and leaving some large trees to die.
- Leave some live wildlife trees.
  - Retain live cavity trees on site. Cavity trees are live trees with holes, open seams or hollow sections that wildlife can use.
  - Leave live trees with rot when cavity trees are not available.
- Leave some mast-producing trees.
  - Species such as oak, beech, apple, black cherry, pin cherry, hickory, and raspberry produce valuable food for many wildlife species.
- Vary the amount of snags, down logs, and wildlife trees across the harvest area.
  - Stream buffers, retention patches and other protection zones provide an opportunity to leave more large trees than may be possible in other harvest areas.
  - Leaving lightly cut or un-cut patches in heavy harvest areas yields more biodiversity benefits than widely dispersed single trees.
  - The larger the retained patch, the greater the benefit to sensitive understory species.
- Leave as much fine woody material as possible.
  - Where possible and practical (depending on harvest method and system) retain and scatter tops and branches (fine woody material) across the harvest area.
  - If trees are delimbed at roadside, haul a portion of the tops and limbs back into the woods. Leave the material along skid trails if carrying it off the trail would cause greater damage.

APPENDIX B

APPENDIX B REVIEW OF WILDLIFE TREE GUIDELINES FOR THE NORTHEAST AND THE MARITIMES

Compiled by Rob Bryan, October 2008

Reference	Forest Type	Silviculture	Cavity Trees[1] (# per acre)	Snags (# per acre)	Live wildlife tree[2] (ft^2 per acre)	Additional Recommendations & Considerations
1	Northern hardwoods	OSR, Thinning, & Mature Selection	1 to 10 (>18" dbh)	all	1.7 to 17	
	Northern hardwoods	Pole selection	BA ≤ 10 sf		≤ 10	
2	Not specified	All	0.4 to 0.5 (>18" dbh) 1 to 1.5 (14" to 18" dbh) 2 to 2.5 (6" to14" dbh)		≥ 1.7 (> 14" dbh)	
3	Not specified	All	0.2 (>22" dbh) 6 (12" to 22" dbh)		5.2 (> 12" dbh)	
4	New Brunswick; (mostly spruce-fir and mixedwood)	Clearcuts & Shelterwood	20 (>10" dbh)	20 (> 10" dbh)	10.9 (> 10" dbh)	HW species, clumps preferred
		Selection	20 (>10" dbh)	All possible	10.9 (> 10" dbh)	
5	All	Even-aged	For every 10 acres harvested, leave uncut patches equal to 5% of area and > 0.25 acre in size		-	Use cavity or den trees > 18" dbh as patch nuclei
		Uneven-aged	≥6 including: (1 >18" dbh & 3 >12" dbh)		>3.3 (> 12" dbh) (includes live trees & snags)	Leave recruitment trees where cavity tree goal not met
6	All	Even-aged	For every 10 acres harvested, leave uncut patch ≥ 5% of area and > 0.25 acre in size			Use cavity or den trees > 18" dbh as patch nuclei
		Uneven-aged	1 (>24" dbh) and 3 (>14" dbh) and 3-5% total stocking as potential cavity trees and future snags		4.2 (> 14" dbh) (includes live trees & snags)	
7	All	All	1 (≥21" dbh) 3 (15-21" dbh)	1 (≥21" dbh) 3 (15-21" dbh)	6.1 (≥15" dbh)	Draft statewide benchmark – not a stand-scale guideline

1. Includes other live decay trees.
2. Count of live cavity trees and other live decay trees converted to square-feet of basal area per-acre.

References:

1. Tubbs, C.H., R.M DeGraaf, M. Yamasaki, and W.M. Healy. Guide to wildlife tree management in New England Northern Hardwoods. USDA Gen Tech Report NE-118. Northeastern Forest Experiment Station, Broomall, PA.
2. Elliott, C.A. ed. 1988. Forester's Guide to Managing Wildlife Habitats in Maine (Page 18). University of Maine Coop Extension, Orono, ME.
3. Elliott, C.A. ed. 1988. Forester's Guide to Managing Wildlife Habitats in Maine. (Appendix G). University of Maine Coop Extension, Orono, ME.
4. Woodley, S. 2005. Snag and Cavity Tree Retention. p. 61-64 in Betts, M.G.. and G.J. Forbes, eds., Forest Management Guidelines to Protect Native Biodiversity in the Greater Fundy Ecosystem. New Brunswick Co-operative Fish and Wildlife Research Unit, University of New Brunswick, Fredericton.
5. New Hampshire Forest Sustainability Standards Work Team (NH FSSWT) 1997. Good Forestry in the Granite State: Voluntary Forest Management Practices for New Hampshire. NH Division of Forest and Lands and Soc. For Protection of NH Forests.
6. Pelletier, S. 2008. Downed woody material, snags, and cavity trees. p. 27-31 in Elliott, C.A., ed., Biodiversity in the Forests of Maine, Guidelines for Land Management. UMCE Bulletin #7147, University of Maine, Orono.
7. Maine Forest Service. 2003. Biennial Report on State of the Forest and Progress Report on Sustainability Standards. Augusta, ME.

APPENDIX C COMPARISON OF STATE BIOMASS HARVEST AND WILDLIFE TREE GUIDELINES

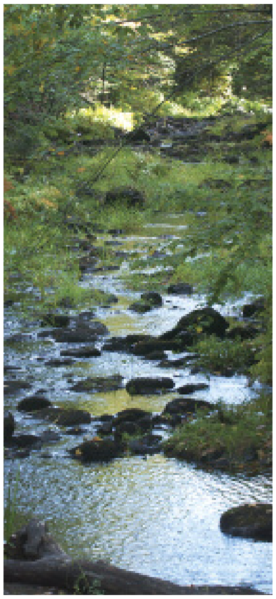
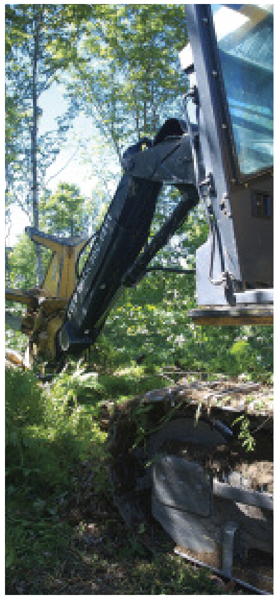
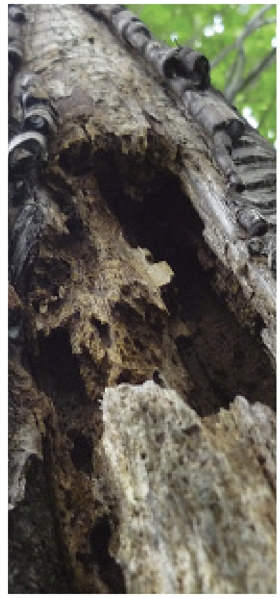
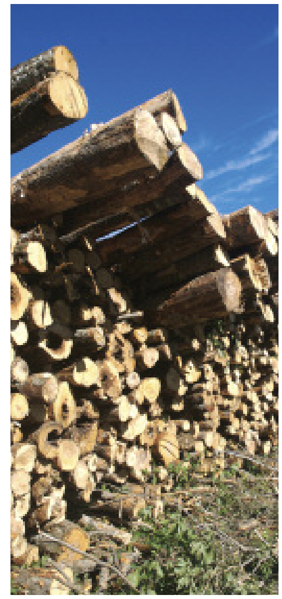
Compiled by Rob Bryan, June 2009

Category	Wisconsin Sept 2008 Draft	Minnesota Voluntary Site Level Guidelines 2007	Pennsylvania 2008	Maine Maine Forest Biodiversity Project(MFBP) & Maine Forest Service Forest Sustainability Standards (MFS-FSS) Draft
Standing Trees				
Snags	• Retain ≥3, preferably large (>12" DBH, preferably >18") in all harvests. Retain as many as possible. If necessary to cut for safety reasons, retain on site as coarse woody debris.	• Retain all possible, with safety exception.	• 1-5 trees/ac (p. 19); leave all possible (p. 38z); no size specified.	MFBP: • Uneven-aged management: ≥4 cavity trees or snags /ac, with 3 >14" and 1 >24" . MFS-FSS • Statewide goal 3 dead trees and snags/ac ≥15" + 1/ac. ≥21".
Cavity Trees	• ≥3/ac ,>12" , preferably >18", in even age intermediate treatments and uneven-aged management. See also Reserve Trees below.	• Included under guidelines for Reserve Trees" below (called "Leave Trees" in the MN Voluntary Site-Level Guidelines)	• Average 5/acre (p. 19), "protect" (p. 36); no size specified.	MFBP: • Uneven-aged management: ≥4 cavity trees or snags /ac, with 3 >14" and 1 >24". In areas lacking cavity trees leave live trees in these diameters likely to lead to cavity formation. • All harvests: Retain as many live cavity trees as possible. MFS-FSS • Not included as a separate category by MFS(see *Recruitment Trees* below)
Mast Trees	• ≥3/ac >12" , preferably >18", in even age intermediate treatments and uneven-aged management. See also "Reserve Trees" below.	• Manage for oak and other mast trees, maintain beech with bear use.	• Protect food producing shrubs and vines	MFBP: • Retain/promote oak and healthy beech, and large mast-producing beech regardless of condition. • Retain apple, black cherry, a component of raspberry and pin cherry, and a diverse and productive herb layer. MFS-FSS • Not included as separate category
Recruitment Trees	• Consider ≥ 3 trees/ac to develop into large. old trees, in even age intermediate treatments and uneven-aged management.	• Included under guidelines for Reserve Trees" below (called "Leave Trees" in the MN Voluntary Site-Level Guidelines)	• Not mentioned	MFBP: • All harvests: Retain as many large unmerchantable trees as possible. MFS-FSS • Statewide goal 3 rough and rotten trees/ac ≥15' + 1/ac. ≥21"
Reserve Trees (individuals and/or and patches) in even-aged regeneration harvests	• Retain 5-15% of even-aged harvest area "rotation harvests" in reserve trees and patches. Include large vigorous trees, mast trees, and cavity trees (see guidelines above). Use a mix of individuals and patches – most benefit in patches 0.1-2 acres.	• Option 1 - Patches (preferred): Leave ≥5% of clearcut area in patches (preferred); do not reduce basal area below 80 ft^2/ac in trees ≥6" DBH, and do not harvest biomass within reserve patches. • Option 2 – Scattered individuals: Leave 6-12 dispersed individuals/acre on average-sized clearcuts, with ≥15 trees per acre on the largest (top 20% of clearcuts). • Identify patches and leave trees prior to initial seed tree or shelterwood cut. • Leave trees should be at least 6" DBH, with about 50% >12" DBH, and at least 1-2 trees per patch or per acre >18" DBH.	• Reduce biomass available for removal by 5-20% from inventory data to retain 10-20 square feet over entire treatment area for biodiversity. • Avoid biomass harvest within clumps left for biodiversity purposes (no guidelines on amount or size of clumps).	MFBP: • Uneven-aged management: Consider designating 3-5% of stocking as potential cavity trees and future snags. • Even-aged management: For every 10 acres, leave ≥5% of area in uncut patches >0.25 ac. in size. MFS-FSS • Indicator 5.6: Degree to which forest management is consonant with natural forest dynamics. • Benchmark 5.3.1. At least 25% of forest area in two storied or multi storied/mosaic stands sawtimber size and at least 15% in high basal area sawtimber.

Category	Wisconsin Sept 2008 Draft	Minnesota Voluntary Site Level Guidelines 2007	Pennsylvania 2008	Maine Maine Forest Biodiversity Project(MFBP) & Maine Forest Service Forest Sustainability Standards (MFS-FSS) Draft
Other Retention	• Species and size diversity is beneficial. • Designate by marking or writing which trees to retain. • If Fine Woody Material is harvested, consider 10-15% reserve tree/patch retention to compensate for increased impacts of biomass removals. • Salvage harvests: retain ≥5% of salvage area in un-salvaged patches 1-20 acres in size.	• Retain conifers >4" in mixed stands. • Allow some trees to reach 200-300 years old.	• None	MFBP: • Maintain softwood inclusions in hardwood forests. MFS-FSS • None
Coarse Woody Debris and Fine Woody Material				
Coarse Woody Debris (CWD)	• CWD is ≥4" DIB small end • Retain and limit disturbance to existing CWD.	• CWD is ≥6" diameter • Avoid damage. • Retain stumps and uprooted stumps. • leave snags that must be felled. • Create 2-5 bark-on logs/ac >12" if fewer exist. • Create 4 logs/ac in RMZs (overall site average still ≥2/ac). • Mixed hardwood and conifer.	• CWD is >6" diameter small end • Leave snags cut for safety where they fall. • Leave 2-5 non merchantable logs/ac.; cull trees can be felled and left to meet this goal (p. 19) • Retain 15-30% of harvestable biomass as CWD (p. 36).	MFBP: • Avoid damaging existing downed woody material (DWM), especially large hollow logs and stumps. • Leave DWM on site when possible. • Leave or haul back several downed logs of decay class 1&2, >12" diameter and >6ft. Retain as many as possible in classes 3, 4&5. • Leave snags that must be felled on site. MFS-FSS • Statewide goal 3 downed logs/ac ≥15' + 1/ac. ≥21".
Fine Woody Material (FWM)	• FWM is <4" DIB large end • Retain ≥4 tons/ac well distributed, including volume in retention patches. • Typical Wisconsin forest has 8-12T/ac FW.	• FWM is <6" diameter • Retain and scatter tops and limbs from 20% of trees harvested and all FWM from incidental breakage. Haul back if using whole tree harvesting. • Leave 20% of small trees and brush.	• Limit whole tree harvests. If whole tree harvesting, retain slash on 10% of site (p. 19). • Retain slash on areas treated with conventional harvests .	MFBP: • Not included as a separate category (would be included under *Soils,* below) MFS-FSS • Not included as a separate category (would be included under *Soils,* below)
Soils				
General	• Do not remove litter layer, stumps, and/or root systems. • ≤3% of harvest area in permanent roads and landings. • ≤15% of harvest area in roads, landings, and skid trails. • (see also FWM guideline)	• Retain stumps and uprooted stumps • (see also FWM guideline)	• Do not remove forest floor, litter layer, or root systems. • Keep landing and road network to a minimum. • Use applicable soil and water BMPs • (see also FWM guideline)	MFBP: • Avoid whole tree removal, particularly on low fertility sites (see below). • ≤15% of harvest area in roads, landings, and skid trails. • When possible, conduct whole tree harvests of hardwoods during leaf-off season to retain nutrients. • Limit short-rotation harvests as much as possible unless replacement of nutrients and organic matter is considered. • When possible, delimb trees and return slash to woods.

Category	Wisconsin Sept 2008 Draft	Minnesota Voluntary Site Level Guidelines 2007	Pennsylvania 2008	Maine Maine Forest Biodiversity Project(MFBP) & Maine Forest Service Forest Sustainability Standards (MFS-FSS) Draft
Soils (cont.)				
				MFS-FSS • Indicator 1.1: Harvested area with soil disturbance (removal of organic matter, exposure of mineral soil, soil erosion, compaction, destruction of soil horizons, or alteration of internal soil hydrology) that alters soil physical properties and degrades soil productivity. Indicator 1.2: Harvested area with significant change in soil chemistry that degrades soil productivity.
Sandy and/or Shallow-to Bedrock Soils	• Do not harvest FWM on soils with <20" to bedrock. • Do not harvest FWM on nutrient-poor soils (list of series to be developed).	• Avoid biomass harvest of deciduous species. • For other harvests of deciduous species, ○ Retain/redistribute slash. If soil not frozen, leaving slash along trail may cause less damage than off-trail distribution. ○ Avoid short rotation or extend rotation age.	• Not mentioned	MFBP: • Avoid whole tree removal, particularly on low fertility sites (i.e., shallow to bedrock soils, coarse sands, wetlands, and areas with high water tables) unless replacement of nutrients and organic matter is considered.
Organic Soils	• Do not harvest FWM on "dysic Histosols" (≥18" organic layer, nutrient poor, with low PH).	• Avoid biomass harvest on organic soils with >24 organic layer. Retain and redistribute slash.	• Not mentioned	
Erosion-prone Sites	• Do not harvest FWM on erosion-prone sites.	• Not mentioned	• Not mentioned	• Not mentioned by MFBP or MFS-FSS
Special Management Areas				
Riparian Management Zones (RMZ)	• Do not harvest FWM within 35' of non-navigable streams and 100' of wetlands.	• Avoid biomass harvest in RMZs.	• Retain dead and down material.	MFBP: • Use single-tree and group selection cuts to maintain 65-70% crown closure. • Consider an inner no-cut zone. • Retain snags, cavity trees, large trees, and downed logs as much as possible. MFS-FSS • Indicator 2.4: Percent of mapped, perennial first and larger order stream kilometers with acceptable levels of large woody material and snags within riparian zone.

Category	Wisconsin Sept 2008 Draft	Minnesota Voluntary Site Level Guidelines 2007	Pennsylvania 2008	Maine Maine Forest Biodiversity Project(MFBP) & Maine Forest Service Forest Sustainability Standards (MFS-FSS) Draft
Rare, Threatened, and Endangered Species (R,T&E)	• Do not harvest FWM where Federal or State T or E species are known, except to improve habitat per guidelines. • ***Under consideration:*** *If Special Concern or Species of Greatest Conservation Need are present, determine if harvest of FWM is consistent with maintaining the species and habitat.*	• Avoid biomass harvest on sites with T or E species.	• Beware of presence of R,T,&E species habitat and unique features and take steps to protect them. (p. 27). • Know their habitat requirements and avoid disturbing or enhance habitats.	MFBP: • No recommendations specific to biomass harvesting.
R,T&E Natural Communities	• Do not harvest FWM on State Element occurrences identified by WI Natural Heritage Inventory. • ***Under consideration****: On sites with exceptional community composition or structure, determine if harvest of FWM will be consistent with maintaining the type.*	• Avoid biomass harvest in rare natural plant communities.	• Not mentioned	MFBP: • No recommendations specific to biomass harvesting.

These guidelines were developed as a collaborative effort between the Maine Forest Service, the University of Maine, and the Trust to Conserve Northeast Forestlands. They are based on a technical review of environmental issues related to woody biomass retention from timber harvest sites in Maine prepared for the Natural Resources Conservation Service. A copy of the full report can be found on the publications link at the following website:

www.forest.umaine.edu/faculty-staff/directory/jeffrey-benjamin

For more information contact:

Jeffrey G. Benjamin
School of Forest Resources, University of Maine
247 Nutting Hall, Orono, ME 04469
(207) 581-2727 • fax (207) 581-2875
jeffrey.g.benjamin@maine.edu

Funding for this effort has been received from the Natural Resources Conservation Service, Maine Forest Service, and the University of Maine's Forest Bioproducts Research Initiative.
(NSF Grant No. EPS-0554545)

NRCS Natural Resources Conservation Service

DEPARTMENT OF CONSERVATION MAINE FOREST SERVICE

FBRI FOREST BIOPRODUCTS RESEARCH INSTITUTE

1865 THE UNIVERSITY OF MAINE Maine Agricultural & Forest Experiment Station