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ENVIRONMENTAL REPORT

ADVANCED SYSTEM DEMONSTRATION FOR UTILIZATION OF BIOMASS AS AN ENERGY SOURCE

Technical Appendix D: Terrestrial Ecosystems and Forestry Studies

APPENDIX D: Terrestrial Ecosystems and Forestry Studies

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PREFACE

This technical appendix is one of a series that reports studies undertaken during the preparation of the Department of Energy's Advanced System Demonstration for Utilization of Biomass as an Energy Source. This document is organized by major environmental topic and does not follow the format of the environmental report. It provides data and analyses to support the environmental report and allows all the material on this topic to be brought together in one report. Although this approach leads to some duplication of text, it allows the reader to understand the conclusions more fully and increases the value of the study for future environmental assessments of biomass facilities.

APPENDIX D: TERRESTRIAL ECOSYSTEMS AND FORESTRY STUDIES

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THE PLANT SITE

EXISTING TERRESTRIAL ECOSYSTEMS

The S.D. Warren property, location of the proposed plant, is developed, paved, or otherwise disturbed, with the exception of a small patch of woodland at the northern end of the property. The areas that would be directly affected by the plant are characterized by annual and perennial herbaceous "weeds" -- that is, plants that colonize disturbed areas. Some of these plants are native, some alien. In the few low damp spots on the site, species differ from the general trend but otherwise there are no discernible distribution patterns. Although the species diversity is high, the vegetative species present on the site are extremely common and can be found on any vacant lot, roadside, or power-line right-of-way in the Northeast. No species were found that could in any way be construed as rare, endangered, or otherwise worthy of protection (Brown 1978).

The small woodlot is dominated by white pine on the north-facing slope and red oak on the south-facing slope. These trees are under fifty years of age. Little understory or ground cover has developed. All species found here are common in the woodlands of southern Maine. A list of these species is presented in Table 1.

Because of the predictability of the vegetation found on the site, an animal inventory was not undertaken. However, one could expect to find small birds and mammals characteristic of most disturbed areas and woodlands in the Northeast (Brown 1978). No rare or endangered animals are known to occur here.

TABLE 1: PLANT SPECIES AT THE S.D. WARREN SITE

Herbaceous Plants:	
Poverty Grass	*Aristida dichotoma*
Witch Grass	*Panicum capillare*
Stink Grass	*Eragrostis megastachya*
Stink Grass	*E. poaoides*
Foxtail Grass	*Setaria glauca*
Nimblewill	*Muhlenbergia frondosa*
Barnyard Grass	*Echinochloa crusgalli*
Burdock	*Arctium minus*
Tall Goldenrod	*Solidago altissima (abundant)*
Grass-leaved Goldenrod	*S. graminifolia*
New England Aster	*Aster novae-angliae*
Bull Thistle	*Cirsium vulgare*
Curly Dock	*Rumex crispus*
Spotted Spurge	*Euphorbia maculata*
Sweet White Clover	*Melilotis alba*
Queen Anne's Lace	*Daucus carota*
Evening Primrose	*Oenothera biennis*
Rabbit's Foot Clover	*Trifolium arvense*
Common Milkweed	*Asclepias syriaca*
Slender-leaved Gerardia	*Gerardia tenuifolia*
Yellow Rocket	*Barbarea vulgaris*
Purple Loosestrife	*Lythrum salicaria*
Bluejoint	*Calamagrostis canadensis*
Scouring Rush	*Equisetum hyemale*
Woody Plants:	
Box Elder	*Acer negundo*
Sweet Fern	*Comptonia peregrina*
Alder	*Alnus rugosa*
Cottonwood	*Populus deltoides*
Black Willow	*Salix nigra*
Smooth Sumac	*Rhus glabra*
White Pine	*Pinus strobus*
Red Oak	*Quercus rubra*

Source: Brown 1978.

IMPACTS ON TERRESTRIAL ECOSYSTEMS

Impacts of the proposed wood-fired power plant project on terrestrial ecosystems of the plant site will result principally from the construction of the new facility.

Construction of buildings, parking lots, and wood storage areas for the proposed wood-fired power plant will result in the permanent destruction of several acres of land characterized by common annual and perennial herbaceous "weeds" -- that is, of an ecosystem composed of early successional species that colonize disturbed areas. As this vegetation provides habitat for small birds, mammals, and rodents, these species will also be displaced from the site. A temporary staging area, established as a parking lot for heavy equipment and a storage site for materials, will temporarily disrupt another portion of the same ecosystem. It is expected that vegetation similar to that now present will recolonize the staging area within several years after construction is completed.

Additional damage may occur to vegetation on adjacent areas of the S.D. Warren property as a result of blowing dust during construction. Dust will be controlled through use of watering trucks, however, and it is expected that the effect on vegetation will be lowered productivity during periods when the foliage is covered with dust. All of the area that will be permanently or temporarily destroyed or affected by blowing dust has been previously used for industrial purposes and has experienced prior devegetation and other disturbance.

All species found on the site are common to disturbed areas and woodlands of Maine; no rare or endangered plants, animals, or birds are known to be present.

No noticeable impacts on terrestrial ecosystems will occur solely as a result of operation of the new facility. Replacement of the S.D. Warren's existing oil-fired system with the wood system will cause only slight changes of air quality in the Westbrook area (see Appendix B). No noticeable change in plant or animal life will occur as a result of this change.

The new plant will release less wastewater and heat into the Presumpscot River than the current facility, and there will be small changes in the chemical characteristics of the effluent (see Appendix C). These changes in water quality will have no impact on river-bank ecosystems.

THE FUELWOOD HARVEST REGION

FOREST SOILS

Soil Characteristics

The soils of the fuelwood harvest region are primarily developed on a parent material of till, outwash plains, and other glacio-fluvial materials, as well as localized marine-lacustrine and alluvial deposits and rock outcrops. The soils are predominantly of the haplorthod and to a lesser degree dystrochrept great groups. Smaller areas of the haplaquod, fragiorthod, eutrochrept, fragioquept, haplaquept, fluvaquent, humaquept, borohemist, udipsamment, and histosol classifications are found. The major characteristics of these soil types are given in Table 2.

The distribution of the soil series in the potential fuelwood harvesting counties of Maine and New Hampshire is shown in Table 3. These data are presented as percentages of total soil coverage within each county.

Table 4a shows some major erosion and silvicultural characteristics of these soils. The soils are presented first by soil subgroup as designated by the U.S. soil classification system, and then by name for each soil series within those subgroups.

Erosion potential, where data are available, is rated in one or two ways. The first classifies erosion hazard as slight, moderate, or severe, as judged by the U.S. Soil Conservation Service according to the amount of erosion that occurs during or following cutting operations on exposed soil along roads, skid trails, fire lanes, log decking areas, and other areas of operation (SCS 1977a).

The second erosion index is a numerical soil erosion index, or K-factor, and refers to the universal soil-loss equation as defined by Wischmeier and Smith (1965). It is an experimentally derived value, based on the erosion potential of a unit plot of a particular soil. When considered along with rainfall, slope, and cover-management, an estimate of annual erosion can be calculated. Applications are discussed in detail later in this appendix. Low values are associated with low erosion potential. In the fuelwood

TABLE 2: MAJOR CHARACTERISTICS OF SOIL TYPES

I. Spodosols: Spodic horizon is precipitated organic matter, aluminum, with or without iron. Little silicate clay; mostly sandy. Vegetation is usually coniferous, but some are under hardwoods. Naturally infertile.

- A. Haplaquods: Commonly saturated (fluctuating groundwater or humid climate). Spodic horizon is principally of organic matter, aluminum. Sandy texture.
- B. Fragiorthods: Freely drained. Spodic horizon is organic matter, aluminum, iron. Fragipan (loamy or sandy horizon, high bulk density, brittle when moist, "cemented" when dry) below spodic horizon.
- C. Haplorthods: Freely drained. Albic horizon (clay, free iron oxides removed or segregated), spodic horizon resting on argillic horizon (clay accumulation).

II. Inceptisols: Some bases, aluminum, iron lost by leaching. Only moderate profile development.

- A. Fragiaquepts: Wet, poor drainage. Mottled gray subsurface. Fragipan at depth 30 to 50 cm. Trees have shallow root system.
- B. Humaquepts: Very wet. Nearly black or peaty. Acid.
- C. Haplaquepts: Groundwater at or near surface, seasonally or artificially drained. Light colored.
- D. Dystrochrepts: Freely drained. Ochric epipedon, cambric horizon (altered). Light colored. Acid. Mostly under deciduous forests.
- E. Eutrochrepts: Base rich, on calcareous sediments, or basic rocks. Brownish. Mostly under deciduous forest.

III. Entisols: Little or no pedogenic development: organic matter may accumulate, possible plowed layer.

- A. Fluvaquents: Wet. Loamy fine sand texture or finer, may be stratified reflecting sedimentation. Bluish or gray and mottled. On flood plains and deltas.
- B. Udipsamments: Low water-holding capacity. In late Pleistocene or more recent sandy deposits. Some weatherable minerals. Brownish. Mostly under deciduous forest. Support wheeled vehicles poorly.

IV. Histosols: Mostly saturated throughout year. Organic soils, over half organic matter by volume.

- A. Borohemists: Up to 2/3 of organic matter decomposed beyond botanic recognition. Vegetation woody or herbaceous.
- B. Borofibrists: High percentage well preserved, identifiable botanic origin.

Source: SCS 1975

TABLE 3: PERCENT OCCURRENCE OF SOIL SERIES BY COUNTY IN FUELWOOD HARVEST REGION

Soil Series[1]	New Hampshire			Maine						
	Belknap	Carroll	Strafford	Androscoggin	Cumberland	Kennebec	Lincoln	Oxford	Sagadahoc	York
Acton	3	1	1							
Acworth										
Adams*		2		12				+	3	2
Agawam				<1			†	†	<1	
Allagash										
Au Gres	<1				1		†			
Balch										2
Bangor										
Barnstead										2
Becket		4						+		<1
Belgrade				3	3		†	†	2	
Berkshire		<1				3		+		
Biddeford			<1	<1	<1	2	†		1	4
Blandford										
Brimfield										1
Brookfield*										13
Burnham								†		
Buxton*			2	3	7	8	+		14	2
Canaan					2					5
Charlton*	5	<1	11	18			+		7	2
Colebrook										
Colrain										
Colton		4						+		4
Crary										
Croghan		<1						†		
Danby										
Deerfield	<1	<1	<1		4	<1				
Dixmont										
Dixville										
Duane		<1								
Elmwood			<1	1	2		†		<1	
Essex										<1
Etna										
Gloucester *	35	6	21							12
Grafton										<1
Greensboro										
Groveton										

1. The soil subgroup of each soil series is shown in Table 4.

Table 3: cont.

Soil Series	New Hampshire: Belknap	Carroll	Strafford	Maine: Androscoggin	Cumberland	Kennebec	Lincoln	Oxford	Sagadahoc	York
Hadley		<1		<1				†	<1	
Hartland				3	1	2	†		2	2
Hermon*		7			19		+	+		
Hinckley	6	2	7	4	6	3	+		1	7
Hiram								†		
Hollis *		3	26	15	9	20	†		39	3
Jaffrey										<1
Leicester		1	5	3				†	2	
Lempster										
Limerick		<1		1	<1	<1	†	†	1	
Littlefield										1
Lyman *		8			2	2		+		
Madawaska										
Marlow		3						+		
Melrose				1	<1		†		<1	2
Merrimac				<1	<1				<1	6
Millis		3								
Monarda						3		†		
Nashua										
Naumburg		1								
Nicholville		<1								
Ninigret				4			†		1	
Ondawa	<1	<1	<1	<1	<1		†	†	<1	<1
Paxton*	14	2	6	4	6	16	+	+	<1	
Peru		2			4	2		+		
Peterboro										
Podunk	<1	<1	<1	<1	<1			†	<1	<1
Potsdam										
Raynham		<1						†		
Red Hook										
Ridgebury	4	2	2		2	6	†	+		
Rifle						<1		†		
Rumney	<1		<1		<1			†		
Saco				<1		<1	†	†	<1	<1
Salmon		<1						†		
Saugatuck			2		<1					2
Scantic			2	5	6		†		7	
Scarboro	<1			3	<1	<1	+	+	<1	4
Scio						3				
Scituate		1								
Sebago					2			†		
Shapleigh*	20									2
Skerry		2						+		
Skowhegan										
Stetson								†		
Sudbury							†			1
Suffield			<1	<1	5	2			3	2

Table 3: cont.

Soil Series	New Hampshire: Belknap	Carroll	Strafford	Maine: Androscoggin	Cumberland	Kennebec	Lincoln	Oxford	Sagadahoc	York
Suncook	<1	<1	<1					†		
Sutton			<1	10			†		6	1
Swanton			<1	1	2		†		<1	
Thorndike										
Togus						1		†		
Vassalboro						<1		†		
Walpole				2	1				<1	
Warwick										
Waterboro										
Waumbek		1						†		
Westford										
Westminster										2
Whately				<1	<1				<1	
Whitman	<1	<1	<1	<1	<1					3
Windsor	4	2	4		10	2	+			
Winooski				<1				†		
Woodbridge*	2	<1	2	2	4	14	+		<1	<1
Other Surface Cover										
Coastal beach					<1				<1	
Cut and fill				<1	<1	<1				
Dune land				<1	<1				<1	<1
Gravel/borrow pits	<1		<1		<1	<1				
Made land	<1			<1	<1	<1	†		<1	
Marsh	<1		<1							
Mixed alluvial	<1		<1					†		2
Muck/peat	3		3	1					<1	
Rock outcrop	<1			<1	<1		†	†	2	<1
Rough mountain										
Tidal marsh			<1		<1				4	<1

†: Present in counties where U.S. Soil Conservation Service survey is not complete.
+: Major distribution in county.
**: Predominant soils in fuelwood harvest region.*

Sources: County soil surveys for Belknap (SCS 1968), Carroll (SCS 1977d), Strafford (SCS 1973), Androscoggin and Sagadahoc (SCS 1970), Cumberland (SCS 1974), Kennebec (SCS 1978), and York (SCS 1952). For Lincoln and Oxford Counties (Ferwerda 1978).

TABLE 4A: EROSION AND SILVICULTURAL CHARACTERISTICS OF THE SOIL SERIES OF THE FUELWOOD HARVEST REGION[1]

Soil Types	Soil Series	Erosion Hazard and Factor[2]	Estimated Productivity[3] WP	UO	NH	SF	Seedling Mortality[4]	Plant Competition[4] Hardwoods	Softwoods	Limitations on Equipment and Roads[4]	Windthrow Hazard[4]
Entic Haplaquod	Au Gres	sl. / .15	good		good	good	sl.-sev.	mod.-sev.	mod.-sev.	sev. /	mod.-sev.
Aeric Haplaquod	Naumberg		fair	poor	fair	poor	sev.	mod.	mod.	sev. / sev.	sev.
	Saugatuck	sl. /	good	fair	fair-good	good	sev.	sl.-mod.	sl.-mod.	sev. / sev.	mod.-sev.
Entic Haplorthod	Agawam	/ .28					sl.	mod.	mod.	sl. /	sl.
	Brookfield	sl. /					sl.	mod.	mod.	sl.-mod. /	sl.
	Charlton	/ .17-.20	fair-good	fair-good	fair	fair-good	sl.	sl.-sev.	mod.-sev.	sl.-sev. / sl.-sev.	sl.

1. *Blanks indicate no data available. Explanation of ratings is given in text. sl.=slight, mod.=moderate, sev.=severe.*
2. *From SCS 1974 and Wischmeier & Smith 1965.*
3. *From SCS 1977a. WP= White pine, UO=Upland oak, NH=Northern hardwood, SF=Spruce/fir.*
4. *From SCS 1977a.*

Table 4A: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Production WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
	Colrain										
	Gloucester		fair- good	poor- good	fair- good	poor	mod.	sl. mod.	sl.-mod.	sl.-sev. ------------ sl. sev.	sl.
	Grafton										
	Hartland	sl.-sev. ------- .49	exc.		exc.	exc.	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------	sl.
	Hinckley	------- .17	poor- fair	poor- fair	poor- fair	fair	sev.	sl.	sl.	sl.-sev. ------------ sl.	sl.
	Jaffrey										
	Melrose	sl. ------ .32	good		good	good	sl.	sl.-sev.	mod.-sev.	sl.-mod. -----------	sl.
	Merrimac	sl. ------ .17	good		good	good	sl.-mod.	sl.-mod.	sl.-mod.	sl. -----------	sl.
Entic Haplorthod	Nashua										
	Suffield	mod.-sev. ------ .28									
	Warwick	sl. -----					sl.	sl.	mod.	sl. -----------	sl.
	Windsor	sl. ------ .17	poor- fair	poor	fair	poor- fair	mod.-sev.	sl.	sl.	sl.-sev. ----------- sl.	sl.

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity				Seedling Mortality	Plant Competition		Limitations on Equipment and Roads	Windthrow Hazard
			WP	UO	NH	SF		Hardwoods	Softwoods		
Entic-Lithic Haplorthod	Brimfield	sl. ----------									
	Hollis	sl. ---------- .20	poor-fair	poor-fair	fair-good	fair	sev.	sl.	sl.	sl.-sev. ------------ sl.-sev.	mod.
	Shapleigh		fair		fair	good	mod.	mod.	mod.	sl. ------------ sl.	mod.
Aquentic Haplorthod	Acton	sl. ---------	fair-exc.	fair-good	fair-exc.	fair-exc.	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------ mod.	sl.-mod.
	Belgrade	sl.-mod. --------- .49	exc.		exc.	exc.	sl.-mod.	sl.	mod.	sl. ------------	sl.
	Deerfield	--------- .17	fair-good	fair-good	fair-good	fair	sl.	sl.	mod.	sl. ------------ mod.	sl.
	Elmwood	sl. --------- .32	exc.	good	good-exc.	exc.	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------ mod.	sl.
	Sudbury	--------- .17					sl.	sev.	sev.	mod. ------------	sl.
	Sutton	-------- .20	fair-good	fair-good	fair-good	fair	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------ mod.	sl.
	Ninigret	-------- .28	good		good	good	sl.	sev.	sev.	sl.-mod ------------	sl.

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
Lithic Haplorthod	Canaan	sl.-mod. / ----------	poor-good	poor	fair-good	fair-good	sev.	sl.	sl.	sl.-sev. / ------------ / mod.-sev.	mod.-sev.
Lithic Haplorthod	Lyman	sl.-mod. / ---------- / .20	poor-good	poor	fair-good	fair-good	sev.	sl.	sl.	sl.-sev. / ------------ / mod.-sev.	mod.
	Thorndike										
	Westminster										
Typic Haplorthod	Acworth										
	Adams	---------- / .17	fair	poor	fair	poor	mod.-sev.	sl.	sl.	sl.-sev. / ------------ / sl.	sl.
	Allagash	---------- / .28									
	Bangor										
	Berkshire	--------- / .20	good	fair	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.-sev. / ------------ / sl.-sev.	sl.
	Colebrook										
	Colton		fair	poor	fair	poor	mod.-sev.	sl.	sl.	sl.-sev. / ----------- / sl.	sl.
	Dixville	Forested areas support good stands of second-growth yellow and white birch, hard maple, and some spruce, fir, hemlock, beech, and popple.									

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
	Duane	--------- .17	fair	fair	fair	fair	sl.	sl.	mod.	sl. ----------- sl.	sl.
	Groveton	sl. ---------					sl.	mod.	mod.	sl. -----------	sl.
	Hermon	sl.-mod. --------- .17	fair-good	poor	fair-good	poor-good	sl.-mod.	sl.-mod.	sl.-mod.	sl.-sev. ----------- sl.-sev.	sl.
Typic Haplorthod	Lempster										
	Stetson										
	Salmon	--------- .49	good	good	good	good	sl.	sl.	sl.	sl. ----------- sl.	sl.
	Peterbcro										
Aquic Haplorthod	Croghan	--------- .20	fair	fair	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.-mod. ----------- mod.	sl.
	Dixmont	sl. --------- .24	exc.		exc.	exc.	sl.	sl.	mod.	mod. -----------	sl.
	Madawaska	--------- .28									
	Nicholville	--------- .49	good	good	good	good	sl.	sl.	mod.	mod. ----------- sl.	sl.
	Skowhegan	--------- .17									

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
	Waumbek	---------- .17	fair	fair	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------ mod.	sl.
Typic Fragiorthod	Becket	---------- .20	fair	fair	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.-mod. ------------ sl.-mod.	sl.-mod.
	Blandford										
	Marlow	--------- .24	good	good	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.- sev. ------------ sl.- sev.	sl.-mod.
	Potsdam	--------- .49									
Entic Fragiorthod	Essex										
	Millis	sl. --------	fair	poor	fair	poor	mod.	sl.	sl.	sl.-mod. ----------- sl.	sl.
	Paxton	sl. --------- .24	fair-good	good-exc.	good-exc.	fair-good	sl.	sl.-sev.	mod.-sev.	sl.-sev. ----------- sl.-mod.	sl.-mod.
Aquentic Fragiorthod	Scituate		fair	fair	fair	fair	sl.	sl.-sev.	mod.-sev.	sl.-mod. ----------- mod.	sl.-mod.
	Woodbridge	--------- .24	good-exc.	good	good-exc.	good-exc.	sl.	sl.-sev.	mod.-sev.	sl.-mod. ----------- mod.	sl.-mod.
	Crary	--------- .49									

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
Aquic Fragiorthod	Peru	---------- .24	good-exc.	good	fair-exc.	fair-exc.	sl.	sl.	mod.	sl. mod.	sl.
Aquic Dystrochrept	Scio	---------- .49									
Fluventic Dystrochrept	Hadley	---------- .49	good	good	good		sl.-mod.	sl.-sev.	sl.-sev.	sl. sl.	sl.
	Ondawa	sl. ----------	fair-good	fair	fair-good	fair-good	sl.	sl.-sev.	mod.-sev.	sl.-mod. sl.	sl.
Fluvaquentic Dystrochrept	Podunk	sl. .20	good-exc.	good-exc.	good-exc.	fair-exc.	sl.	sl.-sev.	mod.-sev.	sl. mod.	sl.
	Winooski	---------- .49	good	good	good	good	sl.	sl.-sev.	mod.-sev.	sl. mod.	sl.
Dystric Eutrochrept	Acton										
Aquic Dystric Eutrochrept	Buxton	sl.-mod. .28	fair-good		fair-good	fair-good	sl.-mod.	sl.-sev.	sl.-sev.	sl.-mod. mod.	sl.-mod.
Typic Fragiaquept	Whitman	---------- .24	poor-fair	poor	poor	poor-fair	sev.	mod.-sev.	mod.-sev.	sev. sev.	sev.
Typic Haplaquept	Burnham	---------- .32									
	Leicester	---------- .17	fair-good	poor-good	poor-fair	fair	mod.-sev.	mod.-sev.	mod.-sev.	sev. sev.	sev.

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
	Monarda	---------- .28									
	Scantic	sl. ---------- .28	fair	poor	fair	fair	sev.	sev.	sev.	sev. ------------ sev.	sev.
Aeric Haplaquept	Raynham	---------- .49	fair	poor	fair	fair	sev.	mod.-sev.	mod.-sev.	sev. ------------ sev.	sev.
	Red Hook	---------- .49									
	Swanton	sl. ---------- .32	fair	poor	fair	fair	mod.-sev	mod.-sev.	mod.-sev.	sev. ----------- sev.	sev.
	Walpole	sl. ---------- .20	good		good	good	sev.	mod.	mod.	sev. -----------	sev.
Mollic Haplaquept	Whately	Does not produce trees of commercial value									
Aeric Fluvaquent	Rumney	sl. ----------	good	fair	fair-good	good	sev.	mod.-sev.	mod.-sev.	sev. ----------- sev.	sev.
Typic Fluvaquent	Limerick	sl. ---------- .20	fair-good	poor	poor-good	fair-good	sev.	mod.-sev.	mod.-sev.	sev. ----------- sev.	sev.
Aeric Fragiquept	Ridgebury	sl. ---------- .24	fair-good	poor-good	poor-good	fair-good	mod.-sev.	mod.-sev.	mod.-sev.	sev. ----------- sev.	sev.
Fluvaquentic Humaquept	Saco						sev.	sev.	sev.	sev. ----------- sev.	sev.

Table 4a: cont.

Soil Types	Soil Series	Erosion Hazard and Factor	Estimated Productivity WP	UO	NH	SF	Seedling Mortality	Plant Competition Hardwoods	Softwoods	Limitations on Equipment and Roads	Windthrow Hazard
Typic Humaquept	Scarboro	sl. ----------	fair		fair	fair	sev.	sev.	sev.	sev. ------------- sev.	sev.
Histic Humaquept	Biddeford		poor			poor	sev.	sev.	sev.	sev. -------------	sev.
Typic Borohemist	Rifle										
Terric Borofibrist	Togus										
Typic Borofibrist	Vassalboro										
Histosol	Balch										
	Littlefield										
Typic Udipsamment	Suncook		poor-fair	poor	poor-fair	poor-fair	sev.	sl.	sl.	sl. ------------- sl.	sl.

The Sebago soil series is classified as being unsuited for commercial production of timber.
The following series are not classified due to an original broad or vague definition: Barnstead, Danby, Etna, Greensboro, Hinsdale, Skerry, Waterboro Muck, and Westford.

harvest region, a range in K-factors from .15 (indicating low erosion potential) to .49 (indicating medium to high) are found. These erosion potentials are determined by such soil properties as texture, organic matter, and structure, all of which affect infiltration, water capacity, and particle detachment and mobility (Wischmeier & Smith 1965).

Soil productivity in Table 4a has been estimated by means of a site index for the tree types that are dominant or codominant within the surveyed counties. This is determined by average tree height in a fully stocked fifty-year-old stand (SCS 1977a).

Seedling mortality refers to the mortality of natural or planted seedlings as influenced by soil or topographic conditions when plant competition is assumed not to be a factor. Plant competition in the table shows the degree of competition the desired tree species receive from undesirable plant species, particularly in their seedling period (SCS 1977a).

The principal limiting factors to the use of equipment are natural wetness, steepness of slopes, and the number of rocks and boulders in or on the soil. The limitations on woodland roads are based on soil characteristics that restrict or prohibit construction of those roads. Natural drainage, rockiness, numbers of boulders, erosion hazards, and gradients are examples. Windthrow hazard is dependent both on the development of tree roots and the ability of soils to hold trees firmly (SCS 1977a).

Table 4b lists the hydrologic and geologic characteristics of the soil series in the fuelwood harvest region. Permeability, measured in inches per hour, describes the estimated rate of water movement through a saturated soil layer. Surface texture classes are given for the major soil layers according to the U.S. Department of Agriculture classification system, keyed in Note 3 at the bottom of the table. Texture refers tothe relative properties of sand, silt, and clay in soil material that is less than two millimeters in diameter (SCS 1977b).

Frequency of flooding and high water table incidence are given for each soil series, along with the months these phenomena are most likely to occur. The runoff potential column shows the

TABLE 4B: HYDROLOGIC AND GEOLOGIC CHARACTERISTICS OF THE SOIL SERIES OF THE FUELWOOD HARVEST REGION[1]

Soil Series	Permeability *(inches/hour)*	Surface Texture Class[2]	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential[3]	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Au Gres	2.0- 6.0	FSL,LS S	None		0- 1		C	>72	Moderate	Low-Very Low
Naumberg										
Saugatuck	6.0-20.0	LS	None		0- 1.5	Dec.-Jun.	C	>60	Moderate	Very Low
Agawam	2.0- 6.0	FSL	None		3-10	Jan.-Mar.	B	>60	Low	Low
Brookfield	0.6- 2.0	SL,FSL	None		4-6		B	48- 72	Moderate	Low
Charlton	0.6- 6.0	FSL, STVFSL	None		3-10	Jan.-Apr.	B	>60	Low	Low
Colrain										

1. Soil types for the soil series are given in Table 3A. Blanks indicate no data available. Explanation of the characteristics given in text.
2. Key: CB=Cobbly, CN=Channery, F=Fine, GR=Gravelly, HM=Henric Material, L=Loamy, MK=Muck, MPT=Mucky Peat, R=Rocky, RE=Extremely Rocky, S=Sandy, SH=Shaly, SI=Silty, ST=Stony, STE=Extremely Stony, V=Very.
3. Ratings range from A (lowest runoff potential) to D (highest runoff potential).

Sources: SCS 1977b and those in Table 3.

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Gloucester	6.0-20.0	SL,STVSL, STESL	None		3- 6	Nov.-Mar.	A	>60	Low	Low
Grafton										
Hartland	0.2- 2.0	SIL, VFSL	None		>6		B	>60	High	Low
Hinckley	6.0-20.0	GRSL	None		>6		A	>60	Low	Low
Jaffrey										
Melrose	2.0- 6.0	FSL	None		1.5- 3.5	Mar.-Apr.	C	>60	Moderate	Low
Merrimac	2.0- 6.0	FSL	None		>6		A	>60	Low	Low
Nashua										
Suffield	0.6- 2.0	SIL VFSL	None		>6		C	>60	High	Low
Warwick	2.0- 6.0	CNL, CNFSL	None		>5		A	72- 84	Low	Low
Windsor	6.0-20.0	LS	None		>6		A	>60	Low	Low
Brimfield										

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Hollis	0.6- 6.0	FSL,L VRFSL,VRL	None		>6		C/D	8- 20	Moderate	Low
Shapleigh										
Acton	2.0- 6.0	FSL,VSTFSL SL,VSTSL	None		1- 2.5		B	48- 72	Moderate	Low
Belgrade	0.6- 2.0	SIL, VFSL	None		1.5- 3.5	Nov.-Apr.	B	>60	Moderate	Low
Deerfield	2.0-20.0	LFS,LS, SL	None		1- 3	Dec.-Apr.	B	>60	Moderate	Low
Elmwood	2.0- 6.0	FSL, VSTSL	None		1- 3	Nov.-May	C	>60	High	Low
Sudbury	2.0- 6.0	FSL SL	None		1- 3	Dec.-Apr.	B	>60	Moderate	Low
Sutton	0.6- 6.0	FSL L	None		1.5- 3.5	Nov.-Apr.	B	>60	Moderate	Low
Ninigret	2.0- 6.0	FSL	None		1.5- 3.5	Nov.-Apr.	B	>60	Moderate	Low
Canaan	2.0-20.0	FSL,VRSL RESL	None		>6.0		C	10- 20	Moderate	Low
Lyman	2.0- 6.0	FSL,L VSTFSL VRFSL,VRL	None		>6.0		C/D	18- 20	Moderate	Low

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding Frequency	Flooding Months	High Ground Water Table Depth	High Ground Water Table Months	Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
Thorndike	0.6- 3.0	SHSIL, SIL,SHVSIL, VRSHIL, RESIL, VSTSIL, VRSIL	None	-	>6.0	-	C/D	10-20	Moderate	Low
Westminster										
Acworth	6.0-20	LS VSTLS	None	-	>6.0	-	A	>60	Low	Low
Adams	6.0-20	LS VSTLS	None	-	>6.0		A	>60	Low	Low
Allagash	2.0- 6.0	FSL	None	-	>6.0	-	B	>60	Low	Low
Bangor	0.6- 2.0	SIL VSTSIL	None	-	4->6	Nov.-May	B	20->60	Moderate	Low
Berkshire	0.6- 6.0	FSL,L NSTL, STEFSL	None	-	>6	-	B	>60	Moderate	Low
Colebrook										
Colton	>6.0	GLS,GSL, SL,VSTSL, STESL RSL,CBSL, GSL LFS	None	-	>6.0	-	A-C	20->60	Low	Low

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding: Frequency	Flooding: Months	High Ground Water Table: Depth	High Ground Water Table: Months	Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
Dixville										
Duane	2.0- 6.0	SL,S, LFS	None	-	1.5-2.0	Feb.-May	B	>72	Low	Low
Groveton	0.6- 6.0	SIL, VFSL, FSL	None	-	>6	-	B	>72	Moderate	Low
Harmon	6.0-20.	SL,VSTSL, STESL	None	-	>6	-	A	20->60	Low	Low
Lempster										
Stetson	2.0- 6.0	FSL GL	None	-	>6		B	>60	Low	Low
Salmon	0.6- 2.0	SIL	None	-	>6		B	>60	Low	Low
Peterboro										
Croghan	6.0-20.0	LS	None	-	1.5-2.0	Nov.-May	B	>60	Moderate	Low
Dixmont	0.6- 2.0	SIL, VSTSIL	None	-	0.5-2.0	Nov.-Jun.	C	>60	High	Low
Madawaska	2.0- 6.0	FSL VFSL	None	-	1.0-3.0	Nov.-May	B	>60	Moderate	Low

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding: Frequency	Flooding: Months	High Ground Water Table: Depth	High Ground Water Table: Months	Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
Nichol-Ville	0.6- 2.0	SIL, VFSL	None		1.5- 2.0	Nov.-May	C	>60	High	Low
Skowhegan	2.0- 6.0	LFS	None		1.5- 2.5	Nov.-May	B	>60	Moderate	Low
Waumbek	2.0-20.0	SL, VSTSL	None		1.0- 3.0	Nov.-May	B	>60	Moderate	Low
Becket	0.6- 2.0	FSL VSTFSL	None		2	Nov.-Mar.	C	>60	Moderate	Low
Blandford										
Marlon	0.6- 6.0	FSL,VSTFSL, VSTL,STFSL	None		2	Nov.-Mar.	C	>60	Moderate	Low
Potsdam	0.6- 2.0	FSL	None		1.5- 3.0	Apr.-May	C	>60	Moderate	Low
Essex	0.6- 6.0	FSL,VSTFSL VSTL,STEFSL	None		2	Nov.-Mar.	C	>60	Moderate	Low
Millis	0.6- 2.0	FSL, VFSL	None		2.5+		C	>48	Moderate	Low
Paxton	0.6- 6.0	FSL,L,VSTFSL, VSTL,STEFSL	None		2	Nov.-Mar.	C	>60	Moderate	Low
Scituate										

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Woodbridge	0.6- 6.0	FSL,L,VSTFSL, VSTL,STEL	None		1.5- 3.0	Nov.-Mar.	C	>60	High	Low
Crary	0.6- 2.0	FSL	None		1.5- 3.0	Apr.-May	C	>60	Moderate	Low
Peru	0.6- 2.0	FSL,L, VSTFSL, VSTL	None		1.0-3.0	Nov.-Mar.	C	>60	High	Low
Scio	0.6- 2.0	VFSL	None		1.5- 3.5	Nov.-Apr.	B	>60	High	Low
Hadley	0.6- 2.0	SIL	Common	Oct.-Apr.	3.0- 6.0	Nov.-May	B	>60	High	Low
Ondawa	2.0- 6.0	FSL, SL	Common	Nov.-May	5		B	>60	Low	Low
Podunk	0.6- 6.0	FSL	Frequent	Nov.-May	1.5- 3.0	Nov.-May	B	>60	Moderate	Low
Winooski	0.6- 6.0	SIL	Common	Sept.-Apr.	1- 3	Dec.-Apr.	B	>60	High	Low
Acton										
Buxton	0.2- 2.0	SIL VST-SIL	None		1- 3	Nov.-May	C	>60	High	Low
Whitman	0.6- 6.0	FSL, L	None		0 0.5	Sep.-Jun.	D	>60	High	Low

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Burnham	0.6- 2.0	SIL, VSTSIL	None		0- 1	Oct.-Aug.	D	>60	High	Low
Leicester	0.6- 6.0	FSL,L VSTFSL,VSTL	None		0- 1	Nov.-Apr.	C	>60	High	Low
Monarda	0.6- 2.0	SIL,VSTSIL, STESIL	None		0- 1.5	Oct.-Jun.	D	>60	High	Low
Scantic	0.2- 2.0	SIL, VSTSIL	None		0- 1	Oct.-Jun.	C	>60	High	Low
Raynham	0.6- 2.0	SIL	None		0.5- 2.0	Mar.-Jun.	C	>60	High	Low
Red Hook	0.6- 2.0	L	None		0.5- 1.5	Dec.-May				
Swanton	2.0- 6.0	FSL	None		0- 1.5	Nov.-May	B/D	>60	High	Low
Walpole	2.0- 6.0	FSL,SL	None		0- 1	Nov.-Apr.	C	>60	High	Low
Whately	2.0-20	MK	None		0- 1	Oct.-Aug.	D	>60	High	High
Rumney	2.0- 6.0	FSL	Frequent	Oct.-Mar.	0- 1.5	Nov.-Jun.	C	>60	High	Low
Limerick	0.6- 2.0	SIL	Frequent	Apr.-Jun.	0.5- 1.5	Jan.-Jun.	C	60	High	Low

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Ridgebury	0.6- 6.0	L,FSL, VSTFSL	None		0- 1.5	Nov.-May	C	>60	High	Low
Saco	0.6- 2.0	SIL, VFSL	Common		0- 0.5	Nov.-Apr	D	>60	High	Low
Scarboro	2.0- 6.0	LFS,FSL, SL	Rare		0- 1.0	Jan.-Dec	D	>60	High	Low
Biddeford	2.0-20+	MPT	None		0- 0.5	Nov.-Aug	D	>60	High	High
Rifle	20 -30	FB	Frequent	Nov.-May	0- 1	Nov.-Jun	D	>60	High	High
Togus	2.0- 6.0	FS	Frequent	Mar.-Jun.	1- 0.5	Sep.-Jul	D	>60	High	Low
Vassalboro	2.0- 6.0	FB	Frequent	Mar.-Jun.	1- 0.5	Sep.-Jul	D	>60	High	
Balch										
Little-field										
Suncook	>6.0	LS	Common	Mar.-May	3- 6	Jun.-Apr	A	>60	Low	Low
Sebago	2.0- 6.0	HM	Frequent	Mar.-Jun.	+ 1- 0.5	Sep.-Jun	D	>60	High	
Barnstead										

Table 4b: cont.

Soil Series	Permeability *(inches/hour)*	Surface Texture Class	Flooding		High Ground Water Table		Hydrological Group: Runoff Potential	Bedrock Depth *(inches)*	Frost Action Potential	Shrink-Swell Potential
			Frequency	Months	Depth	Months				
Danby										
Etna										
Greensboro										
Hinsdale										
Skerry	0.6- 2.0	FSL,SL, VSTFSL, VSTSL	None		1.5- 3.0	Nov.-Mar.	C	>72	High	Low
Waterboro Muck										
Westford										

soil's ability to absorb rainwater. The hydrologic groups run from A (lowest runoff potential) to D (highest runoff potential). Frost action potential estimates the soils' likeliness to heave when freezing occurs, and the shrink-swell potential describes the soils' potential to swell when wet and shrink when dry (SCS 1977b).

Soil Compaction

Soil compaction will result at a cut on sectors that are traversed by the mechanical equipment used for cutting, skidding, landing, chipping, and transporting the fuelwood from the forest. The extent of compaction will depend on the soil texture and moisture content, the type of equipment used, and the size of the harvest at a particular site. Soils most compacted will be medium textured (i.e., loams and silty loams) and wet (Swanston & Dyrness 1973). Within the harvesting area the most frequently occurring soils may have low to moderate compaction potential, as they are predominantly sandy loams (see Table 4b). With a few exceptions, the other soils within the region have similar texture and need some attention to prevent compaction problems. Compaction problems will be exacerbated by wet conditions. For this reason, areas characterized by soils with chronic flooding or high water table conditions should be avoided while harvesting. Within the harvesting area, the major soils are not flooded by streams and are found in regions where water tables at their highest are not within three feet of the surface. The exceptions are soils of the Marlow, Paxton, and Buxton series, all of which have water tables shallower than three feet from November to the spring. Several soils of lesser importance in the area are occasionally flooded and have water tables near the surface. This information is presented in Table 4b.

It should be noted that when the season of high water table coincides with a snow cover, harvest-related soil compaction is reduced in magnitude. In fact, compaction for most soil types will be largely reduced by skidding on the snow. Winter skidding on a snow depth of twelve to sixteen inches with rubber-tired vehicles reduced compaction by over 30 percent in one experiment (Mace, Williams & Tappeiner 1971). Where skidding occurred repeatedly over the same trails and at the landing site where traffic was heavy, snow cover was removed and soil compaction was similar to that in summer operations. Where these disturbances were heavy, no difference in impact was noted between the skidding of whole trees (with branches and tops) and tree-length (bole) skidding. Where disturbance was less severe, the tree-length skidding was found to result in a greater depth of soil compaction. This could occur because the weight is distributed over a larger surface when the whole tree is dragged. In north-central Maine, the compaction on skid trials during winter harvesting of tree lengths was found to be just over half that during summer. Winter-harvested skid trails had bulk densities (a measure of soil porosity) 8.7 percent greater than those in adjacent uncut areas (Hoeman 1977). Winter-cut, but not skidded, areas were found to have bulk densities greater than those in adjacent areas at depths of one to three inches but not at three to six inches.

During summer operations, when soil surfaces are unprotected by snow, the movement of mechanized harvesting equipment will lead to an increase in bulk density or, in other words, a decrease in the porosity of the soil. Zasada (1975), investigating clearcuts on sandy loam soils, found that 76 percent of the total area was disturbed during whole-tree skidding. Mineral soil exposure occurred on 46 percent of the areas with compaction and/or rutting to depths greater than four inches. Tree-length skidding produced these more severe effects on 38 percent of the land, with a total disturbance over 66 percent of the site. Infiltration rates on the medium to heavy disturbance classes (i.e., where compaction of the mineral soil occurred) decreased by as much as 70 and 98 percent. On loamy sandy soils, repeated log skidding resulted in a decrease of infiltration rates by 90 percent in the wheel ruts and by 65 percent on log-disturbed areas (Dickerson 1976). On sandy to clay loams, Campbell, Willis, and May (1973) found total porosity decreased by over 10 percent on secondary skidding trails when rubber-tired skidders were used; other decreases were 15 percent on primary trails and 20 percent at the log landing sites.

In a spruce-fir strip cut in Maine, Hoeman (1977) found that although bulk densities were greater at depths of three to six inches than at one to three inches on uncut areas, the relative increases after skidding and cutting were greater at the shallower depths. Average increases on skid trails were 12 percent at one to three inches and 9 percent at three to six inches. On cut areas, the shallow soils displayed increases of 5 percent and the deeper soils' bulk densities rose by only 3 percent.

The change in soil surface structure caused by compaction also depends on the type of equipment used at the operation. Equipment includes harvesters, skidders, forwarders, and chippers. Table 5 shows various representatives of these equipment types, with their weights, weight distributions, and carrying capacities. Greater stress on the soil is inflicted by rubber-tired vehicles, as they carry their weight on smaller areas than do tracked vehicles. Greater depths and magnitudes of stress were exhibited by the wheeled vehicle, resulting in greater soil compaction. The lower carrying capacity of the tracked skidders, however, requires more trips along the skid roads to transport an equal volume of wood to the landing site. Repeated skidding will cause greater compaction; however, most of the compaction occurs at the first passage (Froehlich 1978; Gill & Vanden Berg 1967).

Within the unincorporated portions of Maine, 96 percent of forestry operations use wheeled skidders, while only 4 percent use crawler tractors (MLURC 1978b). Six percent use animals or other methods for skidding (some operations employ more than one skidding technique).

Other variations in equipment will also affect stress on the soil. The use of a grapple or arch and winch will result in less contact between the ground the transported log than will the use of the winch alone. If trees are skidded butt forward using an arch, not only is site damage reduced but power reductions of up to 32 percent are possible (Conway 1976). Use of forwarders rather than skidders will eliminate all contact between transport-

TABLE 5: GROUND PRESSURE SPECIFICATIONS OF TYPICAL FORESTRY EQUIPMENT

EQUIPMENT	TYPE	WEIGHT *(lb)*	GROUND PRESSURE *(psi)*	MAXIMUM CAPACITY
John Deere 693-B Feller-Buncher	Track	49,000	8.0 (24" track)	
John Deere 743 Feller-Buncher	Wheel	36,900	9.0 (4" penetration)	
John Deere 693-B Feller-Buncher	Track	49,000	6.4 (30" track)	
International PAY 3966 Feller-Buncher	Track	37,840	6.7 (24" track)	26,400 lb.
John Deere 743 Tree Harvester	Wheel	41,400	10.7 (4" penetration)	
John Deere 350-C/6300 Bulldozer	Track	10,300	5.3 (14" track)	10,850 lb.
John Deere 450-C/6405 Bulldozer	Track	14,230	6.1 (16" track)	18,050 lb.
John Deere 550-C/6415 Bulldozer	Track	15,750	6.5 (16" track)	18,470 lb.
John Deere 740 Skidder	Wheel	26,700	6.3 (3" penetration)	49,397 lb.
John Deere 740 Grapple Skidder	Wheel	31,500	7.4 (3" penetration)	30,750 lb.
John Deere 540-B Skidder	Wheel	16,675	5.2 (3" penetration)	30,541 lb.
John Deere 540-B Grapple Skidder	Wheel	18,675	6.0 (3" penetration)	20,700 lb.
Timberjack 225D Skidder	Wheel	12,784	10.6 (front wheel 0" penetration)	20,000 lb.
" "	"	"	36.2 (rear wheel 0" penetration)	"
" "	"	"	22.8 (front wheel 6" penetration)	"
" "	"	"	9.6 (rear wheel 6" penetration)	"
Timberjack 550 Skidder	Wheel	26,308	10.5 (front wheel 0" penetration)	40,000 lb.
" "	"	"	40.2 (rear wheel 0" penetration)	"
" "	"	"	3.5 (front wheel 6" penetration)	"
" "	"	"	13.3 (rear wheel 6" penetration)	"
Timberjack 380 Grapple-Skidder	Wheel	20,500	12.6 (front wheel 0" penetration)	1.5 cord
" "	"	"	51.9 (rear wheel 0" penetration)	"
" "	"	"	3.3 (front wheel 6" penetration)	"
" "	"	"	13.8 (rear wheel 6" penetration)	"

Sources: for John Deere equipment other than skidders-John Deere 1978; for John Deere skidders-Munns 1978; for International equipment-International 1978; for ed logs and the ground. The use of chains or ballast in tires for improved traction or weight distribution, however, can also result in greater disturbance of the surface soil layers.

Soil compaction is of environmental concern for two reasons. First, as stated above, when compaction occurs, infiltration rates are reduced, sometimes drastically. Hornbeck and Reinhart (1964) found that in an area where the infiltration rate of an undisturbed forest floor was at least fifty inches per hour, the rates at compacted treadmarks on a skid road averaged three inches per hour and between treadmarks nineteen inches per hour. Therefore, soils with adequate capacity to allow the seepage of rainwater before disturbance may experience overland flow where repeated skidding or transport has compacted the surface. The ruts and roads offer paths of least resistance to the flow of this runoff and thus encourage concentrated flow, increased velocity, and, ultimately, soil erosion.

Second, compacted soil is not a suitable environment for the reestablishment of most vegetation. By promoting surface runoff, compaction may hinder soil water recharge, thus denying seedling roots of needed moisture. The decreased porosity will also reduce aeration, thereby curtailing root metabolic processes. Further, the more densely packed soil will provide a block to root growth and penetration (Gill & Vanden Berg 1967).

Soil compaction is not a permanent condition. Following compaction, the gradual reintroduction of root systems and burrowing animals and the action of alternating freeze-thaw and wetting-drying cycles will eventually result in a return to preharvest conditions. Rates of recovery will depend on the type of soil and the degree of compaction. Soils with a high frost or shrink-swell potential may recover sooner than others (Pennock et al. 1975). Table 4b shows the frost action potential of the soils in the fuelwood harvest region.

In the fuelwood harvest region, shrink-swell is of less concern. Soils subject to high shrink-swell are those with high clay content. In the region, the only soils with such texture are marine in origin and marine clays do not have the high expanding capacities associated with shrink-swell. Soils composed largely of organic material (histosols) also have high shrink-swell potential. However, in order for the process to manifest itself, the soil must be subject to alternate wetting and drying. In this region, histosols occur in inundated locations whose poor drainage precludes this cyclical change.

Rates of soil structure recovery following compaction vary depending on site characteristics, but in most cases allow for restoration well within the minimum thirty-year cutting rotation predicted for this project. In a spruce-fir forest of central Maine, soil density on clearcuts was found to approximate that of neighboring uncut control sites eight years following cutting (Czapowskyj, Rourke & Frank 1977). Differences in density appeared more likely to vary with parent material than with cutting technique alone. Other estimates of time needed for recovery range from eight years for log-disturbed areas (Dickerson 1976) to eighteen years for wheeled compaction (Hatchell & Ralston 1971), although the most severely compacted areas (e.g., where repeated skidding over wet soils occurred) may need much greater time spans to recover. In strip cuts in central Maine, Hoeman (1977) found that three years after cutting, a summer-harvested area showed continued compaction on skid trails, while cut areas showed complete recovery of pre-cut density. At winter sites, complete recovery was achieved on both cuts and skid trails after three years.

In summary, during whole-tree utilization there are two agents of compaction, the equipment used for skidding and the trees themselves. The lesser compaction generated by the lower ground pressure of tracked vehicles may be balanced by the repeated skidding necessary for those vehicles to transport an equal amount of wood to the landing site.

The skidding of whole trees will compare to tree-length skidding in compaction/disturbance potential according to the season. In the winter, snow protects the soil from disturbance by branches, and the ability of the added tree surface to distribute the weight results in lower ground pressures and less compaction with whole-tree skidding. During the other seasons, the greater spread of the trees' mass will result in greater contact with, and therefore greater disturbance of, the ground surface. As Zasada (1975) found, the increase in extent of all disturbances, as well as moderate to severe compaction and scarring, was as much as 20 percent for whole-tree skidding as opposed to tree-length skidding.

Soil Erosion

A major environmental concern is the effect of the operation of heavy equipment in the forested environment in the loss of top soil. Rates of natural soil erosion within an undisturbed forest area are very low. Average rates range from .05 to .10 tons per acre per year (Patric 1976), with values as low as .015 tons per acre per year reported at Hubbard Brook, in New Hamsphire (Likens et al. 1977). These values compare favorably with erosion from grasslands of .38 tons, croplands of 75.7 tons, and construction sites of 756.8 tons per acre per year (McElroy et al. 1975). Erosion from an undisturbed forest is estimated to be roughly one-half dissolved solids from throughout the area and one-half particulate matter, largely eroded from stream banks and beds by flowing water (Patric 1977).

Estimating Erosion

The universal soil loss equation (Wischmeier & Smith 1965), although originally developed for agricultural lands, can be used for estimating erosion under undisturbed forest cover. The equation uses experimentally or mathematically derived factors of soil types, climate (rainfall), slope and slope length, and crop cover and management for estimating soil loss at a given site.

The rainfall factor, the product of rain's kinetic energy and its maxiumum thirty-minute intensity, is approximately 70 to 100 in the fuelwood harvest region. The soil erosion indices, or K-factors, for the soil series of the harvest region are listed in Table 4a. The K-factor is a value based on the erosion from a unit plot of the particular soil 72.6 feet long with a slope of 9 percent left continuously fallow. Multiplying the K-factor by the rainfall index yields an estimate of eroded soil for the unit plot in tons per acre. Cover and management factors are used for estimating erosion under various land uses. For slope conditions varying from the standard plot, a slope factor is used as a multiplier (see Table 6).

Wischmeier (1975) has derived cover and management factors for undisturbed vegetative covers, including forests. In Maine, 90 percent of all commercial forest lands are categorized as fully stocked or overstocked (Ferguson & Kingsley 1972). Fully stocked forests are defined as those with a closed canopy (Avery 1975). Wischmeier (1975) has derived a cover and management factor (C-factor) of .001 for forests with 75 to 100 percent tree canopy, indicating that erosion from such forests is one-thousandth the value for fallow land. Table 7 shows C-factors for forests with different canopy covers.

As an example, assume a plot of well-stocked forest, on a 9 percent slope of 72.6 feet in length, with a rainfall index of 100, on Harmon soil with K= .17. Erosion would be .17 x 100 x .001 =.017 tons per acre, which matches closely figures reported at Hubbard Brook (Likens et al. 1977).

An approximate conversion from tons per acre to inches of depth can be made. Assuming a bulk density of 1.40 grams per cubic centimeter for sandy loams (Hausenbuiller 1972), an erosion rate of .04 tons per acre per year (Bormann et al. 1974) is roughly equivalent to erosion of .00025 inches per year uniformly distributed throughout the forest. This is relative to a natural soil formation rate for a spodosol of .048 inches per year (Buol, Hole & McCracken 1973).

The operation of skidders and other mechanized harvesting equipment may lead to erosion at a forest site. Unless a site is prepared for conversion to another use or cover type, the disturbance of the soil will not be universal. Zasada (1975) found that whole-tree skidding will expose the mineral soil on 46 percent of a site. However, much of this disturbed surface

TABLE 6: COMBINED SLOPE FACTORS FOR SOIL LOSS EQUATION[1]

Slope (%)	SLOPE LENGTH (feet) 10	60	100	200	500	1000	2000
0	0.04	0.07	0.08	0.10	0.13	0.16	0.20
2	0.10	0.17	0.20	0.25	0.33	0.40	0.49
5	0.17	0.41	0.54	0.76	1.20	1.69	2.40
10	0.43	1.06	1.37	1.94	3.06	4.33	6.13
12	0.57	1.40	1.80	2.55	4.04	5.71	8.07
16	0.90	2.20	2.84	4.01	6.35	8.98	12.70
20	1.29	3.16	4.08	5.77	9.12	12.90	18.24
25	1.86	4.56	5.89	8.33	13.17	18.63	26.35
30	2.52	6.16	7.95	11.25	17.79	25.15	35.57

1. Compared to standard reference of a slope 72.6 feet long with a steepness of 9% (=1.0).

Source: SCS 1977c.

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remains in isolated noncontiguous patches, thus preventing the build-up of surface runoff required for major erosion (Rice, Rothacher & Megahan 1972). In addition, exposure of the mineral soil does not necessarily lead to a decreased infiltration rate.

The universal soil loss equation can be used to estimate erosion from a harvested area (SCS 1977c; Wischmeier 1975). The methodology cover and management factor, "C", is determined based on the percent cover by trees, brush, or weeds and percent ground cover by grass or herbaceous plants and decaying duff.

Table 8 shows the calculation of several soil loss estimates for three soils of the fuelwood harvest region, a low erosion potential soil (Au Gres), an average widely distributed soil (Lyman), and a higher erosion potential soil (Hartland), under differing slope and management conditions.

These erosion rates demonstrate several points. As stated previously, erosion rates from undisturbed forests are low, often to the point of insignificance. Clearcutting has the potential effect of increasing erosion 150 times over undisturbed conditions. This is a high increase but still does not result in extremely high erosion rates, except, perhaps, on the steepest slopes. For this reason, and because mechanized harvesting equipment cannot be operated easily on steep slopes, it is recommended that the timbering not take place on slopes greater than 15 percent. On such slopes, erosion from even the most erosive soils in the region will be less than the average annual loss of 75 tons per acre on croplands. Further, with site revegetation, the annual losses should decrease yearly until preharvesting erosion rates are recovered within five or six years.

These estimates of erosion are based on losses from the sectors of a harvest site that are not mechanically prepared. The universal soil loss equation is not applicable to prepared surfaces because the roads are collecting points for surface waters, may intercept subsurface flow, and may alter unpredictably the structure of the soil (Dissmeyer 1978). Most studies of soil erosion in timber operations show that the great majority of soil loss occurs on the skid trails, landing sites, and trail roads

TABLE 8: SOIL LOSS ESTIMATIONS WITH THE UNIVERSAL SOIL LOSS EQUATION FOR THREE SOILS OF THE FUELWOOD HARVESTING REGION.

SOIL SERIES	K-FACTOR[1]	RAINFALL FACTOR[2]	SLOPE FACTOR[3]	C-FACTOR[4]	ESTIMATED LOSS *(tons/acre)*
Scenario I: Undisturbed forest					
Au Gres	.15	x 70-100	x 0.40	x .001	= .0042- .006
Lyman	.20	x 70-100	x 0.40	x .001	= .006 - .008
Hartland	.49	x 70-100	x 0.40	x .001	= .014 - .020
Au Gres	.15	x 70-100	x 8.98	x .001	= .094 - .134
Lyman	.20	x 70-100	x 8.98	x .001	= .126 - .180
Hartland	.49	x 70-100	x 8.98	x .001	= .31 - .44
Au Gres	.15	x 70-100	x 25.15	x .001	= .264 - .377
Lyman	.20	x 70-100	x 25.15	x .001	= .352 - .503
Hartland	.49	x 70-100	x 25.15	x .001	= .863 -1.23

1. *A value based on erosion from a unit plot of the particular soil 72.6 feet long with a slope of 9% left continuously fallow.*
2. *A measure of the rain's kinetic energy and its maximum 30-minute intensity.*
3. *See Table 5 for sample calculation of slope factors. The factors used here assume a constant slope length of 1,000 feet and slope steepnesses of 2%, 16%, and 30%.*
4. *See Table 6 for sample calculations of C-factors (cover and management factors). Three scenarios assume, respectively, 100% canopy, 50% canopy with 80% herbaceous and residue ground cover, and no canopy with 40% herbaceous and residue ground cover.*

Source: Wischmeier 1975.

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(see Stone 1973; Patric 1977; Swanston & Dyrness 1973). Estimates of the total land area of harvest sites that is mechanically prepared range from 11 percent (MLURC 1978b) to 15 to 20 percent (Hornbeck 1978).

Rates of erosion from these forest-road networks will vary with site conditions. Weitzman and Trimble (1955) found that on heavily used trails a maximum of 5.4 inches of soil eroded during skidding, while an additional 2.1 inches eroded in following years. Patric (1976) reported losses averaging more than 7.0 inches on a heavily traveled logging road. At another clearcut (Hornbeck & Reinhart 1964), .3 inches were removed from the roads during operation, and an additional .03 inches eroded in the following year.

Thus, assuming the situation in which 15 percent of a site is subject to erosion of 7 inches, a total volume of soil lost would be 3,811.5 cubic feet per acre. Assuming a density of 1.40 grams per cubic centimeter for sandy loams (Hausenbuiller 1972), this comes out to be 13.88 tons per acre. In actuality, much of the eroded material may be organic matter with a considerably lower density.

Because of the concentration of soil loss in the road network alone, site degradation as defined by losses in tons per acre may be misleading. These losses are restricted rather than being spread uniformly across the cut area. An estimate is thus reached of soil loss of approximately 93 tons per acre of prepared surface. Because of this distribution, the characteristics of the eroded material will be different from those expected from surface erosion across the cut area. Table 9 shows several profile descriptions of soils found in the fuelwood harvest region. The great majority of exchangeable cations are concentrated at the surface. As erosion from the road network continues, losses are primarily of parent material or less nutrient-rich soil. Thus nutrient loss, or site degradation, is not as severe as it would be if the volume loss was from throughout the cut (see Stone 1973; Rice, Rothacher & Megahan 1972).

TABLE 9: NUTRIENT CHARACTERISTICS OF SOILS IN THE FUELWOOD HARVESTING REGION

Soil Subgroup	Soil Horizon[1]	Depth[2] (cm)	Exchangeable Cations[3] (me/100g) Calcium	Magnesium	Potassium	Sodium
Typic Haplorthods	O_{22}	6- 0	13.5	1.8	1.3	0.4
	A_2	0- 3	0.6	0.5	0.9	0.7
	B_{21h}	3- 8	1.3	0.1	0.2	0.2
	B_{22ir}	8- 23	0.2	-	0.1	0.1
	B_{23ir}	23- 51	0.1	-	0.1	0.1
	B_{24}	51- 76	0.1	-	0.1	0.1
	C	76-109	0.1	-	0.1	0.1
Typic Fragiorthods	O_{22}	5- 0	3.1	1.3	1.4	0.4
	A_2	0- 13	0.1	-	0.1	0.1
	B_{21ir}	13- 20	-	-	0.1	0.1
	B_{22ir}	20- 36	-	-	0.1	0.1
	B_{23}	36- 64	-	-	0.1	-
	C_{1x}	64- 81	-	-	0.1	-
	C_{2x}	81-102	-	-	0.1	0.1
Aquic Haplorthods	H	35.5- 0	6.8	4.1	2.4	0.7
	A_2	0- 7.6	0.2	0	0.4	-
	B_{21h}	7.6- 12.7	0.1	0	0.1	-
	B_{22ir}	12.7- 20.3	0.1	0	-	-
	B_{23ir}	20.3- 43.2	0.1	0	-	-
	B_{24}	43.2- 73.7	0.1	0	-	-
	B_3	73.7- 91.4	0.1	0	-	-
	C_1, C_2	91.4-114.3	0.1	0	-	-
Typic Dystrochrepts	O_{22}	4- 0	5.9	2.2	1.1	0.2
	A_2	0- 5	0.2	0.1	0.2	-
	B_{21h}	5- 13	0.3	0.1	0.3	0.1
	B_{22ir}	13- 33	0.1	-	0.1	-
	B_{23}	33- 58	0.1	-	0.1	-
	IIC[4]	58-102	0.1	-	0.1	0.1

1. *Horizons presented in order of depth, from organic layers of the forest floor through mineral soils.*
2. *Depth measured with 0 = top of mineral soil layer.*
3. *Positively charged ions available for nutrient cycling processes.*
4. *Roman numerals indicate lithologic discontinuities.*

Sources: For 1,2,4,5 - Pilgrim & Harter 1977; for 3 - Hoyle 1973.

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These estimates of erosion are concerned primarily with sheet, rill, and gully erosion. Another form of erosion that may be accelerated by forest cutting is mass-wastage, in which a body of sloping soil becomes unstable and is displaced. The likelihood of this form of avalanching is both decreased and increased by vegetation removal (Brown & Sheu 1975). First, removal of trees reduces the rate of downslope gravitation-induced soil movement, or creep. Also, slope stability is increased by the removal of the overburden of tree weight and wind resistance loading. On the other hand, slope stability is decreased by the binding support lost by the decay of root systems, and decreased evapotranspiration may result in higher groundwater and soil water levels, which decrease stability. The first two, increasing stability, are felt immediately following cutting. The latter two become evident only after the passage of time. Root decay may take four or five years following cutting to decrease the support given to soil (Stone 1973). Although mass movement does occur in eastern forests, Flaccus (1959) found that its rate of occurrence in New Hampshire does not accelerate following forest cutting.

Erosion Prevention

As noted previously, any particular harvesting operation is capable of producing a wide range in quantity of erosion products depending on the characteristics of the particular site and, especially, on management practices employed by the operator. Methods for keeping erosion to a minimum are well-developed. Since the primary source of eroded material is the skidding/yarding/trucking network, most erosion control may be exercised on the roads. Minimizing road lengths in a forest is one way of protecting the soil. Reduction in skidroad areas may be as high as 40 percent when road-layout planning is included in preharvest preparations (Kochenderfer 1970).

Beyond this, the major means for preventing erosion from the woodland roads is to reduce the volume and velocity of the overland flow of water. This can be achieved by maintaining road gradients below 10 percent, as well as by varying the gradient to prevent build-up of runoff speed. A gradient above 3 percent, however, is recommended to prevent the ponding or accumulation of water on road surfaces. Skid roads and haul roads should not go directly up or down slopes. Further, the skidroad network should be laid out to allow trees to be skidded uphill as much as possible, to prevent the ends from digging too severely into the soil (Kochenderfer 1970). Skidding uphill also will reduce the convergence of any overland flow at one point, particularly landing sites, which otherwise concentrate erosive volume and energy.

Good drainage techniques can prevent water that has not infiltrated into the road network from creating erosion damage. Culverts, drainage dips, outsloping, and water bars all direct runoff onto the relatively undisturbed forest floor on the roadside where infiltration can occur. By eliminating the erosive agent, the threat of erosion is also effectively eliminated.

Another way to prevent erosion is to create a barrier between the rutting wheels of forestry equipment and the soil. During harvesting, this can be achieved by using gravel on the roads; after harvesting, the seeding of roads and landing yards will stabilize the exposed soil. On disturbed soils of roads, continued erosion following harvesting can be retarded by grading or providing a mulch. More complete handling of erosion prevention methodologies is readily available in the literature (see Hartung & Kress 1977; Kochenderfer 1970; MDNR 1975).

Despite the availability of this information, standard erosion control practices are not widely used in the fuelwood harvest region. Table 10 shows some findings of the Maine Land Use Regulation Commission on the use of such practices.

In conclusion, it should be stated that total extent of soil erosion from a harvesting operation will be largely a function of management practices employed. By selecting minimally sloping locations, avoiding erosive soils and erosion-conducive conditions (e.g., skidding in wet conditions), and employing water dispersal techniques, erosion need not vary greatly from preharvest norms. Specifically, whole-tree harvesting for eventual chipping should not lead to appreciably more extensive deterioration of site soils than do tree-length skidding operations.

TABLE 10: USE OF EROSION CONTROL PRACTICES IN MAINE

EROSION CONTROL TECHNIQUE	OPERATIONS USING TECHNIQUE (%)
Water turnouts in road construction	16.5
Culverts in road construction	30.9
Metal culverts	16.8
Wood culverts	20.0
Ford crossing	16.3
Wood crib bridge crossing	19.5
Other water crossing	5.4
Waterbars at close of operation	4.7
Pulled culverts at close of operation	2.0
Seeding at close of operation	0.5

Source: MLURC 1978a.

FOREST TYPES AND ECOLOGICAL SUCCESSION

Forest Types

Maine forest ecosystems exhibit gradients in species composition which form groupings or communities. Environmental factors including temperature, growing season, and precipitation also change along geographic gradients in a manner which influences the composition of the forest community. This spectrum of ecosystem types, termed an ecocline (Whittaker 1975), can be classified in a variety of ways.

The lack of a crisp delineation of communities is evidenced by the various schemes used to describe the forest areas in Maine. Westveld (1956) described three zones: the transition hardwoods-white pine-hemlock; spruce-fir-northern hardwoods; and northern hardwoods-hemlock-white pine. Ferguson and Kingsley (1972) identify four major forest types: white pine-red pine, spruce-fir, maple-beech-birch, and aspen-birch. White (1976), studying forests in northern New Hampshire just over the Maine border, describes forests dominated by balsam fir, red spruce, or sugar maple. For simplification, the fuelwood harvest area will be somewhat arbitrarily described in terms of three types: hardwood-pine, northern hardwood, and spruce-fir.

As shown in Table 11 and Figure 1, the most prevalent forest type in the proposed harvest region is hardwood-pine (Ferguson & Kingsley 1972). White pine and, to a lesser degree, red pine and a variety of hardwoods dominate this type. In northern areas, beech, birch, and maple make up the hardwood component of these forests, and red spruce and balsam fir are also found. Hickory, oak, and pitch pine are characteristic of this forest type in the more southerly portion of the harvest region (Westveld 1956; McKinnon, Hyde & Cline 1935). Hemlock, white ash, black cherry, and red maple occur commonly in all geographic regions. The large variety of species in this forest class (most hardwoods indigenous to New England have at least some representation) is somewhat atypical of northern forests. It occurs because of the transi-

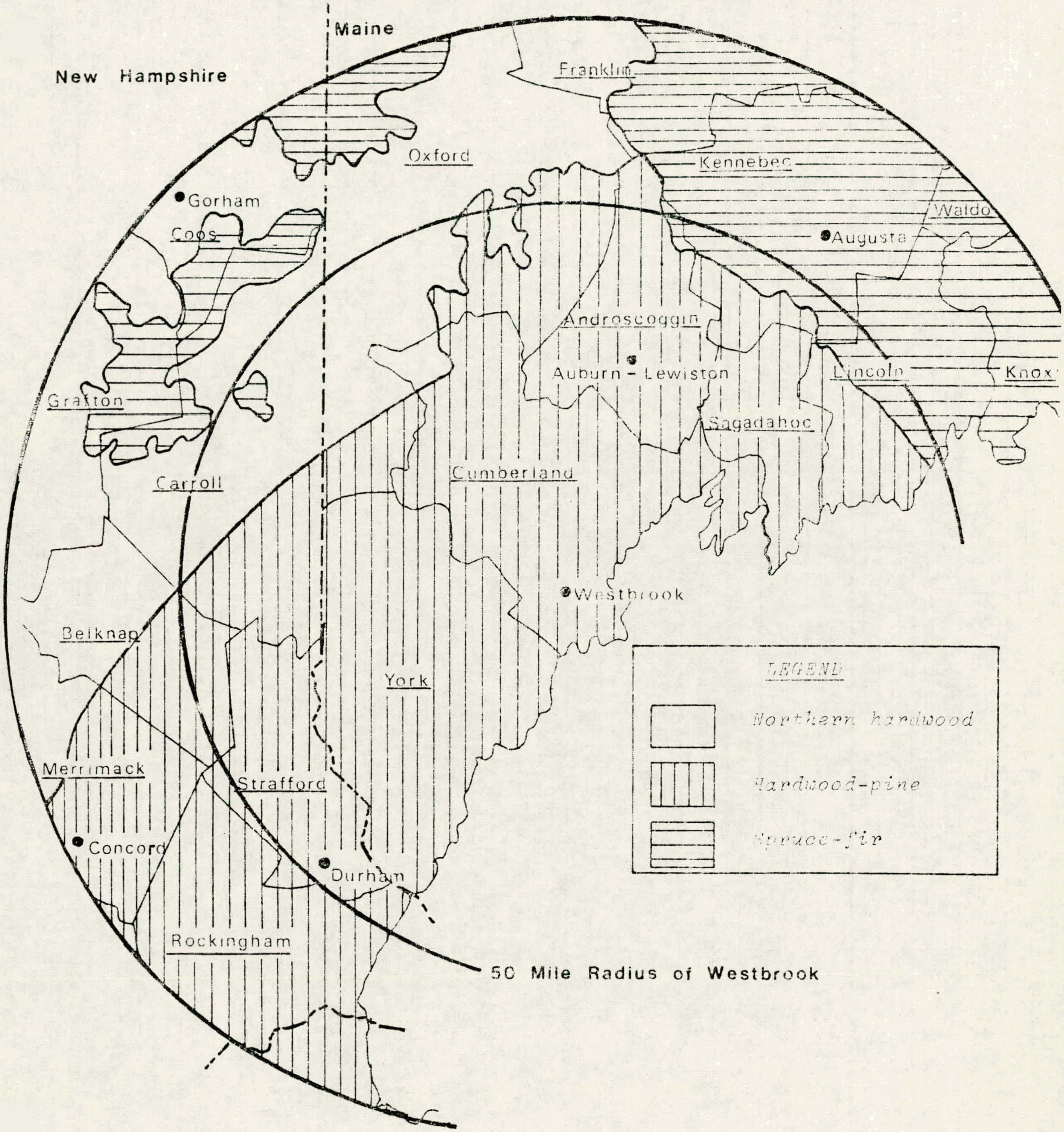
TABLE 11: PRINCIPAL TREE SPECIES OF THE THREE FOREST TYPES IN THE FUELWOOD HARVEST REGION

Species	Hardwood-Pine	Northern Hardwood	Spruce-Fir
Striped Maple		X	
Red Maple	⊠	X	X
Sugar Maple		⊠	X
Mountain Maple		X	
Yellow Birch		⊠	X
Paper Birch	X	X	X
Shagbark Hickory	X		
American Beech		⊠	X
White Ash	X	X	
Quaking Aspen	X	X	X
Bigtooth Aspen	X	X	X
Pin Cherry	X	X	X
Black Cherry	X	X	
Basswood	X		
Red Oak	⊠		
Balsam Fir		X	⊠
Black Spruce			X
Red Spruce		X	⊠
White Spruce			X
White Pine	⊠	X	
Red Pine	⊠		
Pitch Pine	X		
Hemlock	X	X	

⊠ *dominant component*

X *associated component*

FIGURE 1:FOREST TYPES IN THE FUELWOOD HARVEST REGION



Sources: Kingsley 1976: Ferguson & Kingsley 1972.

tional characteristics of the hardwood-pine forest, which lies between the boreal and deciduous types (McKinnon, Hyde & Cline 1935).

Over the past twenty to thirty years, the surveys conducted by the U.S. Forest Service have detected a steady increase in the areal extent of most of the local components of this forest type (Ferguson & Kingsley 1972; Kingsley 1976). Although redefinition of type characteristics has artificially influenced this increase, historical harvest practices and the forestation of farmland have contributed to the trend. To some extent, the pioneer species within this group, including aspen, have declined due to the reduced incidence of fires.

The northern hardwood forest is the second most common in the fuelwood harvest region. Sugar maple, yellow birch, and beech make up about 80 percent of the stand composition in this forest type. Other trees common to this category include red maple, balsam fir, and red spruce. As the hardwood forest blends into the hardwood-pine type to its south, white pine and hemlock become more abundant than the balsam fir and red spruce found increasingly intermixed to the north. White ash, black cherry, sweet birch, paper birch, northern red oak, American elm, and basswood also become more frequent in the southern portion of this type.

High demand for sugar maple and yellow birch over the past several decades is, in part, responsible for a decline in the prevalence of the northern hardwood type. The residual stands from the commonly practiced "highgrading" operations are often dominated by red maple. A growing demand for hardwood pulp may create a market for the increased quantity of red maple (Ferguson & Kingsley 1972).

Although the spruce-fir type occupies 47 percent of Maine's forest land area and 14 percent of New Hampshire's forest region, it occurs only in scattered pockets in the fuelwood harvest region, except at the northeast extremity (Ferguson & Kingsley 1972; Kingsley 1976). Red spruce and balsam fir account for about 75 percent of the composition of the spruce-fir stands. Heart-leaved paper birch, yellow birch, and red maple make up the majority of the remainder. Although the areal extent of this forest type has stayed relatively constant on a statewide basis over the past twenty to thirty years, trends within the harvest region are unknown.

Forest Succession

Like all ecosystems, the forest communities of the proposed fuelwood harvest region are characterized by continuous change. This change occurs because species of forest vegetation have differing abilities to regenerate and grow under varying environmental conditions. In other words, each plant has a characteristic "preference" for a certain range of combinations of available light, temperature, moisture, and nutrients. As these variables change during the development of the forest, their combination becomes less favorable for some species, which will decline, and more propitious for other species, which will proliferate. This process by which the composition of any ecosystem progresses from one form to another is called ecological succession. It is a process which is cyclical, and, to a degree, predictable.

Succession occurs continuously in a forest ecosystem. Usually, as one species of vegetation occupies a site to which it is suited, it alters the environment (the supply of light, temperature, moisture, and nutrients) to such a degree that the site may become more suitable for another species, which, given an available seed source, will regenerate beneath the current vegetation and eventually replace it.

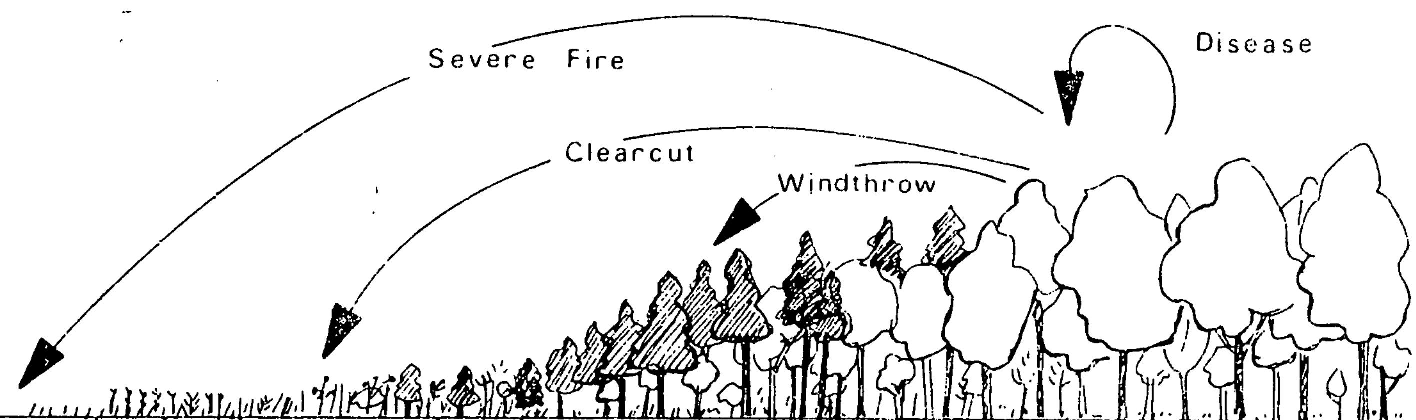
However, there are species which, under certain environmental conditions, will maintain their own preferred conditions for long periods of time and thus will succeed themselves one generation after another. These species occur at the later stages of succession and are sometimes called climax species since, at least theoretically, their ability to self-perpetuate temporarily ends the successional process until a disturbance such as fire, wind, or pest damage occurs to reinitiate it (Whittaker 1975).

When such a disturbance occurs in the forest, succession is interrupted, and, depending on the type and size of the interference, the process retrogresses to some earlier stage (see Figure 2). As a rule, the more severe and extensive the disturbance, the earlier the stage of succession that takes hold in its wake. In the harvest region, large-scale disturbances might result from extensive windfall, fire, or clearcutting. These disruptions of the successional sequence will usually initiate the formation of an even-aged stand of light-tolerant species able to inhabit hot, exposed, and relatively dry sites. The occurrence of small disturbances usually is related to localized outbreaks of tree disease or insects, windthrow, selective harvesting, or damage from ice, lightning, hail, or snow. These disturbances can create an uneven-aged forest.

Early successional species are typically shade-intolerant, fast-growing, and light-seeded. They need high light levels for optimum photosynthesis and can germinate in high temperatures. Paper birch, grey birch, pin cherry, and aspen are examples of such species, and they are often found colonizing cleared sites where the mineral soil has been exposed, such as burned-over areas or clearcuts. Late successional species, such as sugar maple, however, are able to photosynthesize at low light levels and do not germinate at higher temperatures. These species typically regenerate beneath an overstory which provides shade and thus reduces soil surface temperatures and moisture evaporation. Moderately shade-tolerant species such as yellow birch depend on a good supply of nutrients and soil moisture, but also require some exposed soil and direct sunlight to germinate.

The course of succession after a disturbance may or may not follow that which occurred prior to the disturbance, depending on the type and size of the disturbance (White 1976; Davis 1966; Marks 1975; Forcier 1975). The succession of forest species after land clearing depends largely on the use to which the cleared land was put before its abandonment. Forest development on old pastureland, for instance, differs from that on old cropland. In virtually all cases in the fuelwood harvest region, however, succession processes are classified as secondary, indicating that the

FIGURE 2:GENERAL SUCCESSIONAL PATTERN IN A HARDWOOD-PINE FOREST, SHOWING POSSIBLE EFFECTS OF DISTURBANCES



Age in Years		1	2	3 - 20	25 - 100	150+
Community-Type	Bare Field	Grass-land		Grass-Shrub	Pine Forest with Hardwood Understory	Hardwood Forest Climax

Source: Redrawn from Odum 1971.

site in question has supported vegetation before. Freshly exposed sand and bedrock outcrops represent primary successional sites which will develop vegetative cover more slowly (Odum 1971).

Because the tree species present in the fuelwood harvest region are differentially adapted to the environmental conditions of the region, the specific patterns of succession in each of the forest types are different. Further variation can be expected in response to site-specific variation in similar environmental parameters. The following discussion briefly describes the successional processes in the forest types of the region.

Hardwood/pine

Adandoned fields and pastureland in the fuelwood harvest region commonly develop dense, even-aged stands of white pine with a scattering of hardwoods. Little undergrowth or ground cover develops until the canopy of the stand rises. Then, the availability of more light and growing space generally fosters the establishment of a hardwood understory capable of claiming the site if the white pine is removed.

Because white pine has only an intermediate level of shade tolerance, it can survive in the understory but does not generally grow into the canopy of healthy hardwoods (see Figure 3). Only a continuing series of minor disturbances and mortality creates openings which can be claimed by white pine in the understory.

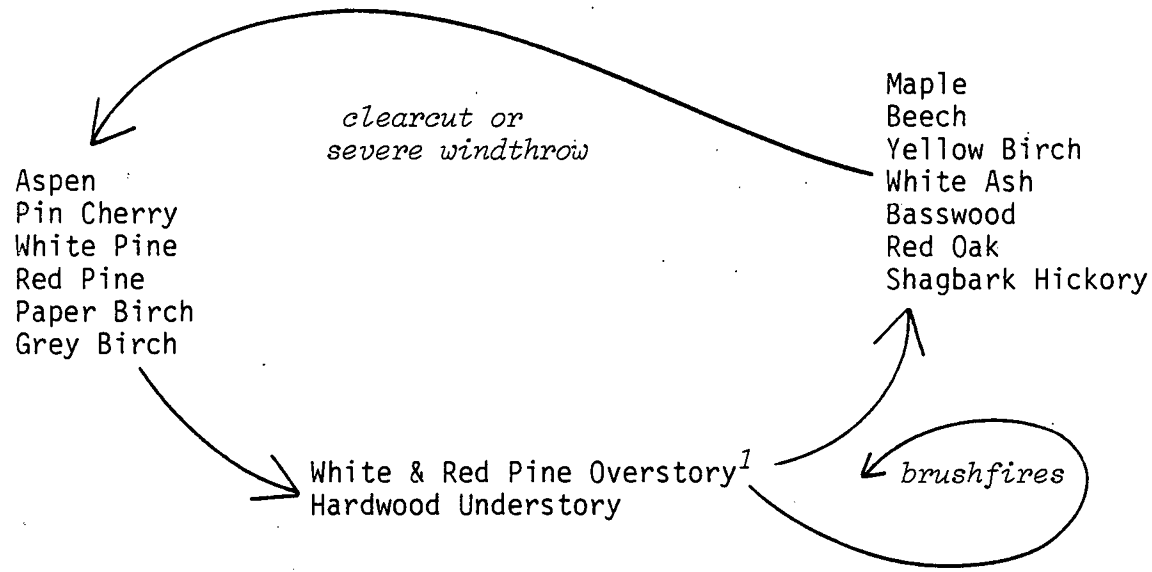
Severe disturbances on these sites which destroy a substantial portion of the forest floor's organic material and expose mineral soil will encourage the regeneration of the light-seeded pioneer species, including grey birch, pin cherry, and aspen, and, in a good seed year, white pine (McKinnon, Hyde & Cline 1935).

Because this forest type covers a transitional zone between northern hardwoods and central hardwoods, the specific hardwood species present in the successional communities will vary throughout the range of this type. In the northern end of this type, birch, maples and beech may be found in some abundance while oaks and hickories become increasingly common to the south.

Northern Hardwood

A variety of hardwood pioneer species are capable of rapidly

FIGURE 3: REPRESENTATIVE SUCCESSIONAL DYNAMICS IN A PINE-HARDWOOD FOREST



1. Overstory: the upper canopy of trees.

colonizing abandoned cropland. Aspen and pin cherry are particularly successful in early successional stages (Marks 1974, 1975). Rapid growth characteristics, wide dispersion of seeds, and the ability to grow on severely disturbed sites allow these species to compete effectively with white pine and hemlock. While pin cherry may not constitute a long-term component of northern hardwood stands, its seed is generally present and viable in the forest floor for many years (Marks 1974, 1975).

The three dominant tree species in the northern hardwood type, sugar maple, yellow birch and beech, ultimately coexist on many sites. By means of an interesting microsuccessional process, these species are able to maintain their importance in the forest stand for long periods of time if no severe disturbances occur (Forcier 1975). Following a small disturbance which opens a patch of forest floor (see Figure 4), yellow birch, a species of intermediate shade tolerance, is the first colonizer. Sugar maple, a highly shade-tolerant species, establishes a slow-growing understory which generally outlives the birch and becomes part of the canopy. Beech follows a pattern similar to the sugar maple. However, few maple or birch seedlings are established under a beech overstory. As the forest ages, beech slowly increases its importance in the stand, subject only to periodic minor disturbances such as windthrow or disease, which reinitiate the successional process.

<u>Spruce-fir</u>

In some situations, white and red spruce (Westveld 1956; Davis 1966) and pin cherry (White 1976) are early colonizers of severely disturbed sites (see Figure 5). Various birch species, white pine, maple, and aspen may also play a role in the early successional stages of this type (Daubenmire 1978; Bormann et al. 1970). Balsam fir and increasing amounts of red spruce are soon established in the stand and assume dominance in the canopy. A twenty- to forty-year old spruce-fir forest is generally very dense with little understory or groundcover. The aging stand remains even-aged but becomes thinner, allowing bryophytes,

FIGURE 4: REPRESENTATIVE SUCCESSIONAL DYNAMICS IN A NORTHERN HARDWOOD FOREST

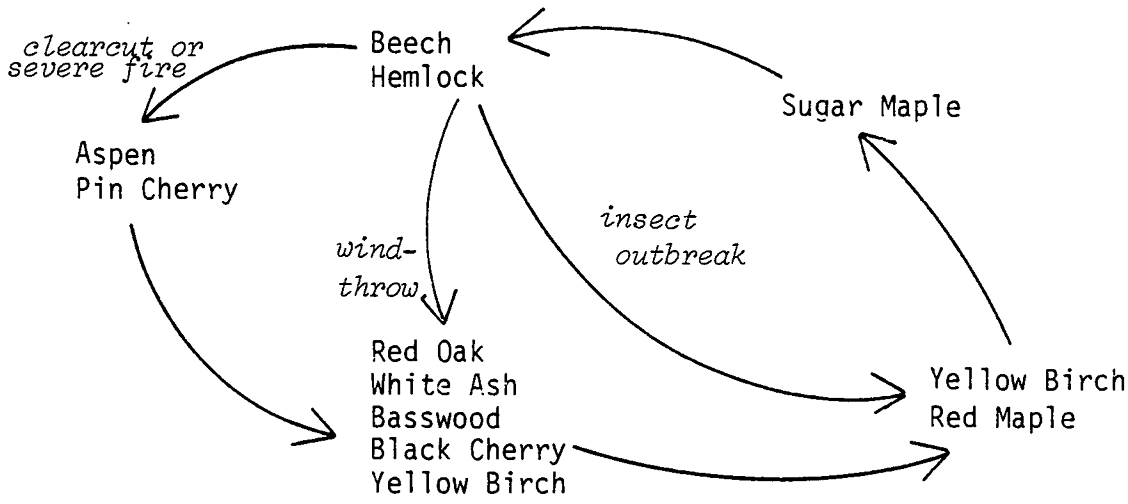
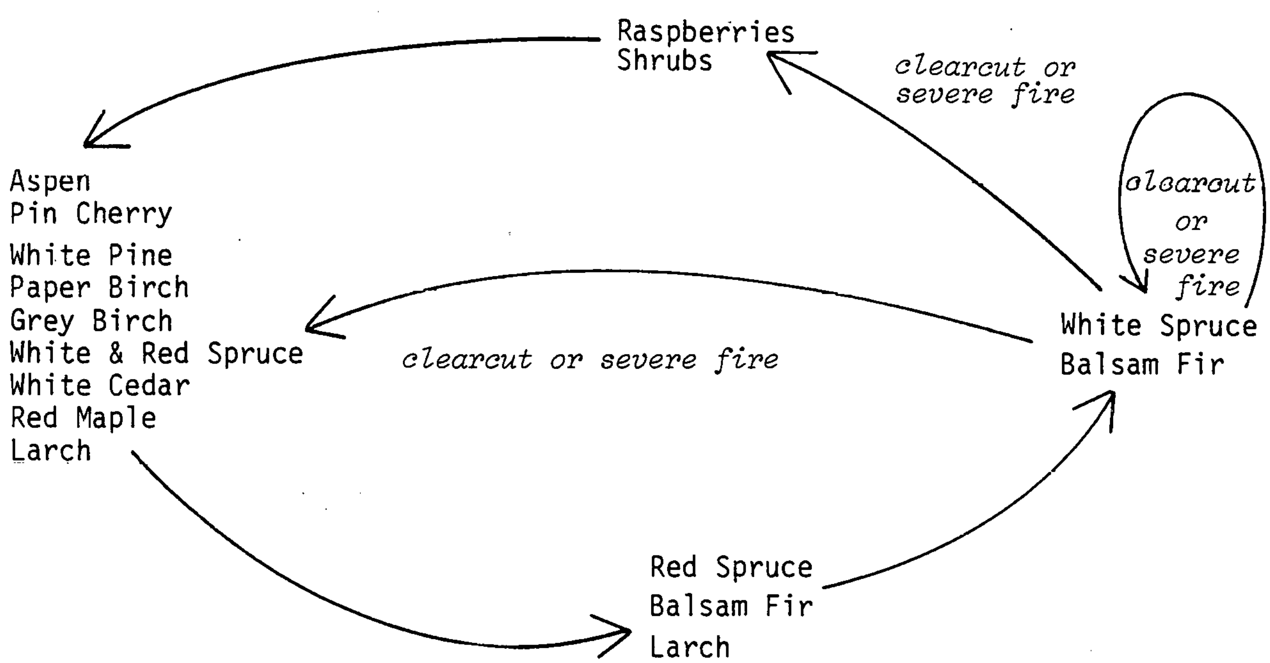


FIGURE 5: REPRESENTATIVE SUCCESSIONAL DYNAMICS IN A SPRUCE FIR FOREST



lichen, herbs, and tree seedlings to be established. Blowdowns and overstory mortality will result in an increase of balsam fir and groundcover (Davis 1966). Natural reproduction under a mature spruce-fir forest includes balsam fir and red spruce in greatest numbers with some representation of paper birch, yellow birch, and red maple (White 1976). Many of these seedlings initially suffer high mortality and only the shade-tolerant species survive for long periods in the understory. Species of intermediate shade-tolerance, such as yellow birch and red maple, may be able to colonize small openings in the forest.

Impacts of Harvesting on Forest Regeneration and Succession

Fuelwood harvest operations will alter successional trends in the forest ecosystem. While similar disturbances are currently widespread throughout the harvest region, the creation of a fuelwood market is likely to encourage the use of mechanized, whole-tree chipping equipment and more numerous harvest operations. Many of the variables which affect the successional processes are dependent on choices made by forest landowners and the harvest practices employed by the loggers. The attitudes and management objectives of the numerous landowners in the fuelwood harvest region will influence their choice of harvest method. The economic pressures on harvest operators will affect the choice and method of harvest technology and method of harvest. These pressures will also influence the quality of planning and execution of harvests which shape the resulting environmental impacts. While landowner attitudes can be expected to vary considerably in their influence of harvest methods, the economic considerations influencing harvest operators clearly will favor early utilization of the most accessible, productive forest stands. So long as fuelwood harvest operations remain commercially marginal, only the most cost-effective harvest methods will be employed. This effect will favor the use of intensive, mechanized operations, often including clearcutting.

The intensity of harvest operations determines the environmental parameters which, in turn, control the regeneration opportunities for new members of the forest community. Available moisture, light, and temperature are critical elements of the microclimate to which different species are differentially adapted, as discussed earlier. Harvest operations will affect the species composition and quantity of available seed sources. Harvesting can also affect the structure and exposure of the soil itself (Smith 1962).

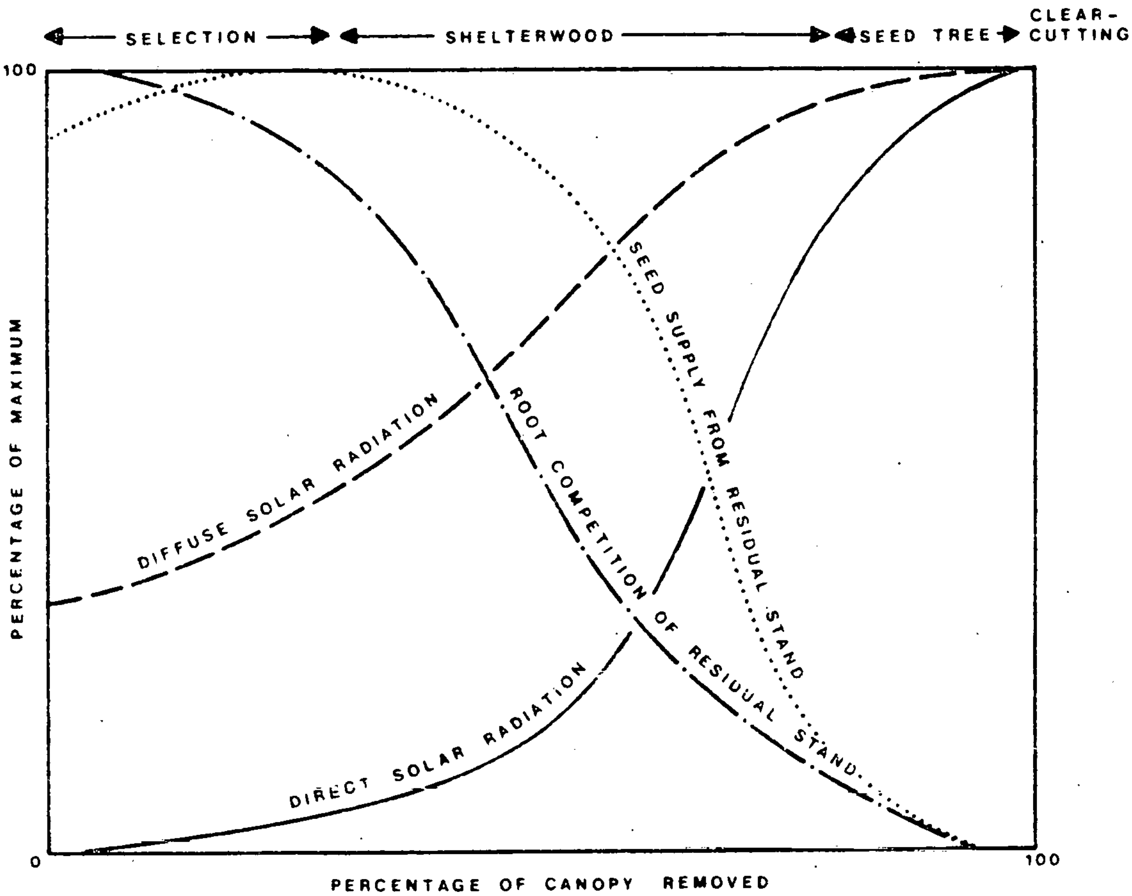
While selection cutting may only slightly alter the conditions of the existing stand, seed tree or clearcutting methods will substantially alter the growing conditions for the new stand. Available light and temperature at the forest floor increase in proportion to the intensity of cutting. While the removal of vegetation reduces competition for, and canopy interception of, available moisture, the seed bed on the forest floor may actually become dryer due to the evaporative effects of increased light and temperature (Smith 1962).

The changes in light, temperature, and moisture can affect the rates of bacterial and fungal decomposition in the upper soil horizons and can result in significant decreases in the organic content of the soil (Likens et al. 1970). This change further affects the moisture regime of the seed bed and limits initial regeneration to species adapted to low moisture availability and temperature extremes.

Natural sources of seed are also changed by harvest practices. The relatively small removals associated with selection cuttings leave behind many potential seed trees which support regeneration of a stand similar to the original. Increased removals diminish readily available seed sources and favor species on adjacent sites with light, easily dispersed seed. The relationship between these factors is generally depicted in Figure 6.

Finally, the equipment used in harvesting can disturb the forest floor, exposing mineral soil as a seed bed. Some species require this condition for regeneration and hence are favored

FIGURE 6: THE EFFECTS OF INITIAL CUTTINGS ON VARIOUS METHODS OF REPRODUCTION



Note: Root competition is for both moisture and nutrients. Seed bed temperature is directly proportional to direct solar radiation.

Source: Smith 1962.

over species that prefer undisturbed, organic forest litter as a seed bed.

As the removal of vegetation from a stand increases, the early successional or pioneer species are favored, as discussed earlier. This tendency is neither inherently beneficial nor detrimental to the terrestrial ecosystems of the area. The effects of harvest operations can, to some extent, be viewed as analogous to natural disruptions including windthrow, disease outbreaks, and fire.

In addition to the parameters discussed above, a variety of site-specific variables can also influence the composition of the regenerating stand. Many of these are related to the care with which the harvest was planned and conducted. For example, most sites will have some amount of advanced regeneration under the stand to be harvested. These young trees can substantially influence the make-up of the new stand if they are not destroyed during harvest operations. While intensive harvests conducted during summer months will typically inflict substantial damage on advanced regeneration, the snow cover of the winter season can provide significant protection.

In many cases the availability of advanced regeneration is a critical determinant in the rapid regeneration of the site (Smith 1962). This is particularly true in the case of sites that are difficult to regenerate from seed, due, for example, to extreme variation in the temperature of the seed bed or to moisture deficiencies. Other factors, including soil type, exposure, browsing pressure, and the degree of soil disturbance, will influence the composition of the regenerating stand.

The extent to which fuelwood harvesting affects the successional trends of the harvest region depends on the application of specific harvest systems and the unique characteristics of the harvested site. Past harvest operations in the fuelwood harvest region have generally encouraged a haphazard mix of early and mid-successional communities. These stands typically include aspen, pin cherry, white pine, and grey birch. Other associated species may also be found, depending on the characteristics of the specific site in question.

The fuelwood market will create a demand for many species and allow the utilization of low-grade material which was not previously merchantable. The relatively low value of this material favors the use of the most efficient harvest methods. From the loggers' point of view the use of mechanized, whole-tree equipment in intensive harvests provides the greatest return. Sites which can be made available to this harvest system are likely to be utilized before sites with more stringent harvesting constraints such as would be encountered in selective cuttings and thinning operations. This situation will result in conditions generally more favorable for the regeneration of early successional even-aged communities. Other, higher value forest products, including pulpwood and sawtimber, however, are also drawn from the fuelwood harvest region. Whole-tree harvesting allows landowners to thin, selectively harvest, or weed low-grade material from their stands to favor existing, higher quality trees. In this case, the proposed action may contribute to the maintenance of later successional communities.

Except in shoreland areas or other special use areas where state laws regulate harvest intensity, landowners will choose the harvest systems to be employed. While these choices can be influenced by regulatory mechanisms and landowner education/assistance programs, the existing situation allows the landowner a wide latitude in his harvest decisions.

Rare and Endangered Species

Only one plant in Maine, the Furbish lousewort, has been federally designated as an endangered species (USFWS 1978). Several other plant species have been proposed for this listing, and a wide variety of additional species are recognized by botanists to be rare or unusual in Maine. The Furbish lousewort occurs along wooded river or stream banks and in low, shaded swampy areas. To date, the lousewort has been found only along the banks of the St. John River. Research indicates that the range of the lousewort is restricted to this area (Nickerson

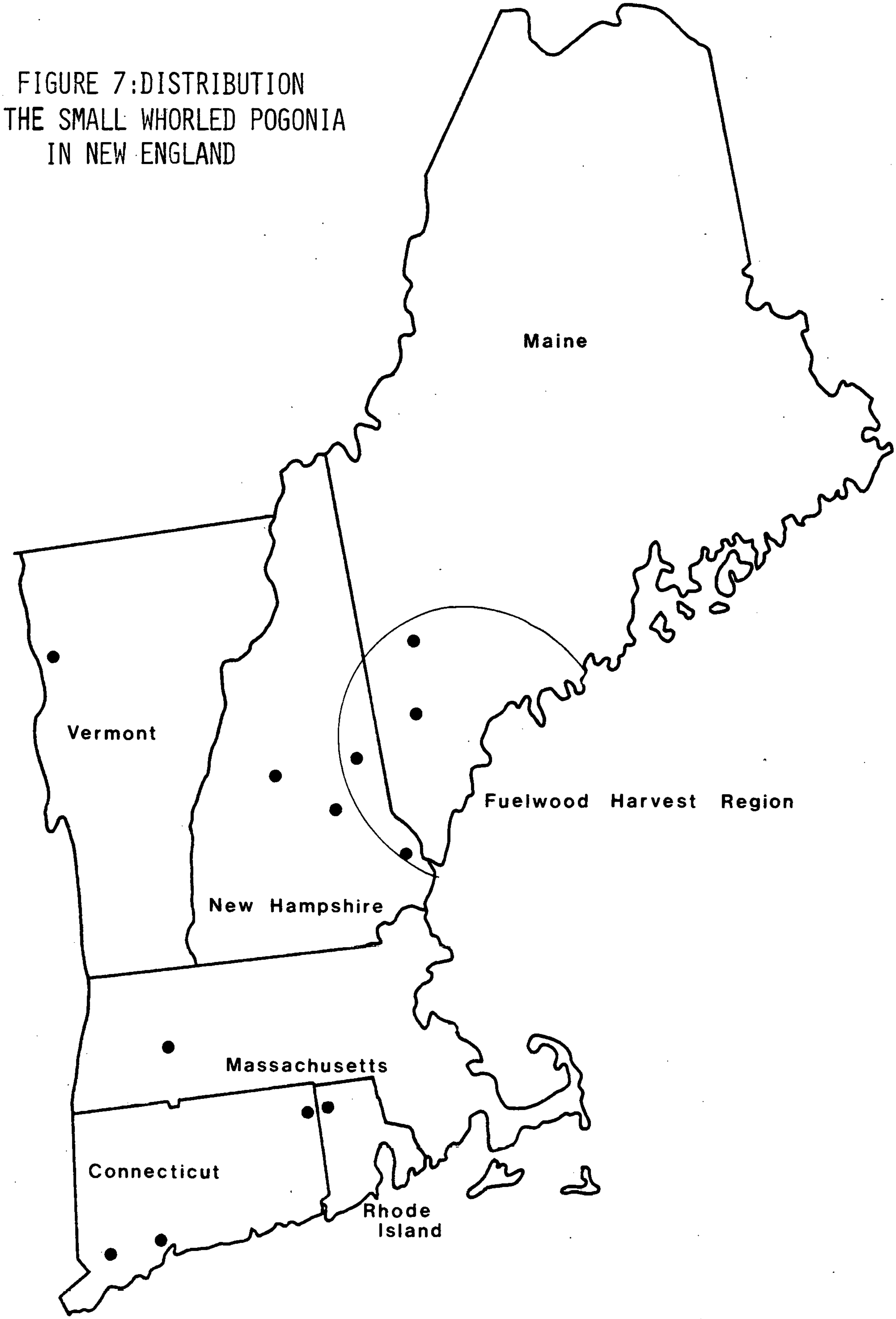
1979). Harvest operations in the proposed fuelwood region would not affect this plant.

Of the species proposed for endangered listing, only one, the small whorled pogonia, could be affected by harvests in the fuelwood region. This orchid grows in dry or moist leaf mould under mixed hardwood forests (Eastman 1977). The small whorled pogonia is very sparsely distributed throughout the North Atlantic states east of the Mississippi River, with the majority of sites occurring in the New York-New England area (Eastman 1977). Of the four sites that have been reported in the fuelwood harvest region, one in North Sebago, Maine, has been proposed for inclusion in the Maine Register of Critical Areas (see Figure 7).

If the small whorled pogonia is listed as an endangered species by the U.S. Fish and Wildlife Service, the Department of Energy will undertake the necessary planning and management efforts to assure the protection of this species. The ongoing research conducted by the U.S. Fish and Wildlife Service in cooperation with the state of Maine would provide the information needed for such an effort (Dyer 1979). The remaining plant species proposed for listing are either not found in the area of the proposed action or are found in habitats which would not be subject to harvesting, such as alpine gardens and marine estuaries (Dyer 1979).

The Maine Critical Areas Program has tenatively identified 233 additional species of plants as significant in Maine. Of this group, 44 percent have been found at only one site and approximately two-thirds of these species are on the periphery of their range (Adamus & Clough 1976).

FIGURE 7:DISTRIBUTION
OF THE SMALL WHORLED POGONIA
IN NEW ENGLAND



Source: Eastman 1977.

NUTRIENT CYCLES IN THE FOREST ECOSYSTEM

The nutrient budget of any ecosystem plays a critical role in its development. Inputs to the budget consist of nutrients in precipitation, the contribution from chemical weathering of the parent material, and gaseous uptake from the atmosphere. Outputs are nutrients that leave the forest in ground water or surface flow, and gaseous losses to the atmosphere (Likens et al. 1977). Within the forest ecosystem of the harvest region, the organic matter in the soil is the largest reservoir of nutrients and a variety of internal mechanisms govern the flow of these elements.

Some seventeen nutrient elements have been shown to be essential for plant growth. Oxygen, carbon and hydrogen are used in the greatest quantities and are derived from the atmosphere and the water of the soil. These elements are generally not limiting factors in plant growth except in cases of drought, disease and excessive moisture (Brady 1974). A second group of elements utilized in significant quantities are referred to as macronutrients. These include nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur (Brady 1974). This group is drawn principally from the soil, although indirect atmospheric inputs are important for nitrogen and sulfur. Finally, a group of elements known as micronutrients are used in very small, but important, amounts. These include iron, manganese, copper, zinc, boron, molybenum, chlorine, and cobalt (Brady 1974).

The following discussion is principally concerned with the mechanisms and processes affecting the flux of the macronutrients described above.

Inputs to the Forest Nutrient Cycle

The relative significance of the nutrient input mechanisms at the Hubbard Brook Experimental Forest in New Hampshire is illustrated by Table 12. It is evident that weathering is the predominant input process, although precipitation, gaseous fixation, and aerosol impaction are particularly important for nitrogen and

TABLE 12: RELATIVE SIGNIFICANCE OF NUTRIENT INPUT MECHANISMS FOR WATERSHED ECOSYSTEMS OF THE HUBBARD BROOK EXPERIMENTAL FOREST

	Nutrient (%)					
Source	Calcium	Potassium	Magnesium	Sodium	Nitrogen	Sulfur
Precipitation input	9	11	15	22	31	65
Net gas or aerosol input	-	-	-	-	69	31
Weathering release	91	89	85	78	-	4

Source: Likens et al. 1977

TABLE 13: SUMMARY OF ANNUAL METEOROLOGIC INPUTS FOR UNDISTURBED FOREST ECOSYSTEMS AT HUBBARD BROOK

Element	Meteorologic Input[1] *(kg/ha-year)*
Calcium	2.2
Magnesium	0.6
Potassium	0.9
Nitrogen	20.7(14.2)
Sulfur	18.8(6.1)
Hydrogen	0.96
Phosphorus	0.036

1. *Note: values in parentheses represent estimates of net gaseous fixation in the case of nitrogen and aerosol impaction and gaseous uptake in the case of sulfur.*

Source: adapted from Likens et al.1977.

sulfur. Weathering rates of phosphorus were not determined at Hubbard Brook.

Precipitation

Nutrients exist in the atmosphere in gaseous, particulate, and aerosol forms which can be removed in solution by precipitation. Many of the readily available nutrients utilized annually in the forest ecosystem are introduced in this manner. Measurements undertaken at the Hubbard Brook Experimental Forest, representative of the fuelwood harvest region, are presented in Table 13.

While the solubility of atmospheric gases in precipitation is well documented, the origin of nutrients in dust and aerosol forms is not well understood (Likens et al. 1977). Although the quantity of most nutrients introduced to the ecosystem via precipitation is small in relation to other input mechanisms, these nutrients are largely in forms immediately available for plant uptake. As is discussed later, precipitation inputs of nitrogen and sulfur represent relatively large portions of the total input of these nutrients. Precipitation also introduces large quantities of hydrogen ions into the forest ecosystem, which affect internal cycling processes and which may affect the rate of weathering (Likens et al. 1977; Hornbeck, Likens & Eaton 1977).

Gaseous Fixation and Aerosol Impaction

Another route by which some nutrients, notably nitrogen and sulfur, are known to enter the forest ecosystem is that of gaseous fixation by microbes and aerosol impaction on stem and leaf surfaces. Todd, Waide and Cornaby (1974) and Likens et al. (1977) concluded from observations in North Carolina and New Hampshire forests, respectively, that gaseous transformations probably represent major inputs and outputs of sulfur and appear to dominate the gains of nitrogen. Roskoski (1977) found that the principal site for microbial nitrogen fixation in northern hardwood ecosystems was the dead woody litter on the forest floor. Quantitative estimates of the amounts of elements in gaseous or aerosol forms which are introduced annually at the New Hampshire site are shown in Table 13. In some situations, nutrients introduced as aerosols can constitute the principal source of available nutrients in the ecosystem (Art et al. 1974).

Weathering

Certain nutrients in the forest ecosystem are principally derived from the chemical weathering of bedrock and mineral soil. While this process is generally considered to be quite slow in comparison with other input and internal cycling mechanisms, weathering, over the long term, provides stable and significant inputs of calcium, potassium, phosphorus, and magnesium (Likens et al. 1977). Estimates of weathering inputs have been derived for the Hubbard Brook watersheds, which may be assumed to be generally typical of the forest ecosystems in the fuelwood harvest region, and are presented in Table 14. Variation in the underlying bedrock may affect these rates to a limited extent from site to site.

Internal Cycling Mechanisms

The internal cycles of nutrients in the forest ecosystem provide the means by which the system mobilizes, uses, and conserves its resources. The undisturbed ecosystem may be accumulating some nutrients over time and losing others due to variation in the efficiency of these cycles.

The quality of nutrients cycled through the system by these mechanisms is generally much larger than the amount made available by the input mechanisms discussed previously, as shown in Table 15. This indicates that the internal cycles play a critical role in the short-term stability of the forest ecosystem.

Uptake and Storage

A vital role in the conservation of nutrients, particularly potassium, nitrogen, and calcium, within an ecosystem is played by the forest vegetation and microorganisms (Likens et al. 1977). Many of the nutrients extracted from the soil and atmosphere to support metabolic processes are subsequently incorporated into the physical structure of these forest organisms (Likens et al. 1977). This storage serves as a buffer against large depletions of the

TABLE 14: DIFFERENTIAL WEATHERING AT HUBBARD BROOK

Element	Abundance in Bedrock (%)	Annual Release from Bedrock by Weathering (kg/ha)
Calcium as Ca^{2+}	1.4	21.1
Magnesium as Mg^{2+}	1.1	3.5
Potassium as K^{+}	2.9	7.1

Source: Adapted from Likens et al. 1977.

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system's nutrient "capital." Table 15 indicates the magnitude of this mechanism in relation to other internal and external nutrient fluxes. The importance of this mechanism is well illustrated by the role of pin cherry in early successional stands studied by Marks and Bormann (1972). Dense stands of these trees develop rapidly after severe disruptions and establish fully closed canopies. The incorporation of nutrients, especially nitrogen and calcium, is also rapid. Marks and Bormann (1972) estimated that the annual uptake of nitrogen by this species is much as 50 percent greater than that experienced in older, undisturbed sites in the same area.

Return from Live Biomass Storage

A variety of mechanisms remove nutrients from the pool of living biomass and return them to the forest floor in both available and unavailable forms. Dead biomass in the form of fallen branches, twigs, leaves, and root litter represents the principal return mechanism for several of the major nutrients including calcium, magnesium, nitrogen, and phosphorus (Likens et al. 1977). Although the nutrients bound in this material are not immediately available for plant uptake, they are released slowly over time as the result of decompositional processes. This dynamic extends the cushioning effect of nutrient storage in biomass in the case of disruptions of the forest ecosystem.

A second recycling mechanism involves the ability of precipitation to remove nutrients from the leaves and stems of the forest stand and bring them to the soil. This process, similar to the leaching of nutrients from the soil, is partially controlled by the acidity of the precipitation. The recent trends of increasing acidity in the precipitation of the northeastern United States (Likens et al. 1976) may have caused a parallel increase in the quantities of nutrients leached from the forest canopy. Research at Hubbard Brook indicates that hydrogen ion exchange between rainfall and the above-ground vegetation accounted for as much as 27 percent of the leaching occurring in the forest canopy (Eaton, Likens & Bormann 1973). Seasonal peaks in the acidity of precipitation occur during the summer, thus heightening the importance of this leaching process in the internal nutrient cycles (Hornbeck, Likens & Eaton 1977). The difficulty of accurately distinguishing precipitation and aerosol impaction nutrient inputs from nutrients actually leached from the cellular structure of leaves and stems renders precise delineation of the mechanism difficult (Likens et al. 1977). Despite this difficulty, the transfer of nutrients from the forest canopy to the forest floor has been found to be particularly important for potassium and sulfur (Likens et al. 1977). This importance is increased since the nutrients transported in this manner are generally in a form readily available for plant uptake (Hornbeck, Likens & Eaton 1977).

The final mechanism in this group is that of root exudation, which has been found to constitute an important pathway for the return of nutrients in biomass storage to the forest soils (Smith 1976). In several cases, the quantitites of nutrients cycled in this manner have been found to be greater than those returned to the soil in root litter (Smith 1976). Similar to the throughflow and stemflow of nutrients from the forest canopy, root exudates are generally in a form available for plant uptake.

Decomposition and Mineralization

Dead biomass is subject to a series of complex transformations which convert nutrients bound in the biomass to inorganic forms available for plant uptake and subject to leaching losses. The initial steps in this process are undertaken by many different soil microbes capable of using the complex, organic nutrient forms. These organisms emit metabolic wastes which contain inorganic nutrient forms. Some of these nutrients can be immediately utilized by plants while others are subject to further biochemical reactions such as nitrification. Specific nutrients follow different pathways in this process although the overall process is generally a transformation of complex, unavailable forms to simplified, available forms (Brady 1974). This process is subject to the influence of many environmental parameters including the availability of light, moisture, and oxygen and the ambient temperature. The relative concentrations of plant nutrients have also been found to interactively influence the rate at which nutrients are made available (Brady 1974).

While these processes are important for each of the major nutrients in the forest ecosystem, mineralization is a particularly important mechanism for nitrogen and calcium (Likens et al. 1977).

Outputs from the Forest Nutrient Cycles

Nutrients lost from the undisturbed forest ecosystem can be leached from the organic or mineral portions of the soil by percolating water, volatilized into the atmosphere, or transported in eroding soil.

Leaching

The chemical forms of nutrients which are available for plant uptake are also easily leached from the soil if not utilized or in some way bound. The leaching process is driven by hydrogen ions which are introduced in precipitation or produced in biological reactions in the soil. These ions displace nutrients bound to humus and clay particles in the soil and remove them, in solution, from the ecosystem.

The rates of leaching are determined by the concentration of hydrogen ions in precipitation, the rates of ion-producing biological processes (decomposition), and the quantity of precipitation flowing through the system (Likens et al. 1977). These factors affect specific nutrients in different ways. At the Hubbard Brook Experimental Watersheds, concentrations of magnesium, sulfate, chloride, and calcium were relatively constant despite wide variations in streamflow. On the other hand, aluminum, hydrogen ion, dissolved organic carbon, nitrate, and potassium concentrations increased with increased stream discharages (Likens et al. 1977). The same study found that biological activity, specifically plant growth, was an important factor in determining the leaching rate of nitrate and potassium.

Measurement of the leaching process is hindered by the inclusion of eroded particulate material in stream flow. In the undisturbed forest ecosystem, this represents a relatively minor output for most nutrients. Table 16 presents the annual output of dissolved and particulate substances from one of the Hubbard Brook watersheds.

Volatilization

The export of nutrients from the forest ecosystem due to the process of volatilization may be significant under some conditions. This mechanism generally operates under anaerobic conditions when microbial activity in the soil utilizes the oxygen in sulfate and nitrate compounds for metabolic needs. By-products of this process include gaseous compounds of sulfur and nitrogen (Alexander 1961). Quantitative estimates of these losses from the types of forest ecosystems found in the fuelwood harvest region have not been made (Likens et al. 1977; Todd, Waide & Cornaby 1974). At the Coweeta Experimental Forest in North Carolina environmental conditions were observed to be favorable for a potential volatilized loss of nitrogen to the atmosphere in amounts two hundred times that measured in streamflow (Todd, Waide & Cornaby 1974), an indication of the possible significance of gaseous output.

Erosion

Losses of soil and nutrients by erosion are minimal in the undisturbed forest, as mentioned earlier in the discussion of soil characteristics. Measurement of the impact of erosion on nutrient budgets has not been attempted since it has to date proved impossible to distinguish completelynutrients carried into streamwater by leaching from those transported in soil particles (Pierce et al. 1972). Thus, estimates of leaching losses in this report include erosion losses. Table 16 presents measurements of nutrient losses in particulate material carried by stream flow. It is evident that this mechanism is most important for phosphorus although it is not possible to completely determine the importance of erosional nutrient losses at this time.

Impacts of Harvesting on Nutrient Cycles

The biogeochemical processes of forest nutrient cycles are

TABLE 16: AVERAGE ANNUAL OUTPUT OF DISSOLVED AND PARTICULATE SUBSTANCES FROM WATERSHED 6 OF THE HUBBARD BROOK FOREST[1]

Element	Total Output *(kg/ha)*	Particulate		Dissolved	
		Output *(kg/ha)*	Percent of Element Total	Output *(kg/ha)*	Percent of Element Total
Calcium	13.91	0.21	40.9	13.7	98.3
Magnesium	3.34	0.19	5.7	3.15	94.3
Nitrogen	4.01	0.11	2.7	3.90	97.3
Phosphorus	0.019	0.012	63.2	0.007	36.8
Potassium	2.40	0.52	21.7	1.88	78.3
Sulfur	17.63	0.03	0.2	17.6	99.8

1 *Particulate matter losses during 1966-1967 to 1969-1970 are modified from Bormann et al. (1974). Dissolved substance losses are averages during the period 1963-1974.*

Source: Adapted from Likens et al. 1977.

all interrupted to some degree by timber harvesting, which results in a loss of nutrients from the system. In the thin, acidic, podzolized soils of the fuelwood harvest region, these post-harvest losses can be particularly high. The precise effects of harvest disruptions and nutrient losses on forest productivity, however, are unknown. As discussed later, these impacts on both the total quantities and flows of nutrients must be considered in order to develop an accurate understanding of the implications of various forest management practices for long-term productivity.

Nutrient Input Mechanisms

Precipitation. The temporary absence of vegetation on a harvested site will not significantly affect the amount of nutrients brought into the system by precipitation, although the manner in which these nutrients actually enter local cycles may be altered (Likens et al. 1977). The amount of precipitation intercepted by the forest canopy will vary depending on the extent of the harvest. This change may alter the subsequent pathways of the precipitation inputs to the ecosystem as described below. Removal of interception surfaces also increases the acidity of precipitation reaching the forest floor due to the diminished buffering effect provided by the forest canopy (Eaton, Likens & Bormann 1973). The potential effects of the resulting increases in the acidity of the soil regime are discussed below under "Weathering" and "Leaching."

Aerosol impaction. Some nutrients suspended in the air are deposited on leaf and stem surfaces and later washed to the forest floor by rainfall. The impact of harvesting on this "aerosol impaction" input mechanism is correlated with the quantity of leaf surface area removed and is not directly related to the harvest technology. In some forested ecosystems, this may constitute one of the primary input mechanisms for many of the critical nutrients (Art et al. 1974). In the northern hardwood forest this mechanism is important in the ecosystem's sulfur cycle (Likens et al. 1977).

Weathering. The impacts of harvest operations on the rate of chemical weathering of bedrock are difficult to assess. The removal of substantial quantities of vegetation reduces the buffering effect of the forest canopy on precipitation as discussed above. The additional hydrogen ions added to the soil water solution could accelerate the rate of chemical weathering in the system. Likens et al. (1977) found that acidity resulting from biological processes, primarily decomposition, also plays an important role in the weathering process. There is evidence that intensive harvest operations initially accelerate decomposition (Likens et al. 1970). There is also evidence that postharvest weathering rates increase by as much as a factor of three although the reasons for this increase are not understood (Likens et al. 1978). If there were a significant increase in weathering, an increase in the rate of leaching output would probably occur until the regenerating vegetation resumed uptake of the surplus of nutrients.

Gaseous fixation. Nitrogen and sulfur fixation processes can be affected by harvest practices. Small woody litter supplies the only major substrate for nitrogen-fixing bacteria (Roskoski 1977). The amount of this material remaining after whole-tree harvests would be substantially less than that abandoned during conventional harvests. Since gaseous fixation constitutes one of the major nitrogen inputs (Likens et al. 1977), this characteristic of whole-tree harvesting could pose a constraint to the recovery of the post-harvest ecosystem.

Vegetation can use sulfur dioxide directly from the atmosphere (Likens et al. 1977). The impact of harvesting on this mechanism, therefore, is directly proportional to the reduction of living foliage surfaces and is not dependent on the technology employed in the harvest. Since the dominant input of sulfur to the ecosystem is delivered in precipitation (Likens et al. 1977), the impact of harvests on the input of sulfur should be moderate and, in any case, limited to the period of initial revegetation.

Internal Cycling Mechanisms

The mechanisms by which an ecosystem transfers nutrients among its various components can be affected by harvest operations. In some cases these processes, when undisturbed, may be very efficient and permit net gains to the system over time; in other cases, net losses may occur. To the extent that harvests disrupt the internal nutrient flux, the stability of the ecosystem may be impaired.

Uptake and storage. Many of the nutrients extracted from the soil and atmosphere to support metabolic processes are subsequently incorporated into the physical structure of the forest organisms (Likens et al. 1977). This storage serves as a buffer against large depletions of the system's nutrient "capital." Disruption of this uptake and storage mechanism during harvesting leaves the site open to a variety of physical and biological forces that may deplete the stock of available nutrients. The importance of this impact is defined by the quantity of vegetation removed in harvesting and the length of the subsequent regeneration period (Bormann et al. 1974; Marks & Bormann 1972). The ability of regeneration to control nutrient losses, however, is not complete (Likens et al. 1978).

Return from live biomass storage. As precipitation enters the forest ecosystem, it is partially intercepted by the canopy vegetation as discussed earlier. Material is leached and washed from the leaves and stems and is returned to the forest floor (Likens et al. 1977). The acidity of water reaching the soil can be substantially buffered by this process (Eaton, Likens & Bormann 1973). Removal of these interception surfaces by harvesting diminishes the amount of nutrients carried to the forest floor and may also increase the acidity of the soil. The significance of this change is unclear, although the increases in acidity could increase the leaching of nutrients from the soil. The effects of removing these nutrient inputs to the forest floor is discussed later.

Harvests, particularly whole-tree harvests, interrupt the flow of litter to the forest floor. This material, which serves as a nutrient reservoir and soil conditioner, also is the principal site of nitrogen fixation in northern hardwood ecosystems (Roskoski 1977). While the effect of conventional clearcutting on nitrogen fixation has not been examined, whole-tree harvests, which remove most harvest slash, could significantly reduce this input (Likens et al. 1978). The effect of harvest operations on root exudation of nutrients could not be ascertained.

Decomposition and mineralization. The decomposition mechanisms in the forest ecosystem transform dead biomass (litterfall) and its constituent nutrients into a variety of organic and inorganic forms. As discussed earlier, these forms either become available for further plant uptake and leaching processes, or remain bound in organic soil components unavailable to either of these processes. Harvest operations can increase the rate of soil decomposition by increasing the light and moisture that reach the forest floor (Bormann et al. 1974). This causes increased mineralization of nutrients, which can then be leached from the system (Likens et al. 1978). The resulting decrease in the organic content of the soil will alter physical properties of the soil such as bulk density and moisture-holding capacity (Smith 1962), which may affect future regeneration. Whole-tree removals also eliminate slash, which may shade the forest floor and consequently may accelerate decomposition more abruptly than traditional harvest systems.

Nutrient Output Mechanisms

Biomass removal. Because trees absorb and store nutrients, their removal from a site results in nutrient loss in proportion to the quantity of trees harvested and removed from the site. Nutrients in biomass represent an important portion of the ecosystem's total nutrient pool and are especially significant in comparison with reserves of available nutrients as evidenced in Table 17. As discussed earlier, the storage of nutrients in biomass provides an important cushion for the system in the event of disturbances.

Because nutrients in living and dead biomass are continually cycled through the internal nutrient fluxes of the ecosystem and, in fact, serve as the primary short-term supply in many cases, this pool assumes an importance out of proportion with its share of the total nutrient reservoir. The point of removal from the ecosystem (i.e., biomass storage) is equally as important as the

TABLE 17: A COMPARISON OF BOLE-LENGTH AND WHOLE-TREE HARVEST REMOVALS OF VARIOUS NUTRIENTS

	Study	Nitrogen	Calcium	Phosphorus	Potassium	Magnesium
Stem harvest (kg/ha)	#1	43;79	98;150	12;11	25;47	8;14
	#2	94	225	16	99	24
	#3	-	-	-	-	-
	#4	104	-	14	80	-
	#5	165	234	-	-	-
Whole-tree harvest (kg/ha)	#1	167;387	276;413	42;52	84;159	27;36
	#2	208	389	30	176	42
	#3	193	428	27	130	-
	#4	254	-	30	165	-
	#5	386	437	-	-	-
Stem harvest as % of available soil reserves	#1	197;558	221;128	39;205	19;73	16;47
	#2	-	1	22	16	2
	#3	-	-	-	-	-
	#4	4	-	3	12	-
	#5	66-660	23-47	-	-	-
Stem harvest as % of total soil reserves	#1	3;4	4;15	2;5	<1;<1	<1;1
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	2-3	1-4	-	-	-
Whole-tree harvest as % of available soil reserves	#1	771;2724	621;353	139;940	63;246	55;126
	#2	-	1	42	29	4
	#3	715	66	24	100	-
	#4	12	-	7	25	-
	#5	154-1544	44-87	-	-	-
Whole-tree harvest as % of total soil reserves	#1	11;19	12;40	6;24	<1;1	1;3
	#2	-	-	-	-	-
	#3	-	-	-	-	-
	#4	-	-	-	-	-
	#5	5-6	2-7	-	-	-

Numbers in table represent studies listed below:

#1. All-aged stand of balsam fir and red spruce, Quebec, Canada (Weetman & Webber 1972). Figures represent data from two different forest stands.

#2. Six "young" natural stands and two plantations, eastern cottonwood (White 1974).

#3. 40-year old aspen mixed hardwood, Wisconsin (Boyle, Phillips & Ek 1973).

#4. 16-year old loblolly pine plantation, North Carolina (Jorgensen, Wells & Metz 1975).

#5. 90-year old northern hardwoods, central N.H. (Hornbeck 1977).

total quantity of nutrients removed when considering the severity of potential impacts (Pierce et al. 1972).

The degree to which harvested trees are utilized is an extremely significant factor in biomass removals of nutrients because some portion of trees are much richer in nutrients than others (Likens & Bormann 1970; Whittaker et al. 1974). Conventional harvest removes only the bole portions of trees, which contain a high percentage of the tree's biomass, as indicated by Table 18, but a low percentage of its nutrient content. Conversely, the branches and especially twigs and leaves have very high nutrient-to-biomass ratios. These nutrient-rich elements are left to decay on the harvest site with conventional methods, but are largely removed with whole-tree harvesting. (Note that "whole-tree" here refers to the above-ground portions of trees only.)

The impacts of biomass removal extend beyond the nutrient losses due to physical export. Despite its low nutrient concentration woody biomass has a highly significant role in the recovery of a harvested site. Wood litter is the most important, if not virtually the only, site for nitrogen fixation in northern forest types (Roskoski 1977; Likens et al. 1978). Furthermore, slash acts as a nutrient reserve during the period of heavy nutrient losses following harvest (Aber 1978). As illustrated in Table 18 the gain in biomass yield accomplished by whole-tree utilization can be as high as 50 percent of conventional harvests; however, these gains are accompanied by significant increases in nutrient removals. In southeastern conifer harvests, each percentage increase in yield gained by intensified utilization of conifers was accompanied by a 3 percent increase in nutrient removal (Switzer, Nelson & Hinesley 1978). Traditional harvesting of loblolly pine yielded two-thirds of the biomass realized from a whole-tree operation but removed only one-third the nutrient content of the stand (Jorgensen, Wells & Metz 1975).

Jorgensen, Wells and Metz (1975) found that short-rotation harvests would increase nutrient removals because of the high nutrient accumulations in ground stands. The high ratio of

TABLE 18: NUTRIENT CONTENT OF BOLES AND WHOLE TREES RELATIVE TO BIOMASS

Species	Portion Removed	Nutrient Removed *(kg/ha)* Calcium	Magnesium	Potassium	Phosphorus	Sulfur	Nitrogen	Biomass
Sugar Maple	Whole tree	3.82	0.267	1.57	0.33	0.33	3.59	100
	Bole	2.65	0.136	0.61	0.06	0.12	1.12	67.1
	Slash	1.17	0.131	0.96	0.27	0.21	2.47	32.9
Yellow Birch	Whole tree	1.63	0.193	0.53	0.15	0.14	2.15	100
	Bole	0.61	0.024	0.09	0.02	0.03	0.41	48.1
	Slash	1.02	0.169	0.44	0.13	0.11	1.74	51.9
Beech	Whole tree	5.28	0.230	1.06	0.22	0.30	3.85	100
	Bole	3.86	0.090	0.41	0.07	0.12	1.11	60.2
	Slash	1.42	0.140	0.65	0.15	0.18	2.74	39.8

Sources: Likens & Bormann 1970 and Whittaker et al. 1974.

branches to stemwood in young stands would accentuate this effect in whole-tree harvest operations (Switzer & Nelson 1973).

In addition to these effects, the repeated exposure of the forest floor caused by short rotations could aggravate leaching losses as discussed below. The removal of all above-ground biomass in a whole-tree harvest halts the flow of nutrients bound in biomass to the soil layer and removes the harvest residues generally abandoned by conventional operations.

This material (slash) slowly decomposes amd serves to cushion the effect of increased leached nutrient losses which have been observed after harvest operations (Aber, Botkin & Melillo 1978; Hornbeck 1977).

Slash also serves several additional functions. Decomposing slash maintains the organic content of the soil which, in turn, increases moisture-holding capacity and sustains microbial activity (Smith 1962). Slash can provide protection from erosion processes by reducing the impact of precipitation. By providing some shelter from the increases in temperature at the forest floor which normally follow intensive harvest operations, slash may ameliorate the effects of increased soil decomposition. This action may reduce the availablity of nutrients for leaching when there is little vegetative uptake occurring. Slash may also provide some shelter from climatic extremes for regenerating vegetation.

Leaching. The principal mechanism removing nutrients from an undisturbed forest ecosystem is the leaching effect of precipitation (Likens et al. 1977). Depending on the ability of the soil to hold nutrients in either organic or inorganic forms and the ability of the existing vegetation to take up nutrients, precipitation can carry nutrients, in solution, out of the system. As described earlier, this process is also affected by the acidity of the system and the amount of precipitation (Likens & Bormann 1970; Hornbeck, Likens & Eaton 1977).

Increases in leaching losses following harvest have been observed at a number of locations in the northeastern United States. At seven clearcut sites in New Hampshire average streamwater concentrations of nitrogen and calcium increased by factors of as high as twenty and five, respectively, two years after clearcutting (Pierce et al. 1972). In all cases, the concentration of nitrate and other major nutrients was greater in streams draining clearcut areas. This pronounced phenomenon appears to be characteristic of the podsolized soils of the Northeast (Pierce et al. 1972; Johnson & Swank 1973; Aubertin & Patric 1972; Likens et al. 1978).

To explain the increased leaching observed in the Northeast, several factors can be examined. These include:

- increased decomposition rates in the forest floor,
- removal of the uptake and storage sink provided by growing vegetation,
- increased precipitation reaching the forest floor, and
- increased acidity of the soil regime.

Leaching is intensified by the acceleration of litter decomposition and mineralization which occurs when the temperature and moisture content of the forest floor is increased by removal of the forest cover. These environmental changes stimulate the activity of the decomposer organisms, as does the increased availability of nutrients resulting from the cessation of vegetative uptake.

There is little, if any, available data on comparable leaching losses between whole-tree and stem-only harvests, although there are various physical effects of slash which could inhibit leaching as discussed earlier. Whole-tree harvested sites will leave bare soils under the full heat of the sun, thus promoting decomposition, while slash could offer some protection.

The elimination of vegetation from a site results in a surplus of available nutrients which are easily carried from the system by ground and surface flows (Marks & Bormann 1972). The quantity of nutrients accumulated in biomass during a year represents only a fraction of the total quantity required for the development of tissues during that year (Switzer, Nelson & Hinesley 1978). A substantial fraction of the nutrient uptake each year is returned to the forest floor via the mechanisms discussed earlier. This internal cycle is an important factor in the conservation of limited nutrients.

A third result of harvesting is the temporary reduction of evapotranspiration. On an undisturbed site, only 87 percent of the incident precipitation actually reaches the forest floor. The remainder is absorbed or evaporated directly from the forest canopy (Leonard 1961). In addition, the reduced vegetative uptake of precipitation increases the quantity of water moving through the forest ecosystem, which has been found to remove at least proportionally large quantities of nutrients (Pierce et al. 1970).

Forest vegetation has been found to have a buffering effect on the pH of precipitation (Eaton, Likens & Bormann 1973). Removal of this buffering mechanism effectively increases the acidity of precipitation reaching the forest floor. The increased rate of decomposition and nitrification in the forest floor following harvest (Likens et al. 1970) also increases the acidity of the soil regime (Frink & Voight 1976). Likens et al. (1970) found that when the forest canopy of an undisturbed site was removed, the pH of stream water decreased from 5.1 to 4.3.

While the precise role of increased soil acidity in leaching losses has not been determined in the context of forest harvest disruptions, increased acidity may facilitate the leaching loss of nutrients from the forest ecosystem.

Volatilization. As described earlier, certain nutrients can be lost from the forest ecosystem as gaseous byproducts of microbial activity. Research at Hubbard Brook was unable to account for losses of nitrogen from the forest floor following clearcutting. It has been suggested that volatilization may be responsible for these unaccounted losses (Likens et al. 1978). Since the specific microbial activity responsible for this often occurs under anaerobic conditions (Brady 1974), harvest in poorly drained areas, for example, may create the anaerobic conditions favorable to volatilization.

Erosion. Although eroded material does not generally constitute a major nutrient output mechanism, harvest operations have the potential to greatly increase the significance of this process in the forest ecosystem. Much of the erosion resulting from harvesting is caused by physical disturbance of the soil on roads and yarding areas. The severity of this occurrence is extremely dependent on the quality of harvest management, as is discussed earlier in this appendix. Some portion of the harvest-related erosion, however, is related to the system's loss of biotic control over erosional processes. Harvesting disrupts a variety of processes, some already discussed, which exert an element of erosion control. For example, harvesting increases the quantity of water reaching the forest floor and reduces the protective abilities of the forest canopy and litter layers. The increased decomposition rates and reduction of litterfall following harvests results in a lower organic content in the soil and a related reduction in moisture storage capacity (Bormann et al. 1974). Harvests have been found to increase the loss of soil particles in streamflow significantly in comparison with undisturbed sites (Bormann et al. 1974).

Impacts on Specific Macronutrients

The impacts of fuelwood harvest operations on six of the primary nutrients are discussed below. A complete understanding of the mechanisms of each impact demands substantial reference to the preceding text.

Nitrogen. Nitrogen is used by plants in relatively large quantities as the ammonium ion and amino acids which are the building blocks of proteins. In northeastern forests, this element is often limiting, and the impacts of timber harvesting on the nitrogen cycle are of great concern (Bormann, Likens & Melillo 1977; Aber, Botkin & Melillo 1979). The validity of this concern is difficult to establish due to extreme complexity of the various components and fluxes of the nitrogen cycle.

Inputs of nitrogen to the forest come principally from precipitation and gaseous fixation by microorganisms (Likens et al. 1977). Concentrations of nitrogen in precipitation vary with geographical location, but are estimated at an average annual input of four to ten kilograms per hectare per year (Wollum &

Davey 1975). Precipitational inputs of 6.5 kilograms per hectare per year have been measured at Hubbard Brook (Likens et al. 1977). This input represents 32 percent of the annual nitrogen input at Hubbard Brook. The remaining nitrogen inputs are derived from fixation mechanisms (Bormann, Likens & Melillo 1977). Nitrogen fixation at the Coweeta, North Carolina, experimental forest has been calculated to be 75 percent of the nitrogen input (Todd, Waide & Cornaby 1974). Weathering does not provide nitrogen in significant quantities (Bormann, Likens & Melillo 1977).

Once in the system, nitrogen is efficiently cycled, with large reserves building in the soil of an undisturbed site and in the forest stand itself. Generally, total nitrogen decreases with increasing soil depth (Wollum & Davey 1975). Of the total nitrogen in ecosystem, 5 percent exists in forms readily available to plants; the remainder exists mostly as organic nitrogen compounds (Bormann, Likens & Melillo 1977).

Organic nitrogen in biomass deposited on the forest floor is converted to inorganic, more available, forms including ammonium, nitrite, and nitrate. Bacteria dominate decompositional processes in alkaline and neutral environments, fungi are dominant in acidic areas, and anaerobic bacteria are important when oxygen is lacking. Soil moisture, pH, and temperature all influence decomposition rates with optimum conditions at 50 to 75 percent of the water-holding capacity of the soil, neutral pH, and temperatures of between 40° and 60° centigrade (Alexander 1961).

Nitrogen can also be immobilized by soil microrganisms since it is an essential nutrient required in large quantities by most life forms. Some nitrogen is also immobilized abiotically by clays and organic material in the soil.

In the undisturbed forest, nitrogen leaves the system through hydrologic export (leaching and erosion) and volatilization. Hydrologic loss in undisturbed systems is not as significant for nitrogen as it is for other nutrients. Nitrogen is efficiently transferred within the system with only 2.5 percent lost annually to hydrologic export (Henderson & Harris 1975). Because nitrogen is readily translocated from dying leaves and needles, because it has a rapid turnover in the forest floor, and because decomposer needs are high, losses through hydrologic export are minimized (Gosz, Likens & Bormann 1976). There is a distinct seasonal pattern to nitrate and ammonia concentrations in streamwater, which correspond to microbial activity affecting the availability of these compounds (Likens et al. 1977).

Gaseous losses of nitrogen resulting from denitrification have not been quantified, but are thought to be minor in undisturbed northern hardwood ecosystems (Bormann, Likens & Melillo 1977). Nitrogen can be volatilized by undergoing a chemical change to nitrous oxide and gaseous nitrogen by anaerobic microbes. Environmental conditions most suitable for volatilization loss include a lack of oxygen, soil at about 60 percent moisture capacity, soil pH greater than 5.5, and temperature below 65°F. Deleterious effects of this denitrification process are found in some lowland forests, principally in wet soil (Wilde 1958).

Timber harvesting can affect the nitrogen budget and cycle in several significant ways. Harvests temporarily remove the uptake and storage mechanism provided by vegetation, thus breaking the tight internal cycles of the undisturbed system. The removal of biomass constitutes a physical removal of nitrogen and, in the case of whole-tree harvests, removes woody litter which forms the primary sites for nitrogen fixation (Roskoski 1977). Harvesting also increases the moisture content and temperature of the forest floor, and accelerates decomposition.

The relationship of plant uptake to nitrogen availability is illustrated by the fact that a large flux of inorganic nitrogen out of the forest ecosystem occurs after clearcutting. This occurs in part because the plants which usually provide a nutrient sink have been removed. The rapid regeneration of vegetation on the harvested site can mitigate post-harvest losses (Likens et al. 1970). It is pertinent to note that stands of pin cherry, one of the early successional species which proliferate following forest disturbance, have been found to take up nearly 50 percent more nitrogen than mature stands (Marks & Bormann 1972). Such species "hoard" nitrogen when it is most available and thereby will mitigate leaching losses.

Some authors (Richardson & Lund 1974; Likens, Bormann & Johnson 1969) theorize that the cessation of vegetative uptake and the subsequent availability of ammonium from decomposition is the mechanism of general nutrient leaching loss. When the ammonium is transformed into nitrates, a large number of hydrogen ions are released that in turn intensify cation exchange with soil colloids. Thus, both nitrates and cations are leached and lost.

In a typical forest ecosystem nutrient concentrations are particularly high in the annual compartments of the tree (foliage, flowers, fruit). Nitrogen accounts for 1.65, 0.42, and 0.17 percent of organic dry weight of the foliage, branch, and bole compartments, respectively (Henderson & Harris 1975). Table 18, presented earlier, contains further support of this distribution. This information indicates that conventional bole-length harvesting techniques do not, in general, result in a significant removal of nitrogen with harvested biomass. General agreement does exist, however, that two to three times the quantity of nitrogen is removed by whole-tree harvests in comparison to conventional operations (see Tables 17 and 18). The relationship between quantities of nitrogen removed in harvested material and the amounts of nitrogen remaining on the site in bound and available forms appears to vary from site to site (see Table 17). This variation may be the result of changes in soil fertility at study sites or may reflect differences in research methods (White 1974).

While comparisons of the nutrient reservoirs in the forest soils and the nutrient losses due to biomass removal provide useful insights into the impacts of harvesting, the full significance of harvest impacts can only be understood in the dynamic context of nutrient fluxes between different components of the forest ecosystem (Aber, Botkin & Melillo 1978; Boyle 1976; Jorgensen, Wells & Metz 1975). The processes which drive these flows also represent, to a large extent, the recuperative mechanisms of the system. For example, while the role of nitrogen fixation in the recovery of the post-harvest ecosystem is not known, whole-tree harvests would remove the principal site of nitrogen-fixing bacteria thus far identified in northern hardwood forests (Roskoski 1977).

As discussed earlier, the decomposition of organic material containing nitrogen and the subsequent nitrification of the decomposition products is an extremely important mechanism in the conservation of nitrogen in the forest ecosystem (Bormann, Likens & Melillo 1977). Harvest operations, particularly those involving clearcutting, can accelerate these processes at a time when other conservation mechanisms such as vegetative uptake and storage are not functioning. To the extent that the forest floor is exposed to high levels of light, temperature, and moisture, the decompositional and nitrifying processes speed up, and release substantial quantities of available nitrogen in the soil (Likens et al. 1970). Until the new stand is established, this nitrogen is leached from the system in runoff (Pierce et al. 1972). The effects of harvests on denitrification processes may be significant under certain site conditions (Likens et al. 1978).

It is evident that harvest operations, particularly whole-tree harvests, have a substantial potential to affect the nitrogen cycle of the forest ecosystem. The direction of these changes, however, and the recuperative abilities of the ecosystem remain subject to considerable uncertainty. The discussion of the long-term productivity of the forest resource later in this appendix will serve to illustrate the scope of these uncertainties.

Phosphorus. Phosphorus behaves similarly to, and is closely associated with, nitrogen. It is second to nitrogen in importance to plants (Gosz, Likens & Bormann 1973), in which it is a constituent of the cell nucleus, is important in cell division, and is vital in development of meristematic tissues (Wilde 1958). There is also a critical relationship between phosphorus and nitrogen whereby phosphorus affects the availability and uptake of nitrogen (Wilde 1958; Gosz, Likens & Bormann 1973). Unlike nitrogen whose principal reserve is the atmosphere, the storehouse of phosphorus is the lithosphere (Epstein 1972). Phosphorus exists largely in sparingly soluble compounds with calcium, iron, aluminum, and magnesium (Wilde 1958; Bergston & Kilmer 1973). Little phosphorous enters the ecosystem through precipitation (Gosz, Likens & Bormann 1973).

Plants depend on their phosphorus nutrition from two inorganic phosphate ions in solution, $H_2PO_4^-$ and HPO_4^{--} (Bergston & Kilmer 1973) and phosphorus pentoxide, P_2O_5 (Wilde 1978). About half of the phosphorus in plants remains in the inorganic state and the rest is converted to organic compounds within the plant. Plant mortality, therefore, results in a return of organic and inorganic phosphorus to the soil (Bergston & Kilmer 1973). Phosphorus is partially resorbed before leaf senescence so that phosphorus is conserved in a manner similar to nitrogen.

Like nitrogen, phosphorus is efficiently cycled within the system (Gosz, Likens & Bormann 1976). Unlike nitrogen, however, phosphorus is more evenly distributed between aboveground biomass, belowground biomass (roots) and the forest floor. Available forms of phosphorus are also highly soluble in water. This would suggest that if the tight cycling of this nitrient in the forest ecosystem were disrupted, severe leaching losses could occur in addition to the phosphorus removed in harvested biomass. On clearcut or other disturbed areas where erosion, increased runoff and accelerated decomposition occur, the ecosystem may experience greater losses of phosphorus.

Significant quantities of phosphorus are lost due to biomass removal. At two sites studied by Weetman and Webber (1972), between 1.5 and 9 times the exchange soil reserves of phosphorous were removed with whole-tree harvesting versus .37 to 2 times for bole-length cutting. Research summarized in Table 17 shows that whole-tree harvesting losses of phosphorous will be two to five times as great as those for stem-only harvesting.

Phosphorus losses were found to be modest compared to total soil reserves, although whole-tree harvesting will remove more than the equivalent phosphorus available in the soil (Weetman & Webber 1972). Because weathering and mineralization play a large role in phosphorus input, soil reserves may be replenished quickly enough to offset the depletion effects of harvesting. On other sites, however, whole-tree harvests resulted in phosphorus losses of twenty to thirty-eight kilograms per hectare, representing a large portion of the available phosphorus (White 1974). From these results, White (1974) concludes the phosphorous could become limiting after a few rotations. In spite of the apparent conflict between these research results, it may be conservatively concluded that increased decomposition rates and delayed revegetation of the site would aggravate the severity of the situation.

Calcium. Calcium is included in general cell metabolism (Wollum & Davey 1975) and is highly concentrated in plant roots and root hairs (Wilde 1958). High calcium concentrations tend to raise the pH of a system, especially when soils are derived from limestone which is rich in calcium carbonate (Epstein 1972).

Inputs of calcium to northeastern ecosystems come largely from the weathering process (Likens et al. 1977). Leaching of calcium from the forest canopy, root exudates, and mineralization in the forest soils, however, provide the majority of the calcium annually available for uptake.

Calcium exists in highly insoluble forms in plant material (Curlin 1970) and is relatively immobile in plant tissue (Gosz, Likens & Bormann 1972; Nelson, Switzer & Smith 1976). Because calcium is not resorbed out of senescing leaves (Gauch 1972), there is an accumulation of calcium up until abscission. Thus leaf litter has high concentrations of calcium relative to other nutrients. Of the annual uptake loss of calcium, 87 percent is returned to the forest floor by various internal cycles (Likens et al. 1977). Because calcium is not readily leached out of decomposing litter (Gosz, Likens & Bormann 1973), the undisturbed system remains highly efficient in its use of calcium (Likens et al. 1977).

Calcium depletion following whole-tree harvests has been found to be a potential problem (Weetman & Webber 1972; Boyle, Phillips & Ek 1973). Hornbeck (1977) found that on a New Hampshire site, harvesting will not remove as much calcium as there is available in the soil, but that subsequent leaching losses significantly reduce the pool of available calcium nutrients. Replenishment of the available calcium reserves may be a potential problem in short rotations (Hornbeck 1977). The rates of available calcium replenishment and the relative significance of this problem in comparision with nitrogen losses appear to vary from site to site.

Potassium. The primary input mechanism of potassium is the weathering of mineral soil and bedrock. Weathering (mostly of feldspars and micas) is the principal source of potassium input into the ecosystem, contributing eight times as much potassium as precipitation inputs at Hubbard Brook (Likens et al. 1977). In chemical weathering, all of the potassium is not released into the soil solution but much is bound in illytic clays, which serve as a potassium reservoir (Likens et al. 1977).

This nutrient is rapidly utilized by vegetation in an undisturbed system and equally rapidly returned to the soil in litterfall and throughfall (Gosz, Likens & Bormann 1973; Foster & Gessel 1972). Potassium in vegetation is concentrated in young leaves, buds, and root tips. Only 40 percent of the annual input of potassium is stored in living and dead biomass annually. Owing to potassium's extremely soluble character, potassium is highly mobile within plant tissue (Gosz, Likens & Bormann 1976) and subsequently is easily retranslocated (Gosz, Likens & Bormann 1972). Like nitrogen, potassium is needed in large quantities but is efficiently cycled.

Studies at Hubbard Brook (Likens et al. 1967) have recorded small net losses of potassium some years and small net gains other years. Over long periods of time it seems that the potassium budget is nearly balanced. There is a strong positive correlation of potassium concentration and stream flow (Likens et al. 1967). In general, the annual output of potassium is small compared to release from leaf and branch litter and other inputs (Gosz, Likens & Bormann 1973; Weetman & Webber 1972).

Although the efficiency of this flux is high, it is susceptible to major leaching loss after harvesting until new vegetation is established. Harvest operations are not expected to deplete potassium reserves seriously (Weetman & Webber 1972; Boyle, Phillips & Ek 1973; Likens et al. 1978). Site variation in available reserves of weatherable bedrock could affect this expectation.

Sulfur. Sulfur is a constituent of all proteins and is important in respiration and root development (Wilde 1958). As its concentration increases, it lowers the pH of the soil solution (Eaton, Likens & Bormann 1973). Like nitrogen, sulfur is a gaseous element at normal biological temperatures and this makes qualitative assessment of its complex biogeochemical cycle difficult (Likens et al. 1977).

Sulfur is incorporated into the ecosystem primarily through precipitation, direct uptake of sulfur dioxide, and the impaction of sulfur aerosols on leaf surfaces.

Sulfur reaching the soil system is subjected to micoorganismal transformations similar to those which convert nitrogen into usable forms. Sulfur is oxidized from elemental sulfur and sulfides to sulfate ions by a group of sulfur bacteria (Likens et al. 1977; Wilde 1958; Epstein 1972). These sulfates can be reduced to hydrogen sulfide in a process analagous to denitrification with nitrogen. The reduction is carried out by a number of autotrophic and heterotrophic organisms capable of anaerobic respiration which is especially important in this role (Wilde 1958).

At any one time, 99 percent of the forest's sulfur is in the soil and 1 percent is in the biomass. Of the annual input of sulfur into the ecosystem each year, 10 percent remains in the biomass or soil and about 90 percent is lost to stream flow (Likens et al. 1977). Sulfate is the most abundant anion in streamwater at Hubbard Brook, on a mass and equivalency basis (Likens et al. 1977; Hornbeck et al. 1975). It maintains a relatively constant concentration despite large fluxes of stream discharge.

Problems with depletion of sulfur following whole-tree harvesting have not yet been studied, except to show that sulfur concentrations decrease following harvesting (Pierce et al. 1972). This may be due to the elimination of substrate (foliage) for aerosol impaction. Decreased oxidation, increased dilution, and a reduction of sulfate to sulfite may also have been responsible

(Likens et al. 1970).

The significance of this finding to the productivity of the regenerating stand has not been determined but is under study at the Hubbard Brook Experimental Forest.

Magnesium. Magnesium serves as a structural component and is the only mineral constituent of chlorophyll. Magnesium promotes the utilization of potassium and is most abundant at growing tips of plants (Wilde 1958). Like many other cations, magnesium enters the ecosystem primarily through weathering, this mode accounting for 85 percent of the annual input of the nutrient. Precipitation supplies the remaining 15 percent of the annual input. Considerable quantities of magnesium are recycled through the litter and root exudates.

Gosz, Likens and Bormann (1976) found that magnesium has a relatively short residence time in the forest, similar to that of calcium and sulfur. Like calcium, magnesium is relatively immobile and consequently not easily retranslocated. Thus, large amounts of magnesium are cycled annually to leaffall and litterfall (Gosz, Likens & Bormann 1976).

The resultant rapid return of this nutrient to the forest floor supports a decomposition and mineralization process which, in turn, creates the bulk of the available reserves. Magnesium is rapidly leached from the system under undisturbed conditions (Likens et al. 1977).

Harvesting operations could be expected to deplete the small pool of available magnesium reserves through increased decomposition and leaching. These losses, however, have been found to constitute a minor portion of the total magnesium reserves available from weathering processes (Weetman & Webber 1972; Boyle, Phillips & Ek 1973).

Summary and Conclusions

Gaseous fixation and aerosol impacts, which are important for nitrogen and sulfur, appear to be the input mechanisms most severely affected by harvest operation. In the case of nitrogen fixation, whole-tree harvesting removes much of the small litter material which serves as a substrate for nitrogen-fixing bacteria.

Virtually all of the internal nutrient fluxes of the forest ecosystem are affected by harvesting. To the extent that these processes allow for the conservation of an easily lost nutrient in short supply, harvest-related disruption can be significant. Losses of nitrogen and calcium are of particular concern. Phosphorus and potassium reserves may also be affected. In this case, whole-tree harvests may aggravate the impacts of conventional operations by removing slash which serves as a nutrient 'cushion' for the regenerating stand. This removal increases the importance of post-harvest nutrient losses due to leaching. The increase in decomposition and nitrification processes following harvest serves to temporarily increase pool of nutrients available for plant uptake. This process, accelerated by the increased climatic exposure following whole-tree harvests, results in higher leaching losses of essential nutrients, including nitrogen and calcium, in the absence of regeneration.

Of the output mechanisms, biomass removal and leaching are most clearly affected by type of harvest operation. Extensive research has consistently shown that the whole-tree operations remove substantially more nutrients than conventional harvests. This appears to be especially true of nitrogen and phosphorus. As described earlier, intensive harvests may encourage substantial leaching loss of nutrients until the site has been revegetated. Increased availability of leaching precipitation and high decomposition rates appear to be principally responsible for this phenomenon. The effect of harvesting on volatilization mechanisms may vary from site to site.

While it is clear that harvest operations increase nutrient losses in relation to undisturbed forest ecosystems, the relationship of whole-tree to conventional harvests and the impact of all harvest systems on the long-term productivity of the forest ecosystem should be examined as part of the continuing monitoring effort of the proposed project. In many cases, however, whole-tree harvests appear to accentuate the disturbances of the nutrient cycle. It is by no means certain that the normal input and cycling mechanisms are capable of sustaining the necessary pools of available nutrients if increasingly intensive harvest methods are employed. The growing interest in wood energy and the concurrent growth in the demand for wood fiber heightens the concern over these questions. The environmental monitoring program to be conducted as part of the proposed action provides an important opportunity for further research on nutrient cycling interactions with harvest operations.

FAUNA OF THE FOREST ECOSYSTEM

Microbes

Protozoa are found throughout the forest ecosystem, but are concentrated in the upper layers of the soil and the litter. They include many different amoebas, ciliates, and especially colorless flagellates (Odum 1971). These organisms are microconsumers (saprotrophs), involved in the decomposition of dead multicellular plants and animals. Microbial decomposers are abundant (approximately 10^{12} to 10^{15} per square meter) and, in combination with bacteria, algae, and fungi, constitute a crucial link in the nutrient recycling process (see Nutrient Section).

Invertebrates

Arthropods (insects, crustacea, arachnids), nematodes, oligochaete worms, slugs, and snails are all abundant in forests, and number in the hundreds to thousands per square meter (Odum 1971). They occur primarily in the litter and soil, but are extremely diverse and specialized and can be found throughout the vegetation in larval or adult forms. In the forest community, invertebrates aid in the mechanical breakdown of dead material, soil aeration, and pollination of plants and also serve as food for larger consumers.

Amphibians and Reptiles

Numerous frogs, toads, salamanders, snakes and turtles can be found in the fuelwood harvest region (see Table 19). Except for the snakes, they are found in wetland areas. All of them are insectivorous as adults.

Birds

Birds are the most important vertebrates in the fuelwood harvest region in terms of numbers and variety. They inhabit all

TABLE 19: REPTILES AND AMPHIBIANS OF THE FUELWOOD HARVEST REGION

Snapping Turtle	*Chelydra serpentina*
Painted Turtle	*Chrysemys picta*
Eastern Garter Snake	*Thamnophis sirtalis sirtalis*
Eastern Smooth Green Snake	*Opheodrys vernalis vernalis*
Eastern Milk Snake	*Lampropeltis doliata triangulum*
Green Frog	*Rana clamitans melanota*
Pickerel Frog	*Rana palustis*
Northern Leopard Frog	*Rana pipiens pipiens*
Wood Frog	*Rana sylvatica*
American Toad	*Bufo americanus*
Northern Two-lined Salamander	*Eurycea bislineata bislineata*
Northern Dusky Salamander	*Desmognathus fuscus fuscus*
Northern Spring Salamander	*Gyrinophilus porphyriticus porphyriticus*
Red-spotted Newt	*Notopthalmus viridescens viridescens*
Red-backed Salamander	*Plethodon cinereus cinereus*

Source: Conant 1975.

levels of the forest from ground to canopy. Table 20 lists the bird species that may occur in the study area.

Raptors frequent forest clearings where they prey on small mammals and birds. They typically nest in standing dead trees. Clinging birds are adapted especially to tree trunks were they nest in cavities and feed on invertebrates. Ground-dwellers feed on mast or insects and take refuge in the lower branches of trees, especially conifers. Perching birds are typically edge or canopy dwellers. They are able to exploit a variety of food sources and nesting sites and so are the most diverse group. Birds associated with freshwater marshes and bogs include wading and swimming species that feed on aquatic plants and animals. Some perching birds also occur in the emergent vegetation of marshes.

Mammals

Mammals inhabit all levels of the terrestrial environment, but are relatively few in total numbers. Species whose range includes the fuelwood harvest region are shown in Table 21, along with the type of habitat they may be found in. The moles and shrews are burrowing mammals, feeding on invertebrates in the soil. Bats are noctural insectivores, roosting in caves or tree hollows during the day. The majority of the carnivores inhabit the forest edges and areas with mixed-aged stands where small animal prey is abundant. Most of the terrestrial carnivores are actually omnivores and some, like the coyote, raccoon, bear, and fox, are occasionally scavengers. The aquatic carnivores feed on fish and large aquatic invertebrates. Squirrels and chipmunks are predominantly arboreal animals, although they may nest in burrows at the base of trees and do most of their feeding on the ground. The other herbivores listed in Table 21 tend to prefer areas with low shrubby growth that provides them with both food and cover. Moose and deer, being larger, usually rely on mature softwood stands for cover, especially during the winter.

TABLE 20: BIRDS OF THE FUELWOOD HARVEST REGION

Birds of Prey (Raptors)	
Sharp Shinned Hawk	*Accipiter striatus*
Goshawk	*Accipiter gentilis*
Red-tailed Hawk	*Buteo regalis*
Broad-winged Hawk	*Buteo platypterus*
Sparrow Hawk	*Falco sparverius*
Rough-legged Hawk	*Buteo lagopus*
Golden Eagle	*Aquila chrysaetos*
Bald Eagle	*Haliaeetus leucocephalus*
Peregrine Falcon	*Falco peregrinus*
Barred Owl	*Strix varia*
Screech Owl	*Otus asio*
Great Horned Owl	*Bubo virginianus*
Saw-whet Owl	*Aegolius acadicus*
Clinging Birds	
Yellow-shafted Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Hairy Woodpecker	*Dendrocopus villosus*
Downy Woodpecker	*Dendrocopus pubescens*
White-breasted Nuthatch	*Sitta carolinensis*
Red-breasted Nuthatch	*Sitta canadensis*
Brown Creeper	*Certhia familiaris*
Ground Dwellers	
Ruffed Grouse	*Bonasa umbellus*
American Woodcock	*Philohela minor*
Perching Birds	
Primarily insectivores:	
Black and White Warbler	*Mniotilta varia*
Tennessee Warbler	*Vermivora peregrina*
Nashville Warbler	*Vermivora ruficapilla*
Parula Warbler	*Parula americana*
Magnolia Warbler	*Dendroica magnolia*
Black-throated Blue Warbler	*Dendroica caerulescens*
Myrtle Warbler	*Dendroica coronata*
Black-throated Green Warbler	*Dendroica virens*
Blackburnian Warbler	*Dendroica fusca*
Chestnut-sided Warbler	*Dendroica pennsylvanica*
Bay-breasted Warbler	*Dendroica castanea*
Black-poll Warbler	*Dendroica striata*
Ovenbird	*Seiurus aurocapillus*
Northern Waterthrush	*Seiurus noveboracensis*
Louisiana Waterthrush	*Seiurus motacilla*
Mourning Warbler	*Oporornis philadelphia*
Yellowthroat	*Geothlypis trichas*
Canada Warbler	*Wilsonia canadensis*
American Redstart	*Setaphaga ruticilla*

TABLE 20: Cont.

Primarily insectivores (Cont.):	
House Wren	*Troglodytes aedon*
Winter Wren	*Troglodytes troglodytes*
Catbird	*Dumetella carolinensis*
Brown Thrasher	*Toxostoma refum*
Robin	*Turdus migratorius*
Wood Thrush	*Hylociachla mustelina*
Hermit Thrush	*Hylocichla guttata*
Swainson's Thrush	*Hylocichla ustulata*
Gray-cheeked Thrush	*Hylocichla minima*
Veery	*Hylocichla fuscescens*
Eastern Bluebird	*Sialia sialis*
Golden-crowned Kingley	*Regulus satrapa*
Ruby-crowned Kingley	*Regulus calendula*
Solitory Vireo	*Vireo solitarius*
Red-eyed Vireo	*Vireo olivaceus*
Philadelphia Vireo	*Vireo philadelphicus*
Warbling Vireo	*Vireo gilvus*
Black-billed Cuckoo	*Coccyzus erythropthalmus*
Eastern Kingbird	*Tyrannus tyrannus*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Phoebe	*Sayornis phoebe*
Yellow-bellied Flycatcher	*Empidonax flaviventris*
Least Flycatcher	*Empidonax minimus*
Eastern Wood Pewee	*Contopus virens*
Olive-sided Flycatcher	*Nuttallornis borealis*
Tree Swallow	*Iridoprocne bicolor*
Bank Swallow	*Riparia riparia*
Barn Swallow	*Hirundo rustica*
Chimney Swift	*Chaetura pelagica*
Omnivores:	
Baltimore Oriole	*Icterus galbula*
Common Grackle	*Quiscula quiscula*
Brown-headed Cowbird	*Molothrus ater*
Scarlet Tanager	*Piranga olivacea*
Blue Jay	*Cyanocitta cristata*
Common Raven	*Corvus corax*
Common Crow	*Corvus brachyrhynchos*
Cedar Waxwing	*Bombycilla cedrorum*
Starling	*Sturnus vulgaris*
Nectivores:	
Ruby-throated Hummingbird	*Archilochus colubris*
Primarily seed-eaters:	
Tree Sparrow	*Spizella arborea*
Chipping Sparrow	*Spizella passerina*
Field Sparrow	*Spizella pusilla*
White-crowned Sparrow	*Zonotrichia leucophrys*
White-throated Sparrow	*Zonotrichia albicollis*
Lincoln's Sparrow	*Melospiza lincolnii*
Swamp Sparrow	*Melospiza georgiana*

TABLE 20: Cont.

Primarily seed-eaters (Cont.):

Song Sparrow	*Melospiza melodia*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Indigo Bunting	*Passerina cyanea*
Evening Grosbeak	*Hesperiphona vespertina*
Purple Finch	*Carpodacus purpureus*
Pine Siskin	*Spinus pinus*
American Goldfinch	*Spinus tristis*
Rufous-sided Towhee	*Pipilo erythrophthalmus*
Slate-colored Junco	*Junco hyemalis*
Black-capped Chickadee	*Parus atricapillus*
Boreal Chickadee	*Parus hudsonicus*

Birds Inhabiting Freshwater Marshes and Bogs

Pie-billed Grebe	*Podilymbus podiceps*
Little-Blue Heron	*Florida caerulea*
Least Bittern	*Ixobrychus exilis*
American Bittern	*Botaurus lentiginosus*
Mallard	*Ana rubripes*
Black Duck	*Anas acuta*
Pintail	*Anas carolinensis*
Green-winged Teal	*Anas discors*
Blue-winged Teal	*Mareca americana*
American Wigeon	*Aix sponsa*
Wood Duck	*Aythya americana*
Redhead	*Aythya marila*
Greater Scamp	*Aythya affinis*
Lesser Scamp	*Laphodytes cucullatus*
Hooded Merganser	*Rallus elegans*
King Rail	*Laterallus jamaicensis*
Virgina Rail	*Rallus limicola*
Sora Rail	*Porzana carolina*
Yellow Rail	*Coturnicops noveboracensis*
Common Gallinule	*Gallinula chloropus*
American Coot	*Fulica americana*
Willet	*Catoptrophorus semipalmatus*
Black Tern	*Chlidonias niger*
Short-eared Owl	*Asio flammeus*
Long-billed Marsh Wren	*Telmatodytes palustris*
Shortbilled Marsh Wren	*Cistothorus platensis*
Palm Warbler	*Dendroica palmgrum*
Wilson's Warbler	*Wilsonia pusilla*
Redwinged Blackbird	*Agelaius phoeniceus*
Rusty Blackbird	*Euphagus carolinas*
Swamp Sparrow	*Melospiza georgiana*

Source: Robbins, Bruun & Zim 1966.

TABLE 21: MAMMALS OF THE FUELWOOD HARVEST REGION

		Old Fields	Northern Hardwoods	Spruce-fir	Pine	Wetlands
Insectivores						
Hairy-tailed Mole	*Parascalops breweri*	x	x		x	
Star-nosed Mole	*Condylura cristata*	x				
Short-tailed Shrew	*Blarina brevicanda*	x	x	x	x	x
Pygmy Shrew	*Microsorex hoyi*	x				
Long-tailed Shrew	*Sorex dispar*			x		
Masked Shrew	*Sorex cinereus*	x	x	x	x	
Smokey Shrew	*Sorex fumus*		x			
Water Shrew	*Sorex palustris*					x
Silver-haired Bat	*Lasionyoteris noctivagens*		x	x	x	x
Red Bat	*Lasiurus borealis*		x	x	x	x
Hoary Bat	*Lasiurus cinereus*		x	x	x	x
Eastern Pipistrelle	*Eastern Pipistrelle*		x	x	x	x
Big Brown Bat	*Eptesicus fuscus*		x	x	x	x
Indiana Myotis	*Myotis sodalis*		x	x	x	x
Small-footed Myotis	*Myotis subulatus*		x	x	x	x
Little Brown Myotis	*Myotis lucifugus*		x	x	x	x
Keen Myotis	*Myotis kenni*		x	x	x	x
Carnivores						
Mink	*Mustela vixon*					x
Black Bear	*Ursus americanus*		x	x		
Raccoon	*Procyon lotor*	x	x			x
Marten	*Martes americana*			x		x
Fisher	*Martes pennanti*		x			
Short-tailed Weasel	*Mustela erminea*	x	x			
Long-tailed Weasel	*Mustela frenata*	x	x			
Striped Skunk	*Mephitus mephitus*	x	x			
Red Fox	*Vulpes fulva*	x	x			
Gray Fox	*Urocyon cinereoargen*	x				
Lynx	*Lynx canadensis*			x		
Bobcat	*Lynx ruta*	x	x			
Coyote	*Canis latrans*	x	x			
River Otter	*Lutra canadensis*					x
Herbivores						
Beaver	*Caster canadensis*					x
Woodchuck	*Mormota morax*	x	x			
Eastern Chipmunk	*Tamias striatus*	x	x	x	x	
Eastern Gray Squirrel	*Sciurus carolinensis*		x			
Red Squirrel	*Tamiasciurus hudsonicus*		x	x		
Southern Flying Squirrel	*Glaucomys volans*		x		x	
Northern Flying Squirrel	*Glaucomys sabrinus*		x			
Deer Mouse	*Peromyscus maniculatus*	x	x	x		
White-footed Mouse	*Peromyscus leucopus*	x			x	

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Impacts on Terrestrial Fauna

The effects of wood harvest on animal populations will be different for each species, depending on its food source and habitat preference. However, the nature of the impacts, beneficial or detrimental, are determined by the extent of the timber harvest. The overall diversity and abundance of fauna can be enhanced when harvest operations are employed in such a way as to create a wide range of habitat types (Webb 1973; Hall et al. 1976). This result, however, is not the inevitable consequence of harvest operations. The immediate impacts of harvesting operations on individuals of a species is usually negative. Logging activity can force animals to leave the area or to relocate to a less than optimum habitat within the vicinity. However, these are short-term effects on individuals which should not threaten the general abundance of most species in the region (Hall et al. 1976). The only exception to this would be in cases where rare species occur in isolated locations and such disruption would threaten the reproductive success of the population.

Microbes and invertebrates are generally so abundant and adaptable to local changes in the physical environment that the impact on them would appear to be negligible. The major impacts are felt by vertebrate species (wildlife).

To a considerable extent, the choices exercised by the harvest operator and the forest landowner determine types of habitat created by harvesting. Clearcutting in narrow strips or small patches, for example, creates a large amount of "edge" habitat along the boundaries of the cut. Wildlife feeding in these areas are never far from the protective cover of the uncut forest stand. Large, unbroken clearcuts, on the other hand, are characterized by a uniformity of habitat unconducive to diverse wildlife populations. Other harvest methods, such as selective cutting, can create a stratification of the forest canopy and thus support a wider range of bird species.

The result of interspersed timber harvests is a restructured physical environment, which, as the area revegetates, offers a wider variety of niches than is available in a mature forest. Removal of much of the forest canopy and creation of open area stimulates the growth of low, shrubby vegetation and saplings. This provides food for browsing animals such as deer, and food and cover for typical "edge" species such as hare, ruffed grouse, woodchuck, black bear, thrush, and sparrows. Most seed-eating birds will be favored in these areas. Populations of many small mammals -- mice, shrews, chipmunks, red squirrels -- and birds are generally as large in cut areas as in uncut ones (Webb 1973). Canopy dwellers, such as ovenbirds and some species of warblers, will decline following harvest but can be expected to reappear as a new canopy becomes established (Conner & Adkisson 1975).

In one study in the Adirondacks, removal of 100 percent of the merchantable timber resulted in the greatest overall benefit to wildlife as compared with stands that had from 0 to 75 percent removed (Webb 1973). However, complete removal of all the standing volume would probably not be as effective. Several species--for example, squirrels, deer, and ruffed grouse--can rely heavily on mast during certain periods of the year (Zumbo 1978). Removal of all mature hardwoods would eliminate this food source. Deer, in particular, depend on some forested area, especially conifers, for winter protection.

The impact of whole-tree harvest and harvest of low-grade material on wildlife is not known. The harvest of cull trees would open up areas that might otherwise be unproductive, but could destroy nesting and feeding areas for several animal species (see Table 22).

Slash, left by traditional harvesting operations, offers cover for some species but can represent hazards to others by providing concealment for predators. Deer sometimes utilize remaining tree tops for food during winter.

The net effect of fuelwood harvests on the wildlife of the region cannot be accurately described without a detailed knowledge of the forest practices to be employed. As has been discussed above, the potential exists to develop and maintain a wide range of habitats supporting a diverse array of fauna populations. Economic pressures and landowner objectives, however, could combine to exclude consideration of wildlife objectives in the choice of harvest method. Widespread use of large, economically efficient

TABLE 22: WILDLIFE SPECIES DEPENDENT ON DEAD AND DEFECTIVE TREES FOR FOOD AND/OR COVER

Birds

- Red-breasted Nuthatch
- White-breasted Nuthatch
- Black-backed 3-toed Woodpecker
- Northern 3-toed Woodpecker
- Red-headed Woodpecker
- Hairy Woodpecker
- Downy Woodpecker
- Yellow-bellied Sapsucker
- Pileated Woodpecker
- Common Flicker
- Wood Duck
- Common goldeneye Duck
- Bufflehead Duck
- Hooded Merganser
- Saw-whet Owl
- Screech Owl
- Sparrow Hawk
- Bald Eagle
- Golden Eagle
- Common Merganser
- American Kestrel
- Barn Owl
- Barred Owl
- Brown Creeper
- House Wren
- Winter Wren
- Starling
- House Sparrow
- American Osprey
- Peregrin Falcon
- Red-tailed Hawk
- Rough-legged Hawk
- Tree Swallow
- Purple Martin
- Eastern Bluebird
- Great crested Flycatcher
- Black-capped Chickadee
- Boreal Chickadee

Mammals

- Little Brown Bat
- Big brown Bat
- Marten
- Fisher
- Red Squirrel
- Northern gray Squirrel
- Eastern flying Squirrel

Sources: Scott et al. 1977 and USDA 1977.

clearcuts will tend to reduce the diversity of habitat types and wildlife in the fuelwood harvest region. Whatever harvest methods are chosen, the increased harvest activity and access to currently remote areas of the region may disturb sensitive wildlife species and drive them permanently from the area (Zumbo 1978).

Species of Commercial and Recreational Value

Animals that are important as game animals or furbearers in the fuelwood harvest region are listed in Table 23. Deer are the most important animal because of their hunting value. Considerable research and management efforts have been devoted to maintaining this species. Food availability, predation and parasitism, and shelter from the deep snow are the three main factors limiting deer populations. Thinning and clearing of forests would increase the deer's food supply, resulting in an increase in deer numbers. However, it would also disrupt unbroken tracts of mature softwoods, which the deer rely on for winter yarding areas. Very small clearings will not create enough understory browse to support large deer herds. On the other hand, very large clearings would not provide adequate cover and protection. The most effective clearcut is a long narrow strip which provides nearby cover but also creates plenty of understory browse (Roach 1974).

Rare and Endangered Species

The bald eagle and short-nosed sturgeon are the only species of fauna known to exist in Maine that have been designated as endangered under the Endangered Species Act of 1973 (USFWS 1978; Gramlich 1979; Squires 1979). Harvest operations can affect bald eagles in several ways. Physical removal of trees suitable for nesting and roosting limit eagle populations. Harvests and other management activities can also affect eagles indirectly by reducing fish populations or introducing persistent chemicals into the food chain. These detrimental activities are controlled to some extent under state laws, but compliance is largely dependent on decisions made by individual landowners and harvest operators.

Direct interference with bald eagles is prohibited under the Endangered Species Act of 1973, as amended, and the Bald Eagle Act of 1940. A successful identification and protection program is

TABLE 23: GAME AND FUR-BEARING ANIMALS IN THE FUELWOOD HARVEST REGION

Big Game

- White-tail Deer
- Black Bear
- Moose

Fowl

- Woodcock
- Ruffed Grouse
- Canada Goose
- Duck

Aquatic Fur-bearers

- Beaver
- Mink
- Otter
- Muskrat

Small Game

- Gray Squirrel
- Snowshoe Hare

Upland Fur-bearers

- Bobcat
- Coyote
- Fox
- Skunk
- Fisher
- Marten
- Raccoon

Source: MDIFW 1976.

now underway, conducted by the U.S. Fish and Wildlife Service in cooperation with the state of Maine. The location and habits of the few eagles that nest on the periphery of the fuelwood harvest region have been well documented and protected by this program (Gramlich 1979). Harvest activity associated with the proposed action will not jeopardize these populations.

The impacts of harvesting on the short-nosed sturgeon are discussed in Appendic C.

The historical distribution of the eastern cougar, grey wolf, Indiana bat, all listed as endangered, extends into the fuelwood harvest region (USFWS 1978). Current populations in this region, however, are nil and the species are not scheduled for reintroduction efforts at this time (Nickerson 1979). The peregrine falcon, also an endangered species, may migrate through the harvest region but does not use the region for nesting and breeding (Nickerson 1979). Harvest activities will not affect populations of this species (Nickerson 1979).

FOREST PRACTICES IN THE FUELWOOD HARVEST REGION

History of Forest Practices

One of the first sawmills in the United States was built in Berwick, Maine, in 1631 (Wackerman, Hagenstein & Mitchell 1966). From this date to the present, the timber industry has more or less continuously followed the same pattern of forest management practices in the region: loggers have selectively cut the best-quality and highest-valued trees for sale to demanding markets. Until about 1800, high-quality white pine cut both for sawlogs and ship masts was virtually the only product of the forest industry in Maine and New Hamsphire. After 1850, sawmills began producing spruce and balsam fir lumber. These species were not predominant in the proposed harvest region, however, and white pine continued to be the most sought-after species. Prior to 1900, the only significant market for hardwood in Maine or New Hampshire was that for oak in the shipbuilding industry. The widespread selective harvest of this species continued the trend of removing only the best-quality wood in the forest.

This practice of cutting only the best quality trees in a stand (called high-grading) leaves only inferior trees for the next harvest and results in the progressive deterioration of a forest's gene pool. Therefore, the quality of trees for future harvests is successively lowered. A variation of high-grading, called diameter-limit cutting, has also been common practice in the fuelwood harvest region. With this technique, all trees of a size larger than the minimum considered merchantable are removed from the stand. This system can be simply applied and provides high short-term returns per unit of wood harvested. This practice, however, also removes the fastest growing, most promising, and most vigorous trees and allows no control over the distribution of the cut, the spacing of the remaining trees, or the type and distribution of regeneration. Again, with this type of harvest, the forest deteriorates.

Present-day Influences on Forest Practices

A number of factors have prevailed throughout the 350-year history of forest use in the region to deter both commercial harvesters and individual landowners from practicing better forest management. As the brief historical sketch above demonstrates, the market for forest products has determined the quality and species of trees harvested from the region's forests. Because there was little demand for low-quality trees before 1900, there was little economic incentive to harvest anything but the highest-quality trees of the most desirable species.

Since 1900, the pulp industry has created a more diverse market for softwoods and, increasingly in recent years, for hardwoods as well. Because the pulping process reduces wood to its fiber content, the industry is less restrictive regarding the size, quality, and species of its raw material than is the sawtimber industry. Pulpwood harvest can include trees as small as five inches in diameter, as well as those with some roughness of form.

Because of the pulpwood market's relative flexibility in accepting materials of varying qualities, some clearcutting of forests has been conducted in the proposed harvest region, particularly in the scattered spruce-fir stands. This harvest technique is generally more cost-efficient for the operator than selective harvests when most of the material in the stand is of pulpwood quality. The environmental impacts associated with clearcutting, like selective harvesting, depend on the application of the technique to a particular ecosystem.

In most pulpwood harvests in the proposed harvest region, however, high-grading has continued to be the predominant cutting technique. Despite the less demanding standards for pulpwood, both industrial and harvesting technologies have dictated that trees harvested for pulp be reasonably straight to ensure ease of transportation and handling at the mill. This means that there still exists no incentive to cut significantly deformed and otherwise unmerchantable trees.

Landowner attitudes have also reduced the use of optimal forest management practices in the area. Forest land within a 50-mile radius of Westbrook is held almost entirely in small, non-industrial, private parcels. Such ownerships in New Hampshire have an average size of about 45 acres, a mean that continues to decrease (Hovland 1978; Kingsley 1976). No corresponding statistic is presently available for the state of Maine, but it is certain that the trend, at least in the fuelwood harvest region, is also toward diminishing acreage per parcel and an increasing number of owners.

In effect, much forest land is now held by owners who are not dependent on their land for even a portion of their incomes and whose primary ownership objectives are residential and aesthetic. These landowners typically do not favor clearcutting and may not be inclined to cut any timber for commercial sale. In a recent study of New England landowners who have not harvested timber on their lands, the reason most frequently cited was a concern for impact on "the scenery" (Kingsley & Birch 1977). These landowners have not undertaken deliberate timber stand improvement measures because these efforts typically are unprofitable in terms of the immediate return from the removed material.

Despite these disincentives, two forces have maintained some level of timber stand improvement in the fuelwood harvest region: 1) the efforts of some landowners who associate such practice with good land stewardship; and 2) financial and technical assistance programs such as the U.S. Forestry Incentives Program, the U.S. Agricultural Conservation Program, and various private tree farm programs. These programs make funds and advice available to landowners who wish to manage their lands for future forest production.

Future Forest Practices

Changing markets for forest products could significantly affect the demand for low-quality wood in the future. Nationwide, consumption of paper, particle board, and oriented-strand fiber-board is increasing rapidly (see Figure 8) and should continue to do so as reconstituted boards fill the materials gap left by decreasing supplies of products produced from declining stocks of old-growth timber in the Western U.S. As demand for these products has risen, the pulpwood industry has increased its reliance on forest materials once left unused.

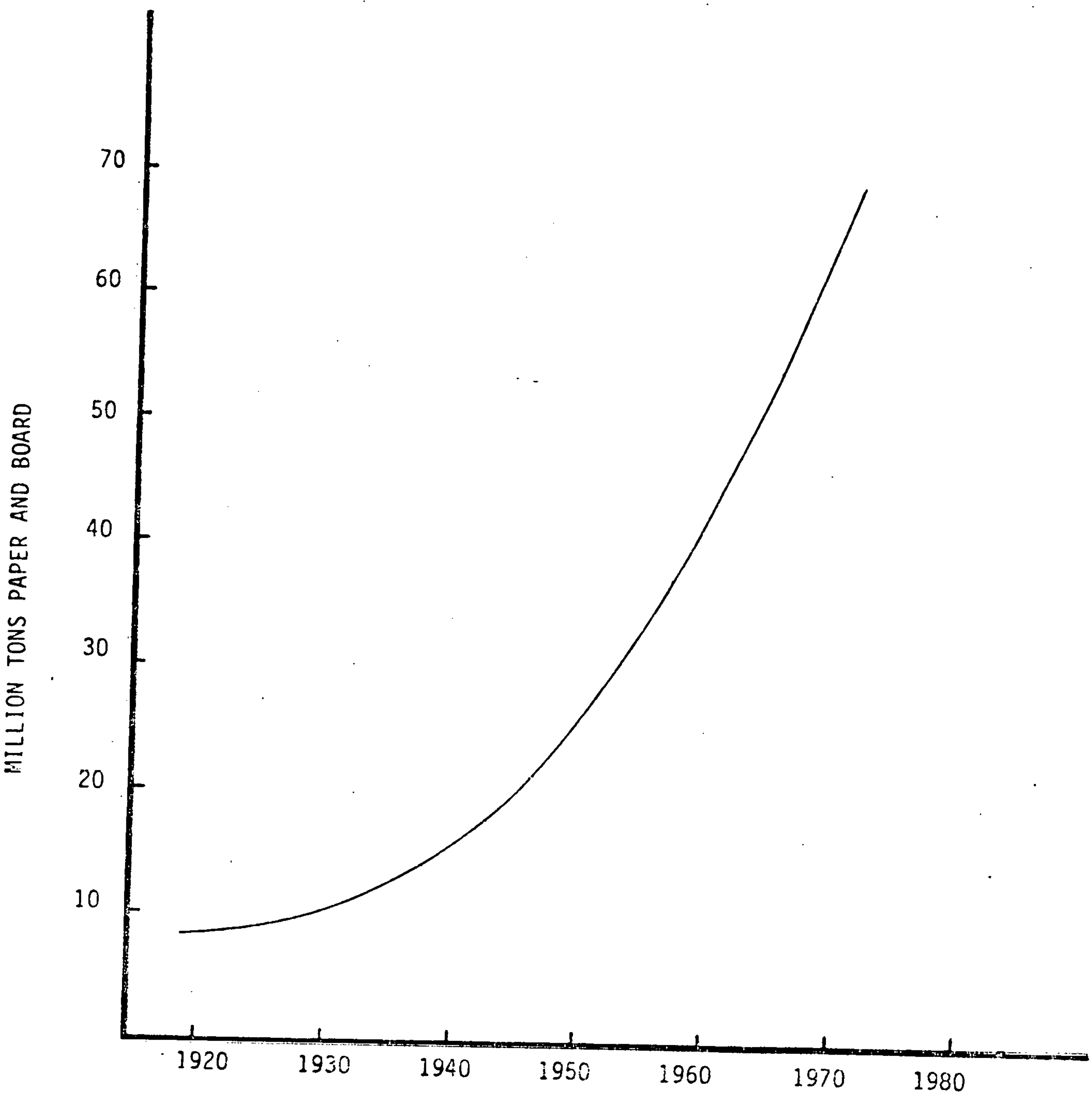
Over the past twenty years, the proportion of hardwood in the annual pulpwood harvests in Maine has remained constant due to the limitations of Maine pulpmills. These constraints will be greatly reduced as mills and processes are modernized; hardwood will constitute an increasing percentage of the pulpwood cut (Ferguson & Kingsley 1972). In New Hampshire, the hardwood pulpwood harvest has increased dramatically since 1959 (FRG 1978). In addition, the pulp industry is increasing its reliance on whole-tree and mill-residue chips as a raw material. These trends mean that there will be a greater economic incentive for landowners to remove low-quality trees from their property.

With an improving market for a wider variety of tree qualities and species, such as that provided by a wood-fired power plant, landowners will have more flexibility in their approach to forest management. If efficient harvest techniques are developed, trees of lower value, which exist in quantities for greater than the amount currently cut (Sewall 1978), can profitably be thinned or harvested, creating room for improved growth on adjacent trees of better form or species. Landowners would thus have more of an incentive to undertake timber stand improvement and to use harvesting techniques that do not result in highgrading.

Currently, the majority of logging contractors in the fuelwood harvest region use conventional harvesting techniques. Each operator has a crew typically consisting of a sawyer, a skidder driver, and a worker in the log landing. Most operators' equipment inventories include several chain saws, a skidder, and a pickup truck. In most cases, the transportation of the logs is contracted to an independent trucker.

Some harvest operations in the region are less mechanized. Fuelwood operations rely on convenient access and generally do not include a skidder but only one or two chain saws and a pickup

FIGURE 8: ANNUAL PAPER AND BOARD CONSUMPTION, 1920 - 1972



Source: USFS 1974.

truck.

Five independent contractors in the study area currently run whole-tree chipping operations. These activities, at their most mechanized level, depend on feller bunchers to cut and stack whole trees, grapple skidders to forward the trees to the chipping site, and mobile whole-tree chippers which convert the logs to chips and blow the chips into semitrailer vans. This type of harvest operation could lead to increased clearcutting of hardwoods, as this approach is most cost-efficient from the operator's standpoint. The effects of such operations could be either good or bad, depending on the care with which they were applied and the ecosystems that were involved. Whole-tree removals could also be conducted as thinning or selective harvest techniques and could consequently lead to significant improvement of the region's timber stands if forest management with a sound, long-term view could be encouraged.

Impact of the Proposed Action on Forest Practices

The proposed wood-fired power plant will improve the merchantability of wood currently considered "waste," increase the number of highly mechanized harvesting operations in the region, and alter the characteristics of the woods labor force; consequently, the project will cause changes in the region's forest practices.

Wood will be delivered to the proposed plant as low-quality chips, a product that does not demand specific tree form or quality. Portions, sizes, species, and grades of timber that are currently unusable, therefore, will acquire commercial value when the plant begins operating. This increased merchantability will simultaneously improve the economics of forest management and accelerate the need for measures to prevent forest mismanagement.

The addition of a market for low-quality wood chips in the fuelwood harvest region will create an alternative to the traditional practice of harvesting only the highest quality trees and leaving the poorer trees to reestablish the forest. The fuel chip market will make it possible to conduct profitable harvests while leaving high quality trees to accrue significant additional value and restock the forests with young trees from their seed. Thus, the project opens the possibility of greater consideration for the future forest in the planning of timber harvests.

The provision of a market for waste wood and for small trees will also improve the feasibility of timber stand improvement. For example, because small trees thinned from stands in the fuelwood harvest region have typically had no commercial value, investments in forest improvement have been costly and have not yielded returns until the remaining forest has grown for one or more additional decades (Hillstrom & Steinhilb 1976). Consequently, this type of timber stand improvement has only rarely been undertaken. By excepting material from such thinnings, the power plant will accord it merchantable status and thus improve the opportunities for timber stand improvement while lengthing the incomeproducing portion of the forest rotation. In addition, the project will create a market for the slash resulting from on-going harvest operations. To be collected economically, however, this slash must be skidded to the forest landing as part of the merchantable portion of the tree and then sorted for shipment to the power plant. It is unlikely that it would be cost-effective to collect slash left on the forest floor for this project.

Potential losses in timber value due to its use for products of lower than the maximum value could occur as a result of this project. Loggers find it operationally simpler to chip all material and to neglect sorting sawtimber and other high-value products during fuelwood harvest operations (Bourassa 1978). Similarly, operators will be tempted to harvest and chip well-formed young trees that might otherwise have grown into high-grade pole or sawtimber. Nonetheless, some chipping contractors today achieve their best economic returns by sorting lumber, pulp, and pole-quality logs and selling these to mills for a higher price than that received for fuel chips (Percival 1978). Likewise, some landowners demand that small, high-quality trees be left to grow into more valuable mature stock. Thus, economic considerations somewhat mitigate the tendency to chip indiscriminately.

Because the power plant will accept low-quality and consequently low-value material, the most efficient means of harvesting and transporting this material must be employed. Experience in this region and abroad indicates that a system employing sawyers or feller-bunchers to shear the trees, large grapple skidders to haul the whole tree to the landing, and a portable chipper to chip the tree and blow it into truck vans will be the most cost efficient harvest method (Rich 1978). This type of system is significantly more mechanized than the typical system used to harvest wood in the region today.

Highly mechanized harvest operations could result in increased damage to the residual stand and to the forest harvest site. Residual stand damage is often characterized by mechanical injury to uncut trees during felling and skidding operations. The use of large grapple skidders associated with whole-tree harvests raises the likelihood of this sort of damage (Hillstrom & Steinhilb 1976). Feller-bunchers, large machines that both cut and pile trees, reduce the likelihood of a falling tree damaging the remaining stand but can themselves abrade or break remaining trees if poorly operated. Careful planning and machinery maneuvering can reduce both skidding and felling damage to acceptable levels (Zasada 1975).

There is popular concern that mechanized whole-tree harvesting is inextricably associated with both clearcutting and overcutting. Because all grades and types of trees are acceptable as fuel, the project will provide an incentive to increase clearcutting. Also, since clearcutting offers one means to improve harvest efficiency (Smith 1962), it is an attractive system to loggers seeking to maximize returns on the high capital and operating costs associated with mechanized operations. However, the resistance to drastic visual impacts and the use of large machinery, which is characteristic of many landowners in northern New England, will continue to act as a restraint on the use of this method. A number of profitable whole-tree harvesting operations currently practice selective cutting on small landholdings in the Northeast; clearcutting is not necessitated by whole-tree harvesting. Clearcutting, however, may be the most acceptable harvest procedure under some conditions.

A 50-megawatt power plant 70-percent fueled with whole-tree chips would require the output of an estimated seven to thirty-eight whole-tree chipping operations working single shifts (Percival 1978; Dashnaw 1978). At present there are five such operations in the fuelwood harvest region. Because the project could almost double the number of whole-tree harvesting operations in the region, it would provide a highly visible demonstration of the feasibility of whole-tree harvesting on private land holdings. If mechanized harvesting is proven practical and economic on these lands, widespread adoption of these methods for the production of wood chips would be hastened. Nationwide trends indicate increasing reliance on reconstituted wood products made from chips, as well as on the use of wood for energy (USFS 1974). While overcutting (when tree removals exceed growth) should not result from the current project (Sewall 1978), a successful demonstration could attract other users of wood to the region, an event that would increase the danger of overharvest. Current land management policies in Maine and New Hampshire do not protect against such an outcome.

In the long run, widespread forest industry changes resulting indirectly from the project could profoundly influence forest practices in the fuelwood harvest region. The development of a materials and energy industry based on wood chips rather than logs could lead to management of the forests for fiber rather than timber production. Called biomass farming, this type of management often implies harvesting at much shorter intervals than those presently used. Such practices would obviously alter the aesthetic character of the forest and could change current patterns of land use within it. Perhaps most importantly, the long-term impacts on the forest associated with such practices are not well understood.

Finally, changes in harvest practices associated with the project will affect the responsiblities, independence, and working conditions of those workers employed in the woods. If many contractors find the capital cost of mechanized harvest equipment prohibitive, the federal government, the mill, or the power plant could provide loans or subsidies to assist in the purchase of such equipment. In any case, assistance would diminish the independence of logging contractors, an issue that currently is highly controversial (Granskog & Siegel 1978). Financial assistance and the stable demand for fuelwood chips will serve to strengthen the contractual agreements between loggers and the wood-fired power plant. In sum, the wood procurement labor force for the project may move closer to being in the direct employment of the mill, a trend which may lead to an enjoining of the mills to provide full labor benefits for woods workers. This outcome could result in higher wood costs.

In addition to affecting the employment status of loggers, the increase in mechanized harvesting caused by the project will redefine the nature of the loggers' jobs and the skills required to do them. Woods workers employed at fuelwood harvesting will need the skills of heavy equipment operators, in addition to those of timber fellers. In general, they must possess greater mechanical ability for operation, maintenance, and repair of the equipment. Refined supervisory skills, including detailed knowledge of the time/cost factors in the components of a mechanized harvest system, will be required of foremen, in order to maximize the efficiency of the machinery and minimize the cost of fuelwood procurement.

Use of Pesticides

Several possible changes in the current patterns of pesticide use would have impacts on populations of flora and fauna. Fuelwood harvests may, in some instances, constitute an alter native silvicultural tool for operations that currently require the use of pesticides. For example, the fuelwood market may provide an alternative to the use of herbicides currently applied to convert stands of low-grade hardwood into commercially desirable conifer stands. Fuelwood harvest could also be employed as a silvicultural tool in the effort to reduce the long-term susceptibility of spruce-fir stands to the spruce budworm. In addition, to the extent that whole-tree harvests remove logging slash that serves as shelter for breeding populations of insect pests, a reduction in the use of insecticides might be indirectly realized.

The developing fuelwood market and the expanded use of mechanized whole-tree chipping operations may ultimately stimulate an increased dependence on monocultural forestry. This would result in the need for increased use of both herbicides and insecticides to suppress undesirable species and insect pests.

The use of forest pesticides in the fuelwood harvest region will be monitored as part of the continuing environmental assessment program of the proposed action.

LONG-TERM PRODUCTIVITY OF THE FOREST RESOURCE

The productivity of a forest is principally dependent on adequate supplies of moisture, light, and various elemental nutrients. Over the period of several rotations, harvest methods and other forest practices have little effect on supplies of moisture and light, although these factors may be critically affected in the early post-harvest period. Supplies of essential nutrients and the mechanisms of nutrient replenishment, however, can be affected over the long term. To the extent that these nutrients constitute limitations to forest growth, reduced nutrient availability can diminish productivity.

Widespread concern has been voiced over the potential effects of intensive harvest methods, particularly whole-tree methods and shortened rotations, on the supply of nutrients and long-term productivity of the forest ecosystem (Likens et al. 1978; Aber, Botkin & Melillo 1979; Hornbeck 1977; Boyle 1976; Jorgensen, Wells & Metz 1975; Waide & Swank 1975; Switzer & Nelson 1973). Despite a broad geographic range of research sites, general agreement exists that both the physical removal of nutrients in harvested biomass and the harvest-related disturbances of nutrient fluxes are of critical importance to an evaluation of impacts on productivity. These changes in the structure and dynamics of the nutrient cycle have been discussed at length earlier in this appendix. It is valuable at this point, however, to review those effects that are of particular relevance to long-term forest productivity.

Of the "pools" of reserve nutrients in the forest ecosystem, several are directly and indirectly affected by harvesting. Clearly, whole-tree clearcuts remove significant quantities of nutrients bound in living biomass. In addition, harvest residues (slash), which constitute an important input of nutrients and organic material to the forest floor, are greatly reduced by whole-tree removals. In a complementary manner, the reservoir of nutrients bound in the forest floor is depleted by the increased level of decomposition activity following harvests. This is particularly important on the acidic, podzolized soils of the harvest region which depend on the litter and organic layers of forest for their fertility. Although these two reservoirs are at least temporarily depleted, the pool of available nutrients is greatly enlarged by the effects of both the cessation of vegetative uptake and the increased decomposition and mineralization rates. In effect, this surplus of available nutrients encourages the rapid reestablishment of vegetation and hence represents a stabilizing influence.

Less well understood are the effects of intensive harvest operations on the mechanisms by which nutrients move into, through, and out of the forest ecosystem. It is these processes which constitute the means by which an ecosystem recovers from the effects of harvesting. Increased light and moisture availability at the forest floor accelerate the rates of decomposition, nitrification, and mineralization of nutrients. While these increases facilitate revegetation, as mentioned above, the available nutrient forms are also readily leached from the ecosystem. The reduction of evapotranspiration rates following harvest increases the flow of water through the ecosystem, which can further accelerate leaching losses. These increased losses have been found to continue even after the revegetation of the site (Likens et al. 1978). Denitrification, causing a loss of volatile forms of nitrogen, may also be affected by harvest operations, although the direction of this impact is not known. While the rate of precipitation inputs to the forest ecosystem appears to be unaffected by harvests, other input rates may change. Variation in the acidity of the soil regime following harvest is caused by removal of the buffering vegetation and stimulation of acid-producing decompositional processes. These increases may have a role in the increased weathering rates observed after harvests (Likens et al. 1978). Gaseous fixation constitutes a major input for nitrogen which may be affected by harvest operations. Whole-tree harvesting removes the slash which, after conventional operations, may serve as the principal site for nitrogen-fixing bacteria (Roskoski 1977).

Much attention has been focused on possible depletions of available nutrients; however, variation in site characteristics, research methods, and assumptions regarding nutrient replenishment have resulted in widespread disagreement over the mechanisms and significance of harvest impacts. The nutrients of primary concern have variously been identified as nitrogen (Aber, Botkin & Melillo 1979; Jorgensen, Wells & Metz 1975; Waide & Swank 1975) and calcium (Boyle 1976; Weetman & Webber 1972).

Each of the changes in the flux of nutrients in the forest ecosystem has implications for the status of the forest floor. In the Northeast, as mentioned earlier, the litter layers and upper soil horizons in the forest floor contain the majority of nutrients readily cycled through the ecosystem that are not already stored in live biomass. The high relative cation exchange capacity of this organic material in these layers serves to hold nutrients against leaching pressure. The widespread infertility of the mineral soil in this glaciated region limits its ability to retain and recycle critical nutrient elements (Pierce et al. 1972).

The humus layer, made up of partially decomposed organic material, diminishes over a long period following harvesting (Hart 1961; Dominski 1971). The impact of various harvest methods on the status of the forest floor over various rotation lengths has been examined with modeling techniques (Aber, Botkin & Melillo 1978). An extension of this effort attempts to link forest floor dynamics with nitrogen availability and forest productivity (Aber, Botkin & Melillo 1979). Although use of the quantitative model outputs is limited by critical assumptions regarding the rates of litter production and recovery of the forest floor over a ninety-year rotation, the trends in productivity are indicative of differential effects following various harvest methods and rotation lengths.

The model results support the conclusion that the amount of wood left on a harvested site has a strong effect on the recovery of the organic content and nitrogen reserves in the forest floor.

Figure 9 illustrates the modeled response of the organic content of the forest floor following three types of harvest operations: clearcutting, whole-tree harvesting, and complete-tree harvesting.

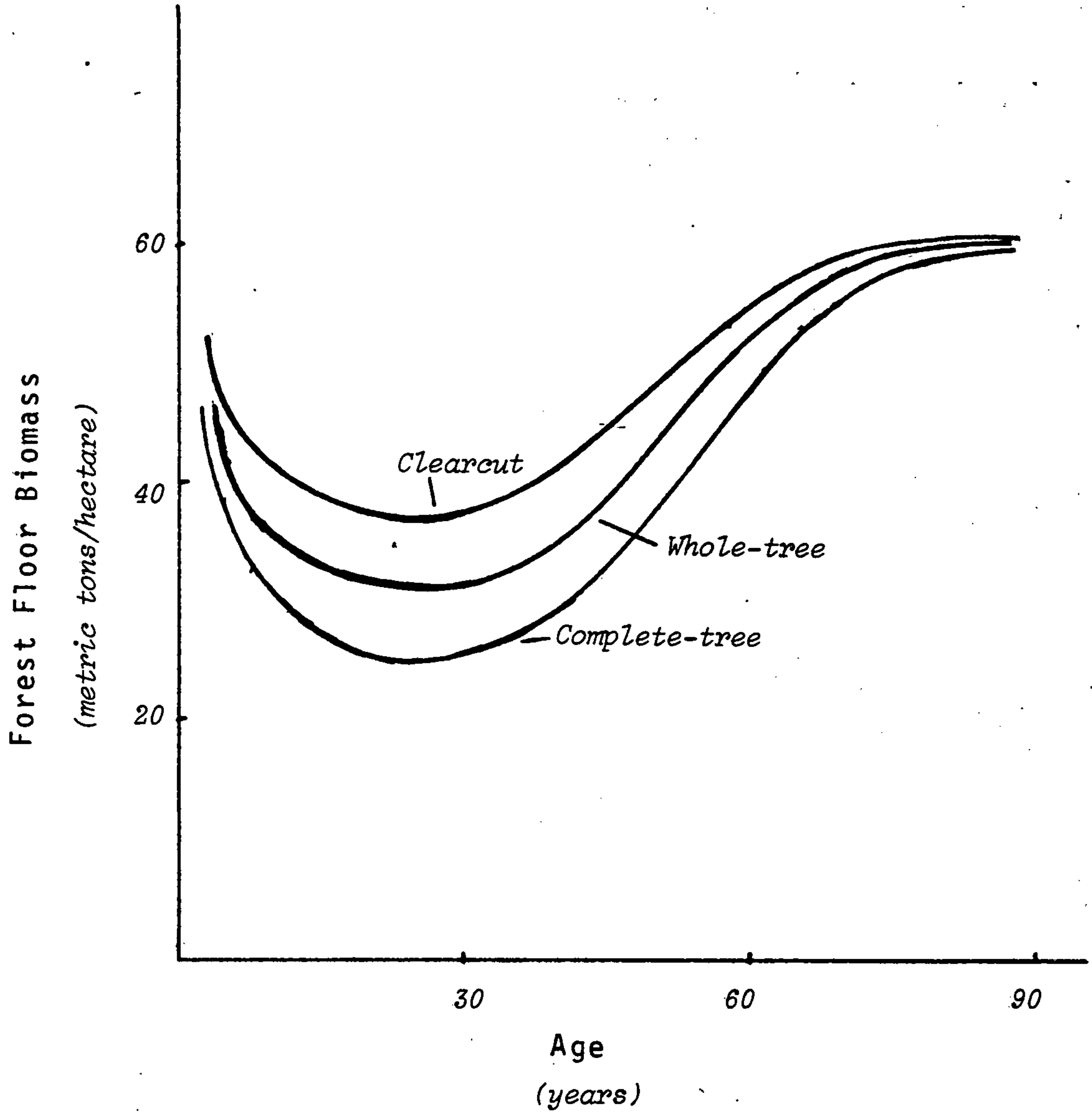
The same model was utilized to examine the effects of different harvest rotations. Figure 10 presents the modeled response of the forest floor to a conventional clearcut in comparison with whole- and complete-tree harvests of thirty-year rotations.

These results have significant implications for rotation lengths under various regimes. The reduction in the forest floor which occurs with more intensive utilization is likely to have large impacts on soil characteristics such as cation-exchange capacity and moisture retention, as well as nutrient availability.

The extended analysis includes the effects of different harvest techniques and rotation lengths on biomass productivity and yield in northern hardwood types (Aber, Botkin & Melillo 1979). This effort, drawing on previous research into forest successional productivity (Botkin, Janak & Wallis 1972) and the effects of nitrogen availability on forest growth (Mitchell & Chandler 1939), estimated that shortened rotations with intensive harvest techniques would significantly reduce both the productivity and the yield of the forest stand over a ninety-year period (see Table 24). These results were related to the depletion of available nitrogen stocks over the ninety-year period as illustrated in Figure 11. It is evident from the results presented in Table 24 that the length of rotation had the most noticeable influence on net productivity and, to a slightly lesser extent, on the harvest yield. The intensity of harvest appears to have only a weak influence on net productivity for any given rotation length and a somewhat stronger effect on the harvested yield.

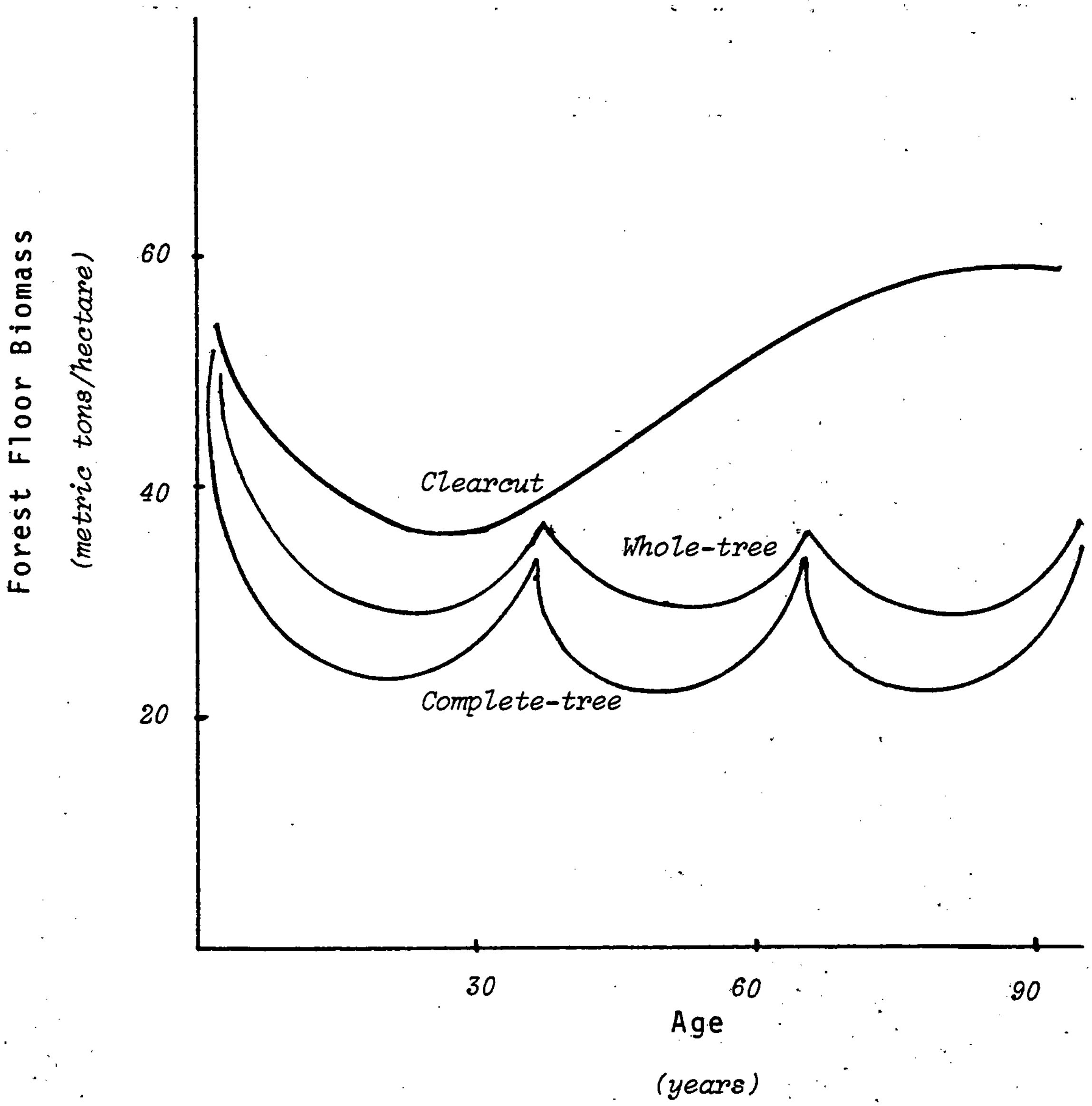
Several conservative assumptions involving rates of litter production and regeneration were made in the model which, if incorrect, would increase the severity of nitrogen depletion and further reduce forest growth. A variety of other factors, including social, economic, and technological variables, will influence the choice of harvest method and rotation length (Aber, Botkin & Melillo 1979). Fertilization may be a possible means of averting

FIGURE 9: COMPARISON OF PREDICTED TRENDS IN FOREST FLOOR BIOMASS FOLLOWING DIFFERENT CUTTING REGIMES



Note: The forest floor recovery following conventional clearcutting has been observed to require 60 to 90 years. Recovery following whole-tree and complete-tree harvests is assumed to be identical, in absence of evidence to the contrary.
Source: Aber, Botkin & Mellilo 1979.

FIGURE 10: COMPARISON OF ONE 90-YEAR CLEARCUT ROTATION WITH THREE 30-YEAR WHOLE-TREE AND COMPLETE-TREE FOREST ROTATIONS ON FOREST FLOOR BIOMASS



Source: Aber, Botkin & Mellilo 1979.

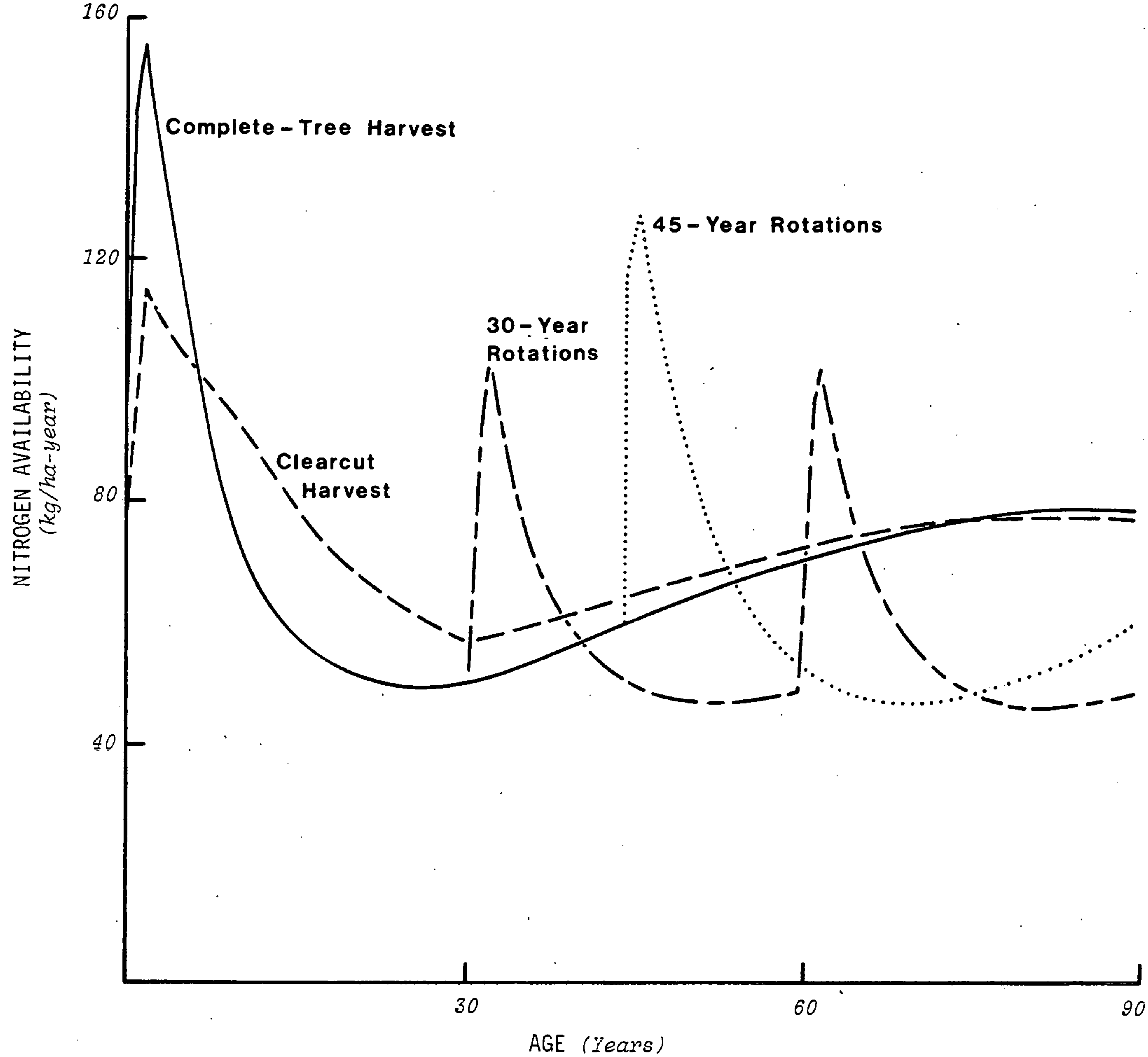
TABLE 24: ESTIMATES OF TOTAL PRODUCTION AND YIELD FOR SEVEN HARVESTING REGIMES[1]

Type of Harvest	Length of Rotations[2]	Total Net Production[3] *(metric tons/hectare)*	Total Yield[3] *(metric tons/hectare)*	Percent of Total Harvested
Clearcut	90 (1)	1090	154	14
Whole-tree	90 (1)	1120	197	18
Whole-tree	45 (2)	853	108	13
Whole-tree	30 (3)	478	93	19
Complete Forest	90 (1)	1055	252	24
Complete Forest	45 (2)	841	171	20
Complete Forest	30 (3)	476	150	32

1. *From forest floor - forest growth model.*
2. *Number in parentheses indicates number of rotations in 90-year period.*
3. *Total net production and yield in 90-year period.*

Source: Aber, Botkin, & Melillo 1979.

FIGURE 11: ESTIMATES OF NITROGEN AVAILABILITY FOLLOWING CLEARCUTTING AND COMPLETE-TREE HARVESTS



Source: Aber, Botkin & Melillo 1979

the problems associated with nitrogen depletion. In this case, however, both the timing of fertilizer application and the overall energy yield of the fuelwood operation would have to be carefully examined. In addition, the economic feasibility of the widespread use of forest fertilization is questioned by many researchers (Jorgenson, Wells & Metz 1975).

The remaining, significant uncertainties about the actual dynamics of the forest floor and its role in the utilization and conservation of nutrients dictate that further reseach be conducted to document the effect of perturbations in nutrient cycles on the productivity of the forest ecosystem. Such research can resolve many of the issues currently surrounding wood energy and has direct applicability to the broader questions surrounding intensive utilization of forest resources. The proposed wood-fired power plant would provide an opportunity to investigate and resolve these important problems.

SUMMARY

The proposed action will affect the terrestrial ecosystems of the plant site and the fuelwood harvest region. While the modifications to the plant site will be substantial, the areal extent of disturbance will be limited to several acres. The terrestrial ecology of the plant site is typical of disturbed areas throughout southern Maine and its disruption will not represent a significant loss to the region.

The effects of increased harvest activity will be largely determined by management practices chosen by individual landowners and the care with which logging contractors execute harvests. Choice of harvest system and the quality of the operation determine in large part the extent of erosion, changes in successional trends and species composition, and the impacts on wildlife populations.

As discussed earlier, harvest operations in Maine typically do not employ erosion control techniques and it is expected that additional soil erosion will occur as a result of increased harvesting activity in the region. Nonetheless, this erosion, while adverse, typically is of much smaller magnitude than that associated with other land uses such as farming.

Choice of harvest systems and the skill with which operations are planned will determine the changes in successional patterns in the region's forests which result from harvesting. The differential economics of harvesting operations indicate that independent loggers will choose to harvest initially those lands on which landowners will allow clearcutting. Choice of this harvest system will encourage the formation of early and mid-successional forest communities. Whole-tree harvests can also be employed in other harvest systems and may be used in the management of forest stands on a selective basis. In this case, the proposed action may contribute to the maintenance of late successional communities.

Choice of harvest system and the size of cuts will also determine the impacts of fuelwood harvesting on wildlife populations. To the extent that harvest operations create a patchwork of forest stands of varying age and species and thus create "edge habitat," many wildlife species will be favored. However, harvests that remove critical habitat areas, such as deer wintering yards, could negatively affect populations of species dependent on these areas. Increased use of dead and rotten trees may also impact certain bird and mammal populations. The bald eagle is the only endangered species known to occur in the terrestrial ecosystem of the fuelwood harvest region. Well-documented knowledge of the location and habitat requirements of bald eagles in Maine and an active restoration program should protect this species from any potentially adverse impacts of fuelwood harvesting.

Fuelwood harvesting can also impact the nutrient cycles and long-term productivity of the forest to be cut. Despite exensive research into the dynamics of nutrient cycles, considerable uncertainty remains over the effects of forest management practices on long-term forest productivity. Researchers have expressed concern over the continued availability of nitrogen, potassium, phosphorus, and calcium following repeated short- rotation, whole-tree removals of forest stands. Current research indicates that in New England, clearcutting with rotations of less than ninety years may result in reduced biomass production due to nitrogen depletion and reduction in the organic matter content of the forest floor. Further research and monitoring of the effects of the proposed action in the fuelwood harvest region will be undertaken as part of this effort to assess the viability of wood energy facilities.

REFERENCES

Aber 1978 — Aber, J.D., Professor, Department of Forestry, University of Wisconsin, Madison, WI. Telephone conversation (November 1978).

Aber, Botkin & Melillo 1978 — Aber, J.D.; Botkin, D.B.; and Melillo, J.M. "Predicting the Effects of Different Harvesting Regimes on Forest Floor Dynamics," Canadian Journal of Forest Research, vol. 8 (1978).

Aber, Botkin & Melillo 1979 — Aber, J.D.; Botkin, D.B.; and Melillo, J.M. "Predicting the Effects of Different Harvesting Regimes on Productivity and Yield," Canadian Journal of Forest Research, vol. 9 (1979).

Adamus & Clough 1976 — Adamus, P.R. and Clough, G.C. A Preliminary Listing of Noteworthy Natural Features in Maine, prepared for Maine Critical Areas Program, Maine State Planning Office, Augusta, ME (June 1976).

Alexander 1961 — Alexander, M. Introduction to Soil Microbiology (New York: John Wiley & Sons, 1961).

Art et al. 1974 — Art, H.W.; Bormann, F.H.; Voight, G.K.; and Woodwell, G.M. "Barrier Island Forest Ecosystem: The Role of Meteorological Nutrient Inputs," Science, 184 (1974).

Aubertin & Patric 1972 — Aubertin, G.M., and Patric, J.H. "Quality Water from Clearcut Forest Land," Northern Logger and Timber Processor 10(8) (1972).

Avery 1975 — Avery T.E. Natural Resources Measurements (New York: McGraw-Hill, 1975).

Bergston & Kilmer 1973	Bergston, G.W., and Kilmer, V.J. "Fertilizer and Water Quality Considerations for Agriculture and Forestry," in B. Berniek and C. H. Winget, eds., Forest Soils and Forest Land Management (Quebec: Les Presses de L'Universite Laval, 1973).
Bormann et al. 1970	Bormann, F.H.; Siccama, T.G.; Likens, G.E.; and Whittaker, R.H. "The Hubbard Brook Ecosystem Study: Composition and Dynamics of the Tree Stratum," Ecological Monographs 40 (4) (1970).
Bormann et al. 1974	Bormann, F.H.; Likens, G.E.; Siccama, T.G.; Pierce, R.S.; and Eaton, J.S. "The Export of Nutrients and Recovery of Stable Conditions Following Deforestation at Hubbard Brook," Ecological Monographs 44 (3) (1974).
Bormann, Likens & Melillo 1977	Bormann, F.H.; Likens, G.E.; and Melillo, J.M. "Nutrient Budget for an Aggrading Northern Hardwood Forest Ecosystem," Science 196 (1977).
Botkin, Janak & Wallis 1972	Botkin, D.B.; Janak, J.F.; and Wallis, J.R. "Some Ecological Consequences of a Computer Model of Forest Growth," Journal of Ecology 60 (1972).
Bourassa 1978	Bourassa, G., Director of Utilization and Marketing Division, Bureau 4, Maine Department of Conservation, Augusta, ME. Meeting (August 26, 1978).
Boyle, Phillips & Ek 1973	Boyle, J.R.; Phillips, J.J.; and Ek, A.R. "Whole-tree Harvesting: Nutrient Budget Evaluation," Journal of Forestry 71 (1973).
Boyle 1976	Boyle, J.R. "A System for Evaluating Potential Impacts of Whole-tree Harvesting on Site Quality," TAPPI vol. 59(7) (1976).
Brady 1974	Brady, N.C. The Nature and Properties of Soils, 8th edition, (New York: Macmillan Publishing Co., 1974).

Brown 1978	Brown, L. Botanical Survey of S.D. Warren Property Westbrook, Maine, prepared for the Thayer School of Engineering, Dartmouth College, Hanover, NH (1978).
Brown & Sheu 1975	Brown, C.B., and Sheu, M.S. "Effects of Deforestation on Slopes," Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, 101(GP2), paper 11141 (February 1975).
Buol, Hole & McCracken 1973	Buol, S.W.; Hole, F.D.; and McCracken, R.J. Soil Genesis and Classification (Ames: Iowa State University Press, 1973).
Campbell, Willis & May 1973	Campbell, R.G.; Willis, J.R.; and May, J.T. "Soil Disturbance by Logging with Rubber-tired Skidders," Journal of Soil and Water Conservation 28(5) (1973).
Carpenter & Siegler 1974	Carpenter, R.G., and Siegler, H.R. A List of New Hampshire Mammals and Their Distribution, New Hampshire Fish and Game Department, Concord, NH (1974).
Conant 1975	Conant, Roger. A Field Guide to Reptiles and Amphibians of Eastern and Central North America, 2nd edition (Boston: Houghton-Mifflin Company, 1975).
Conner & Adkisson 1975	Conner, R.N., and Adkisson, C.S. "Effects of Clearcutting on the Diversity of Breeding Birds," Journal of Forestry, 73(12) (1975).
Conway 1976	Conway, Steve. Logging Practices: Principles of Timber Harvesting Systems (San Francisco, CA: Miller Freeman Publications Inc., 1976).
Curlin 1970	Curlin, J.W. "Nutrient Cycling as a Factor in Site Productivity and Forest Fertilization," in C.T. Youngberg and C.B. Davey, eds., Tree Growth and Forest Soils (Corvallis: Oregon State University Press, 1970).

Czapowskyj, Rourke & Frank 1977	Czapowsky, M.M.; Rourke, R.V.; and Frank, R.M. Strip Clearcutting Did Not Degrade the Site in a Spruce-Fir Forest in Central Maine, Research Paper NE-367, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Forest Service, Broomall, PA (1977).
Dashnaw 1978	Dashnaw, H.N., Owner, Dashnaw Lumber, Peru, NY. Telephone conversation (November 30, 1978).
Daubenmire 1978	Daubenmire, R. Plant Geography (New York: Academic Press, 1978).
Davis 1966	Davis, R.B. "Spruce-fir Forests of the Coast of Maine," Ecological Monographs, 36 (1966).
Dickerson 1976	Dickerson, B.P. "Soil Compaction After Tree Length Skidding in Northern Mississippi," Journal of the Soil Science Society of America 40 (6) (1976).
Dissmeyer 1978	Dissmeyer, George, Staff Hydrologist, Southeastern Area, U.S. Forest Service, Atlanta, GA. Telephone conversation (November 1, 1978).
Dominski 1971	Dominski, A.S. "Nitrogen Transformations in a Northern Hardwood Podzol on Cutover and Forested Sites," Ph.D. thesis, School of Forestry and Environmental Studies, Yale University, New Haven, CT (1971).
Dyer 1979	Dyer, R., Botanist, U.S. Fish and Wildlife Service, Newton Corners, MA. Telephone conversation (April 2, 1979).
Eastman 1977	Eastman, L.M. "Small Whorled Pogonia, Isotaria medeoloides (Pursh) Raf., in Maine, and its Relevance to the Critical Areas Program," Maine Critical Areas Program, State Planning Office, Augusta, ME (1977).
Eaton, Likens & Bormann 1973	Eaton, J.S.; Likens, G.E.; and Bormann, F.H. "Throughfall and Streamflow Chemistry in a Northern Hardwood Forest," Journal of Ecology 61(2) (1973).

Epstein 1972 — Epstein, E. Mineral Nutrition of Plants: Principles and Perspectives (New York: John Wiley and Sons, 1972).

Ferguson & Kingsley 1972 — Ferguson, Roland H., and Kingsley, Neal P. The Timber Resources of Maine, Resource Bulletin NE-26, U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1972).

Ferwerda 1978 — Ferwerda, J., State Soil Scientist, U.S. Department of Agriculture, Orono, ME. Letter (October 1978).

Flaccus 1959 — Flaccus, E. "Landslides and Their Revegetation in the White Mountains of New Hampshire," Ph.D. thesis, Department of Biology, Duke University, Durham, NC (1959).

Forcier 1975 — Forcier, L.K. "Reproductive Strategies and the Co-occurence of Climax Tree Species," Science 189 (1975).

Foster & Gessel 1972 — Foster, N.W., and Gessel, S.P. "The Natural Addition of Nitrogen, Potassium, and Calcium to a Pinus banksania lamb Forest Floor," Canadian Journal of Forest Research 2 (1972).

FRG 1978 — New Hampshire Forest Resources Group. Forests and Forestry in New Hampshire, Society for the Protection of New Hampshire Forests, Concord, NH (1978).

Frink & Voigt 1976 — Frink, C.R. and Voigt, G.K. "Potential Effects of Acid Precipitation on Soils in the Humid Temperate Zone," in Proceedings of The First International Symposium on Acid Precipitation and the Forest Ecosystem, General Technical Report NE-23, Northeastern Forest Experiment Station, U.S. Department of Agriculture, Forest Service, Broomall, PA (1976).

Froehlich 1978

Froehlich, Henry. Soil Compaction from Low Ground-pressure, Torsion-suspension Logging Vehicles on Three Forest Soils, Research Paper 36, Forest Research Laboratory, Oregon State University, Corvallis, OR (1978).

Gauch 1972

Gauch, H.G. Inorganic Plant Nutrition (Stroudsburg, PA: Hutchinson and Ross, Inc., 1972).

Gill & Vanden Berg 1967

Gill, William R., and Vanden Berg, Glen E. Soil Dynamics in Tillage and Traction Agriculture Research Service, Agriculture Handbook No. 316, U.S. Department of Agriculture, Washington, DC (1967).

Gosz, Likens & Bormann 1972

Gosz, J.R.; Likens, G.E.; and Bormann, F.H. "Nutrient Content of Litter Fall on the Hubbard Brook Experimental Forest, New Hampshire," Ecology 53:769 (1972).

Gosz, Likens & Bormann 1973

Gosz, J.R.; Likens, G.E.; & Bormann, F.H. "Nutrient Release from Decomposing Leaf and Branch Litter in the Hubbard Brook Forest, New Hampshire," Ecological Monographs 43(2) (1973).

Gosz, Likens & Bormann 1976

Gosz, J.R.; Likens, G.E.; and Bormann, F.H. "Organic Matter and Nutrient Dynamics of the Forest and Forest Floor in the Hubbard Brook Forest," Oecologia 22 (1976).

Gramlich 1979

Gramlich, F., Wildlife Biologist, U.S. Fish and Wildlife Service, Augusta, ME. Telephone conversation (March 29, 1979).

Granskog & Siegel 1978

Granskog, J.E., and Siegel, W.C. "Legal Distinction Between Employee and Independent Contractor as Applied to Collective Bargaining Activities in Timber Harvesting," Forest Producers Journal 28 (9) (1978).

Hall et al. 1976	Hall, E.H.; Allen, C.M.; Ball, D.A.; Burch, J.E.; Conkle, H.N.; Lawhon, W.T.; Thomas, T.J.; and Smithson, G.R. Comparison of Fossil and Wood Fuels, EPA-600/2-76-056, Battelle-Columbus Laboratories, Columbus, OH (1976).
Hart 1961	Hart, G. "Humus Depths Under Cut and Uncut Northern Hardwood Forests," Research Note 113, U. S. Department of Agriculture, Forest Service, Forest Science Laboratory, Durham, NH (1961).
Hartung & Kress 1977	Hartung, R.E., and Kress, J.M. Woodlands of the Northeast: Erosion and Sediment Control Guides, U.S. Department of Agriculture, Soil Conservation Service and Forest Service Offices, Broomall, PA (1977).
Hatchell & Ralston 1971	Hatchell, G.E., and Ralston, C.W. Natural Recovery of Surface Soils Disturbed in Logging, Free Planters Notes 22, U.S. Department of Agriculture, Forest Service, Washington, DC (1971).
Hausenbuiller 1972	Hausenbuiller, R.L. Soil Science: Principles and Practices (Dubuque: Wm. C. Brown Co., 1972).
Henderson & Harris 1975	Henderson, G.S., and Harris, W.F. "An Ecosystem Approach to Characterization of the Nitrogen Cycle in a Decidous Forest Watershed," in B. Bernier and C.H. Winget, eds., Forest Soils and Forest Land Management (Quebec: Les Presses de L'Universite Laval, 1975).
Hillstrom & Steinhilb 1976	Hillstrom, W.A., and Steinhilb, Helmuth M. "Mechanized Thinning Shows Promise in Northern Hardwoods," Northern Logger 24 (12) (1976).

Hoeman 1977	Hoeman, G.T. "The Effects of Mechanized Harvesting on Site and Soil Conditions in the Spruce-Fir Region of North-Central Maine," unpublished M.S. Thesis, School of Forestry and Environmental Studies, University of Maine, Orono, ME (1977).
Hornbeck 1977	Hornbeck, J.W. "Nutrients: A Major Consideration in Intensive Forest Management," in <u>Proceedings of Symposium on Intensive Culture of Northern Hardwoods</u>, Technical Report NE-29, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1977).
Hornbeck 1978	Hornbeck, J.W., Principal Forest Hydrologist, Forest Science Laboratory, Durham, NH. Telephone conversation (November 28, 1978).
Hornbeck & Reinhart 1964	Hornbeck,. J.W., and Reinhart, K.G. "Water Quality and Soil Erosion as Affected by Logging in Steep Terrain," <u>Journal of Soil and Water Conservation</u> 19(1) (1964).
Hornbeck et al. 1975	Hornbeck, J.W.; Likens, G.E.; Pierce, R.S.; and Bormann, F.H. "Strip Cutting as a Means of Protecting Site and Streamflow Quality when Clearcutting Northern Hardwoods," in B. Bernier and C. H. Winget, eds., <u>Forest Soils and Forest Land Management</u> (Quebec: Les Presses de L'Universite Laval, 1975).
Hornbeck, Likens and Eaton 1977	Hornbeck, J.W.; Likens, G.E.; and Eaton, J.S. "Seasonal Patterns in Acidity of Precipitation and their Implications for Forest Stream Ecosystems," <u>Water, Air, and Soil Pollution</u> 7 (1977).
Hovland 1978	Hovland, Bruce, Forester, Society for the Protection of New Hampshire Forests, Concord, NH. Meeting (August 7, 1978).

Hoyle 1973 — Hoyle, M.C. Nature and Properties of Some Forest Soils in the White Mountains of New Hampshire, Research Paper NE-260, U.S. Department of Agriculture, Forest Service, Broomall, PA (1975).

International 1978 — International Harvester. Forestry Guide, International Harvester, Chicago, IL (1978).

John Deere 1978 — John Deere, Inc. Equipment Purchasing Guide for 1978: Forestry, John Deere, Moline, IL (1978).

Johnson & Swank 1973 — Johnson, P.L., and Swank, W.T. "Studies of Cation Budgets in the Southern Appalachians on Four Experimental Watersheds with Contrasting Vegetation," Ecology 54 (1) (1973).

Jorgensen, Wells & Metz 1975 — Jorgensen, J.R.; Wells, C.G.; and Metz, L.J. "The Nutrient Cycle: Key to Continuous Forest Production," Journal of Forestry 73 (1975).

Kingsley 1976 — Kingsley, Neal P. The Forest Resources of New Hampshire, Resource Bulletin NE-43, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1976).

Kingsley & Birch 1977 — Kingsley, Neal P., and Birch, T.W. The Forest Landowners of New Hampshire and Vermont, Resource Bulletin NE-51, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1977).

Kochenderfer 1970 — Kochenderfer, J.N. Erosion Control on Logging Roads in the Appalachians, Research Paper NE-158, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1970).

Leonard 1961	Leonard, R.E. Interception of Precipitation by Northern Hardwoods, Station Paper #159, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1961).
Likens & Bormann 1970	Likens, G.E., and Bormann, F.H. "Chemical Analysis of Plant Tissues from the Hubbard Brook Ecosystem in New Hampshire," Bulletin Number 79, School of Forestry and Environmental Studies, Yale University, New Haven, CT (1970).
Likens, Bormann & Johnson 1969	Likens, G.E.; Bormann, F.H.; and Johnson, N.M. "Nitrification: Importance to Nutrient Losses from a Cutover Forested Ecosystem," Science 163 (3872) (1969).
Likens et al. 1967	Likens, G.E.; Bormann, F.H.; and Johnson, N.M.; and Pierce, R.S. "The Calcium, Magnesium, Potassium, and Sodium Budgets for a Small Forested Ecosystem," Ecology 48 (1967).
Likens et al. 1970	Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; and Pierce, R.S. "Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-ecosystem," Ecological Monographs 10 (1) (1970).

Likens et al. 1976	Likens, G.E.; Bormann, F.H.; Eaton, H.S.; Pierce, R.S.; and Johnson, N.M. "Hydrogen Ion Input to the Hubbard Brook Experimental Forest, New Hampshire, during the Last Decade," in Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem, Gen. Tech. Report NE-23, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1976).
Likens et al. 1977	Likens, G.E.; Bormann, F.H.; Pierce, R.S.; Eaton, J.S.; and Johnson, N.M. Biogeochemistry of a Forested Ecosystem (New York: Springer-Verlag, 1977).
Likens et al. 1978	Likens, G.E.; Bormann, F.H.; Pierce, R.S.; and Reiners, W.A. "Recovery of a Deforested Ecosystem," Science 199 (1978).
Lynch, Corbett & Hutnik 1975	Lynch, J.A.; Corbett, E.S.; and Hutnik, R.J. Clearcutting in Pennsylvania (State College, PA: Pennsylvania State University Press, 1975).
Mace, Williams & Tappeiner 1971	Mace, Arnett, C., Jr.; Williams, Thomas; and Tappeiner, John C. "Effects of Winter Harvesting Methods on Soil Bulk Density and Infiltration Rates," Minnesota Forestry Research Notes No. 228, College of Forestry, University of Minnesota, St. Paul, MN (1971)
Marks 1974	Marks, P.L. "The Role of Pin Cherry (Prunus pensylvanica L.) in the Maintenance of Stability in Northern Hardwood Ecosystems," Ecological Monographs 44 (1) (1974).

Marks 1975	Marks, P.L. "On the Relation between Extension Growth and Successional Status of Deciduous Trees of the Northeastern United States," Torry Botanical Club Bulletin 102, Department of Biological Sciences, State University College, Brockport, NY (1975).
Marks & Bormann 1972	Marks, P.L., and Bormann, F.H. "Revegetation Following Forest Cutting: Mechanisms for Return to Steady-state Nutrient Cycling," Science 176 (1972).
McElroy et al. 1975	McElroy, M.N.; Chiy, S.Y.; Nebgen, J.N.; Aleti, A.; and Vandergrift, H.E. "Water Pollution From Nonpoint Sources," Water Research 9(7)(1975).
McKinnon, Hyde & Cline 1935	McKinnon, G.S.; Hyde, G.R.; and Cline, A.C. "Cut-over Field Pine Land in Central New England," Harvard Forest Bulletin, no. 18. Petersham, MA (1935).
MDIFW 1976	Maine Department of Inland Fisheries and Wildlife. Maine's Wildlife Management Program, MDIFW, Augusta, ME (Fall 1976).
MDNR 1975	Michigan Department of Natural Resources. Michigan Soil Erosion and Sedimentation Control Guidebook, MDNR, Lansing, MI (1975).
Mitchell & Chandler 1939	Mitchell, H.L., and Chandler, R.F. The Nitrogen Nutrition and Growth of Certain Deciduous Trees of Northeastern United States, Black Rock Forest Bulletin 11, Harvard University Black Road Forest, Cornwall-on-the-Hudson, NY (1939).
MLURC 1978a	Maine Land Use Regulation Commission. A Survey of Erosion and Sedimentation Problems Associated with Logging in Maine: Preliminary Draft, MLURC, Augusta, ME (December 1978).

MLURC 1978b	Maine Land Use Regulation Commission. Draft, 208 Preliminary Non-Point Source Assessment Report, MLURC, Augusta, ME (January 1978).
Munns 1978	Munns, Dennis, John Deere Engineering Division, Dubuque, IA. Telephone conversation (October 23, 1978).
Nelson, Switzer & Smith 1976	Nelson, L.E.; Switzer, G.L.; and Smith, W.H. "Dry Matter and Nutrient Accumulation in Young Loblolly Pine (Pinus taeda, L.)," in C.T. Youngberg and C.B. Davey, eds., Tree Growth and Forest Soils (Corvallis: Oregon State University Press, 1976).
Nickerson 1979	Nickerson, Paul, Senior Staff Specialist, U.S. Fish and Wildlife Service, Newton Corners, Ma. Telephone converstation (April 2, 1979).
Odum 19717	Odum, Eugene P. Fundamentals of Ecology, 3rd ed. (Philadelphia: W.D. Sanders Co., 1971).
Patric 1976	Patric, J.H. "Soil Erosion in the Eastern Forest," Journal of Forestry 74 (1976).
Patric 1977	Patric, J.H. "Soil Erosion and its Control in Eastern Woodlands," Northern Logger and Timber Processor (May 1977).

Pennock et al. 1975 — Pennock, R., Jr.; Wood, G.W.; Shogren, P.W. Jr.,; Reinhart, K.G.; Miles, V.C.; and Younkin, P. "The Forest Soil," in E.S. Corbett, ed., Clearcutting in Pennsylvania, School of Forest Resources, College of Agriculture, Pennsylvania State University, University Park, PA (1975).

Percival 1978 — Percival, Dave, Owner, Percival Logging Company, Andover, ME. Meeting (June 20. 1978).

Pierce et al. 1970 — Pierce, R.S.; Hornbeck, J.W.; Likens, G.E.; and Bormann, F.H. "Effects of Elimination of Vegetation on Stream Water Quantity and Quality," in International Symposium on Results of Research on Representative and Experimental Basins, International Association of Science of Hydrology, Wellington, New Zealand (1970).

Pierce et al. 1972 — Pierce, R.S.; Martin, C.W.; Reeves, C.C.; Likens, G.E.; and Bormann, F.H. "Nutrient Loss From Clearcuttings in New Hampshire," in S.C. Csallany, T.G. McLaughlin, and W.D. Striffer, eds., Watersheds in Transition (Urbana, IL: American Water Resources Association, 1972).

Pilgrim & Harter 1977 — Pilgrim, S.A.L., and Harter, R.D. Spodic Horizon Characteristics of Some Forest Soils in the White Mountains, New Hampshire, Station Bulletin 307, New Hampshire Agricultural Experiment Station, University of New Hampshire, Durham, NH (1977).

Rice, Rothacher & Megahan 1972	Rice, R.M.; Rothacher, J.S.; and Megahan, W.F. "Erosional Consequences of Timber Harvesting: An Appraisal," in Watersheds in Transition, S.C. Csallany, T.G. McLaughlin, and W.D Striffer, eds., Proceedings of the Fort Collins, CO Symposium. (Urbana: American Water Resources Association, 1972).
Rich 1978	Rich, J. Phillip. "Identification of Sequential Harvesting Procedure, Preliminary Draft," J.P.R. Associates, Stowe, VT (1978).
Richardson & Lund 1974	Richardson, C.J., and Lund, J.D. "Effects of Clearcutting on Nutrient Losses in Aspen Forests on Three Soil Types in Michigan," in F.G. Howell, J.B. Gentry, and M.H. Smith, eds., Mineral Cycling in Southeastern Ecosystems, National Technical Information Service, Springfield, VA (1974).
Roach 1974	Roach, B.A. "Scheduling Timber Cutting for Sustained Yield of Wood Products and Wildlife," General Technical Report NE-14, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, PA (1974).
Robbins, Bruun & Zim 1966	Robbins, C.S.; Bruun, B.; and Zim, H.S. Birds of North America (New York: Golden Press, 1966).
Roskoski 1977	Roskoski, J.P. "Nitrogen Fixation in Northern Hardwood Forests," Ph.D. thesis, School of Forestry and Environmental Studies, Yale University, New Haven, CT (1977).

Scott et al. 1977	Scott, V.E.; Evans, K.E.; Patton, D.R.; and Stone, C.P. Cavity-Nesting Birds of North American Forests, Agriculture Handbook 511, U.S. Department of Agriculture, Forest Service, Washington, DC (1977).
SCS 1952	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of York County, Maine (Washington: U.S. Government Printing Office, 1952).
SCS 1968	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Belknap County, New Hampshire (Washington: U.S. Government Printing Office, 1968).
SCS 1970	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Androscoggin and Sagadahoc Counties, Maine (Washington: U.S. Government Printing Office, 1970).
SCS 1973	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Strafford County, New Hampshire (Washington: U.S. Government Printing Office, 1973).
SCS 1974	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey: Cumberland County, Maine (Washington: U.S. Government Printing Office, 1974).
SCS 1975	U.S. Department of Agriculture, Soil Conservation Service. Soil Taxonomy, Agriculture Handbook no. 436 (Washington: U.S. Government Printing Office, 1975).
SCS 1977a	U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Carroll County, New Hampshire (Washington: U.S Government Printing Office, 1977).
SCS 1977b	U.S. Department of Agriculture, Soil Conservation Service. Statewide Set of Brief Soil Descriptions - Maine Agricultural Experiment Station, Orone, ME (1977).

SCS 1977c — U.S. Department of Agriculture, Soil Conservation Service, Engineering Division and Ecological Sciences and Technology Division. Procedure for Computing Sheet and Rill Erosion on Project Areas, Technical Reference No. 5 (Rev.2), SCS, Washington, DC (September 1977).

SCS 1977d — U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Carroll County, New Hampshire (Washington: U.S. Government Printing Office, 1977).

SCS 1978 — U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Kennebec County, Maine (Washington: U.S. Government Printing Office, 1978).

Sewall 1978 — James W. Sewall Company. Preliminary Biomass and Volume Estimates for Westbrook Study Area 1978, James W. Sewall Co., Old Town, ME (1978).

Smith 1962 — Smith, D.M. The Practice of Silviculture, (New York: John Wiley & Sons, Inc., 1962).

Smith 1976 — Smith, W.H. "Character and Significance of Forest Tree Root Exudates," Ecology 57 (1976).

Squires 1979 — Squires, Thomas, Marine Scientist, Maine Department of Marine Resources, Augusta, ME. Letter (April 10, 1979).

Stone 1973 — Stone, Earl C. The Impact of Timber Harvest on Soils and Water, Report of President's Advisory Panel on Timber and the Environment, Appendix M, U.S. Government Printing Office, Washington, DC (1973).

Swanston & Dyrness 1973 — Swanston, D.N., and Dyrness, C.T. "Stability of Steep Land," Journal of Forestry 71 (1973).

Switzer & Nelson 1973	Switzer, G.L. and Nelson, E.L. "Maintenance of Productivity Under Short Rotations," in Proceedings of the Conference of International Union of Forest Research Organizations, IUFRO Secretariat, Wien, Austria (1973).
Switzer, Nelson & Hinesley 1978	Switzer, G.L.; Nelson, E.L.; and Hinesley, L.E. "Effects of Utilization on Nutrient Regimes and Site Productivity," in Charles W. McMillin, ed., Complete Tree Utilization of Southern Pine (Madison, WI: Forest Products Research Society, 1978).
Todd, Waide & Cornaby 1974	Todd, R.L.; Waide, J.B.; and Cornaby, B.W. "Significance of Biological Nitrogen Fixation and Denitrification in a Deciduous Forest Ecosystem," in F.G. Howell, J.B. Gentry, and M.H. Smith, eds., Mineral Cycling, in Southeastern Ecosystems, National Technical Information Service, Springfield, Va (1974).
USDA 1977	U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Final Environmental Impact Statement Clear Creek Planning Unit Land-Use Plan, USDA-FS-R6-FES (Adm)-75-08, U.S. Forest Service, Washington, DC (1977).
USFS 1974	U.S. Department of Agriculture, Forest Service. The Outlook for Timber in the U.S., Forest Resource Report No. 20 (Washington: U.S. Government Printing Office, 1974).
USFWS 1978	U.S. Department of Interior, Fish and Wildlife Service. "List of Endangered and Threatened Wildlife and Plants," Federal Register, Part III (December 11, 1978).

Wackerman, Hagenstein & Mitchell 1966	Wackerman, A.E.; Hagenstein, W.D.; and Mitchell, A.S. Harvesting Timber Crops (New York: McGraw-Hill, Inc., 1966).
Waide & Swank 1975	Waide, J.B., and Swank, W.T. "Nutrient Recycling and the Stability of Ecosystems: Implications for Forest Management in the Southeastern U.S.," presented at the Society of American Foresters annual meeting, Washington, DC (September 1975).
Webb 1973	Webb, W.L. "Timber and Wildlife," Appendix N, Report of the President's Advisory Panel on Timber and the Environment, Office of the President, Washington, DC (April 1973).
Weetman & Webber 1972	Weetman, G.F., and Webber, B. "The Influence of Wood Harvesting on the Nutrient Status of Two Spruce Stands," Canadian Journal of Forest Research 2 (1972).
Weitzman & Trimble 1955	Weitzman, S., and Trimble, G.R., Jr. "Integrating Timber and Watershed Management in Mountain Areas," Journal of Soil and Water Conservation 10(2) (1955).
Westveld 1956	Westveld, M. "Natural Forest Vegetation Zones of New England," Journal of Forestry 54 (1956).
White 1974	White, E.H. "Whole-tree Harvesting Depletes Soil Nutrients," Canadian Journal of Forest Research 4 (1974).
White 1976	White, P.S. "The Upland Forest Vegetation of the Second College Grant, New Hampshire," Ph.D. thesis, Department of Biology, Dartmouth College, Hanover, NH (1976).
Whitlock 1978	Whitlock, Tim, Eaton-Yale Company Engineering Division, Ontario, Canada. Telephone conversation (October 3, 1978).
Whittaker 1975	Whittaker, R.H. Communities and Ecosystems (New York: Macmillan Publishing, 1975).

Whittaker et al. 1974	Whittaker, R.H.; Bormann, F.H.; Likens, G.E.; and Siccama, T.G. "The Hubbard Brook Ecosystem Study: Forest Biomass and Production," Ecological Monographs 44 (1974).
Wilde 1958	Wilde, S.A. Forest Soils (New York: Roland Press Co., 1958).
Wischmeier 1975	Wischmeier, Walter H. "Estimating the Soil Loss Equation's Cover and Management Factors for Undisturbed Acres," Present and Prospective Technology for Predicting Sediment Yields and Sources, Agriculture Research Service S-40, U.S. Department of Agriculture, Washington, DC (1975).
Wischmeier & Smith 1965	Wischmeier, Walter H. and Smith, Dwight, D. Predicting Rainfall Erosion Losses From Cropland East of the Rocky Mountains, Agriculture Handbook No. 282, U.S. Department of Agriculture, Washington, DC (1965).
Wollum & Davey 1975	Wollum, A.G., and Davey, C.B. "Nitrogen Accumulation, Transformation and Transport in Forest Soils," in B. Bernier and C.H. Winget, eds., Forest Soils and Forest Land Management" (Quebec: Les Presses de L' Universite Laval, 1975).
Zasada 1975	Zasada, Z.A. "Timber Harvesting Effect on Forest and Silvicultural Practices," Intensive Forest Management Conference, Report No. 22, College of Forestry, University of Minnesota, St. Paul, MN (1975).
Zumbo 1978	Zumbo, Jim. "Impacts of the Wood-for-Energy Push," American Forest 84 (10) (October 1978).