

Managing Soil Quality in Forests



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Managing Soil Quality in Forests

- Landforms and soils where forests typically occur
- Management impacts on soils, and mitigations
- Guidelines and tools for sustainable management



Forest soils compared with agricultural soils

More likely to have these characteristics:

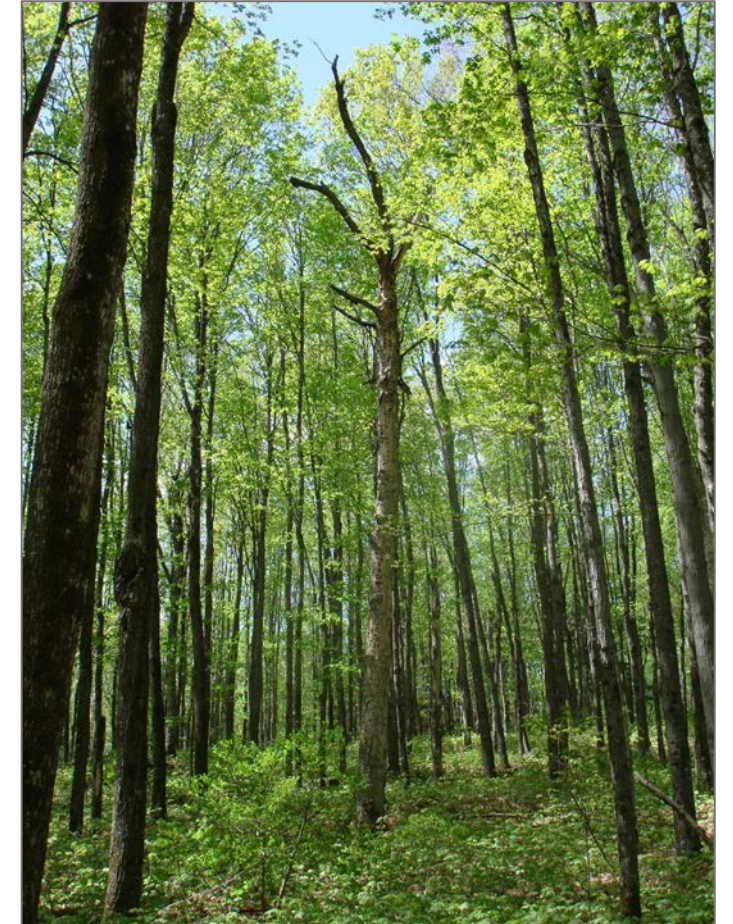
- Rocky/shallow
- Hardpan/fragipan
- Steep, often dissected terrain
- Wet, or dry
- Lower fertility
- Unfavorable climate
- Degraded
- Trees in the way
- Variable



Forestry and agriculture – soil management issues

Mutual issues:

- Compaction
- Erosion
- Nutrient supply
- Organic matter
- Soil biota
- Effects of invasive species
- Atmospheric deposition
- Climate change



Forest soils – environmental services

- Water cycle – infiltration, purification
- Decomposition, nutrient cycling
- Carbon sequestration and storage
- Productivity/sustainability to support humans and wildlife



Desirable characteristics of forest soils

- Texture and structure that provides for aeration and water movement.
- Organic matter and nutrients.
- Moderately deep or deeper rooting zone.
- Not readily susceptible to damage from management or natural disturbance.
- Active soil biota suited to the site.



*You can't always
get what you
want...*



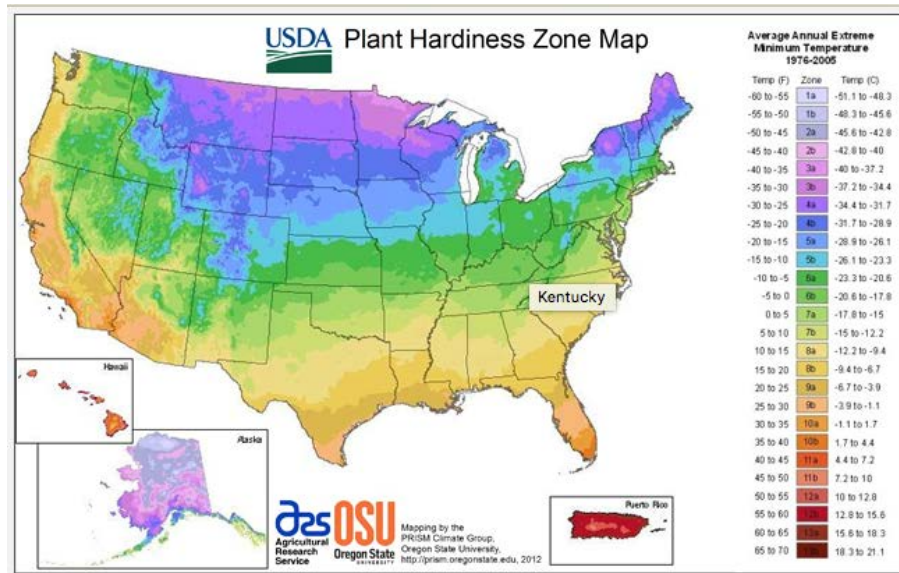
Indicators of forest soil quality

- Herbaceous and midstory vegetation suited to site
- Height and quality of trees (sometimes)
- Woody debris in appropriate amounts
- Forest floor and A horizon
- Soil and forest floor organisms



Forest soil management issues

- Physical effects
- Chemical changes
- Biological changes
- Disturbance
- The future



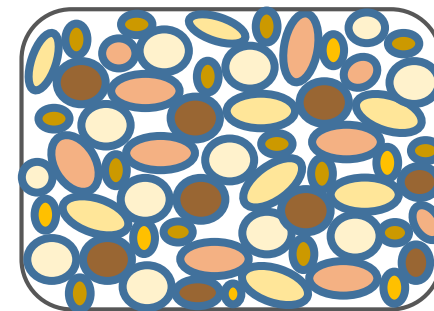
E. P.oley



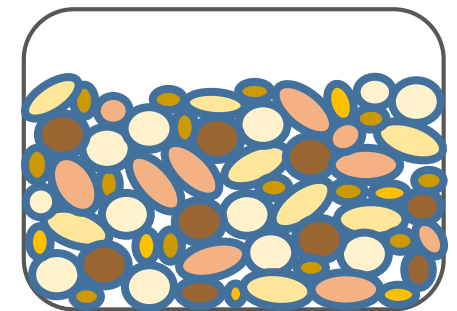
C. Hardin

Compaction

- Increase in bulk density from loads applied to the soil.
- Caused by movement of heavy equipment during felling, processing, forwarding, skidding and site preparation.
- Soil volume decreased by compression of macropores.
- Inhibits root access to gas exchange – impacts seedling establishment and tree growth.
- Slows moisture infiltration and drainage
- Degree and duration of compaction, and effects on tree growth, are dependent on climate, moisture regime, soil texture, structure, and organic matter content.



Not compacted



Compacted

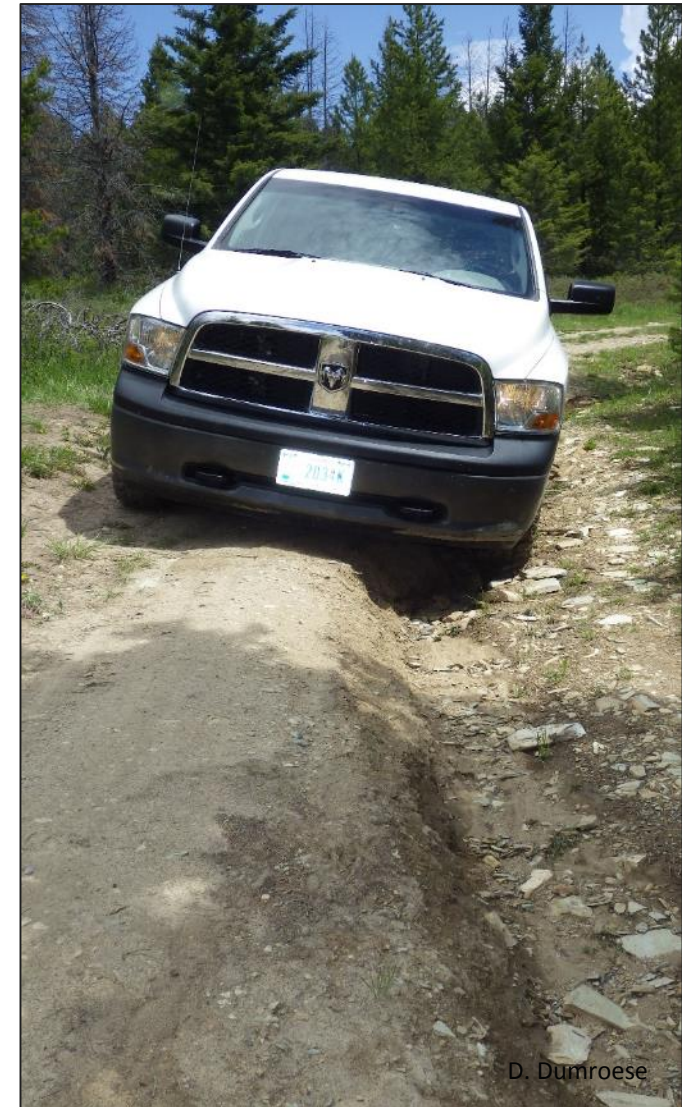
Rutting

- Depressions made by equipment, usually under wet conditions, when soil strength is not sufficient to support vehicle traffic.
- Disrupts surface water flows; can block drainages and pool water, or drain water away from the site.
- Damages roots.
- Compacts soils, with effects on aeration, infiltration, etc.
- Can lead to puddling (soil particles dispersed in water; after drying and settling, the smaller particles form a crust).



Erosion and sedimentation

- Not always a problem in forests – where forest vegetation is healthy, roots hold soil in place.
- Most erosion is associated with roads and major trails.
- Areas with steep topography, shallow bedrock, and erodible soils are at greater risk.
- Removes nutrients and organic matter from the site.
- Channelized flows remove moisture from the site rapidly.
- Tree roots can be exposed.
- Sediment is detrimental to water, wetlands, and sensitive vegetation.
- Thickets of invasive brush sometimes block light to the forest floor, leaving the soil bare and contributing to erosion.



D. Dumroese

Displacement

- Surface layers are removed during mechanical operations; exposed areas revegetate slowly due to loss of nutrients and organic matter.
- Exposed soils can experience further degradation due to wind and water erosion.
- During mechanical site preparation where displacement is of concern, remove only the amount of surface soil needed to establish seedlings; monitor and follow up as needed.



Soils particularly susceptible to physical damage

Wet and organic soils

- Low bearing strength increases risk of compaction, rutting, surface displacement; also susceptible to windthrow.

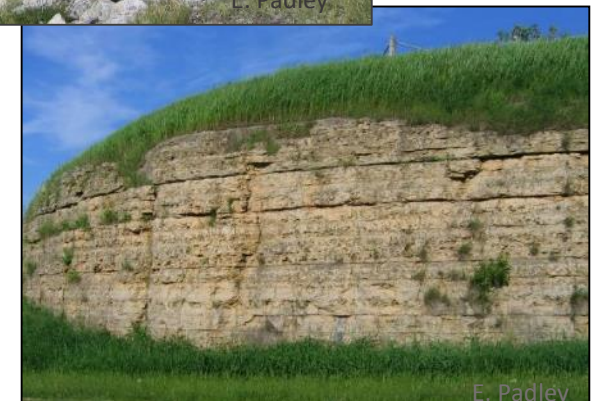
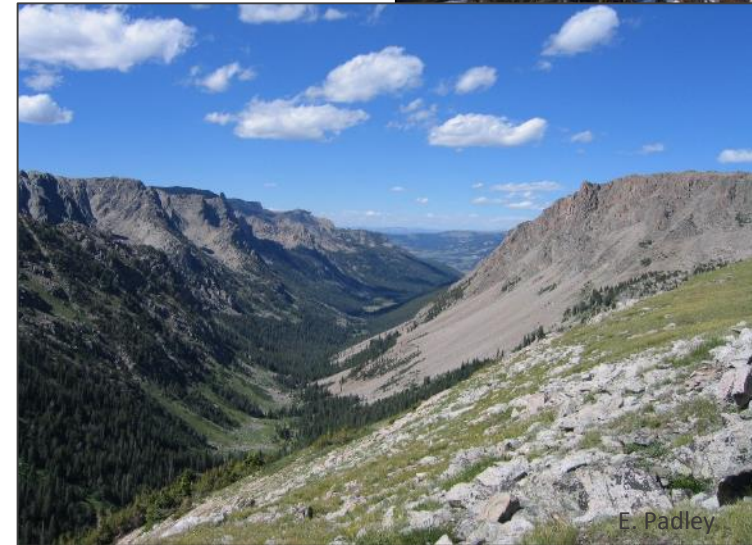
Steep slopes

- Erosion related to roads and trails; worse on soils with texture/structure that's more easily eroded.

Shallow bedrock

- Soil compression between equipment and rock increases the likelihood of compaction.
- Bedrock may inhibit drainage and contribute to rutting,
- Thin surface layers are susceptible to displacement, and shallow rooting contributes to windthrow

Unstable soils and landforms – slumps and slides



Forested Wetlands

- Sensitive organic soils.
- Low bearing strength, easily rutted and compacted, with resulting changes in hydrology.
- Shallowly rooted; susceptible to windthrow.
- May support vegetative communities of concern.
- In the north, these sites are often harvested in winter under frozen conditions. In recent years it has become more difficult to freeze these sites. When snow falls before the ground is frozen, it insulates soils and limits freezing.



Exemptions to Clean Water Act permit requirements

- In most cases, Section 404 of the federal Clean Water Act (CWA) requires permits for the discharge of dredged or fill material into waters of the United States, including wetlands. However, certain normal, ongoing activities are exempt from permit requirements under Section 404(f)(1).



- “Established (ongoing)... silviculture activities such as seeding, cultivating, minor drainage, harvesting for the production of forest products...”



Exemptions for minor silvicultural drainage do not allow conversion of a wetland to an upland.

- Section 402 of the CWA addresses the discharge of pollutants. The Agricultural Act of 2014 codified Section 402 exemptions: silvicultural activities, including the use of logging roads, do not require a National Pollutant Discharge Elimination System (NPDES) permit.

Water tables

- After harvesting, water tables can rise due to decreased evapotranspiration, or hydrologic changes. This “swamping out” can inhibit regeneration.
- Some soils exhibit a cycle of water table rise and fall through a rotation, especially on sites with high rates of evapotranspiration (e.g., densely-stocked with fast-growing trees).



Aspen on a site with a water table



Water table at around four feet

Practices that maintain soil physical properties

- Minimize the potential for compaction:
- Avoid operating equipment on wet soils: operate when ground is dry or frozen. After rainfall, allow the soil to drain before resuming operations.
- Reduce compaction by using smaller equipment, low-pressure tires or tracked equipment, and where possible, fewer passes and lighter loads.
- Operate large equipment like skidders and forwarders only if the water table is at least 18" below the surface (dependent on OM, texture, and other factors).
- Operate equipment on slash or mats, use equipment with a long reach.
- Sequence management from the back of the forest/woodlot to the front.



Slash on trail

Roads and trails – planning and design

- Minimize the area devoted to haul roads, skid trails, and landings. Designate these areas and use them again in future management. Set an upper limit of 10-15% of the forest/woodlot in roads, trails, and landings.
- Plan access roads, skid trails, and landings using topographic maps and soils maps. Note water flow and any springs/seeps. Understand how water moves over and through soils.



Roads and trails – planning and design, cont.

- Design roads and other structures to minimize concentrated flow and safely disperse water. Preserve drainage patterns; avoid blocking flows.
- Consult engineers.
- Avoid locating roads and major skid trails on hydric soils, wetlands, streams, springs, seeps, and erodible areas.
- Design stream crossings suited to the site and uses.



Mitigation practices for soil physical properties

Mitigate compaction:

- Till or rip compacted areas (often impractical); revegetate.
- Increase the interval for re-entry; may partially mitigate reduce compaction and rutting.
- Soil compaction is not readily ameliorated and effects can persist for several decades (NCASI 2004).

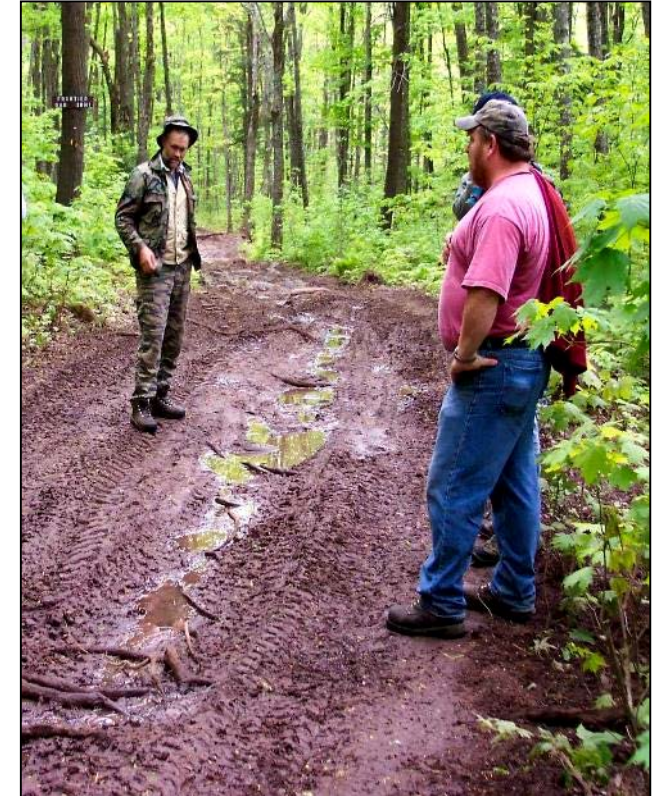


Roads and trails – maintenance

- Establish cover on roads and landings where needed.
- Avoid introducing invasive plants; control them as needed.
- Manage use by recreational vehicles.
- Maintain drainage structures so they continue to function properly.



Invasive plant spread by equipment



Off-road vehicle impacts

Control erosion in forest stands

- Avoid disturbing litter and surface soil, especially on steep slopes
- Minimize soil disturbance during site preparation.
- Establish cover on areas with exposed soil when natural revegetation is not likely to occur, especially when there is high erosion potential.

Former log landing with exposed soil, West Virginia



Site preparation



Gully erosion, Mississippi

USDA Forest Service

Soil chemistry - essential forest nutrients obtained from soil

Macronutrients

- Nitrogen, phosphorous, potassium, calcium, magnesium, sulfur

Micronutrients

- Iron, manganese, boron, copper, molybdenum, chlorine, zinc



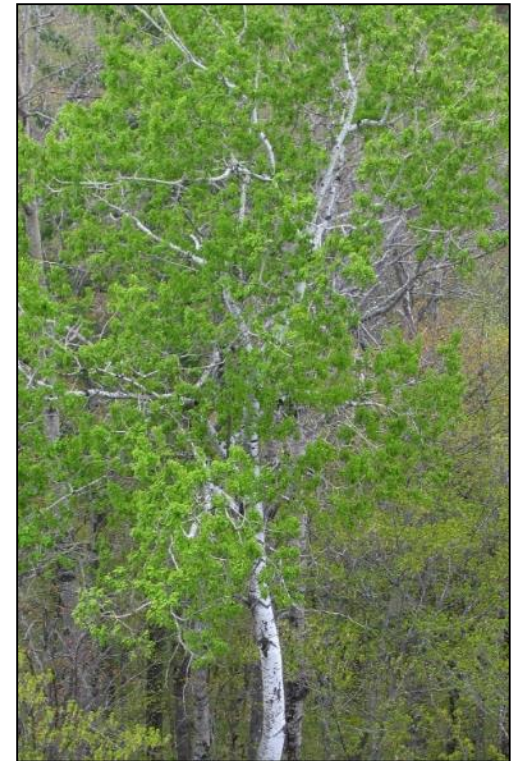
Rawsonville Soil Series: typical profile from an undisturbed forest, Maine

Soil chemistry - nutrient supply

- Soil-site productivity based in part on nutrient pools and cycling.
- Removals in harvest: whole-tree harvesting removes a larger proportion of nutrients in small branches, twigs, leaves.
- Incremental over long time periods; hard to detect.
- Greater concern on infertile sites, and shallow soils.



Aspen



Forest floor and surface horizons

Surface layers of forest soils are crucially important to site productivity and sustainability.

- Rich in organic matter – note percent C and N in the 0-8 cm A & E layer.
- Responsible for much of the soil's nutrient and moisture-holding capacity.
- Support microbial populations.
- Cushion soil from traffic.
- Buffer extremes in temperature.

GRAYLING
 CLASSIFICATION: Typic Uclipsamment, mixed, frigid
 S 78MI- 13 - 1 SAMPLE NOS. 78P 1 - 7 DATE 01/03/85 MICHIGAN TECHNOLOGICAL UNIV.
 EARAGA COUNTY SOIL SURVEY SOIL SURVEY LABORATORY FCRD FORESTRY CENTER
 GENERAL METHODS 1B1A, 2A1, 2B L ANSE, MICHIGAN

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	TOTAL				CLAY		SILT		SAND		COARSE FRACTIONS (MM)		>2MM	
				CLAY	SILT	SAND	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE
78P1	1	0-8	A&E	4.3	4.3	92.2	2.5	1.8	3.0	20.7	48.4	18.0	2.1	7	90	7	
78P2	2	8-15	B1	3.4	3.4	92.2	2.5	1.5	3.1	21.7	49.0	14.2	2.2	2	99	2	
78P3	3	15-20	B2	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P4	4	20-25	B3	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P5	5	25-30	B4	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P6	6	30-35	B5	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P7	7	35-40	B6	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P8	8	40-45	B7	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P9	9	45-50	B8	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P10	10	50-55	B9	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P11	11	55-60	B10	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P12	12	60-65	B11	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P13	13	65-70	B12	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P14	14	70-75	B13	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P15	15	75-80	B14	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P16	16	80-85	B15	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P17	17	85-90	B16	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P18	18	90-95	B17	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P19	19	95-100	B18	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P20	20	100-105	B19	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P21	21	105-110	B20	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P22	22	110-115	B21	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P23	23	115-120	B22	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P24	24	120-125	B23	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P25	25	125-130	B24	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P26	26	130-135	B25	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P27	27	135-140	B26	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P28	28	140-145	B27	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P29	29	145-150	B28	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P30	30	150-155	B29	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P31	31	155-160	B30	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P32	32	160-165	B31	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P33	33	165-170	B32	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P34	34	170-175	B33	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
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78P37	37	185-190	B36	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P38	38	190-195	B37	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P39	39	195-200	B38	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P40	40	200-205	B39	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P41	41	205-210	B40	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P42	42	210-215	B41	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P43	43	215-220	B42	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P44	44	220-225	B43	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P45	45	225-230	B44	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P46	46	230-235	B45	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P47	47	235-240	B46	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P48	48	240-245	B47	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P49	49	245-250	B48	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P50	50	250-255	B49	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P51	51	255-260	B50	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P52	52	260-265	B51	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P53	53	265-270	B52	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P54	54	270-275	B53	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P55	55	275-280	B54	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P56	56	280-285	B55	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P57	57	285-290	B56	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P58	58	290-295	B57	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P59	59	295-300	B58	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P60	60	300-305	B59	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P61	61	305-310	B60	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P62	62	310-315	B61	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P63	63	315-320	B62	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P64	64	320-325	B63	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P65	65	325-330	B64	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P66	66	330-335	B65	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P67	67	335-340	B66	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P68	68	340-345	B67	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P69	69	345-350	B68	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P70	70	350-355	B69	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P71	71	355-360	B70	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P72	72	360-365	B71	3.4	3.4	92.2	2.5	1.5	3.1	19.0	47.1	14.2	2.2	2	99	2	
78P73	73	365-370	B72	3.4	3.4	92.2	2.5	1									

Nutrient inputs, outputs, and cycles

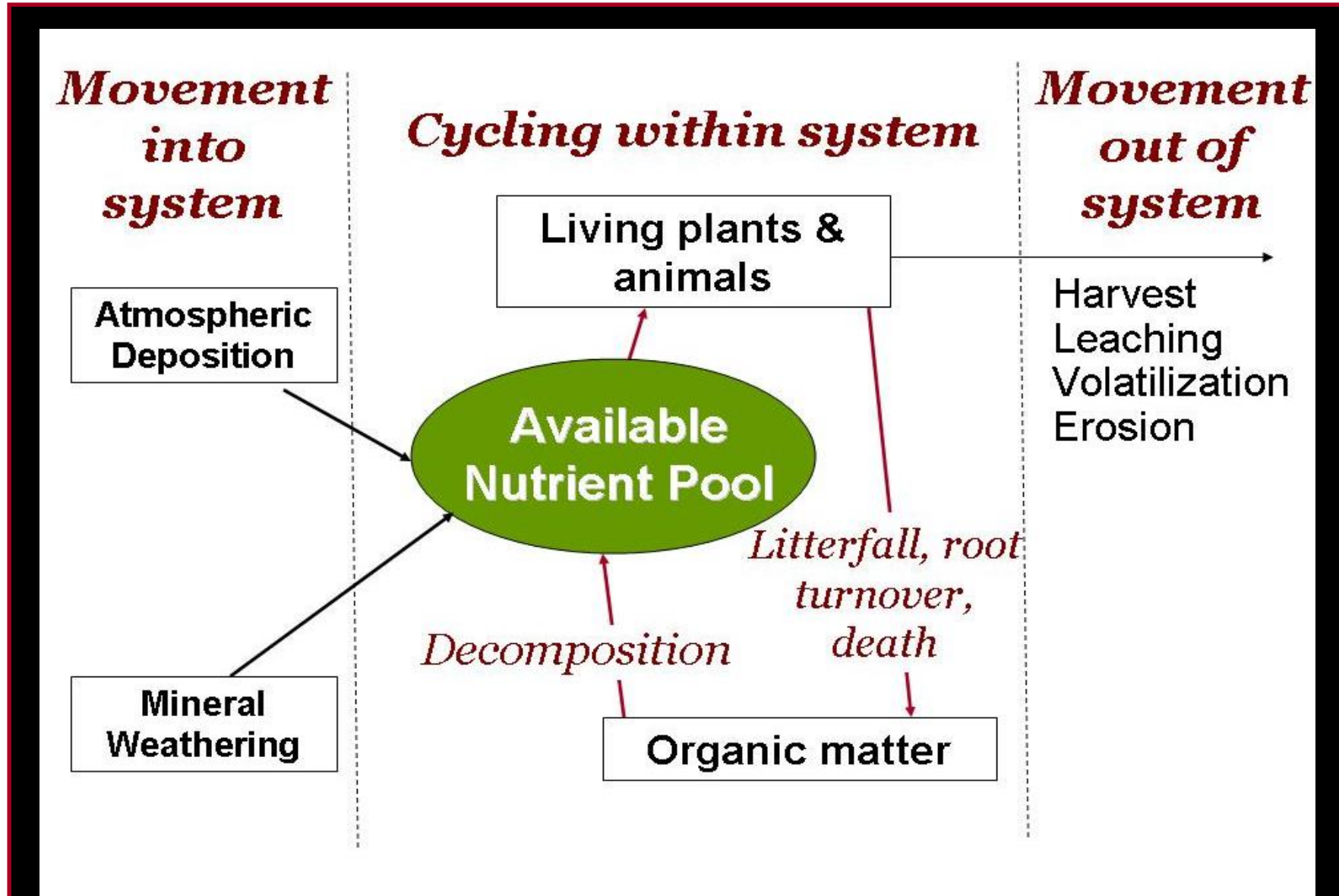


Chart adapted from Likens (2003).

Comparison of organic matter and nutrient content for four northern tree species (Perala and Alban, 1982)

- Tree species differ greatly in nutrient demands.
- Tree species allocate nutrients differently. Aspen has high amounts in bark. Conifers typically allocate more to foliage.
- Tree species and type of harvest affects the amount of nutrients removed from the site. Whole Tree Harvesting (WTH) takes foliage and bark and removes more nutrients as compared with bole harvests.

Table 2. Organic matter (tonnes per hectare) and nutrients (kilograms per hectare) in vegetation and loam soil

Stand	Overstory vegetation							Understory vegetation				Soil					
	Foliage	Branches	Bole bark	Bole wood	Root + stump	Above ground tree	Total tree	Herbs	Shrub leaves	Shrub stems	Total under-story	Forest floor	Mineral soil*				Total** complex
													0-10 cm	10-25 cm	25-36 cm	36-61 cm	
<i>Organic matter</i>																	
Aspen	3.6	16.6	27.6	119	38	167	205	0.09	0.19	2.9	3.2	27	35	10	4	17	284
Spruce	17.4	35.8	11.2	91	35	155	190	0.02	0.01	0.1	0.2	33	49	16	6	16	294
Red pine	13.8	26.3	14.0	153	46	207	253	0.03	0.45	4.0	4.4	30	58	15	5	18	365
Jack pine	5.5	24.0	12.7	109	29	151	180	0.04	0.27	2.7	3.0	33	48	14	5	17	283
<i>Nitrogen</i>																	
Aspen	87	82	115	84	89	368	457	1.8	3.9	8.8	15	667	1313	520	225	1100	3197
Spruce	153	131	44	61	69	389	458	0.3	0.3	0.5	1	752	1608	652	282	1145	3753
Red pine	131	63	44	118	78	356	434	0.5	10.9	15.4	27	538	1894	617	239	1142	3749
Jack pine	65	78	34	87	38	264	302	0.8	5.7	10.3	17	700	1731	640	256	1165	3646
<i>Phosphorus</i>																	
Aspen	9.0	11.3	16.4	9.8	20	47	67	0.2	0.5	0.9	1.6	60	26	38	22	23	214
Spruce	27.0	17.8	8.5	5.2	7	59	66	0.1	0.1	0.1	0.2	61	21	27	20	26	195
Red pine	18.7	8.1	6.7	9.3	8	43	51	0.1	1.5	2.1	3.6	40	24	34	19	20	172
Jack pine	7.7	7.9	4.8	4.7	5	25	30	0.1	0.6	1.3	1.9	51	24	35	20	26	162
<i>Potassium</i>																	
Aspen	47	42	86	112	80	287	367	2.4	2.1	5.0	9	78	102	105	87	867	748
Spruce	86	83	32	33	26	234	260	0.4	0.2	0.3	1	76	104	101	94	837	636
Red pine	59	33	17	71	31	180	211	0.7	6.3	7.7	15	62	112	101	91	838	592
Jack pine	20	26	12	41	23	99	122	0.9	2.6	5.6	9	68	94	98	89	843	480
<i>Calcium</i>																	
Aspen	37	215	435	171	216	858	1074	1.1	3.9	17.6	23	1081	1195	765	683	7151	4821
Spruce	256	224	166	88	93	734	827	0.2	0.3	0.9	1	1398	1451	714	644	7104	5035
Red pine	42	67	73	120	46	302	348	0.3	10.9	32.6	44	660	2187	1005	711	7371	4955
Jack pine	20	52	57	74	43	203	246	0.4	5.4	21.6	27	770	2080	1029	694	7269	4846
<i>Magnesium</i>																	
Aspen	6.0	12.4	20.5	18.7	18	58	76	0.2	0.5	3.6	4.3	89	91	75	100	1475	435
Spruce	13.3	13.9	7.5	6.5	6	41	47	0.1	0.1	0.1	0.2	77	136	97	105	1636	462
Red pine	14.4	9.3	8.7	27.0	15	59	74	0.1	1.5	2.7	4.3	65	138	87	103	1587	471
Jack pine	5.6	10.1	5.8	16.9	8	38	46	0.1	0.8	1.5	2.3	81	134	83	105	1566	451

* 0-36 is the main rooting profile; **Excludes 36-61 cm profile.

Comparison of calcium content in above-ground components for four northern tree species (Perala and Alban, 1982)

Table 2. Organic matter (tonnes per hectare) and nutrients (kilograms per hectare) in vegetation and loam soil

182

Stand	Overstory vegetation						Understory vegetation				Soil					Total**	
	Foliage	Branches	Bole bark	Bole wood	Root + stump	Above ground tree	Total	Herbs	Shrub leaves	Shrub stems	Total under-story	Mineral soil*					Total** complex
												Forest floor	0-10 cm	10-25 cm	25-36 cm		
<i>Organic matter</i>																	
Aspen	3.6	16.6	27.6	119	38	167	205	0.09	0.19	2.9	3.2	27	35	10	4	17	284
Spruce	17.4	35.8	11.2	91	35	155	190	0.02	0.01	0.1	0.2	33	49	16	6	16	294
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Jack pine	5.6	10.1	5.8	16.9	8	38	46	0.1	0.8	1.5	2.3	81	134	83	105	1566	451

PERALA AND ALBAN

* 0-36 is the main rooting profile; **Excludes 36-61 cm profile.

Total above-ground Ca content in lbs/acre:
(1 kg/ha = 0.892 lb/ac)

Aspen 765
Spruce 655
Red pine 269
Jack pine 181

Nutrient balance calculations

- Inputs: wet and dry deposition, mineral weathering, N-fixation.
- Outputs/losses: harvest removals and accelerated leaching.
- Nutrient balances (inputs minus outputs) can be calculated for different cover types and rotation lengths. Results are approximations.
- Availability to trees may be different than soil tests indicate, due to mycorrhizal influences and soil conditions at the site.
- Consider net losses relative to total soil nutrient capital.



Calcium balance for aspen whole tree harvest (WTH)

40 year rotation, average atmospheric inputs,
low mineral weathering inputs
(typical scenario for dry nutrient-poor sandy soils)

■ Inputs

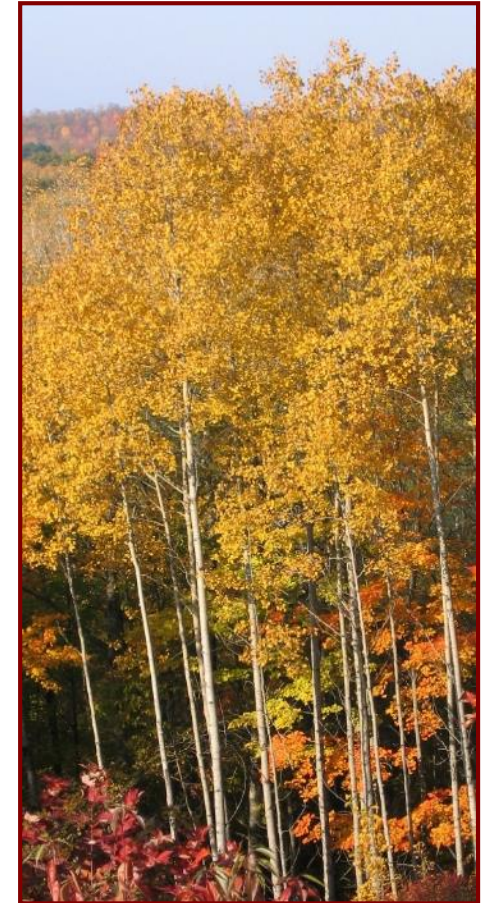
- Atmospheric deposition: $3.4 \text{ lb/acre/year} \times 40 \text{ yrs} = 136 \text{ lb/acre}$
- Mineral weathering: $1.7 \text{ lb/acre/year} \times 40 \text{ yrs} = 68 \text{ lb/acre}$

■ Outputs/losses

- Leaching: 56 lb/acre total
- Harvest: 616 lb/acre Ca

■ Balance

- $136 + 68 - 616 - 56 = -468 \text{ lbs/acre Ca}$



Calcium balance for jack pine WTH - 40 year rotation, average atmospheric inputs, low mineral weathering inputs (typical scenario for dry nutrient-poor sandy soils)

■ Inputs

- Atmospheric deposition: $3.4 \text{ lb/acre/year} \times 40 \text{ yrs} = 136 \text{ lb/acre}$
- Mineral weathering: $1.7 \text{ lb/acre/year} \times 40 \text{ yrs} = 68 \text{ lb/acre}$

■ Outputs/losses

- Leaching: 56 lb/acre total
- Harvest: 137 lb/acre Ca

■ Balance

- $136 + 68 - 137 - 56 = \mathbf{11}$ lbs/acre Ca



Minnesota soil nutrient capital for an average site

- An average Minnesota soil is loamy with a relatively good supply of nutrients from mineral weathering.
- The average forest cover type is not the most nutrient-demanding.
- Ca, K outputs are greater than inputs.
- No concerns about Ca on sites with nutrient capital of 16,000 lbs/acre.

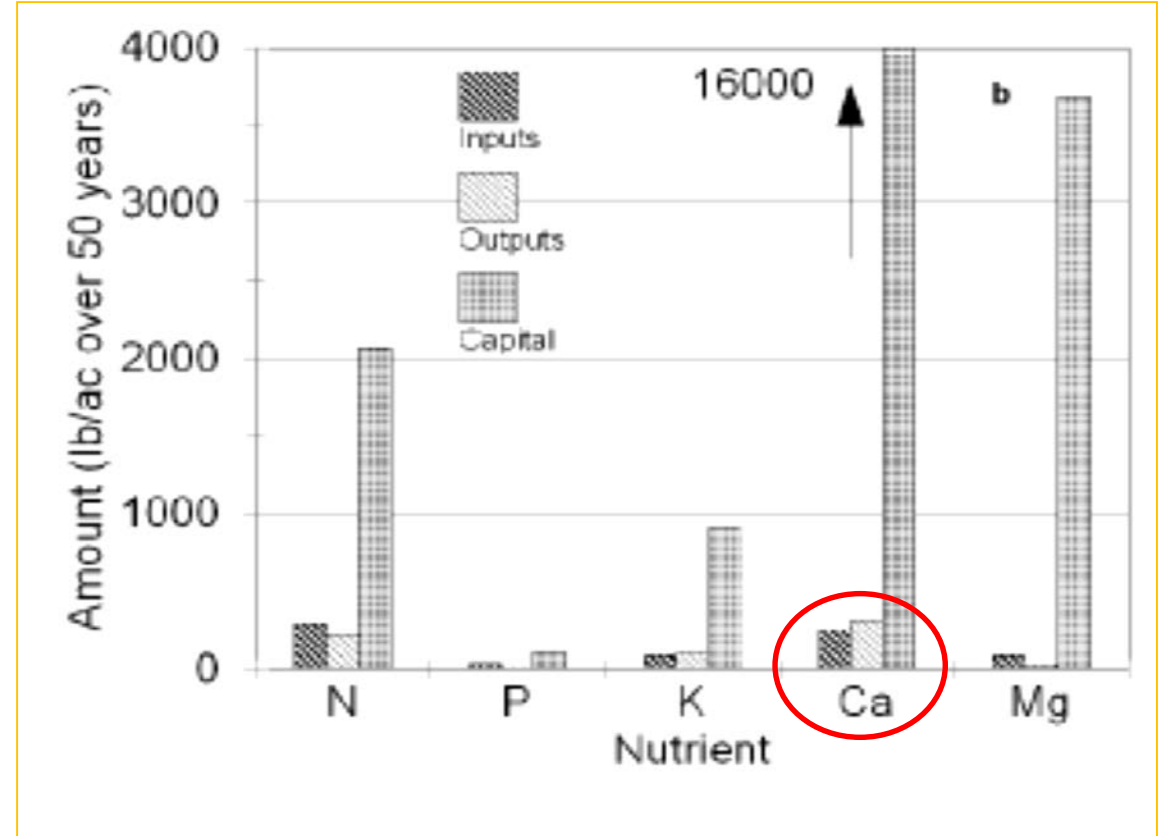
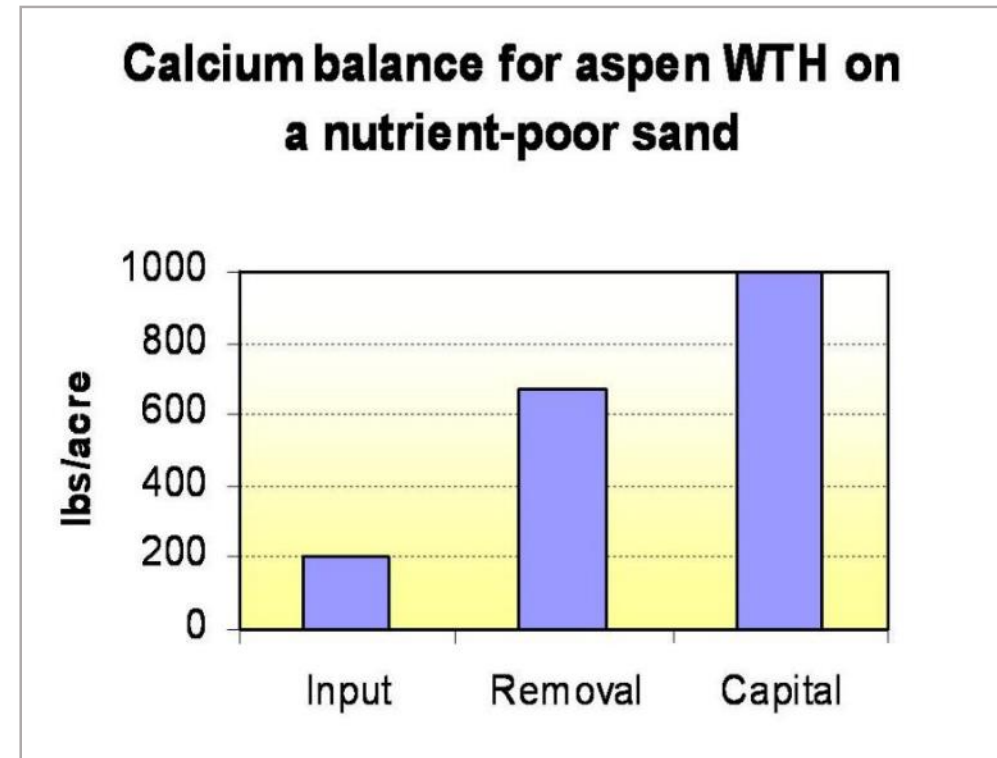


Figure 2b in Grigal, 2004. "An Update of Forest Soils: A technical paper for a generic Environmental Impact Statement on timber harvesting and forest management in Minnesota."

Minnesota soil nutrient capital for a below-average site

- An average Minnesota soil is not of concern with regard to nutrient depletion.
- However, there are less-than-average sites with capital of 1,000 lbs/acre Ca, lower weathering inputs, and higher harvest removals. On this site, capital could be depleted in two rotations.



Minimizing nutrient losses

- Retain woody debris (“slash”) and forest litter wherever it will not interfere with forest regeneration or future equipment movement, or contribute to wildfire hazard.
- Use alternatives to burning woody debris. Consider biochar production where feasible.
- Avoid management systems and practices that remove high amounts of nutrients (e.g., short rotations, WTH), especially on sites with low nutrient capital or slow mineralization rates (arid sites, wetlands).
- Minimize erosion, displacement, or other damage to the soil surface.



Kelpie Wilson, Wilson Biochar Associates

Oregon kiln, for on-site biochar production



Soil pH

- Impact of acidic deposition – increases soil acidity. Implicated in sugar maple decline in the northeast U.S.
 - Depletion of base cations through leaching.
 - Soluble forms of Al affect root uptake of water and nutrients.
 - Soluble Al and Fe can form compounds with P that are not available to most plants.
- Unnaturally high pH sometimes occurs where soils were limed for agricultural production, or used for disposal of sludge or ash.



Sugar maple

Fire effects on belowground sustainability

- Complex and variable
- Greatly dependent on burn severity - influenced by fuel load, soil moisture, and duration.
- Low-impact burning can promote a herbaceous flora, increase plant available nutrients, and thin overcrowded forests.
- Severe fires can:
 - Alter species composition, including microbial populations
 - Volatilize nutrients
 - Alter C : N ratios
- Potential secondary effects of severe fires:
 - Nutrient losses through accelerated erosion, leaching or denitrification
 - Changes in soil hydrologic functioning
 - Degradation of soil physical properties
 - Alterations in microbial processes



Pit and mound topography

- “Pit and mound topography” is a term that describes the soil surface where trees have fallen or been blown down, pulling up a mound of soil, and leaving a pit where the tree formerly stood.
- The pits are important sites for water infiltration into soils, especially on slopes where runoff is rapid. They also create puddles and ephemeral pools that benefit amphibians and invertebrate organisms.
- Harvesting reduces the likelihood of having large trees fall, and equipment travel tends to smooth the surface of forested sites.



Biological components of forest soils

- Support for biota that carry out nutrient cycling is essential to forest sustainability.
- Changes in soil biology are often a consequence of changes in physical and chemical soil properties.
- Some soil organisms are sensitive to disturbance and can be adversely affected by intensive harvesting.
- Adequate populations of soil organisms are needed to establish a new stand after harvest, and to obtain good growth.



Decomposers in the Forest Floor and Soil

The decomposer community is a complicated food web. Early decomposers break down fresh leaf litter and woody material.

- Small mammals / amphibians
- Fungi
- Arthropods - millipedes, termites, ants, beetles, mites, etc.
- Earthworms

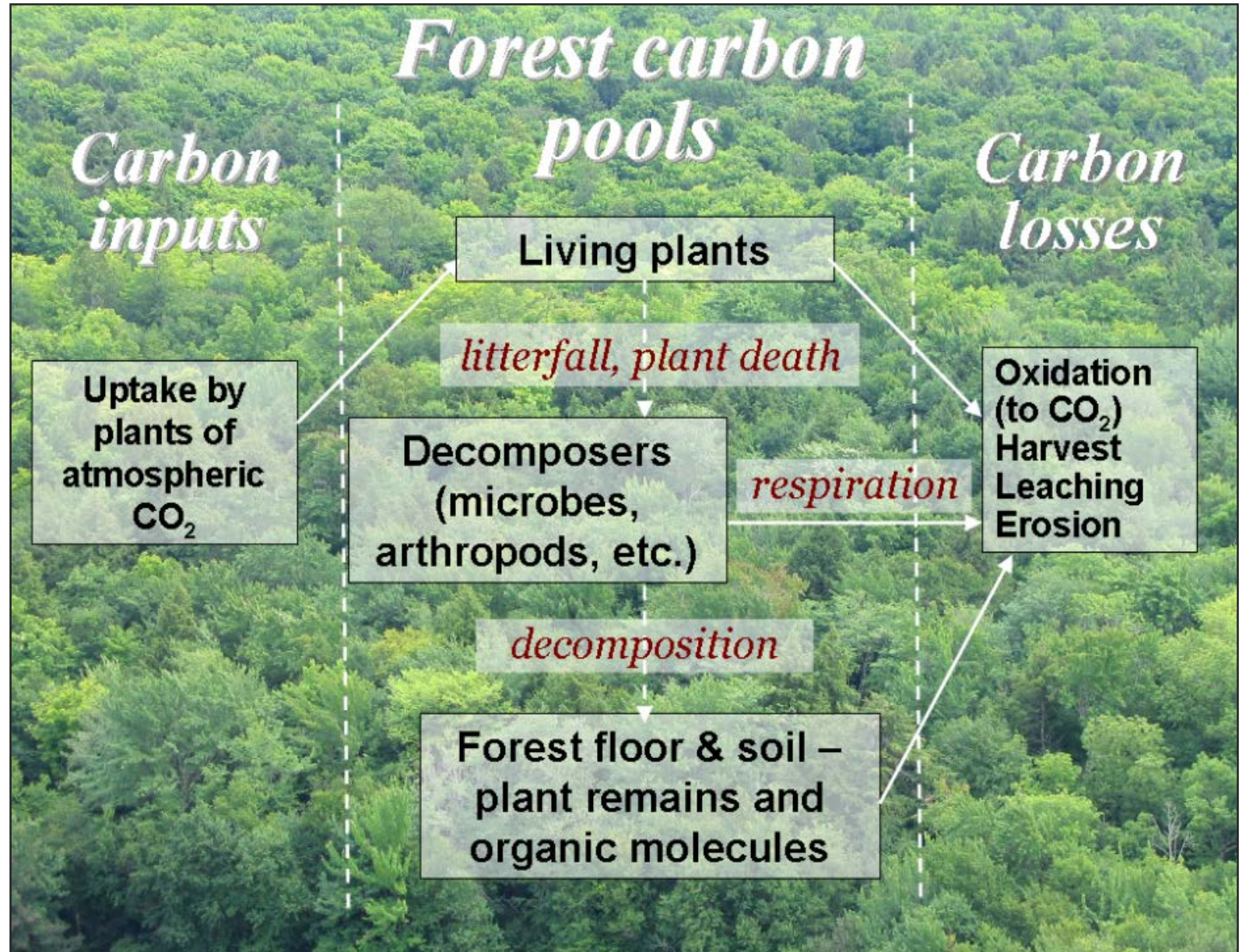
Microbes in the soil continue the decomposition process and release nutrients to plants when they die.

- Bacteria – 500 million in a teaspoon of soil; as many as 40,000 species
- Actinomycetes
- Fungi
- Algae
- Protozoa & nematodes - predators on other microbes.



Forest carbon cycle

- Forests fulfill an important role in greenhouse gas (GHG) mitigation by capturing and storing carbon.
- Carbon cycling is carried out by decomposers.
- Some carbon moves to long-term storage in soils.



Largest organism on the planet

- A mycorrhizal fungus, “honey fungus” measuring 2.4 miles across in the Blue Mountains in Oregon is thought to be the largest living organism on Earth. It is an *Armillaria solidipes*, which colonizes and kills woody plants.
- Many mycorrhizal fungi are beneficial to trees, and most native tree species have associations with them. They obtain carbohydrates from the tree, and make nutrients and water more available to roots through increased absorptive surface area.
- Inoculation of tree seedlings with mycorrhizae is common in nurseries; growth can be poor without them.
- Some beneficial fungi are sensitive to light and heat, and can be reduced in clearcuts and burned areas.



Photo of honey fungus by W. J. Pilsak at the German language Wikipedia



The role of dead wood in forest ecosystems



- Site for decomposition and nutrient cycling - soil biota consume carbon-based material (including woody debris) for energy.
- Nutrients in dead wood are cycled to living plants.
- Decomposition moves a portion of carbon into the soil - important in climate change mitigation, soil chemical & physical properties.
- N & P in plant-available forms are derived mainly from microbial decomposition of plant material; available N is a small fraction of total N.
- Woody debris is a also site for N-fixation.
- Wildlife utilization of snags and down woody debris.

Historical impacts and long-lasting effects



Some sites have been affected by past unsustainable agriculture practices, destructive logging during the Cutover period, or intense fires, and may have lost organic matter, nutrients, and beneficial soil organisms. These effects have long-term consequences for forest re-establishment and growth.

Managing to maintain forest soil biota

Soil organisms are living creatures that need food, water, air, and shelter.

- Carbon source, for energy.
- Nutrients for cellular growth (N, P, S, K). Sites with high C:N ratios may be N-limited.
- Moisture source
 - Protect from desiccation – avoid intensive harvesting in systems that are not adapted to catastrophic disturbance.
- Oxygen
- Habitat that provides shelter, as well as food, oxygen, & water.
 - Soil structure that has aeration, moisture movement, hiding spots.
- If soil organisms are lacking, consider inoculation.



The future: climate and potential forest changes by 2100

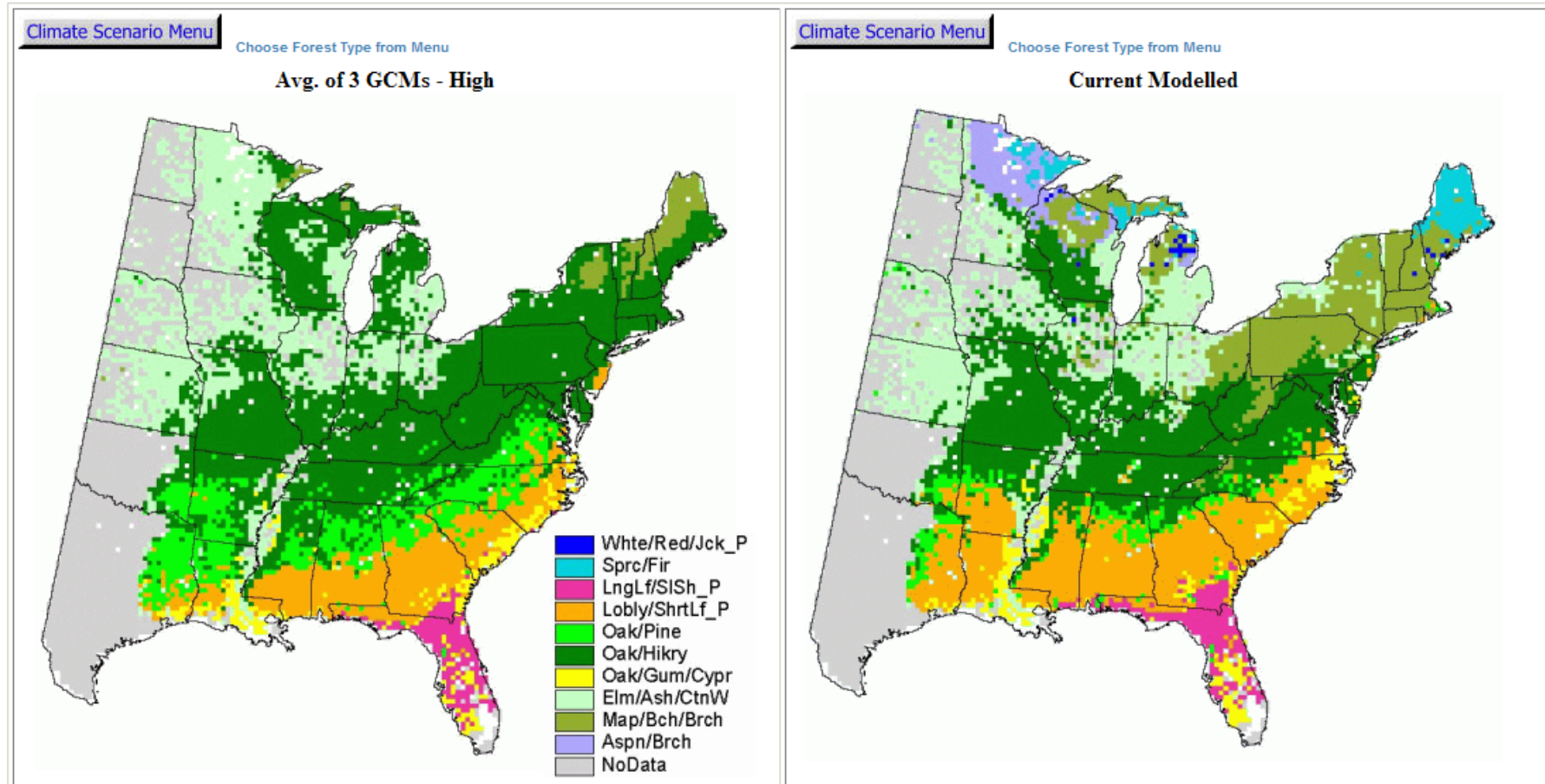
Potential Future Forest Type Changes

The links below allow comparison of maps of potential forest-type changes according to the various GCM scenarios.

IMPORTANT: Make sure you read the help file before interpreting the changes.



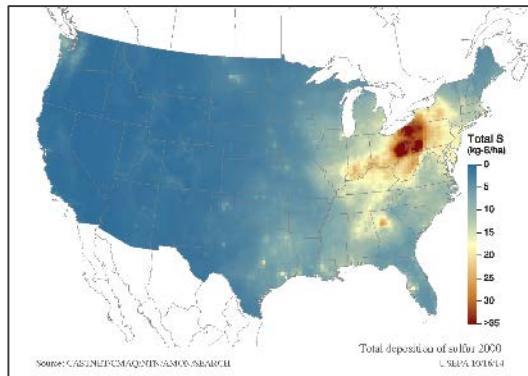
[View Summary of Changes](#)



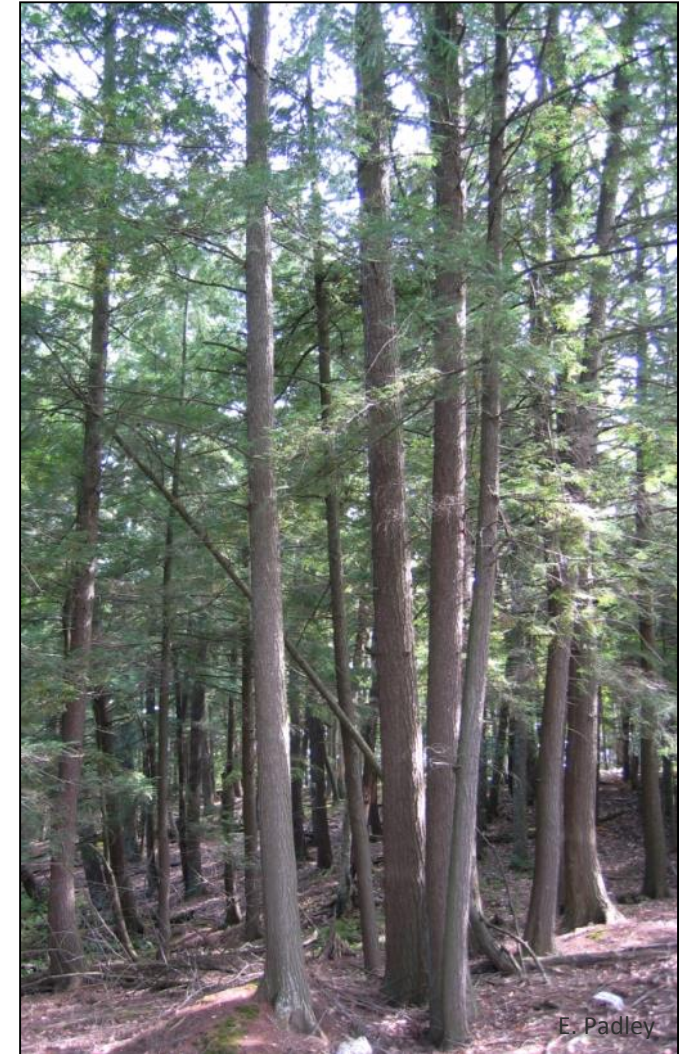
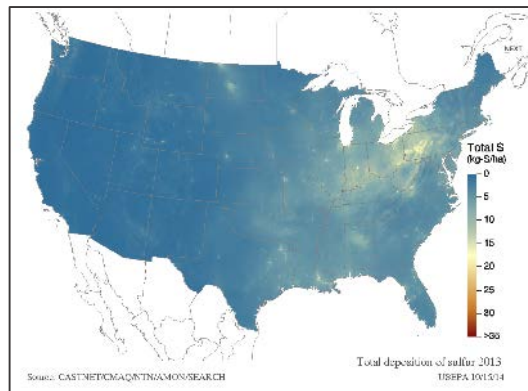
The Climate Tree Change Atlas - <http://www.nrs.fs.fed.us/atlas/tree/>

Soil chemistry changes

- Acid deposition - improving
- Nitrogen saturation, nitrate leaching
- Forest composition changes, further effects on soil chemistry



*Total (wet + dry)
sulfate deposition,
2000 and 2013*



Invasive species

- Effects of tree diseases and insect outbreaks (non-native and native)
- Allelopathy, changes in existing vegetation
- Non-native earthworms



Buckthorn



Garlic mustard



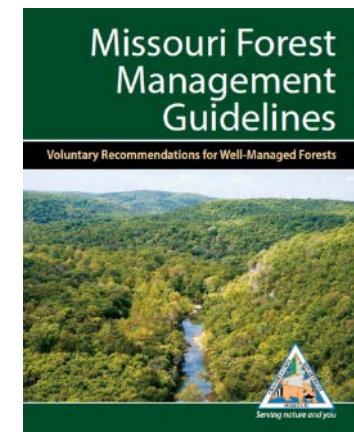
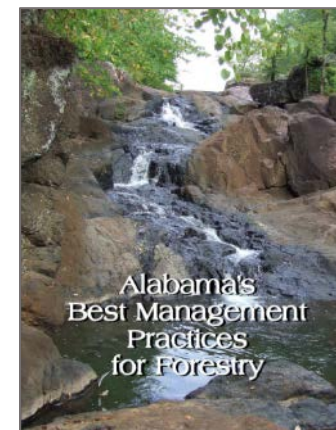
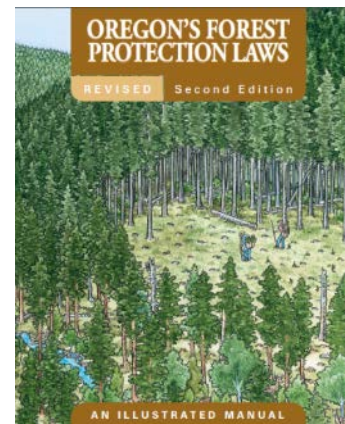
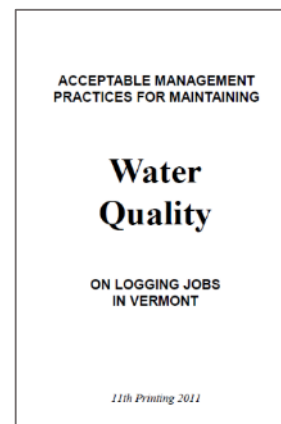
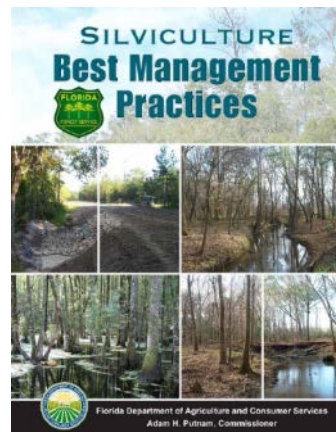
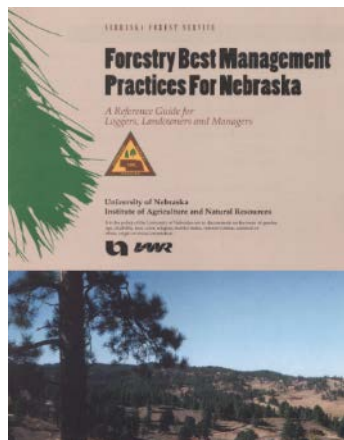
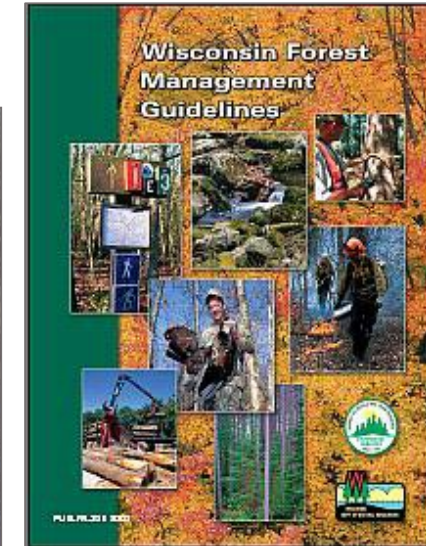
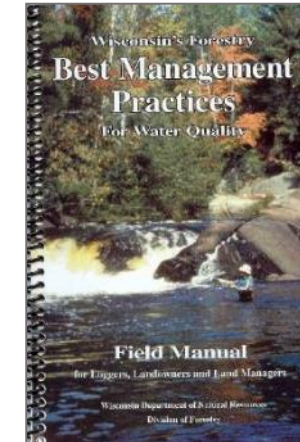
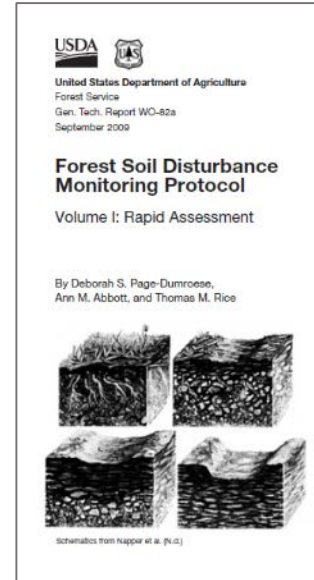
E. Padley



Earthworm damage

Tools for avoiding and mitigating soil impacts

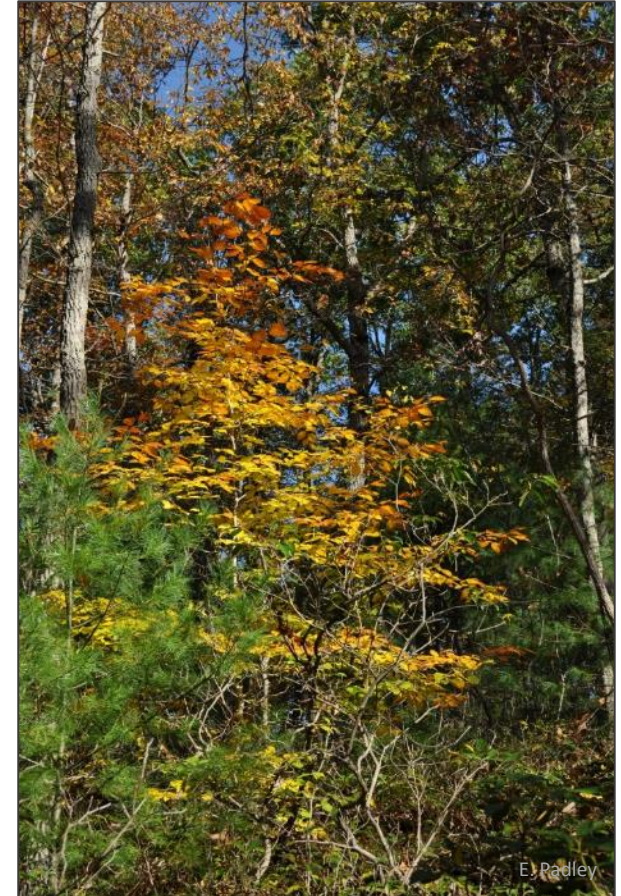
- Planning
- NRCS Conservation practice standards
- BMPs for water quality (by state)
- State forestry agency guidelines
- New technology; changes in equipment
- Certification standards
- Soil disturbance monitoring protocols
- Training for forestry practitioners and landowners



A good plan, well-executed

Importance of carefully planning forest management and harvest operations.

- A silvicultural strategy that takes into consideration needs for future stand entries (e.g., site preparation, planting, thinning).
- Carefully plan the extent, location, and treatment of access roads, skid trails, and landings, for the life of the stand and beyond.
- Treat any existing soil and water resource concerns prior to stand management.
- Implement and maintain critical soil and water conservation practices, including state BMPs, during and after management operations. Follow practices for minimizing impacts and mitigating any damage.



Soils information

- Web Soil Survey <http://websoilsurvey.nrcs.usda.gov/app/>
- Growth/productivity information varies.
- Some states have interpretations for trees and shrubs to plant (not in Web Soil Survey).

Map Unit Legend Summary
Douglas County, Wisconsin

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
43C	Antigo silt loam, 6 to 15 percent slopes	7.4	0.2
309C	Metonga-Rock outcrop complex, 6 to 20 percent slopes	38.7	1.1
419A	Seelyeville, Cathro, and Markey soils, 0 to 1 percent slopes	452.1	13.3
426D	Emmert-Mahtomedi-Menahga complex, 12 to 30 percent slopes	3.5	0.1
461A	Bowstring muck, 0 to 1 percent slopes, frequently flooded	71.7	2.1
631A	Giese muck, 0 to 1 percent slopes, very stony	88.5	2.6

Productivity (Cubic Feet per Acre per Year)
Productivity (Tree Site Index)

View Description View Rating

Options

Map Table Description of Rating Printing Options Detailed Description

Options

Tree: loblolly pine (Schumacher 1928 (050))

View Description View Rating

Summary by Map Unit — Liberty County, Florida (FL077)

Map unit symbol	Map unit name	Rating (feet)
2	Albany sand, 0 to 5 percent slopes	
6	Blanton sand, 0 to 5 percent slopes	
11	Chipley-Foxworth complex, 0 to 5 percent slopes	
12	Rutlege and Plummer soils, depressional	
13	Dorovan-Pamlico complex, depressional	
26	Foxworth sand, 0 to 5 percent slopes	
30	Elloree, Bibb, and Meggett soils, 0 to 3 percent slopes, frequently flooded	
31	Hurricane and Chipley soils, 0 to 3 percent slopes	
32	Plummer and Pelham soils	
34	Lakeland sand, 0 to 5 percent slopes	77
38	Leefield loamy sand, 0 to 5 percent slopes	
39	Leon sand, 0 to 2 percent slopes	
45	Lynn Haven sand	

Soil interpretations for forestry

- Web Soil Survey
<http://websoilsurvey.nrcs.usda.gov/app/>
- Interpretations for equipment limitations, erosion hazard, construction limitations.
- Drainage class, hydric soils information also in this menu.
- When reviewing CAP-106 Forest Management Plans, check to see that information on limitations is included.

irrigated Capability Subclass

Taxonomy Classification

Management

Construction Limitations for Haul Roads and Log Landings

[View Description](#) [View Rating](#)

View Options

Map

Table

Component Breakdown and Rating Reasons

Numeric Values

Description of Rating

Rating Options

Detailed Description

Advanced Options

[View Description](#) [View Rating](#)

Construction Hazard (Off-Road, Off-Trail)

Construction Hazard (Road, Trail)

Compaction, Post Depth 24 Inches or Less

Compaction, Post Depth 36 Inches or Less


Ground Penetrating Radar Penetration

Investment Equipment Operability

Mechanical Site Preparation (Deep)

Mechanical Site Preparation (Surface)

Pesticide Leaching Potential

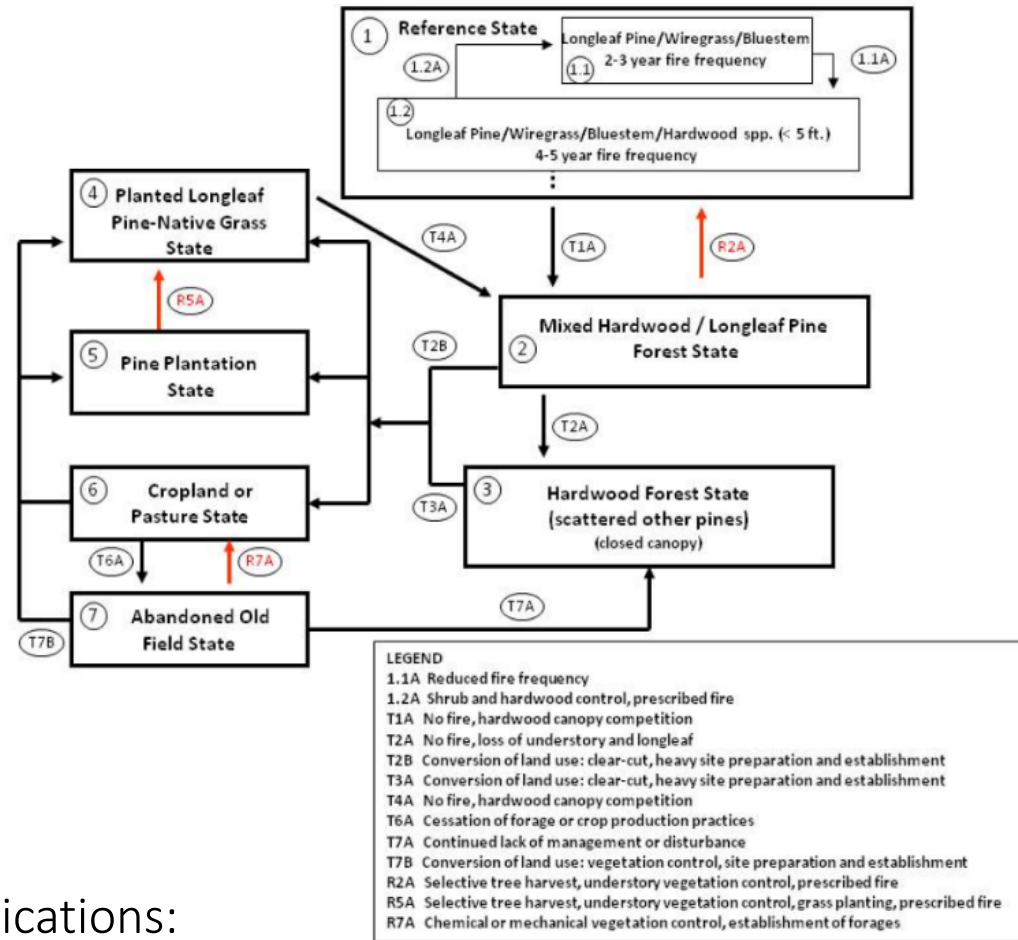


Tables — Construction Limitations for Haul Roads and Log Landings — Summary By Map Unit

Summary by Map Unit — Liberty County, Florida (FL077)

Map unit symbol	Map unit name	Rating	Component name (percent)	Rating reasons (numeric values)	Area
2	Albany sand, 0 to 5 percent slopes	Slight	Albany (85%)		4,9
			Leefield (2%)		
6	Blanton sand, 0 to 5 percent slopes	Moderate	Blanton (85%)	Sandiness (0.50)	
11	Chipley-Foxworth complex, 0 to 5 percent slopes	Moderate	Chipley (50%)	Sandiness (0.50)	3,1
			Foxworth (40%)	Sandiness (0.50)	
			Lakeland (5%)	Sandiness (0.50)	
			Leon, non-hydric (5%)	Sandiness (0.50)	
12	Rutlege and Plummer soils, depressional	Slight	Rutlege (45%)		20,2
13	Dorovan-Pamlico complex, depressional	Severe	Dorovan (50%)	Low strength (1.00) Dusty (0.09)	
			Pamlico (45%)	Low strength (1.00) Dusty (0.09)	
26	Foxworth sand, 0 to 5 percent slopes	Moderate	Foxworth (95%)	Sandiness (0.50)	3,1
			Lakeland (4%)	Sandiness (0.50)	
			Chipley (1%)	Sandiness (0.50)	
30	Ellore, Bibb, and Meggett soils, 0 to 3 percent slopes	Severe	Ellore (35%)	Flooding (1.00)	4,9

Ecological Site Descriptions - State and transition models



Red-cockaded Woodpecker habitat in longleaf pine forest

- S&T model applications:
- States can be alternatives in plans
- Restoration goals – use reference state
- Use in assessing level of effort needed to achieve alternative states

Site productivity, sustainability, resilience

Forestry operations can affect all these soil properties:

Physical properties

- Texture, organic matter, structure, aeration, drainage

Chemical properties


- Nutrient supply, rates of cycling

Biological properties

- Organisms important to plant growth, particularly mycorrhizae, microbial populations, and other decomposers (e.g. worms)



*Forestry operations have the potential to degrade soil quality if not managed properly –
Minimize and mitigate the impacts*

A photograph of a winter forest. The ground is covered in a thick layer of snow. In the foreground, there are evergreen trees heavily laden with snow. The background consists of many tall, thin, bare deciduous trees, their branches also dusted with snow. The sky is a pale, clear blue. The overall scene is bright and serene.

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Questions?

