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FOREWORD

The Northern Global Change Program meeting was held March 14-16, 1995, in Pittsburgh, Pennsylvania. Its purpose was to chronicle the research activities of the Northern Global Change Program over the past five years, and outline the implications of these research results for natural resource management. We thank the authors for their participation and for promptly submitting their papers in both paper and electronic form.

SPATIAL PATTERNS IN CARBON STORAGE IN A LAKE STATES' LANDSCAPE

J. C. Bell[1], D. F. Grigal[1], P. C. Bates[1], and C. A. Butler[2]

Abstract: We estimated total organic carbon storage (C -- kg m^{-2}) in biomass, forest floor, and soil for a gently undulating glacial outwash landscape in east-central Minnesota (45° 25'N, 93° 10'W). Abandoned agricultural tracts are common, and nearly 40 percent of the area is wet mineral or organic soil. Quantitative models based on 745 point-observations were used to define empirical relationships between C storage and landscape variables describing forest cover type and terrain characteristics. Exponential regressions for individual cover types explained from 31 to 70 percent ($p<0.05$) of the variation in soil C and 39 percent ($p<0.05$) of the variation in peatland depth. Spatial patterns and quantities of C storage were estimated by applying these functions to a digital geographic database of cover type and terrain attributes. Landscape scale (~1:20,000) estimates of soil C followed a bimodal distribution with means at 4 kg m^{-2} (mineral soils) and 130 kg m^{-2} (peatlands). Biomass carbon for individual cover types ranged from 1 to 13 kg m^{-2}. Total C storage in all components, based on a 1m soil depth, was 32 kg m^{-2}, with over 90 percent stored in peatlands.

INTRODUCTION

Organic carbon (C) storage and its change are central issues in global change, but the magnitude of storage in forested systems is uncertain. Although the catena concept is firmly established in soil science, quantification of changes in soil C with landscape position is lacking. This is especially true in more recently glaciated regions such as the Lake States, where climate and a poorly-developed drainage network have led to abundant peatlands, occupying 10 to 30 percent of most basins. Modeled scenarios of global change suggest that both forest tree distribution and the balance between precipitation and evaporation may change, affecting C storage. Quantification of the C stored in these immature landscapes, the pools in which it is stored, and the relationship of that storage to landscape features will all aid in predicting the magnitude of C response to various scenarios of global change.

The overall objective of our research is to better understand the mechanisms responsible for C sequestration at landscape scales. Although not our ultimate goal, the predictive mapping of C storage is a necessary first step in this understanding. Our specific objective for this study was to quantify the magnitude and spatial patterns of organic C storage in a typical landscape in the Lake States.

METHODS

We sought to quantify spatial patterns of organic C storage (kg m^{-2}) in three pools on the landscape: 1) biomass, 2) forest floor, and 3) soil.

Site

We worked at the Cedar Creek Natural History Area (CCNHA), located 50 km north of Minneapolis-St. Paul, Minnesota, on the Anoka Sand Plain (45° 25'N, 93° 10'W). This National Science Foundation-Long Term Ecological Research (NSF-LTER) site is typical of sandy outwash areas of much of the Lake States. Natural vegetation includes prairie, oak savanna, closed forests, shrub carrs, marshes, lakes, and bogs (Pierce 1954). Many of the present ecosystems developed following agricultural abandonment. Soils are derived from deep (20 m), well-

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sorted glacial outwash of very uniform fine sand (> 90 percent sand). Slopes are gentle, usually less than 15 percent, and local relief ranges up to about 5 m. The regional climate is continental with a mean annual temperature of 6°C and annual precipitation of 660 mm (Grigal et al. 1974). The regional water table is at or near the soil surface in low-lying areas and only a few meters below the surface in the highest elevations. Nearly 40 percent of CCNHA is occupied by wet mineral or organic soils so that the 2200 ha site is an intricate upland-wetland mosaic. A few meters of horizontal distance often separate upland oak forests or old fields from adjacent wetlands.

Field Sampling

Samples and descriptions of soils, vegetative cover, and organic debris at the soil surface, referred to hereafter as forest floor, were collected along 19 transects crossing topographic changes of the major vegetation types. We sampled at two levels of intensity. Level #1 sites were at 25m increments along the transects (total = 745). We recorded landscape position and topography (slope gradient, curvature, and aspect); vegetation type; tree basal area, diameter, and condition; tall shrub cover and height; low shrub and forb cover; forest floor and A-horizon thickness; fiber type and depth of organic soil materials (if present); and location (based on global positioning system). Approximately one third of the level #1 sites were randomly selected for level #2 sampling (total = 250). Forest floor and soil samples were collected for laboratory determinations of organic C content. Mineral soils were sampled at 0-25 and 26-100 cm depths with a bucket auger, and organic soils were sampled in 50-cm increments until impenetrable with a McCauley peat auger. A 5 percent subset of soils was sampled for bulk density using the core method.

Laboratory Methods

Loss-on-ignition (LOI) was determined for all forest floor and soil samples by ashing overnight at 450°C. Approximately 30 percent of the samples were used to develop relationships between LOI, total organic C on a gravimetric basis (g kg^{-1}) (David 1988), and soil bulk density (kg m^{-3}) (Grigal et al. 1989). The relationships were used to calculate C and bulk density for the remaining samples. Organic C on a volumetric basis was calculated to 1 m for mineral soils and to the depth of sampling for organic soils.

Forest floor C concentrations were converted to mass per unit area based on the quantitative field sampling. Biomass of trees was based on published allometric relationships (Alemdag 1983, 1984). We developed our own biomass relationships for shrubs and forbs based on either cover and height (shrubs) or cover (forbs). These latter data had been previously collected at CCNHA (Suhartoyo 1991). All biomass data included estimates of root mass. Biomass was expressed as mass per unit area, and its C content was considered to be 47.5 percent (Raich et al. 1991).

Spatial Data

We developed a digital geographic database that included vegetation cover type, peatland locations from an order II soil survey, and a digital terrain model. The information was stored in a raster format using 10-meter grid cells. Scales for input data ranged from 1:15,000 to 1:20,000. Digital maps of slope gradient, slope curvature, aspect direction, plan and profile slope curvature, and both horizontal and vertical proximity to local topographic highs and lows (peatlands) were calculated for each grid cell in the geographic database using methods described by Moore et al. (1993) and Bell et al. (1992). The transect sampling locations and the digital geographic database were registered to standard geographic coordinates to facilitate spatial comparisons.

Spatial Modeling

Estimates of total organic C were partitioned by vegetation type. Eight types (pine, oak, upland mixed hardwoods, savanna, old field, lowland conifers, lowland hardwoods, and lowland non forested) were recognized in both the geographic data base and at transect locations. The latter three types were primarily located in peatlands.

Using digital overlay techniques, each transect location was defined by combinations of landscape features (slope, vegetation type, etc.) as defined in the geographic database. Simple means were used to describe forest floor and biomass C by vegetation type. Linear and exponential statistical models were developed for soil C. Peatland depths cannot be ascertained from simple surface data (Swanson and Grigal 1989), and were estimated by functions related to distance to mineral soil and elevation. A 75 percent random subset of transect observations was used to calibrate statistical relationships between landscape attributes and soil organic C concentrations. The remaining observations were used to obtain an unbiased estimate of model performance (model validation).

After the quantitative relationships were calibrated and validated, digital overlay techniques were used to define the landscape attributes for each grid cell in the geographic database, and the statistical models were applied to these attributes on a cell-by-cell basis to predict and map organic C storage for each pool (biomass, forest floor, soil).

RESULTS AND DISCUSSION

Organic C and LOI were closely related, with $r^2 = 0.97$ for mineral soils with LOI < 14 percent dry weight, $r^2 = 0.83$ for mineral soils with LOI >= 14 percent, and $r^2 = 0.88$ for organic soil materials.

Biomass and forest floor C varied among vegetation types (Fig. 1). For upland sites, soil organic C concentration varied significantly with terrain attributes including slope gradient and horizontal distance and elevation above peatland. Correlations with the data used to calibrate the relationships (r_c^2) ranged from 0.93 to 0.95, and correlations with the validation data (r_v^2) ranged from 0.31 to 0.70 among vegetation types. Peatland depth was best estimated by distance to nearest mineral soil and elevation, with $r_c^2 = 0.29$ and $r_v^2 = 0.39$. Carbon density varied significantly with depth in peatlands because of differences in both C concentration and bulk density. It ranged from 0.52 kg m^{-2} cm^{-1} for the 0 to 50 cm depth, 0.76 kg m^{-2} cm^{-1} for the 50 to 100 cm depth, and 0.49 kg m^{-2} cm^{-1} for depths below 100 cm ($p < 0.001$). For all of the predictive relationships, the mean $r_c^2 = 0.83$ and the mean $r_v^2 = 0.50$.

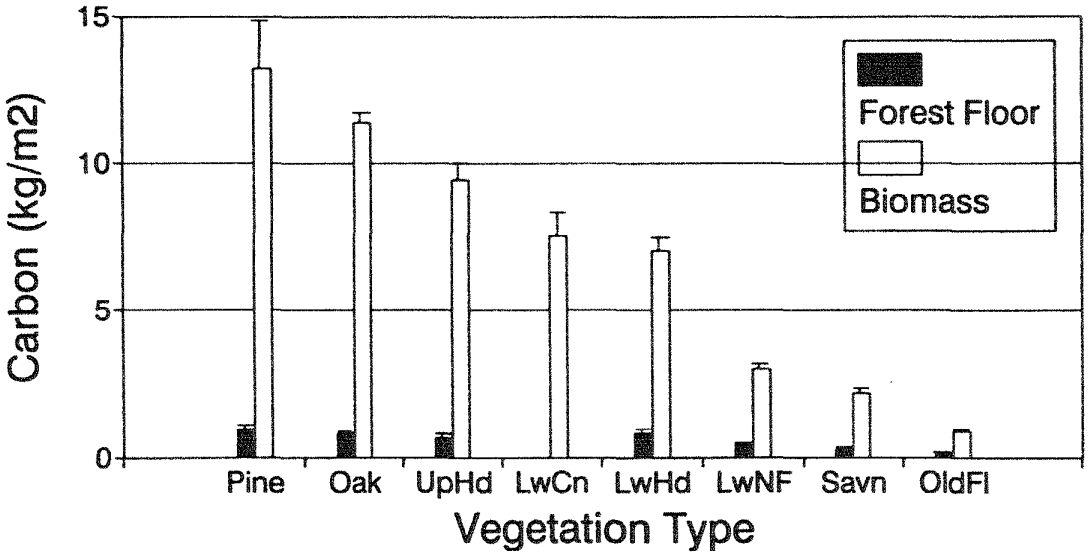

Figure 1. Carbon storage in biomass and forest floor in eight vegetation types of the Cedar Creek Natural History Area. Mean and standard error indicated. Pine = pine, Oak = oak, UpHd = upland mixed hardwoods, LwCn = lowland conifers, LwHd = lowland hardwoods, LwNF = lowland non forested, Savn = savanna, and OldFl = old field.

When applied to all of CCNHA, organic C storage is heavily weighted to the peatlands (Table 1). Reports of C storage in peatlands are rare. Gorham (1991) estimated global carbon storage in peatland soils, and his estimate (133 kg m^{-2}) is nearly equal to our estimate for peatland soils at CCNHA (131 kg m^{-2} -- Table 1).

In terms of C storage in uplands, Grigal and Ohmann (1992) reported mean C storage of five upland forest cover types in five geographic zones in a gradient across the Lake States. The C data for upland sites at CCNHA are at the low end of their range for forest floor (0.5 - 3.0 kg m^{-2}) and biomass (7.0 - 10.0 kg m^{-2}), and are much lower than their range for soil C (7.0 - 15.0 kg m^{-2}) (Table 1). As a result, total system C at CCNHA is much lower that reported by Grigal and Ohmann (1992) for upland forests (12.0 - 24.0 kg m^{-2}); total C storage in uplands of CCNHA is only 9 kg m^{-2}. The lower estimates for CCNHA reflect the influence of the coarse texture of the mineral soil. Although the pine types in the gradient study were also coarse textured, their surfaces were somewhat finer-textured. In addition, CCNHA has experienced more agricultural disturbance than have the sites from the gradient study. Finally, because CCNHA is at the southwest extreme of Lake States forests, precipitation is lower and temperatures are higher than for most of those forests, further reducing C storage.

Table 1. Carbon storage in the landscape of Cedar Creek Natural History Area. All data in kg m^{-2}. Sums are based on either the full depth (Total System) or 1 m of organic soil in peatlands. Standard errors, based on cell-to-cell variation in estimates, were less than 1% of the mean in all cases.

	Uplands	Peatlands	Landscape
Biomass	6.0	6.0	6.0
Forest Floor	0.5	0.5	0.5
Soil	4.0	131	52
Total System	9.0	138	59
Total (1 m soil)	9.0	69	32

Total organic C storage over all 2070 ha of CCNHA (excluding lakes) is 1.22×10^{12} g, of which the soil contributes nearly 90 percent, 1.08×10^{12} g. If C storage in peatlands is only considered to 1 m, as is mineral soil, C storage in soil is 0.55×10^{12} g. Our approach to estimating organic C storage in soil, which explained roughly half the spatial variation at CCNHA, treats the landscape as a continuum rather than as a set of discrete map units. The soil organic C storage was based on terrain attributes derived from a continuous representation of the topographic surface. In contrast, a discrete approach can also be used to estimate soil C, based on the area and the estimated C density of each soil map unit. Using that approach, estimated soil C storage to 1 m at CCNHA is 0.50×10^{12} g. The continuous approach is much more amenable to modeling changes in C storage with changes in climate on these landscapes.

CONCLUSIONS

Peatlands store over 90 percent of the organic C in the landscape at CCNHA, and are important when considering the C storage of forested systems in the Lake States. More work is needed to reduce the uncertainty currently associated with estimates of C pools in northern forests. The techniques that we used are applicable to broader areas, and could rapidly move our understanding of C storage forward.

ACKNOWLEDGEMENTS

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CARBON STORAGE IN MANAGED FORESTS OF THE NORTHERN GREAT LAKE STATES

Jeanette L. Rollinger[1] and Terry F. Strong[2]

Abstract: Carbon (C) storage in forest ecosystems is a significant part of the total terrestrial C pool, and may potentially be manipulated as an important C sink. The influence of management on C pools must be understood before guidelines can be suggested for maximizing C sequestration in forests. Studies of hardwood, red pine (*Pinus resinosa* Ait.), aspen and hybrid poplar stands located primarily in Minnesota, Wisconsin and Michigan have been and are currently being conducted to address the effects of common management practices on C storage. Factors studied include: (1) the effect of harvest intensities on soil and biomass C, (2) the effect of forest conversion from second growth hardwoods to red pine, and from old fields to hybrid poplar plantations or red pine, on ecosystem C, (3) the effects of soil compaction and biomass removal on stand productivity. Total aboveground C ranged from 303 to 335 Mg/ha, and did not differ by harvest intensity 40 years after partial cutting northern hardwoods on a ten-year cycle. However, distribution of C among aboveground components was significantly different (proportionately more C was in the understory with increased intensity of harvest). In both hardwood and some red pine stands, increasing harvest intensity appears to reduce C storage in soil. Soil compaction and forest floor removal reduced aspen shoot biomass and quantity of C in the forest floor. Total ecosystem C continued to decrease for five years after aspen harvest. However, the ecosystem began to gain C after seven years and accumulation continued until C reached a maximum at 70 years post-harvest. Total soil C was generally unchanged after aspen clear-cutting. Adjacent red pine plantations and hardwood stands on the same soils averaged the same mass of C in vegetation, in soil across the entire profile, and in total ecosystem C (211 and 206 Mg/ha, respectively), although the hardwood averaged 14 years older than red pine. Soil C accumulation in twelve to eighteen year old hybrid poplar plantations exceeded that on adjacent agricultural fields.

INTRODUCTION

In the United States, forest C pools constitute approximately 558 billion tons of C (Birdsey 1992). The land has been losing C to the atmosphere since about 1860, and until the end of the 1970s more C came from terrestrial ecosystems than from fossil fuel combustion (Houghton *et al.* 1983). Because soil, litter, and peat contain more than twice as much C than does the atmosphere, and because forested ecosystems can store substantial C in vegetation and soil (Birdsey 1992), speculation has arisen on how afforestation, land management and reforestation strategies can be employed to mitigate the rise in atmospheric CO_2 and expected global warming (Keeling 1984, Schneider 1989, Thompson and Matthews 1989). Among these strategies is the choice of which species to grow, and practices employed to manage those species.

The northern Great Lakes forests are located within the transition zone between the northern hardwood type and boreal forests. Prior to large scale logging that began in the middle 1800's until the early 1900s, forests were approximately 30 percent pine (Benzie 1977), with the remainder being upland mixed hardwood, hardwood/conifer, and lowland conifer types. Following upland logging, second growth deciduous forests, primarily even-aged, have become established on most of the area. Pines occur primarily in plantations. Trees in most of these forests have reached merchantable size and are under some type of management.

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The effect of both forest harvest practices and species conversion on the size of ecosystem C pools have been studied in this area. Manipulations associated with tree harvest were hypothesized to affect stored carbon including harvest intensity, soil compaction and forest floor removal (Alban *et al.* 1994, Perala and Alban 1993, Strong 1995). Land use conversion studied included the planting of red pine on second growth hardwood sites and planting hybrid poplars on old fields (Perala *et al.* 1995, Hansen 1993).

METHODS

Although the seven case studies featured in this review were conducted independently, the methods share some common features. Individual tree biomass was usually established from published regression equations (Perala and Alban 1993, Hansen 1992) or from a combination of plant diameter, height, and directly measured biomass relationships obtained by felling and drying. Understory biomass was estimated using techniques similar to those used for trees, and root biomass was also estimated. Biomass of coarse woody debris (minimum measured diameter varied among studies from 1 to 2.5 cm; too sound to be penetrated by a soil coring device) was estimated from oven-dried subsamples. Soil samples were collected from small pits, and usually separated into forest floor (exception, Hansen 1993) and various depth layers of mineral soil to a maximum depth below the main rooting profile (varied among studies from 40-100 cm). Bulk density was determined for each layer collected and percent C was measured either with a Carlo Erba C analyzer or by relationships with loss on ignition. Soil C was based on percent of C concentration in the soil and bulk density measurements.

CASE STUDIES

Cutting intensity among hardwoods

In this study, C was measured in various components of a northern hardwood ecosystem that has been managed under different intensities for forty years (Strong 1995). These data provide information on current effects of and potential forest management strategies on above- and below-ground forest C resources. Five cutting treatments were evaluated in 1992, including a control, a 20 cm stump diameter-limit cut, and three levels of individual tree selection cuts. The individual tree selection cuts were: heavy - 13.8 m^2/ha, medium - 17.2 m^2/ha, light - 20.7 m^2/ha residual basal area of trees 12 cm dbh and larger after cutting. The individual selection treatments had been cut at ten-year intervals since 1951. The diameter-limit treatment was only cut in 1951. Total aboveground biomass was separated into the following components: dead trees from 1951-1992, cut trees from 1951-1992, overstory live trees in 1992 (trees 12 cm dbh and larger), saplings in 1992 (trees and shrubs 2 m tall to 12 cm dbh), and ground vegetation in 1992 (all plants less than 2 m tall). The ratio of C to biomass was assumed to be 50 percent. The study was a randomized block. Data were analyzed by analysis of variance.

Differences in total aboveground biomass of components were significant among treatments. Generally, increased harvesting resulted in a greater proportion of biomass in saplings, and less in dead trees and ground vegetation. However, these differences were not significant when components were combined. Average total aboveground biomass for the treatments (331 Mg/ha) is similar to that estimated by Mroz *et al.*(1985) for northern hardwoods in the same region.

Soil C at the 3-10 cm depth differed in the diameter-limit treatment from other treatments. No differences were detected among treatments at the other depths, or when C was summed to 40 cm. However, linear regression revealed a trend of less soil C with increasing intensity of cutting ($p= 0.028$, $R^2 =0.84$). Soil C summed to 40 cm ranged from 90 Mg/ha in the diameter-limit treatment to 120 Mg/ha in the control treatment. Soils under red pine have a similar trend (Rollinger, unpublished data).

No differences in total ecosystem C were detected among treatments. However, a trend of less ecosystem C with greater cutting intensity appears to exist. Distribution of C in over- and understory vegetation and soil was similar

among all treatments; total ecosystem C ranged from 291 Mg/ha to 317 Mg/ha for the diameter-limit treatment and medium individual selection treatment, respectively.

Aspen harvesting method

Aspen (*Populus tremuloides* Michx. and *Populus grandidentata* Michx.) in the Lake States is rapidly being harvested for pulpwood (Hackett 1992), often using the whole-tree method with large equipment in clear-cuts. In the eastern USA, typical rotations range from about 35-50 years (Alban *et al.* 1991). Aspens are short lived, early successional trees, and in general are fast growing and ubiquitous throughout temperate North America. Quaking aspen (*P. tremuloides*) also extends into high altitude and boreal forests. The distribution, harvesting issues and silvicultural qualities of these trees have stimulated interest in the effects of aspen management on long term site productivity, C sequestration, and resulting impacts on global climate change (Alban *et al.* 1991 and references therein). This discussion will focus on two studies of aspen management, one on the effect of clear-cutting disturbance on C storage (Alban and Perala 1992), the other on the effects of biomass removal and soil compaction on these ecosystems (Alban *et al.* 1994).

A range of aspen ecosystems (including a chronosequence from 0 to 80 years) was surveyed for C in soil and vegetation (Alban and Perala 1992). Neither stand development nor timber harvesting affected soil C, but changes in total ecosystem C were correlated with changes in standing biomass. Total ecosystem C in these northern Great Lakes forests reached a maximum between 60 and 80 years (> 200 and < 250 Mg/ha). Soil compaction did not influence the results of in this study, because trees were harvested during the winter when the ground was frozen.

As part of a long term site productivity project, plots with various intensities of soil compaction and biomass removal were established within aspen stands (Alban *et al.* 1994). Both forest floor removal and soil compaction reduced biomass and height of 2-year-old aspen sprouts. Forest floor C decreased by about 9 t/ha immediately after forest floor removal, but there was little or no immediate change in mineral soil C. One year after harvesting, C in the forest floor and in the 0-10 cm mineral layer increased, probably because of root death. Within several years, this ongoing study should produce estimates of rates of soil recovery and effects of treatments on vegetation growth. Relatively mild levels of soil compaction and severe forest floor removal had similar effects on aspen growth.

Old field conversion

The interest and practice of growing trees on formerly agricultural land are increasing. Trees are often grown, because the land owner no longer cultivates crops, or are grown as a biological fuel source. During the first 20 years of cultivation, most grassland soil C decreases, particularly if the soil had high initial C (Burke *et al.* 1989, Mann 1986). Recovery of soil C after cultivation in certain systems is therefore a possible future C sink. The amount of C released by energy crops in combustion is equal to that captured in the material used for fuel; however C sequestered belowground as decomposed leaves, roots or root exudates could serve as a C sink. Trees, not grown for energy, on the other hand, could store C in the aggrading vegetation.

The C in soil under hybrid poplar plantations was compared to that in adjacent row crops or mowed grass at locations in Minnesota, Wisconsin, eastern North Dakota, and in Iowa (Hansen 1993). The Establishment of these plantations resulted in early soil C loss, but the trend later reversed and soil C became positively associated with plantation age. Significant amounts of soil C were sequestered by hybrid poplar plantations older than about 6 to 12 years-old, grown on previously tilled agricultural land. The higher quantity of C under poplars was particularly noticeable among the deeper sampled layers (below 30 cm). Flux of C out of the soil C pool most frequently occurred in the shallowest layers (above 30 cm), indicating the loss was due to mineralization.

Forty-six years after establishment, a red pine plantation converted from an old field showed a decrease in C per unit soil depth per volume of soil (Pregitzer and Palik unpublished manuscript). However, this change in C mass could be almost entirely ascribed to decreased soil bulk density: C concentration did not change significantly. Carbon gain to this plantation occurred in forest floor, understory and tree biomass.

Conversion of second growth hardwood to red pine

The distribution of C in soil and biomass was studied across Minnesota, Wisconsin, and Michigan, U.S.A., in 40 pole-sized red pine plantations paired with adjacent hardwood stands (Perala *et al.* 1995). Pine and hardwood stands shared a common boundary and soil. Hardwood stands were mixed species, naturally regenerated second growth following logging.

Carbon in total standing crop averaged the same in both hardwood (AVG=96 Mg/ha, SD=24) and red pine (AVG=97 Mg/ha, SD=20) forest types, although the hardwoods averaged 14 years older than the red pine. Coarse woody debris, shrubs, and herbs contained little C. Only the forest floor carbon pool was different between forest types, with a greater mass beneath red pine (AVG=23 Mg/ha) than hardwoods (AVG=17 Mg/ha). There was no significant difference in total ecosystem C between red pine and hardwood stands (211 Mg/ha, SD 48; and 206 Mg/ha, SD 41, respectively). Total mineral soil aggregated with depth contained the same total C in both pine and hardwood stands. However, the C occurred in different vertical patterns. Amounts of C in the upper levels of soil (0-4 cm) were higher under hardwoods, and amounts were higher under red pine at the 8-16 cm and 16-32 cm soil depths. Grigal and Ohmann (1992), in contrast, found that red pine sequestered less total soil C than did sugar maple or aspen, trees common to the hardwood stands studied by Perala *et al.* (1995). This discrepancy is likely due to the different study objectives and hence different site selection criteria. The paired design adopted by Perala *et al.* (1995) allowed careful same-soil pairing of stands.

Regression modeling showed that red pine stored carbon more efficiently both in the forest floor and deep in the soil, in areas where July air temperatures were relatively cool. Red pine also sequestered more C in mineral soil with increasing April-September precipitation. In warmer, drier climates, hardwood stands stored more soil C. July average air temperature was the only climate variable to be related to total ecosystem C, a decline of 21.5 Mg/ha/°C. Thus, restoration of pine to historically pine forested areas rather than conversion to second growth hardwood stands may increase stored C in the soil and vegetation of these ecosystems, provided that the climate remains relatively cool and moist. Further C increases can be expected in red pine biomass accumulation. Similarly, conversion of historically hardwood forest back to hardwoods from red pine may slightly increase C stored in the soil in relatively warm and dry climates.

Comparisons among forest types

Grigal and Ohmann (1992) sampled 169 forest stands, across Minnesota, Michigan and Wisconsin for total ecosystem C. Stands represented major regional upland forest types: balsam fir (*Abies balsamea* [L.]), jack pine (*Pinus banksiana* Lamb.), red pine, quaking aspen, and northern hardwoods. Regression analysis showed that about 63 percent of total ecosystem C variation was explained by forest type, stand age and soil clay content. Among the forest types measured, jack pine averaged the least total ecosystem C (13.9 kg/m^2) and northern hardwoods the most (23.4 kg/m^2). Time since disturbance influenced C in vegetation and the forest floor. Both components stored more C with increased time.

CONCLUSION

Differences in harvesting techniques and forest conversion usually had little or transitory effects on the total stored C in the ecosystem. However, within components of the ecosystem, at least some effects were noticed in every case. In general, tree harvesting activities slightly reduced carbon storage. Cutting intensity of typical mixed hardwood stands apparently affected the size of the stored soil C pool, but the effect was not significant when considering total ecosystem carbon. Carbon in aspen stands was reduced by compaction and forest floor removal, but the significance of the effect varies among years. The mineral soils in these stands were unaffected by clear-cutting. The effect of conversion of old fields to tree plantations varied with the type of trees planted. Hybrid poplars increased stored ecosystem C compared to agricultural crops and mowed field species. In contrast, red pine did not increase carbon stored in soil after conversion from an old field, but did increase biomass C. When maximization of C accumulation is a factor in choosing the trees to plant, managers should consider the potential of certain species to store more C

than others, and climatic factors. Over the entire region, conversion of second growth hardwoods to red pine neither increased nor decreased total ecosystem C. However, when the two stand types were corrected for age differences, the C pool in red pine vegetation could be expected to be larger than that in hardwoods. Whether red pine or hardwood stands were expected to accumulate more C depended on warm season precipitation. Dominant species also affected C pools, with jack pine stands having the least total ecosystem C. Although certain of these studies found effects of harvesting technique and forest conversion on mineral soil C, effects on forest floor and biomass C were more common and of larger magnitude. Vegetation and forest floor are also sensitive to disturbance related to stand replacement.

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TEMPERATURE AND EARTHWORM EFFECTS ON C AND N DYNAMICS IN OAK STANDS ALONG AN URBAN-RURAL LAND USE GRADIENT

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In previous studies of an urban-rural land use gradient in the New York City metropolitan area, urban forest soils had higher heavy metal concentrations, soil temperatures, and abundances of earthworms than rural soils, while rural soils had higher abundances of fungi. Leaf litter collected along the gradient had higher concentrations of lignin in urban than in rural stands. The effects of site (soil organisms, soil temperature) and substrate quality (lignin) on decomposition and N dynamics was tested by transplanting litter and soil between urban and rural stands. Rural derived litter decomposed more rapidly than urban derived litter regardless of site conditions and the urban sites exhibited higher decomposition rates regardless of litter type. In a laboratory experiment, initial lignin concentrations of leaf litter explained 50% of the variation measured in decomposition rate. Similar to the site effect on litter decomposition, net N mineralization rates were higher in urban than in rural stands regardless of soil type. Nitrification rates increased in urban stands; however, rate increases were only measured in urban soil cores. In contrast to litter decomposition rates, urban soil had higher N mineralization rates than rural soil, regardless of site conditions. An earthworm microcosm study was conducted to test whether earthworm activity explains the increased N transformation rate in the urban forest soils. N mineralization rates were significantly higher in urban soil with earthworms (0.15 mg N kg^{-1} d^{-1}) than in urban soil without earthworms. Rural soil with earthworms (0.57 mg kg^{-1} d^{-1}) had significantly higher rates than urban soil with earthworms and rural soil without earthworms (0.28 mg kg^{-1} d^{-1}). Net nitrification rates were 2 to 3 times higher in urban soil with earthworms than in the other treatments. These results suggest that earthworms may explain the relatively high N transformation rates in the urban stands despite the input of poorer quality litter.

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