FINAL REPORT

Climate change consequences of forest management practices

NSRC Theme 3: Forest Productivity and Forest Products

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Climate change consequences of forest management practices

Summary.

Forestry may yet play an important role in policy responses aimed at reducing climate-warming greenhouse gases. This is because when forests grow they remove from the atmosphere the principal greenhouse gas, carbon dioxide, and store it as carbon in wood and other biomass. Payment for carbon storage has been discussed as a potential incentive for forest owners to manage their lands to take up and store carbon. There are many unresolved scientific and policy issues relating to such schemes and how they might affect present forest management practices. A recent scientific concern relates to the consequences of afforestation and the decrease in the reflectivity (albedo) of a forested land surface compared to crops or grassland, and the impact that these changes in albedo may have on the climate system. In essence, snow covered fields reflect away more winter sunlight than evergreen forests, so planting forests could lead to the absorption of more solar energy and further warming of the climate system. However, the climate models that are used to estimate the impact of forests on the climate system rely on often outdated estimates of albedo and do not consider the effects of management on forest albedo, even though these impacts can be significant and many forests are managed. We assembled estimates of albedo based on shortwave radiation data obtained at AmeriFlux sites to evaluate the estimates used in climate models. We found that albedos used for grassland and needle-leaf deciduous conifers were in need of revision. We also carried out measurements of albedo in managed conifer forest in central Maine, focusing on comparing shelterwood harvest forest with intact forest. We found that the more open canopy of a shelterwood had a slightly higher albedo than closed coniferous forest, especially in the winter. This means that in addition to potentially high rates of carbon sequestration, such shelterwood systems will lead to *reduced* climate warming compared to unmanaged forest but climate model simulations indicated limited change in surface temperatures to such slight changes in albedo.

Introduction.

Forests are important in the debate over mitigating greenhouse gas induced climate change for several reasons. Tree growth removes carbon dioxide from the atmosphere and stores it in woody biomass, so many have proposed increasing the area of forests or managing to enhance forest productivity as climate change mitigation options (e.g. Dewar and Cannell 1992; Hoen and Solberg 1994; Nilsson and Schopfhauser 1995; Stavins 1999). However, forests play another role in the climate system by absorbing or reflecting solar radiation. When vegetation absorbs solar (shortwave) radiation, this energy is converted to sensible and latent heat (warming the air and evaporating water), and emitted as additional (longwave) infrared radiation; all of which influence the operation of the climate system. The overall reflectivity of a surface is termed its albedo. Surfaces such as snow have a high albedo (~0.80) and reflect away most solar radiation while forest canopies have a low albedo (~0.15) leading to increased solar radiation absorption and atmospheric heating.

Until recently, the role of albedo change has been overlooked in the carbon sequestration/climate change debate. However, changes in albedo arising from afforestation can potentially lead to forests *increasing* climatic warming. In this study we measured albedo over several Maine forests including a larch plantation, undisturbed spruce-hemlock forest, and spruce-hemlock forest that has been partially harvested using the shelterwood system. We compared these results with other albedo data and with estimates commonly used in climate models.

Partial cutting systems such as shelterwood or selection cutting, have long been used by land managers to promote the regeneration and success of one species over another. The goal of such management is to create a forest stand environment that most benefits the ecophysiology of a desired species (Dumais and Prévost, 2007). Shelterwood systems encourage late-successional (shade tolerant) species over their competitors (Mathews, 1989) by evenly removing a fraction of the overstory trees in the harvest area in 2 or 3 cuts (separated by 10-15 years) that progressively increase understory light; the first harvest stimulates seedling regeneration, the second (if used) encourages sapling growth, and the final cut removes the remaining overstory In the northeastern USA and adjacent areas of Canada this method is used, for example, to encourage red spruce and balsam fir (Seymour 1992). Shelterwood and other partial harvest systems are now the dominant management method in Maine (left).

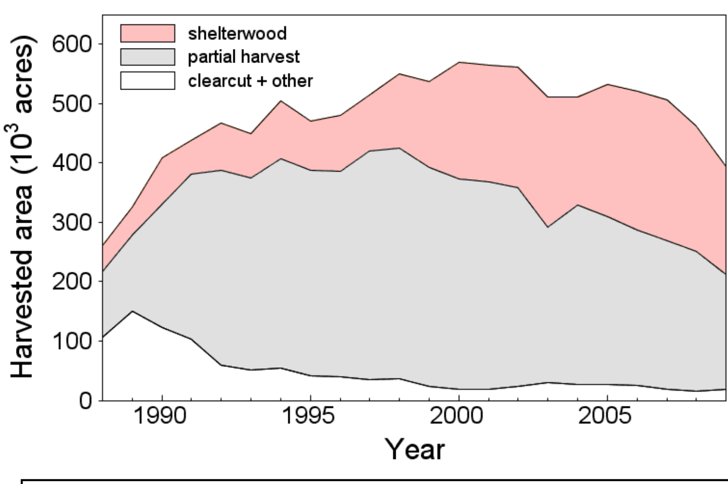

Figure 1. Shelterwood and other partial harvest methods are dominant in Maine. Shelterwood harvest as described in this paper is now used on almost one-half the harvested lands in Maine, USA. Data from “Silvicultural Activities Report, 2009” and earlier years published by Department of Conservation, Maine Forest Service, www.maineforestservice.gov.

Methods.

We made comparative measurements of incoming and reflected shortwave radiation with Kipp and Zonen CMA6 albedometers above different forest stands including a recent shelterwood treatment. Continuous measurements were made from research towers extending above spruce-hemlock and larch forest at the Howland site (Fernandez et al. 1993; Hollinger et al. 1999), located ~50 km north of Bangor, ME. The vegetation at Howland is broadly similar to that found across the northern forest region. For comparative purposes we analyzed incoming and reflected shortwave radiation at a number of forested sites.

Results.

Forest. A comparison of albedo values across forested sites shows wide variations in absolute albedo and seasonal patterns between sites (Fig. 2). The Howland spruce and larch data were obtained with the albedometers purchased from NSRC funds. When foliage is present, deciduous forest albedo can be more than twice that of evergreen conifers. Deciduous forest albedos are also more seasonally variable than evergreen forest albedos. In the AmeriFlux data, deciduous forest albedos increase by 20 – 50% from spring lows to seasonal maxima, a transition that occurred within about 30-40 days as the foliage expanded (Fig. 2). The beginning of canopy development occurred around day 100 at the southern-most sites (Duke and Chestnut Ridge), preceding that of the northern-most sites (Willow Creek, UMBS, and Bartlett) by 30-40 days (~4 days/degree latitude). Following a spring maximum of ~0.14 (Ozark) to ~0.18 (Willow Creek),

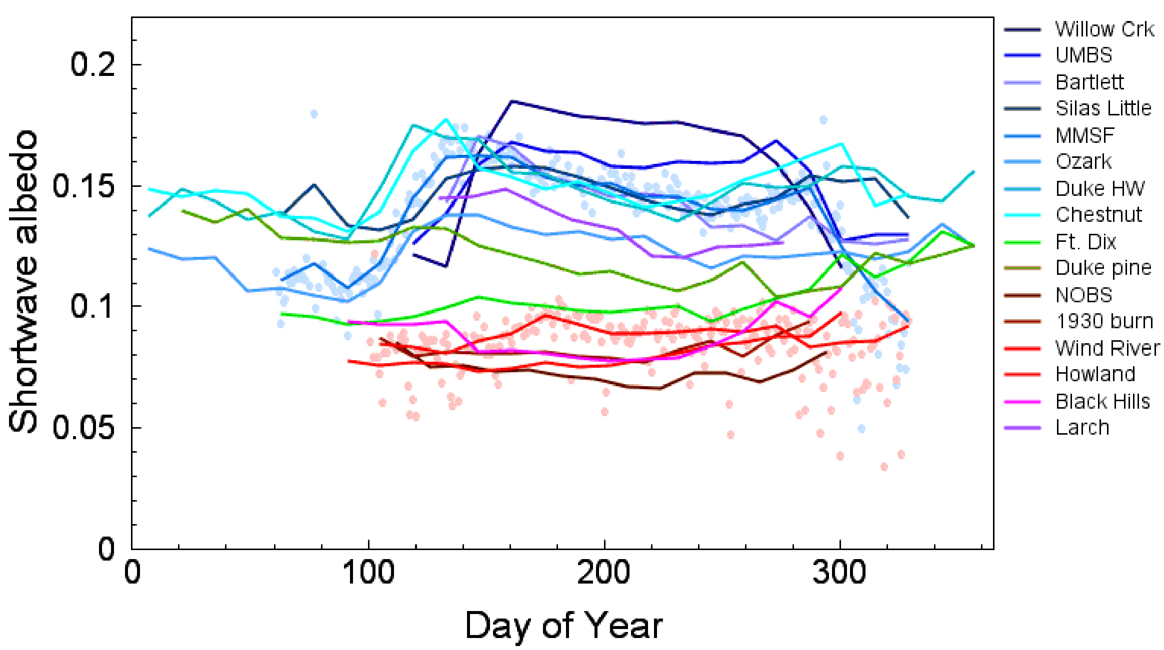

Figure 2. Snow-free seasonal albedos integrated over a 2-week period (solid lines) and integrated over 1 day (dots). Blue lines signify temperate, broadleaf deciduous trees, green lines, pine forest (needleleaf evergreen trees), red lines, evergreen conifer forest (needleleaf evergreen trees), and purple line, larch forest (deciduous needleleaf trees). The lengths of the various lines are coincident with the snow free season at each site. The blue dots indicate daily albedo at the Morgan Monroe site, the red dots at the Howland forest.

deciduous forest albedos declined gradually through the summer before declining more rapidly around day 280 (northern sites) and 20-30 days later at the southern sites. At many of the deciduous sites, albedo increased slightly in the early fall before decreasing; presumably leaf reflectance and transmittance in the visible wavelengths increased as a result of the destruction of chlorophyll. Mid-summer albedos for broadleaf deciduous forests varied by more than 30% across sites, from ~0.13 at the Ozark site to ~0.17 at Willow Creek. The two sites with the highest growing season albedos were also the most northerly.

Evergreen needle-leaf forest albedos were lower than broad-leaf deciduous forest albedos, with the exception of the Duke loblolly pine site where winter values were greater than several of the leafless hardwood sites (Fig. 2). The pines at the southern-most sites (Duke and Ft. Dix) had consistently higher albedos than the more northerly conifer forests. When averaged across a season, albedos at these more southerly sites were about 0.11, 60-70% that of deciduous forest whereas the albedo at the more northerly conifer sites averaged between about 0.08-0.09, only ~50-60% that of the mean deciduous forest values. There is no clear signal of canopy phenology as evidenced by spring increase or autumn decline in any of the evergreen conifer albedos. The general pattern seen at the different sites of a midyear minimum is presumably due to the impact of higher solar elevations in the summer. The deciduous needle-leaf tree (larch) seasonal albedo exceeded all other conifers (Fig. 2) and overlaps the albedo range seen in broadleaf deciduous trees. Seasonal variation of larch albedo resembles that of a broadleaf deciduous forest more than an evergreen needle-leaf forest (Fig. 2).

Grasslands and Crops. The growing season albedos of grassland and crop surfaces generally exceed those of forests (Fig. 3), although there is overlap between grassland albedo and those of the highest albedo forests (compare Fig. 2 and 3a). The Mediterranean climate (summer drought) Vaira grassland site was qualitatively different from the other (temperate) the grassland sites. The temperate grassland site albedos reached a minimum near the middle of summer. By contrast, the crop sites tended to show late summer maxima in albedo. Although maize and soybean albedos were similar at the

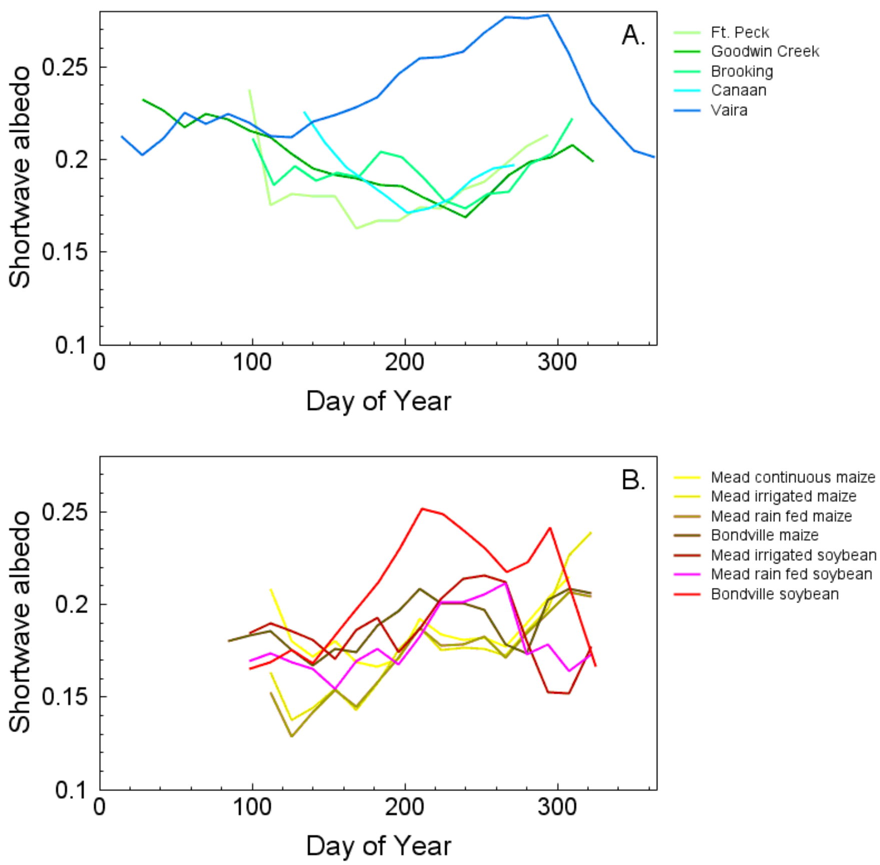

Figure. 3. Snow-free seasonal albedo integrated over 2-week periods for grasslands (A.) and crops (B.).

beginning of the growing season, presumably because most reflectance at this time was from the soil surface, soybean canopies had significantly higher albedos than maize grown on the same site throughout much of the summer. However, during the fall when post harvest debris lay in the fields, this pattern reversed and maize residue albedos were greater than soybean. Specifically, soybean albedos were ~20% higher than maize at both Bondville, Illinois, and Mead, Nebraska, in August but about 20% lower in October. When averaged between sites and over a season, grassland albedos were slightly lower in the summer at about 0.18 than in spring or fall (~0.20).

Shelterwood Albedo. Spruce-hemlock forest that had been partially harvested (40% basal area reduction in 2008) had a higher albedo than nearby unharvested spruce-hemlock forest (Fig. 4). The differences were greatest in the winter when snow was present. The open structure of the shelterwood stand allowed more snow to reach the ground than in unharvested forest. In addition, the dark canopy of the unharvested forest mostly obscured the snow covered ground in the winter reducing stand albedo. In the shelterwood forest winter albedo was continuously elevated for several months due to the visibility of the snow covered ground while in the unharvested forest snow would stay in the canopy elevating albedo for only a few days after snowfall. Thee shelterwood treatment also showed a midseason (May) albedo increase compared to unharvested forest that was likely due to the development of deciduous ground cover (Fig. 4).

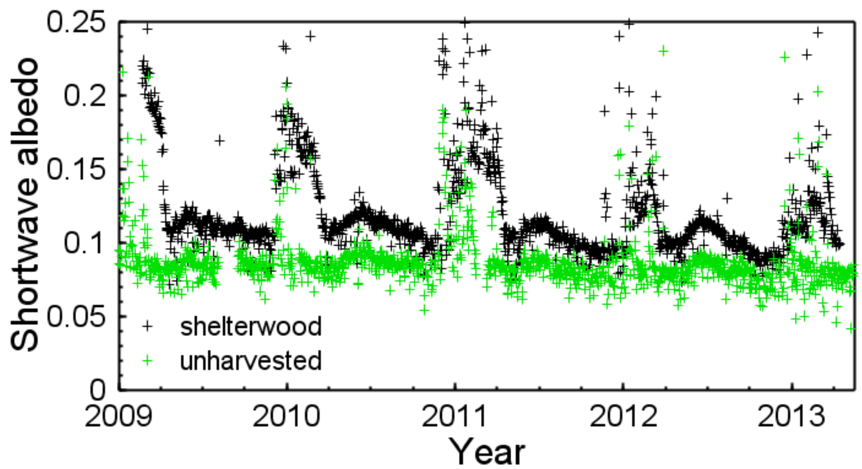

Figure 4. Midday albedo for unharvested (green) and partially harvested (shelterwood) spruce-hemlock forest in central Maine.

Over the 4 years of the study, the weighted albedo of the shelterwood treatment decreased from 0.124 in 2009 to 0.109 in 2012 while the albedo of unharvested forest remained roughly constant at 0.09. This was presumably due to increases in leaf area of existing spruce and hemlock trees, and the growth of new seedlings and advance regeneration in the understory. The albedo impact of a shelterwood treatment was minor. In climate model simulations using albedos discussed in Figs. 2-3, Heilman et al. (2011) found that biome level albedo changes of 0.05 (more than double the growing season difference observed here) had a < 1 degree C impact on seasonal temperatures.

Comparison of tower albedos to values used in climate models. A variety of climate models have been used to forecast the future state of the climate system (see Randall *et al*., 2007 for summary) and these models employ several different albedo formulations. Many (e.g. GFDL-CM2, UKMO-HadCM3, GISS) specify albedos that depend on a broad grouping of plant functional types (PFTs) such as broadleaf deciduous trees, grassland, or crops. In some cases (e.g. models based on data from Mathews, 1984), a slight seasonal variation in albedo is incorporated.

For the broadleaf deciduous tree (BDT) vegetation type, the albedo values used by Mathews (1984), Milly and Shmakin (2002), and Cox *et al*. (1999) are within 2 standard deviations of our seasonal means, although ~10-15% below our mean (Table 1). Values suggested by Henderson-Sellers *et al*. (1986) and Dickinson (1986) for broadleaf deciduous tree albedo are more than 2 standard deviations (~20-30%) above the mean value from our observations. For the needle-leaf evergreen tree (NET) type, all models use albedos that are well above our values for northerly evergreen forests (boreal and sub-boreal) but representative of more temperate pine forests. The large difference in albedo between these two types of needle-leaf evergreen trees (~25%) and their geographically distinct locations suggest that it may be useful for climate modelers to subdivide the evergreen needle-leaf tree type. The mean seasonal grassland and crop surface albedos used in a number of climate models are consistent with the results reported here (Table 1).

Implications for land surface modeling Errors in albedo will translate into land surface model biases in sensible and latent heat production, except where errors in grid cells composed of multiple vegetation types are offsetting. Because of the non-random global distribution of plant functional types, errors in albedo of a specific PFT can thus lead to regional warm or cold biases of climate models incorporating these PFTs.

Table 1. Land Surface Model Albedos. Plant functional types (PFTs) include broadleaf deciduous tree (BDT), needleleaf deciduous tree (NDT) such as larch, broadleaf evergreen tree (BET), and needleleaf evergreen tree (NET) such as spruce or hemlock.

			Spring (April-May)			
PFT	*this study*	*Mathews*[a]	*HS*[b]	*Milly*[c]	*Dickinson*[d]	*Cox*[e]
BDT	0.145 (0.012)	0.12	0.19	0.13	0.18	0.13
NDT	0.145	-	-	0.13	0.14	0.13
BET	-	0.11	0.11	0.13	0.12	0.12
NET	0.084 (0.006) northerly 0.111 (0.018) southerly	0.12	0.13	0.11	0.14	0.14
Grassland	0.209 (0.021)	0.20	0.19	0.20	0.20	0.19-0.20
Crop	0.178 (0.013)		0.20	0.16	0.2	0.17-0.25
			Summer (June-August)			
PFT	*this study*	*Mathews*	*HS*	*Milly*	*Dickinson*	*Cox*
BDT	0.152 (0.013)	0.15	0.19	0.13	0.18	0.13

NDT	0.133	-	-	0.14	0.13	0.13
BET	-	0.11	0.11	0.13	0.12	0.12
NET	0.079 (0.007) northerly 0.105 (0.018) southerly	0.15	0.13	0.11	0.14	0.14
Grassland	0.181 (0.008)	0.20	0.19	0.20	0.20	0.19-0.20
Crop	0.189 (0.020)		0.20	0.16	0.2	0.17-0.25
			Fall (September-October)			
PFT	*this study*	*Mathews*	*HS*	*Milly*	*Dickinson*	*Cox*
BDT	0.146 (0.015)	0.12	0.19	0.13	0.18	0.13
NDT	0.127	-	-	0.13	0.13	0.13
BET	-	0.11	0.11	0.13	0.12	0.12
NET	0.089 (0.006) northerly 0.107 (0.004) southerly	0.11	0.13	0.11	0.14	0.14
Grassland	0.197 (0.008)	0.18	0.19	0.20	0.20	0.19-0.20
Crop	0.193 (0.018)		0.20	0.16	0.2	0.17-0.25

a. Mathews et al. 1984, used in GISS models.
b. Henderson-Sellers et al. 1986.
c. Milly and Shmakin 2002, used in GFDL-CM2.
d. Dickinson et al. 1986, used in BATS.
e. Cox et al. 1999, used in UKMO-HadCM3.

Products.

Howland Forest albedo data resulting from this work were submitted to the AmeriFlux network database. The following publications resulted in whole or part from data obtained by the albedo instrumentation purchased with NSRC funding:

1) Hollinger, D.Y., S.V. Ollinger, A.D. Richardson, T.P. Meyers, D.B. Dail, M.E. Martin, N.A. Scott, T.J. Arkebauer, D.D. Baldocchi, K.L. Clark, P.S. Curtis, K.J. Davis, A.R. Desai, D. Dragoni, M.L. Goulden, L. Gu, G.G. Katul, S.G. Pallardy, K.T. Paw U, H. Schmid, P.C. Stoy, A.E. Suyker, and S.B. Verma. 2010. Albedo estimates for land surface models and support for a new paradigm based on foliage nitrogen concentration. Global Change Biology 16:696-710.

2) Heilman, W.E., D.Y. Hollinger, X. Li, X. Bian, S. Zhong. 2010. Impact of Revised and Potential Future Albedo Estimates on CCSM3 Simulations of Growing-Season Surface Temperature Fields for North America. Atmospheric Science Letters. DOI: 10.1002/asl.301

3) Wang, Z., C.B. Schaaf, A.H. Strahler, M.J. Chopping, M.O. Román, Y. Shuai, C.E. Woodcock, D.Y. Hollinger, D.R. Fitzjarrald. 2014. Evaluation of MODIS albedo product (MCD43A) over grassland, agriculture and forest surface types during dormant and snow-covered periods. Remote Sensing of Environment 140:60–77.

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