Carbon Storage and Oregon's Land-Use Planning Program

James F. Cathcart, Jeffrey D. Kline, Matt Delaney, and Mark Tilton

ABSTRACT

Research and policy discussions highlight the role of forests in reducing greenhouse gases by storing carbon. An important factor regarding forests and carbon is simply maintaining the amount of land that is retained in forest cover. Since 1973, Oregon's statewide land-use planning program has sought to maintain forest and agricultural lands in the face of increasing development by maintaining forest and agricultural zones and to limit growth to within urban growth boundaries. We combine projections of forest and agricultural land development with estimates of average carbon stocks for different land uses to examine what effect land-use planning has had in maintaining forest carbon in western Oregon. In addition to other benefits arising from the conservation of forestland, results indicate that Oregon's land-use planning system in western Oregon yields significant gains in carbon storage equivalent to a reduction of 1.7 million metric tons of carbon dioxide (CO_2) emissions per year.

Keywords: climate change, forest carbon, carbon storage, carbon dioxide emissions, carbon sequestration, ecosystem services, land use and development

The 1992 Earth Summit held in Rio de Janeiro, Brazil, marked the beginning of international efforts to check global warming by reducing "human-induced" sources of greenhouse gases such as carbon dioxide (CO_2). By 1998 more than 170 nations including the United States had ratified the resulting United Nations Framework Convention on Climate. Beginning in 1995, the ratifying nations met at annual Conference of the Parties conventions for the purpose of implementing the Framework. The third Conference of Parties meeting, held in Kyoto, Japan in 1997, developed the Kyoto Protocol, which strengthened international commitments to greenhouse gas reductions beyond the year 2000. In 2004, the Kyoto Protocol was ratified by enough countries to become binding to the signatories, setting the stage for greenhouse gas allocation plans in most of Europe, Russia, and Japan and implementation of resulting greenhouse gas trading schemes such as the Joint Implementation and the Clean Development Mechanism. Even countries that chose not to ratify the Kyoto Protocol, such as Australia and the United States, are still investigating voluntary and market-based schemes to reduce greenhouse gas emissions. Examples in the United States include the US Department of Energy's Voluntary Reporting of Greenhouse Gases, the Chicago Climate Exchange, the California Climate Action Registry, and The Climate Trust based in Oregon.

Forests naturally sequester CO_2 from the atmosphere through photosynthesis and store it as carbon in both live and dead above- and belowground biomass including organic soil material. Given this ability to sequester and store carbon, ongoing research and policy development is investigating how forests and their management can further reduce greenhouse gases such as CO_2. For example, the Intergovernmental Panel on Climate Change's special report on Land Use, Land-Use Change, and Forestry stresses the role of afforestation, reforestation, forest management, and land use with respect to implementing the Kyoto Protocol (Watson et al. 2000). Efforts are underway to formally assess and inventory forests as sinks for carbon storage (Global Change Program Office 2004, Smith et al. 2004, US Environmental Protection Agency 2006). Other studies look at how to best manage forests and forest products for improved carbon

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James F. Cathcart (jcathcart@odf.state.or.us) is forest resource trust manager, Oregon Department of Forestry, Salem, OR 97310. Jeffrey D. Kline (jkline@fs.fed.us) is research forester/economist, US Department of Agriculture, Forest Service, Pacific Northwest Research Station. Matt Delaney (mdelaney1@centurytel.net) is president, Delaney Forestry Services. Mark Tilton (marktilton@oregonfast.net) is resources inventory specialist, USDA Natural Resources Conservation Service (retired), Oregon Resources Inventory Team. *The authors express their appreciation to the anonymous peer reviewers for this article, especially for their receptiveness to the work and suggestions and comments that led to several improvements. Also, the authors appreciate the courtesy review provided by Ralph Alig, US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon.*

storage (e.g., Wayburn et al. 2000 and Perez-Garcia et al. 2004). Urban forests also retain some capacity to store carbon in shade trees and associated landscaping and play an important role in conserving energy in home and business heating and cooling (McPherson and Simpson 1999, Nowak and Crane 2002). Alig (2003) suggests that a mixture of forest-based greenhouse gas reduction strategies nationally may be beneficial, including afforestation and reforestation incentives, and land-use policies focused on retaining forestland. Although it is important to consider how forests and forest products can be managed for carbon storage, it may simply be the act of maintaining or increasing the amount of land area in forest cover and use that is the most important determinant in avoiding increases in greenhouse gas emissions.

In Oregon, forestland conservation occurs primarily through the State's land-use planning program (Oregon Department of Land Conservation and Development 1997). Enacted in 1973, the state directs counties and municipalities to focus new development inside urban growth boundaries and to restrict development outside of urban growth boundaries by zoning those lands for agricultural or forest use. We estimate the amount of carbon loss avoided in western Oregon as a result of conserving forest and agricultural lands from development under Oregon's land-use planning program. We identify average carbon stock values for different land-use categories based on a review of literature and available data. We apply these values to estimates of low-density and urban development in western Oregon described in previous studies.

We estimate carbon benefits for two scenarios: (1) assuming Oregon's land-use planning program as enacted in 1973 and (2) assuming Oregon's land-use planning program was not enacted in 1973. Calculations are in terms of units of carbon because forests store carbon, but we report the land-use planning effects on stored carbon in terms of CO_2 because CO_2 equivalency is the standard for emissions reporting (1 unit of carbon is equivalent to 3.67 units of CO_2). Our calculations only account for changes in carbon stocks arising from development and do not account for changes in CO_2 emissions arising from the change in land use. For example, the calculations show a gain in carbon storage when cultivated agriculture land is developed because of increased carbon storage in shade trees and landscaping ascribed to development; however, we ignore that the developed land-use activity may emit more CO_2 emissions than agricultural activity. Our results suggest that Oregon's land-use planning program has played a significant role in avoiding CO_2 emissions from development by avoiding losses of forest carbon, highlighting the importance of maintaining Oregon's forestland base to any strategy designed to reduce greenhouse gas emissions.

Oregon's Land-Use Planning Program

Enacted in 1973, Oregon's land-use planning program often is cited as a pioneering approach to maintaining resource lands for agricultural and forest uses, by concentrating human populations and business development within urban growth boundaries (Gustafson et al. 1982, Abbot et al. 1994). The foundation of the program is a set of 19 statewide planning goals that define the state's policies on land use and related topics, including maintaining productive agricultural lands (goal 3) and commercial forestlands (goal 4) and conserving open spaces, scenic and historic areas, and natural resources such as fish and wildlife habitats (goal 5). The program directs local governments to plan and adopt land-use regulations by developing local comprehensive plans, based on standards set by the state. This process has resulted in a system of state-approved local comprehensive plans that cover the entire state and define where development of different types can occur on forest, agricultural, and other resource lands.

Oregon's land-use planning program generally is considered successful with respect to its original purpose as the state has incurred relatively modest losses of farm and forests to development since the program was implemented. In western Oregon, e.g., losses of forest, mixed forest/agricultural, and agricultural lands to development from 1973 to 2000 are estimated at 348,000 ac (Lettman 2002). In eastern Oregon, losses of forest, range, mixed forest/range, mixed forest/agriculture, and agricultural lands to development from 1975 to 2001 are estimated at 192,000 ac (Lettman 2004). In total, Oregon has lost just 540,000 ac of agricultural, range, and forestlands to development from the mid-1970s to the turn of the century; roughly 21,600 ac/year. Sixty-four percent of those losses occurred in western Oregon—primarily in the Willamette Valley and in southern Oregon communities along Interstate 5. Different data and analysis from the US Department of Agriculture, Natural Resource Conservation Service's (NRCS) National Resources Inventory (Nusser and Goebel 1997) of land cover for nonfederal lands in Oregon found comparable losses of resource lands to development, with 19,560 ac lost annually from 1982 to 1997 (NRCS 2003). The National Resource Inventory (NRI) estimates of conversion of forestland to urban land within Oregon were developed by the Oregon NRCS utilizing queries to the national NRI database through the web-based Online Analysis System. All estimates were derived from the 1997 NRI database (revised December 2000).

Oregon's land-use planning program is not without its opponents. Since its inception, the program has created tension between its advocates, who see land-use planning as necessary to the long-term conservation of forest and farmlands, and its detractors who argue that land-use regulations unduly burden private landowners. That tension culminated with the passage of a 2004 ballot measure—Measure 37—which mandates "just compensation" to landowners when land-use regulations enacted after the current owner or a family member became the owner of the property, reduces the fair market value of the property by restricting its use. In lieu of compensation, Measure 37 allows government jurisdictions to not apply the regulation, effectively nullifying the conservation intent of the program.

Projecting Forestland Development and Estimating Stored Carbon

Previous research has evaluated changes in forest and farmland development patterns from 1974 to 1994, resulting from implementation of the forest and farmland zoning and urban growth boundaries found in Oregon's land-use planning program (Kline 2005). The evaluation relies on relatively well-documented spatial land-use modeling techniques created and tested for western Oregon (Kline 2003, Kline et al. 2003). The model describes changes in building densities as a function of prevailing development pressures, existing building densities, slope, elevation, and land-use zoning. Development pressures are represented in the model using a gravity index describing the spatial location of land relative to western Oregon cities of varying population sizes. As computed, the gravity index describes the commuting opportunities offered by land in different locations, which are assumed to be a primary factor affecting development. The model was used to estimate future building densities on forest and farmlands based on historical populations of cities included in the gravity index computation. The conservation of Oregon's forest and farmland base under the State's land-use planning program was evaluated using zoning variables included in the empirical model, which enable computing estimated distributions of forest and farmlands among building density classes, with and without land-use zoning in effect.

The land-use projections define three stages (or classes) of increasing development that affect the resource land-use categories of forest, agriculture, and mixed forest/agriculture. These development classes include relatively undeveloped (0–16 buildings/mi^2), low density (16–64 buildings/mi^2), and developed (greater than 64 buildings/mi^2). The 0- to 16-buildings/mi^2 density class describes relatively undeveloped lands consistent with average minimum parcel sizes of 40 ac/building (house). The 16- to 64-buildings/mi^2 density class describe low-density developed lands consistent with average parcels sizes ranging from 10 to 40 ac. The greater than 64-buildings/mi^2 density class describes relatively developed lands consistent with maximum average parcel sizes of 10 ac or less (Kline 2005). To estimate potential future forest carbon benefits resulting from forest and agricultural land conservation, land-use change estimates for the period of 1973–94 provided in Kline (2005) were extended to 2024 and used to compute potential gravity index values for future years. The extended land-use change estimates were based on reported population numbers for the 1994–2004 period and projected population numbers for the 2005–24 period (Office of Economic Analysis 1997). The potential gravity index values were then entered into the land-use change model reported in Kline (2005) to project future distributions of forest and agricultural lands among building density classes for 2004, 2014, and 2024, with and without Oregon's land-use planning program in effect (Figure 1). The estimates of land-use change from the 1974 baseline year to 2004 are based on numbers depicting actual population growth, while the land-use estimates for 2014 and 2024 are based on state-reported population projections.

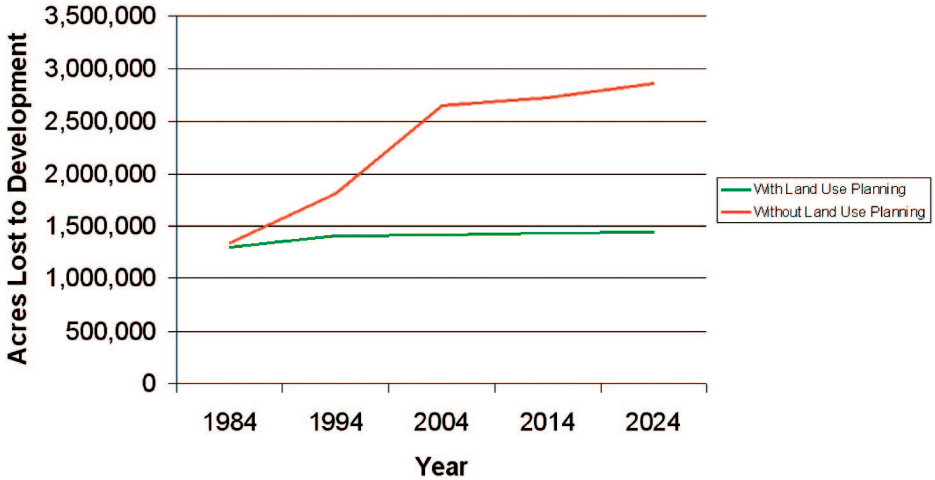

Figure 1. Loss of undeveloped forest, agriculture, and mixed forest/agriculture lands with and without land-use planning.

We assumed that forestlands contain carbon stocks approaching live tree stocks found in young, second-growth Douglas-fir (*Pseudotsuga menziesii*) forest conditions. An average carbon stock value of 45.4 metric tons of carbon per acre was used (Table 1). The value corresponds to the live tree carbon stocks listed in the 2006 US Department of Energy's voluntary reporting of greenhouse gas program technical guidelines for forests for a 25-year old Douglas-fir stand created from afforestation for the Pacific Northwest Region–West (Smith et al. 2006 as reported in US Department of Energy 2006). This is a simplifying assumption that ignores species composition, forest structure and type, dead and down woody material, and other factors (including any effects from climate change) that determine the actual amount of carbon storage on a given forested site. We feel that this value provides a lower bound for estimating avoided emissions from maintaining the forestland base, under the assumption that most forestland converted to nonforest use is likely older than 25 years. Further, projections of climate change impacts to Oregon's vegetation suggest that Oregon is going to experience an overall increase in vegetative cover and stored biomass overtime, not less (USDA Forest Service 2004). However, our analysis does not give credit to the fact that some of the stored carbon assumed lost from forestland conversion to other land uses actually continues to be stored in wood products derived from the converted forest (Row and Phelps 1996, Perez-Garcia et al. 2004). In forecasting the CO_2 emission reduction benefits from afforestation activity in western Oregon, the Oregon Office of Energy awarded 35% of the preharvest carbon stock as continuing in storage in forest products; although this carbon pool was further debited for wood decay emission of 1.5%/year thereafter (Oregon Office of Energy 1996).

Agricultural land use in western Oregon was assumed to be cultivated cropland use. The average carbon stock factor for cultivated agriculture was 1.8 metric tons of nonsoil carbon per acre (Table 1). This value is consistent with the nonforest vegetation cover carbon stock reported in the voluntary reporting of greenhouse gas technical forestry guidelines for afforestation in the Pacific Northwest–West region (US Department of Energy 2006). We assumed that the carbon stocks for low-density residential use to be 2.5 times the carbon stock value for cultivated agriculture since the class of development contain a mixture of land cover in pasture, noncultivated agricultural, and woody agricultural (e.g., orchards, Christmas trees, and berry farms) uses. This value, 4.5 metric tons of nonsoil carbon per acre (Table 1), falls between the cropland and pastureland nonsoil carbon stocks calculated from values reported for the Pacific Coast region in Birdsey (1996).

The average carbon stock value for urban lands in western Oregon was compiled from a study of changes in forest canopy cover and associated impacts to carbon stocks for the Willamette and Lower Columbia Rivers of western Oregon (American Forests 2001). Specifically, the value in Table 1 is the estimated per acre carbon stocks for urban forest canopy cover for the cities of Portland (and surrounding metropolitan

Table 1. Carbon stock factors used in estimating the CO_2 emission reductions from land-use planning.

Building density class/land use	Carbon stock factor (metric tons of carbon per acre)	Land cover assumptions
Undeveloped (0–16 buildings/mi^2)		
Agriculture	1.8	Assumes cultivated agriculture
Forest	45.4	Assumes 25-yr-old Douglas-fir forest
Mixed agriculture/forest	21.8	Midpoint interpolation between agriculture and forest
Low-density residential (16–64 buildings/mi^2)	4.5	Assumes mixture of land cover in pastureland, other rural lands and noncultivated cropland typical of rural residential land uses
Developed (greater than 64 buildings/mi^2)	3.3	Assumes urban lands

Table 2. Avoided changes in carbon stocks from development as a result of Oregon's land-use planning system: 1974–2004 (western Oregon).

Undeveloped land use	Acres lost to low-density development if land-use planning is not implemented	Per acre change in carbon stock as a result of low-density development[a] (metric tons carbon per acre)	Total change in carbon stock as a result of acres lost to low-density development (metric tons of carbon)	Acres lost to high-density development if land-use planning is not implemented	Per acre change in carbon stock as a result of high-density development (metric tons carbon per acre)	Total change in carbon stock as a result of acres lost to high-density development (metric tons of carbon)
Forest	269,195	−40.9	−10,989,617	66,748	−42.1	−2,809,696
Agriculture	605,984	+2.7	1,649,246	166,496	+1.5	241,672
Mixed forest/agriculture	59,987	−17.3	−1,033,984	52,583	−18.5	−973,147
Totals	935,166		−10,374,355	285,827		−3,541,171
Total acres lost to low- and high-density development if land-use planning not implemented						1,220,993
Total change in carbon stock due to both low- and high-density development (metric tons of carbon) if land-use planning not implemented						−13,915,526
Emission equivalent of change in carbon stock from development (metric tons of CO_2 equivalent) if land-use planning not implemented						−51,069,980

[a] Per acre change in carbon stocks rounded and will not yield exact total change in carbon stocks as indicated in table.

area), Albany, Corvallis, Eugene, Salem, and Wilsonville in Oregon and the City of Vancouver in Washington.

In all cases, the average carbon stock values applied were aboveground stocks associated with aboveground, live vegetation. We did not account for differences in dead wood and soil organic carbon pools under agriculture and forestland use. The implication is that the results presented here likely underestimate the avoided carbon emissions from conserving forestland because both of these pools, especially for forests, store more carbon than under a developed land use.

Average carbon stocks were assigned to the land-use and building development classes used in the land-use projections according to Table 1. Incremental avoidance of forest carbon stock losses from conserving forest, agricultural, and mixed forest/agricultural lands were estimated by computing the difference between the carbon stock equivalent for the mix of land uses found under Oregon's land-use planning and the carbon stock equivalent for the mix of land uses that might have occurred had the program not been implemented. In general, carbon stocks were reduced on forest and agricultural lands falling into the low-density developed and developed classes, relative to those lands remaining in the undeveloped class. For example, every acre of forestland that was converted to low-density development results in a decrease in carbon stocks of 40.9 metric tons of carbon because the original forest contained 45.4 metric tons carbon per acre and the resulting carbon stock after development is 4.5 metric tons of carbon per acre. Similarly, a loss of 1,000 ac of undeveloped forest to low-density development results in a loss of carbon stocks of 40,900 metric tons of carbon, or 150,103 metric tons of CO_2 equivalent.

Results

Model projections suggest that by 2004 Oregon's land-use planning program had prevented shifts to low-density development (16–64 buildings/mi^2) on 269,195 ac of forestland, 605,984 ac of agricultural land, and 59,987 ac of mixed forest and agricultural land (Table 2). Model projections also suggest that by 2004 Oregon's land-use planning program had prevented shifts to development (greater than 64 buildings/mi^2) on 66,748 ac of forestland, 166,496 ac of agricultural land, and 52,583 ac of mixed forest and agricultural land. Given these projections, our analysis suggests that by 2004 the prevention of development on forest and agricultural lands resulted in avoided carbon losses of 13.9 million additional metric tons with Oregon's land-use planning program in place (Table 2). This is equivalent to an avoided loss of nearly 51.1 million metric tons of CO_2 emission, or 1.7 million metric tons per year over 30 years.

Projections from 2004 through 2024 suggest that continued implementation of Oregon's land-use planning program would continue to save additional forest and agricultural lands from development, yielding additional forest carbon benefits. Model projections suggest that by 2024 Oregon's land-use planning program could prevent shifts of an additional 204,688 ac of forest, agricultural, and mixed forest and agricultural lands, yielding an additional 3.5 million metric tons of avoided carbon losses—equivalent to a reduction in CO_2 emissions of almost 12.8 million metric tons (Table 3). Table 3 indicates that some of the develop-

Table 3. Projected avoided changes in carbon stocks from development if Oregon's land-use planning system continues 2005–2024 (western Oregon).

Undeveloped land use	Acres lost to low-density development if land-use planning not implemented[a]	Per acre change in carbon stock as a result of low-density development[b] (metric tons carbon per acre)	Total change in carbon stock as a result of acres lost to low-density development (metric tons of carbon)	Acres lost to high-density development if land-use planning is not implemented	Per acre change in carbon stock as a result of acres lost to high-density development (metric tons carbon per acre)	Total change in carbon stock as a result of acres lost to high-density development (metric tons carbon)
Forest	−57,947	−40.9	2,365,628	115,894	−42.1	−4,878,451
Agriculture	−462,325	+2.7	−1,258,264	582,110	+1.5	844,944
Mixed forest/agriculture	−44,845	−17.3	772,984	71,801	−18.5	−1,328,812
Totals	−565,117		1,880,349	769,805		−5,362,319
Total acres lost to low- and high-density development if land-use planning not implemented						204,688
Total change in carbon stock due to both low- and high-density development (metric tons of carbon) if land-use planning not implemented						−3,481,970
Emission equivalent of change in carbon stock from development (metric tons of CO_2 equivalent) if land-use planning not implemented						−12,778,830

[a] Negative loss indicates a gain in acres.
[b] Per acre change in carbon stocks rounded and will not yield exact total change in carbon stocks as indicated in table.

ment represents development of low-density class acres to high-density class acres. This is modelled in Table 3 as a gain of 565,117 ac from low density back to forest, agriculture, or mixed forest/agriculture land use; which then are shifted to the high-density development class (which gains 769,805 ac). The net difference of 204,688 represents the estimated amount of development of forest, agriculture, and mixed/forest agriculture acres from 2004 to 2024.

Discussion

The estimates of avoided carbon stocks lost to development suggest a lower bound to the actual level of forest carbon benefits provided by Oregon's land-use planning program—1.7 million metric tons of CO_2 per year over the period of 1974–2004. Had this development occurred, Oregon's total reported increase in greenhouse gas emissions for the 1990 to 2000 period (0.9 million metric tons of CO_2 equivalent per year as reported in Governor's Advisory Group on Global Warming 2004) would have increased 200%. In other words, savings in greenhouse gas emissions from 1990 to 2000 resulting from land-use planning more than twice offset the total increase in Oregon's reported greenhouse gas emissions for the same period. Results such as these have led Oregon's Advisory Group on Global Warming to recommend continuation of Oregon's land-use planning program as a significant action for reducing greenhouse gas emissions (Governor's Advisory Group on Global Warming 2004). Such recommendations tend to underscore the need to resolve the uncertainty regarding the future of Oregon's land-use planning program after passage of Measure 37.

A related question is what the greenhouse gas reduction benefits would be from adopting newer and stricter land-use initiatives that increase forestland conservation above current levels under land-use planning. Such a policy was evaluated in a Pacific Northwest Ecosystem Research Consortium study of historical and projected land use in Oregon's Willamette Valley (Hulse et al. 2002). The consortium evaluated a conservation land-use policy that would place greater emphasis on conserving and restoring Willamette River floodplain forests as well as other forested natural habitats relative to Oregon's current land-use program. The evaluation indicated that by 2050, adopting such a policy would avoid the loss of 280,000 ac of mature forest, as well as increase mature forest by 248,000 ac, for a total amount of mature forestland of 528,000 ac—acres that would otherwise not be there under Oregon's current land-use program. Under the conservation strategy, agricultural lands would take the brunt of development pressure, losing 208,000 additional ac to development than would occur under Oregon's current planning program.

Applying the carbon factors in Table 1 to these projected land-use changes, the conservation strategy would result in carbon stock losses on agricultural lands of 3.5 million metric tons, but would avoid carbon stock losses of 46.6 million metric tons on conserved forestlands and would increase carbon stocks by 40.0 million metric tons on restored forestlands. Although adoption of such a conservation-oriented land-use policy may be considered unacceptable by some Oregonians, owing to the amount of development allowed on agricultural lands, greater emphasis on maintaining and creating forests can yield significant benefits in stored carbon.

Conclusions and Policy Implications

Land-use planning most typically is implemented to enable more orderly and efficient use of land and to conserve forest and farmlands and facilitate transportation planning among other objectives. However, our results suggest that land-use planning also can be an important part of larger mitigation strategies focused on greenhouse gas emissions and climate change. Noting the potential carbon storage benefits of land-use planning has immediate implications in Oregon as Oregonians decide the fate of their land-use planning program after passage of Measure 37; i.e., there may be additional benefits to land-use planning that Oregonians had not thought about. The analysis also has broader implications as well for the conservation of forestland nationally. Increasingly, land use and natural resource policymakers are recognizing the role of forest, grasslands, and other open space in providing ecosystem services, such as air and water quality, flood control, climate stabilization, pollination, and nutrient cycling (USDA Forest Service 2006). Policymakers are pondering what combination of land-use policy tools, including greater use of market-based trading, offer the best hope of securing ecosystem services in the future. Our analysis suggests that, at least for storing carbon and avoiding CO_2 emissions from the loss of forestland to development, traditional policy approaches such as land-use planning, the use of conservation easements, and other approaches focused on retaining land in forests, remain quite relevant even as the objectives and focus of policymakers may shift to newer and perhaps broader interests.

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