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Urbanization in the US: land use trends, impacts on forest area, projections, and policy considerations

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ABSTRACT

Since World War II, socio-economic drivers of US urbanization such as population totals and personal income levels have increased substantially. Human land use is the primary force driving changes in forest ecosystem attributes including forest area, which is the focus of this paper. The percentage of the US population residing in urban areas is higher than that in India. In the last few decades, the primary reason behind conversion of large areas of US forests is for urban and development uses.

Since 1990, land use changes in the US that have affected forests have been heavily concentrated in the South. Nationwide, more than 60% of US housing units built during the 1990S were constructed on or near areas of wildland vegetation. Between 1982 and 1997, the US population grew by 17%, while the urbanized area rose by 47%. The amount of land area per additional individual dedicated to new housing has almost doubled in the last 20 years. About 18 million hectares of private forest are projected to experience housing density increases by 2030, with the most heavily impacted watersheds occurring in the East. The US population is projected to grow by more than 120 million (40%) by 2050. Deforestation associated with this growth is projected to exceed 20 million hectares (13% of the existing private forest area). Fragmentation of remaining forests is also projected, and is expected to be concentrated in distinct sub-regions, namely, the US South, that include urbanizing areas and areas close to interstate highway corridors.

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Introduction

In the US, urbanization plays a key role in conversion of rural lands to developed uses. The process often involves deforestation,[1] which has a considerable impact on forest ecosystems. Conversion of forests to other uses can threaten the ability of forestland-based ecosystems to provide a variety of habitat for wildlife, cleanse the air and water, supply timber, fuelwood, and other harvested products, serve as places for recreation, and provide other goods and environmental services such as mitigation of global climate change (Alig and Thompson 2006). Forest ecosystems range from pure forests to urban forests.[2] An increasing number of structures such as houses spreading through forests has led to higher costs of fire suppression and potential loss of substantial home asset values. Long-term assessment of the condition of forests and of relationships between forest conditions and socio-economic factors related to deforestation is key in defining policy questions and actions that are needed to sustain forest-based goods and services.

Forestland conversion is a persistent issue for US forest managers and policy-makers. For example, a recent position statement concerning loss of forestland by the Society of American Foresters (2004) lists ecological effects (effects on water quality and wildlife habitat, among others) and socio-economic effects (such as expansion of the urban-forest interface, reduction of forest recreation opportunities, reduction of long-term timber production possibilities, and loss of open spaces) as important implications of forest loss. In this paper, I examined recent trends and projections of forestland conversion to urban and developed uses in the US. I have also summarized principal features of the US policy regime addressing this issue. Examples with more detailed treatments, supporting tables, and figures are available in Alig *et al.* (2003, 2004, 2010a) and Alig and Ahearn (2006).

Here, I have examined how socio-economic drivers of land use change in the US such as population growth and personal income have increased substantially since the Second World War and have led to changes in land use and forest ecosystem attributes. In addition, I have briefly noted the methods used for making such projections. Projections reflect population growth that spurs demand for land for development uses. At the same time, demand for certain forest products and forest benefits are also on the rise (Alig 2007). Formulating effective policy in this area will require careful deliberation on private and social viewpoints. For example, some forest benefits (such as wildlife habitat and other ecosystem services) can be effectively generated at scales greater than the individual private parcel one, simply because market imperfections can create some social forest-related benefits (such as open spaces) to be undersupplied when this is the case (Kline, Alig, and Garber-Yonts 2004a).

Six categories of significant changes affecting forest area are: 1) afforestation; 2) deforestation (either to urban and developed uses, including

1. Deforestation is the conversion of usage of land from forest use to another use such as urban and developed or agriculture. Clear cut harvesting of a forest area is not considered deforestation unless the owner resorts to another land use. This is because many such harvested areas often revert to forest cover (Alig and Butler 2004).
2. Forestland in the US is land, at least 10% of whose area is covered by forest trees of any size. It also includes land that had such tree cover earlier, and where the cover will be naturally or artificially regenerated. Forestland includes transition zones such as areas between heavily forested and non-forested lands that have forest trees in at least 10% of their total area, and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 0.4 ha. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 36.6 m to qualify as forestland. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if these are less than 36.6 m wide. Within USDA, the Forest Service (e.g. Forest Inventory and Analysis, or FIA) and Natural Resources Conservation Service (e.g. National Resources Inventory, or NRI) have agreed on at least a 10% stocking in trees to define forests. Operationally, however, FIA uses 10% or more crown cover, while the NRI uses 25% or more.

infrastructure such as roads, pipelines, and so on, and agriculture Figure 1); 3) forest fragmentation; 4) forest ownership parcelization; 5) increased numbers of structures, such as houses, on forest land; and 6) forest type transitions or changes in forest cover type (Alig and Butler 2004). Land use changes involving urban and developed uses are primarily affected through activities associated with deforestation, forest fragmentation, and increase in number of structures on forest land. Although the influence of people on forests involves a spectrum of activities, I shall focus on the three that are most closely related to changes in urban and developed areas, and shall supplement with a brief summary of forest parcelization, changes due to their relatively recent and substantial impact in the US. In the country, millions of hectares of land shift uses each year (USDA NRCS 2001), reflecting billions of choices made by individuals, corporations, non-governmental organizations, and governments. Examining historical trends provides guidance in identifying key factors that are likely to influence forestland condition and the associated natural resources in future.

Trends in US urbanization and associated land use changes

The land area of the contiguous US[3] is approximately 0.8 billion ha, as compared to about 0.3 billion ha for India (Table 1). India has more than 10 times the average US population density. New Jersey's population density-highest in the US- is similar to that of India. On a somewhat comparable total land base, the US has about 10 times higher population density than Canada. As the population density continues to rise in the US, the pressure on forest environmental conditions can be compounded if more people start living on the remaining forestland. In 2010, the US had about 36 individuals per square kilometre (km²) of land (USDC Census Bureau 2010), as compared to less than two individuals per km² in 1790.

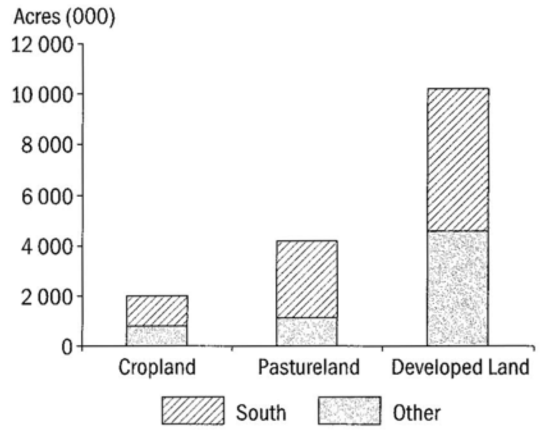

Figure 1 Conversion of forestland by destination, 1982–97 and South vs. non-South (USDA NRCS 2001)
Note Does not include rangeland

Table1 Comparison of land area and population measures for selected countries

Country	Land area (million sq. km.)	Population (million)	Population density (people/ sq. km.)	% of population in urban areas
United States	9629.1	309.8	36.5[4]	82
India	3287.3	1183.9	360.1	30
China	9597.0	1338.8	139.5	45
Canada	9984.7	34.2	3.4	81
Australia	7682.3	22.4	2.9	83
Norway	385.2	4.9	12.7	80
South Africa	1221.0	49.3	40.4	59
Argentina	2780.4	40.1	14.4	87
Russia	17,098.2	141.9	8.3	73

3 Total land area and population is included in Table 1, but in rest of the paper Alaska and Hawaii are not included because major data sources of land use changes, such as the National Resources Inventory (USDA NRCS 2001), have not included them in the past.

4 For contiguous 48 states

The percentage of US population living in cities is considerably higher than that in India (80% in 2010, as compared to 29% in India, see Table 1). In China, another fast-growing economy, 46% of its population resides in urban areas; while the percentages in Australia, Norway, and Canada are much closer to that of the US. Argentina displays a higher percentage (87%), while Russia (73%) and South Africa (59%) fall somewhere in between. In the past few decades, the US population living in urban areas has risen steadily (Figure 2). Although an expansion of urbanized area has occurred, simultaneously, a few central cities have also recorded reduction in population densities. Manhattan's population density reached its zenith at around 1910 when European immigration into New York was at its peak. Concentrating the entire US population at current Manhattan population density of around 30000 people per km^2 would mean that only about 10 areas the size of Portland, Oregon's urban growth boundary, would be required to fit in the US population.

Determining the extent of human settlements across countries presents a challenge because there are numerous definitions of 'developed', 'built-up', and 'urban' land (Alig and Healy 1987). Human settlements vary widely in density (Alig, Kline, and Lichtenstein 2004),

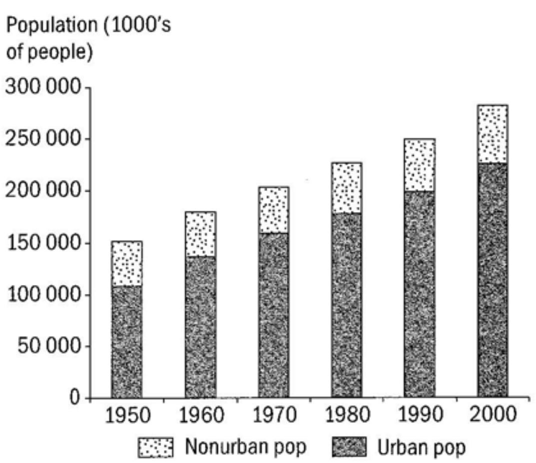

Figure 2 US population by urban and nonurban components (1950–2000)

Box 1 Characterizing urban and developed areas

When examining changes in US' developed area over time, estimates by the US Census Bureau and US Department of Agriculture's National Resource Inventory (NRI) show a steady increase in recent decades. Estimates by the Census Bureau extend farthest back in time, and reveal at least a doubling in census-defined urban area between 1960 and 2000. Census urban area comprises all territory units in urbanized areas and in places outside of urbanized areas with more than 2500 persons. The Census measure of urbanization labels as 'built-up' land that is still-to some extent-available for rural productive uses, thereby probably erring on the side of overgenerous inclusion (Alig and Healy 1987; Alig, Kline, and Lichtenstein 2004). The NRI attempts to exclude areas devoted to agricultural crops, forestry, or similar purposes when they are within a parcel or contiguous area that is otherwise built-up.

Even within North America, US, Canadian, and Mexican census definitions are not consistent. Several other classification schemes for defining and mapping settlements have been developed (such as categorization of developed land as well as a variety of methods based on satellite imagery). One method of approximating settled land cover at a continental scale is the Global Rural-Urban Mapping Project (CIESIN 2005). This method, which is based on nighttime lights satellite imagery, estimates 1039450 sq. km, or almost 5% of the total continental land area to be developed, similar to the 5.2% estimate in 1997 by the USDA's NRI (USDA NRCS 2001) of developed area forthe US' 48 contiguous states. Looking back to frontier days, the Census reported in 1890 that" ...up to and including 1880, the country had a frontier of settlement, but at present the unsettled area had been so broken into by isolated bodies of settlement that there can hardly be said to be a frontier line." Rapid western settlement meant that "there can hardly be said to be a frontier line." In just a quarter of a century, the far western frontier had been settled." (Mintz 2007)

form, and distribution. In North America, urban settlements-as they have been defined by the census bureaus of each nation-contain most of the population. Approximately 75%-80% of the continent's population is 'urban' (as defined by the census bureaus of the US, Canada, and Mexico), and this proportion is expected to go up (United Nations 2004).

Recent changes in US developed area

Developed land in the US, covering approximately 5% of the non-federal land area, is at least ten times the percentage of developed land in Canada-the other major producer of forest products in North America. Around the year 2000, the total developed area for the 48 contiguous states of the US was about 40 million ha on non-federal land (USDA NRCS 2001). The largest increment in developed area in recent decades has been in the southeastern region (13 states from Virginia to Texas) (see Appendix). This region alone has more timber harvest than any other country in the world (Wear and Greis 2002). According to the USDA, between 1982 and 1997, the US South had seven of the ten states with the largest average annual additions of developed area (NRCS 2001). The top three, namely, Texas, Florida, and North Carolina, each added more developed area than California, the country's most populous state.

Several factors contribute to expansion of developed area in the US South. These include: above average population growth due in part to climatic factors and attractiveness to immigrants (Glaeser and Shapiro 2001); above-average marginal consumption of land per additional resident; and income growth. The Southern Forest Resource Assessment (Wear and Greis 2002) identified urbanization as one of the major threats to forests in the region.

Next to the South, the largest increments in urban and developed area in the US have occurred in the North. Between 1982 and 1997, the North accounted for about one-thir of the total addition to US' developed area. Since 1982, areas of urban and developed uses have steadily increased in the North. Between 1992 and 1997, such areas in the Northeast increased from 10-4% to 11.9% of the land base.

The NRI estimate of US developed area rose by 34% between 1982 and 1997. During the same period, developed area, as a percentage of the total land area in the 48 contiguous states, increased from 3.9% to 5.2%. Besides urban areas, the NRI also includes developed land occupied by non-farm rural built-up uses (such as, rural transportation land), which are not included in the Census' urban category. A significant amount of low-density development has been part of the expansion in developed area.

More land converted per additional person

Over the years, US development patterns have become significantly more consumptive of Iand.s Between 1982 and 1997, the US population grew by 17%, while the urbanized area increased by 47%. The land area per additional person dedicated to new housing has almost doubled in the last 20 years. Since 1994, 55% of the additional developed land in the US is being used as 4+ ha housing lots, and 90% as 0-4+ ha lots. Eighty per cent of all new development has occurred beyond existing urban boundaries (non-metro areas) and are not used for farm housing (USDA ERS 2006). For the US South in particular-a region with considerable private timber harvest and substantial biodiversity- the increment in developed area for each new resident has been increasing (Alig, Kline, and Lichtenstein 2004), resulting in lower density development. A contributing factor there and in other regions is the fall in the number of people per household (Alig, Plantinga, Ahn, *et al. 2003),* due to decreasing family size, popularity of second homes, divorce rate, and a growing number of older adults living in single homes or alone.

Based on nationwide rural-urban continuum classes (Smith, Miles, Vissage, *et al. 2004),* 13% of US forestland is now located in major metropolitan counties (Figure 3), while 17% is found in intermediate and small metropolitan

5 Although not the focus here, it is also true that house sizes in the US have increased considerably. In 1950, an average single family home measured about 1000 sq. ft, while in 2006 it was roughly 2400 sq. ft (excluding a large garage). These sizes dwarf the average homes in most other countries.

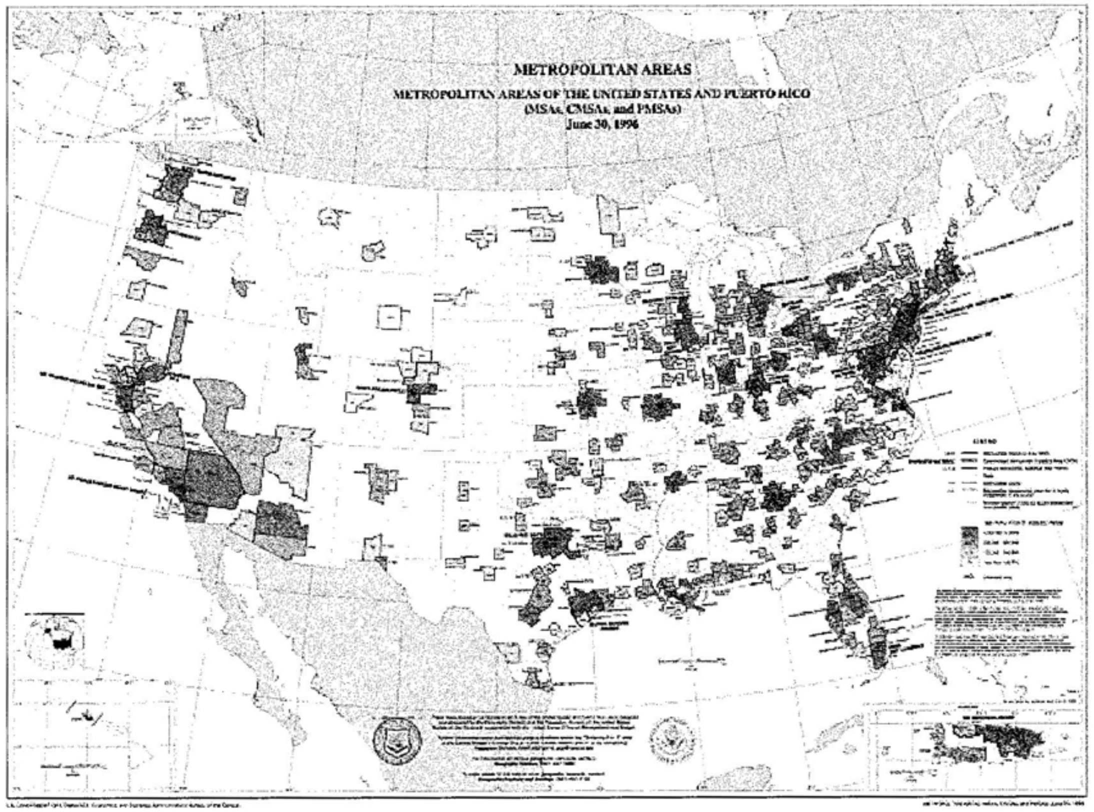

Figure 3 Standard metropolitan statistical areas in the US (US Office of Management and Budget)

counties and large towns (Smith, Miles, Vissage *et al.* 2004). Between 1997 and 2002, the forest area within major metropolitan regions increased by 5%, or more than 5 million acres. For the whole US, more than one-quarter of the counties are currently classified as 'metropolitan', as compared to less than one-tenth 50 years ago. Metropolitan areas are characterized as major nodes in a national circulation system, with technological changes in transportation and communication affecting size and function of cities (Hart 1991). Even though the last few decades have seen additional movement from central cities and suburbs to rural areas, in aggregate, the US population has become more concentrated in urban areas, with the percentage doubling since 1900 (40%).

For non-metropolitan counties, the proportion of land converted per additional person is higher. Many Americans prefer living in less-congested areas, even though it entails spending additional commuting time along US' excellent road system. Moreover, an ever-increasing proportion of retirees, no longer tied to their workplaces, has added to migration from central cities and suburbs to rural areas. Natural amenities may be a more important determinant of population growth than proximity to metropolitan centres or type of local economy (McGranahan 1999).

Amenity migration has also led to additional stress on coastal ecosystems and a few mountain-dominated ecosystems. Coastal areas are more urbanized than other ecosystems, and even rural populations in coastal ecosystems are much denser than in other rural areas. In addition to settlement pattern and overall population growth, amenity-based migration has contributed to inter-regional shifts in population, with the

West growing faster than the national average. For example, a growing number of 'ranchettes' (lots as large as 16 ha) and sub-divisions has cropped up in the Rocky Mountains. Inmigration has resulted from the desire of many residents for forested settings, leading to construction of primary residences or leisure homes in forests or on rangelands, very often accompanied by a view of the mountains. Between 1992 and 1997, the Rocky Mountain area recorded the highest amount of developed area per additional person (Alig, Kline, and Lichtenstein 2004; USDA NRCS 2001).

Realizing that the census measure of urbanization probably errs on the side of overgenerous inclusion, many prefer using the term 'paved over' to describe urban land. Researchers, while totalling the concrete, paved roads, buildings, and other man-made hard surfaces in the contiguous 48 states, estimated a combined area of nearly 114000 km^2, which is approximately the area of the state of Ohio (Rozell 2004). The transformation from wilderness to city has also led to the formation of 'heat islands', where due to blacktop and heat-absorbing shingles, cities record higher temperatures than the surrounding countryside. Los Angeles, for example, is about 7 °F warmer than areas around it. Fairbanks, Alaska is a heat island, with winter temperatures downtown being up to 20 degrees warmer than outlying regions. For some fast-growing cities, despite substantial population growth, the extent of increase in impervious surfaces due to urban and residential development during recent decades remains unquantified (Powell, Cohen, Yang, *et al. 2008)*. For a 500 000 ha water resource inventory area near Seattle, composed of a complex mixture of forest, agriculture, residential, and urban components, Powell, Cohen, Yang, *et al. (2008)* estimated a 15% increase in impervious area over an eight-year period.

Impacts on forest area

Forests cover about one-third of the area of the US, and range from wildland forests to urban forests. The loss in US forest area since the early 1950S has occurred due to a combination of factors, but in recent decades it has happened primarily due to conversion to urban and developed uses (Alig *et al. 2003,* 2004). Deforestation is the conversion from forest to non-forest use, and between 1982 and 1997, 9.3 million ha were deforested on non-federal land in the US (Figure 1). According to NRI estimates, about half of the converted forest acres was put to urban and developed uses, while more than 4 million ha of US non-federal forests were converted to developed uses-an area larger than the combined current forest area of five northeastern states, namely, Connecticut, Delaware, Maryland, New Jersey, and Rhode Island. Between 1992 and 1997, urban and developed uses accounted for 55% of the total deforestation (USDA NRCS 2001), with about 400 000 ha converted to developed uses on an annual basis. Some forestland is projected to be converted to agricultural uses, but opportunities exist for substantial afforestation, including enhanced amounts if government farm programmes are reduced (Alig, Adams, and McCarl 1998) or if carbon markets become significant (Alig, Latta, Adams *et al.* 2010a).

Net changes (area in forest - area out of forest) are typically much smaller than total or gross changes (area in forest + area out of forest). Between 1982 and 1997, gross area changes totaled about 20 million ha in the multiple pathways of land use change for non-federal forests for the contiguous 48 states (USDA NRCS 2001). The gross change in forest area was 14 times greater than the net change in forest area (Figure 4). When forests are converted to other uses, the new forest area arising elsewhere does not necessarily provide the same ecosystem services. In view of such land use dynamics, land moving into forest will not be the same as older forest being converted to other uses. In other words, just considering the total 'net' number of forest acres on the landscape does not take into account the loss of many attributes people care about. Recent advances in data availability and modelling have allowed transitions among land uses to be projected in national land base

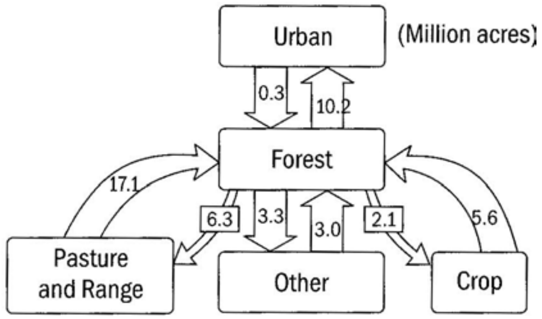

Figure 4 Gross and net changes in US' forest area between the last two reported NRI surveys (USDA NRCS 2001).

assessments in the US (Alig, Plantinga, Haim, *et al.* 2010b).

Relating changes in US population to forest area-where the former has grown substantially, while forest area has been roughly fluctuating by a constant amount or getting reduced over a longer time period-indicates a significant fall over time in the amount of forest area per person. By 2010, the US forest area per capita has declined from about 5.5 ha to less than 2 ha (Alig 2007). In contrast, over the same period, Canada's per capita forest area has remained above 10 ha.

Forest fragmentation: more and smaller habitat patches

Land-use change can lead to forest fragmentation, which is the transformation of a contiguous patch of forest into disjunct patches. Forest fragmentation is widely considered to be a primary threat to terrestrial biodiversity (Armsworth, Kendall, and Davis 2004), and recent analysis of fragmentation of continental US forests indicates that its pervasiveness can potentially affect ecological processes on a majority of forestlands (Riitters, Wickham, O'Neill, *et al.* 2002).

There are several definitions of forest fragmentation based on the questions or policy issues of interest (Alig, Butler, and Swenson 2000). One major distinction among these definitions deals with treating fragmentation as a process and as a pattern (Alig, Butler, and Swenson 2000). Here, we shall consider forest fragmentation as a pattern. Fragmented forests may occur naturally across the landscape (as in the Great Basin, Nevada). Alternatively, the pattern may be due to human activities, resulting in edge, core, or interior habitat, and interspersion changes (Butler, Swenson, and Alig 2004). Forest fragmentation can be spatially quantified using various indices of landscape structure, with different metrics for different scales of analysis and measurements of interest.[6] Although many fragmentation statistics are available, none provides a definitive indicator of landscape fragmentation. The majority only offers a snapshot at one point in time, and lacks in means of comparing characteristics and relative degree of fragmentation across landscapes or periods. Studies of forest fragmentation that link fragmentation to changes in human-related disturbances associated with shifts in population and income are included in Butler, Swenson, and Alig (2004) and Alig, Lewis, and Swenson (2005). Smail and Lewis (2009) review economic issues for policy considerations, while Plantinga, Alig, Eichman *et al.* (2007) provide projections of US' forest fragmentation at different scales. Scale is important in estimation of fragmentation, which poses a challenge in quantifying the effects of forest conversion on ecological processes.

More people in the US woods

An increasing number of houses and other constructions in and near forests portend to growing costs, complications in fire suppression and other public services, and potential loss of many values derived from forests. Long-term assessment of the condition of forests and relationships between forest conditions and socio-economic factors is key in defining policy questions and actions needed to sustain forest-based services, including effects of urbanization on forest ecosystems (Kline, Azuma, and Alig 2004b).

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[6] The three commonly used measures are percentage non-forest cover, percentage edge, and interspersion (Butler, Swenson, and Alig 2004).

Each year, a significant proportion of forestland is used for dispersed residential development in fringe suburbs and smaller cities, commonly known as 'sprawl'. Sprawl is characterized by low-density residential and commercial settlements. Increases in housing density at or adjacent to forests can result in changes to the forest's quality and function, and changes in forest investment (Kline, Azuma, and Alig 2004b). Forestlands are quite popular as residential building sites; forests provide homeowners with shade, screening from neighbours, scenic view, wildlife and bird-watching opportunities, and often, easy access to forest-based recreation opportunities. Evolving communication and transportation technologies reduce the isolation factor of remote locations, and make possible long-distance commuting while making a wide variety of remote work arrangements available. These developments effectively reduce the costs associated with living far from cities and towns.

A significant amount of low-density development has characterized expansion in developed areas. Rural America is home to a fifth of the nation's people. Rural residential lots, while fewer in number than their urban counterparts, tend to be larger, averaging more than one hectare per household, as compared to less than a one-quarter hectare per household in urban residential areas (USDA ERS 2006). Eighteen million hectares, 60% of all rural residential lands, are in the largest lot-size category, over 4 ha. Rural land in this category is 3 1/2 times as large as the area of urban land in this category. The wide acreage disparity between rural and urban large-lot categories is likely attributable to relative land values-lower land prices in rural areas make large lots more affordable (USDA ERS 2006).

Projections of housing density increases on forestland were made in the 'Forests on the Edge' study (Stein, McRoberts, Alig, *et al.* 2005; Stein, Alig, White, *et al.* 2007; White, Alig, Stein *et al.* 2009). This project ranked watersheds across the 48 contiguous states. Watersheds included in the assessment had a minimum of 10% forest cover with at least half private land. Three housing density thresholds were identified, namely, rural (no more than 15 units for every square mile), urban (at least 64 units per square mile), and ex-urban (16-63 units per square mile). For areas of 18 million ha, housing was projected to increase from either rural or ex-urban to urban (9 million ha) or from rural to ex-urban (9 million ha) (Stein, McRoberts, Nelson, et *al.* 2005; Theobald 2005).

More houses burning: wildland-urban interface

The co-location of houses and forests (as well as other wildlands) is depicted in national maps of the Wildland Urban Interface (WUI). These are created to aid analysis of the national wildland fire situation (Radeloff, Hammer, Stewart, *et al.* 2005; Alig, Stewart, Wear, *et al.* 2010C) (Figure 5). The WUI definition that guided creation of such maps and analysis is found in the Federal Register (USDA and USDI 2001). It specifies minimum housing density of one structure per 40 acres (or 6.17 structures per km^2) and either co-location with-or close proximity to-wildland vegetation. National Land Cover Data and Census Bureau housing data are used in combination to determine where these conditions exist. Two main types of WUI, namely, intermix and interface, are identified. Intermix exists where housing and wildland vegetation (at least 50% of all pixels in the Census block are forests, grasslands, or

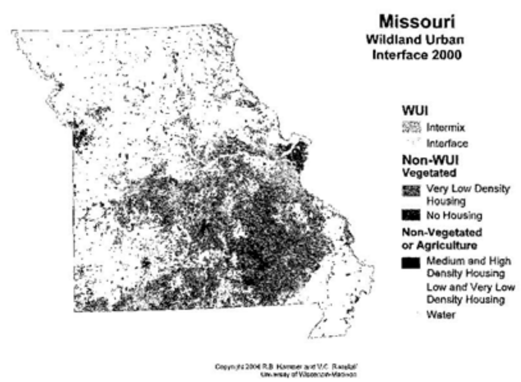

Figure 5 Example of WUI map (Radeloff et al. 2005)

shrublands) coincide. Areas that meet the housing density minimum, but where wildland vegetation is less dense, are considered interface if they are within 2-414 km of extensive wildland vegetation (defined as an area larger than 5 km^2 with more than 75% wildland vegetation). Together, intermix and interface make up the WUI (Radeloff, hammer, Stewart, *et al. 2005).*

In areas where forest conditions, weather, and climate might lead to wildfire, the WUI is a zone where the threat of property loss due to wildfire is high. Consequently, the WUI has high priority for wildfire hazard reduction treatments. The WUI is also the area where wildland fire outreach programmes focus their attention. Resource managers and their outreach partners work with communities and property owners to mitigate wildfire hazards, and plan for evacuation and other emergency measures.

Across the US, the 1990S were a period of rapid housing growth, with a net gain of 13.5 million housing units, or a 13% increase (Alig, Stewart, Wear, et *al.* 2010C). The WUI was clearly a preferred setting for new housing-the overall WUI growth was 22%, and intermix growth was 37%. Most of this WUI housing growth took place in areas already designated as WUI in 1990. The distribution of housing units across the high, medium, and low density interface categories changed little over the decade in the US.

Analysing housing growth within the WUI classification offers insight into aspects other than the location and density characteristics of recent change. It also indicates the impact of this growth on forests, grasslands, and other wildland vegetation. More than 60% of housing units in the 1990S were constructed in or near wildland vegetation. Although the fire management community originated the WUI concept as an approximation of where property values are at risk from wildland fire, the WUI zone is significant for a broader range of ecosystem services. Clean water, timber, recreation, and other services and outputs from undeveloped land are at risk when development encroaches, with such encroachment being a significant feature of the 1990S.

More forest owners (forest parcelization)

Forest parcelization is the sub-division of forest tracts into smaller ownerships. This phenomenon can have profound impact on the economics of forestry and lead to reduced forest management, even when land is not physically altered. In addition, per unit costs of forest management practices usually increase.

Many of the increases in population density on US forests have been on non-industrial private forest (NIPF) lands. This is the ownership class historically associated with land-use changes (Smith, Miles, Vissage, et *al.* 2004). Since NIPF owners, on are average, are older than the general population and have descendants who live farther from the forest and for whom timber management is not a primary objective, dealing with real estate price appreciation may have acquired a centralized focus to family succession planning. These lands often provide critical wildlife habitat, for example, in the Pacific Northwest, where lowlands and riparian areas critical to threatened and endangered species are primarily in NIPF ownership (Bettinger and Alig 1996). Family forests that include lands at least 0-4 ha in size, are 10% stocked with trees, and owned by individuals, married couples, family estates, and trusts, or other groups of individuals who are not incorporated or otherwise associated as a legal entity, constitute a large component of the NIPF ownership class in the US. Between 1993 and 2003, the number of family forest owners increased from 9.3 million to 10.3 million. These owners now control 42% of the US' forest land (Butler and Leatherberry 2004).

Recent shifts in ownership of the most intensively managed forests in the US could lead to a change in the distribution of forest owners across parcel or property size classes. The number of potential buyers for large forest properties is often relatively small. However, there often is a spin-off of specific parcels for real estate development ('highest and best use'). Overall, the amount oflarge industrial forest ownership has been reduced within a relatively short period. A large share of the forests held by consolidated forest products companies has recently been sold to institutional investors.[7] Many of these transactions have occurred in the U.S. South, Northeast, and Pacific Northwest. Institutional investors currently hold about 8% of the investable US timberland (Wilent 2004).

More area in urban forests

The extent of urban forest area in the US has appreciably increased in recent decades. As urban lands expand into surrounding areas, natural resources are often affected or displaced. Between 1990 and 2000, most urban expansion in the US was on forested or agricultural land (Nowak and Walton 2005). Urban areas in the US, as defined in the 2000 census, has approximately 3.8 billion trees, with an average tree canopy cover of 27% (Nowak, Noble, Sisinni, et *al.* 2001).

Urbanization, in some cases, can concentrate people, materials and energy into relatively small geographical areas to facilitate functioning of an urban society. Urbanization often degrades the quality of local and regional environment, altering the natural landscape. Byproducts of urbanization (e.g., heat, combustion, and chemical emissions) affect the health oflocal people and visitors. Urban vegetation can improve environmental quality and human health in and around adjoining areas through energy conservation, cooler air, and reduction in ultraviolet radiation. As urban lands expand into surrounding areas, retaining trees and conservation areas can prove to be immensely beneficial. Currently, monetary benefits of urban vegetation on environmental quality at the national level are to the tune of several billion dollars per year (Nowak and Crane 2002; Nowak, Crane, and Stevens 2006).

Socio-economic factors driving land use change

Econometric studies indicate that drivers of deforestation differ notably from those of afforestation and reforestation activities (Table 2). With most US forests being privately owned (Figure 6), changes in demographic and economic variables can affect forest area. Major determinants of deforestation associated with conversion to urban and developed uses in the US are population totals and personal income levels. Revealed behaviour by landowners indicates that land values for developed uses (such as residential uses) are generally higher than those for rural uses (for example, forestry and agriculture) (Alig and Plantinga 2004. Within the rural land base, relative land rents for forestry and agriculture affect decisions on deforestation (i.e. forest converted to agriculture) (Alig 1986), afforestation, and reforestation. A number of econometric studies offer insights on determinants of afforestation (Plantinga 1996) and reforestation activities (Alig, Lee, and Moulton 1990; Lee, Kaiser, andAlig 1992; and Kline, Butler, and Alig 2002), including tests of government subsidies and policies (Kline and Alig 1999). For example, Lubowski (2002) finds

Figure 6 Distribution of private and public land in the US

[7] By the end of 2003, the top 10 timberland investment organizations (TIMOs) were managing approximately 3.5 million ha of US' timberland. Some analysts predicted that TIMOs and other investor groups (such as Real Estate Investment Trusts, or REITs) will purchase another 4–6 million ha in the next decade (Wilent 2004). Although data is lacking, sales and acquisitions of forest industry (FI) lands appear to continue to be active as market forces, globalization, and consolidation impact the forest sector.

Table 2 Sources of land use projections (by region)

Land base change	*Approach*	*Studies*	*Projected amount in the US*
Deforestation	Econometric and mathematical optimization	Alig and Healy 1987; Alig, Kline, and Lichtenstein 2004; FASOM (Alig, Adams, and McCarl 2002); Alig and Plantinga 2004	More than 50 million acres deforested by 2050, mostly for developed uses
Afforestation	Econometric and mathematical optimization	Lee, Kaiser, and Alig 1992; Kline, Butler, and Alig 2002; FASOM (Alig *et al.* 1998, 2002) Alig *et al.* 2003; Alig and Plantinga 2004	About 20 million acres converted from agriculture to forest by 2050 (FASOM)
Forest fragmentation	Econometric	Wear, Pye, and Riitters 2004	South projected to lose about two million acres of interior forest by 2020
Structure additions to forests	Statistical	Stein *et al.* 2005	44 million acres of private forest with substantial increase in housing density by 2030
Urban forest changes	Statistical	Nowak and Walton 2005	29 million acres of forest to be urbanized by 2050

Note No large-scale forest parcelization projections were located.

that between 1982 and 1997, rising government subsidies for agricultural crops restrained an increase in forest area in the Mississippi delta area by 10%.

Since 1900, the US population has increased almost four-fold. The Census Bureau projects that by 2050, the nation's population will rise by more than 120 million, which is more than 40% over the population in the year 2000. The two major components driving population growth are fertility (births) and net immigration. Almost one-third of the current population growth is caused by the latter. Net immigration remains constant at 880000 per year, while the Census Bureau recognizes that there is considerable uncertainty about the future flow of migrants. By 2050, the nation's population is projected to be 82 million larger than it would have been without growth through migration.

The distribution of population has also changed, as noted earlier regarding preferences for amenity-related settings (Garber-Yonts 2004). For example, population has decentralized relative to city centres. Around 1900, about 80% of the population lived within three miles of those centres. Today, the corresponding figure is less than 30%. However, the proportion of people who live in more broadly categorized 'urban areas' has steadily increased since 1950, and now stands at approximately 80%. The largest increases in population between 1980 and 2000 have occurred in metropolitan edges (Heimlich and Anderson 2001). At the same time, the population of some non-metropolitan counties adjacent to the metropolitan ones has risen as well.

The location of population is important in connection with vulnerability of communities and assets such as houses. In a growing trend, more than half of the US population lives in coastal areas (within 50 miles of a coast). This aspect has implications as far as vulnerabilities to extreme weather events such as last year's hurricanes on the Gulf Coast are concerned. At a broader level, coastal ecosystems are increasingly facing pressure from factors such as lowland development in states such as Florida and Texas.

The average family income (in real or inflation-adjusted dollars) increased by more than 150% between 1950 and 2000, thus, offering individuals more income to spend. The per capita disposable income in the US in 1998 was $22353, which represents a more than a 10% increase, in real terms, during the 1990S alone.

Further hikes in personal income are projected, but not at the level of increase in the 1990S (USDA Forest Service 2001). Even with constant tastes and preferences, a larger population base with higher income levels will result in greater consumption and demands for developed space. For example, consumers may require more shopping space, as was witnessed between 1990 and 2000 when the US shopping area rose by 27% (in sq. ft), while the number of shopping centres increased by 24% (USDC Census Bureau 2001).

Projections of land use changes

The 2010 Renewable Resources Planning Act (RPA) Assessment is the sixth one prepared in response to the RPA legislation (USDA FS 2001; Adams and Haynes 2007; Haynes, Adams, Alig, et *al.* 2007). Since the first RPA renewable resources assessment was completed in 1975, the context has broadened. The Forest and Rangeland Renewable Resources Planning Act (RPA) (PL 93-378,88 Stat 475, as amended) in the United States was enforced in 1974, with Section 3 of the Act requiring a national renewable resource assessment to provide reliable information on status and trends of the nation's renewable resources for a ten-year cycle. Interest in sustainable management of the world's forest resources was heightened during the United Nations Conference on Environment and Development in 1992 (USDA FS 2001). Since then, various countries have come together to discuss and reach a consensus on ways to evaluate progress towards the management of their forest ecosystems within a sustainability context. The US participates in the Montreal Process, which is designed to use a set of criteria and indicators for the conservation and sustainable management of temperate and boreal forests. The criteria provide a common framework for describing, assessing, and evaluating a country's progress toward sustainability at the national level.

Land use projections are a key component of RPA Assessments (Alig et *al.* 1990, 2003, 2010b). In general, RPA Assessments include a wide range of economic and ecological phenomenon. Individually, these systems are quite complex. Moreover, the process of integrating effects between these systems leads to additional complexity. Considerable uncertainty exists regarding projections, particularly those that look 50 years ahead. In the past, RPA Assessments have typically focused on a 'business as usual' future, although variations are found in analysing other scenarios. For example, different assumptions about future population have been used to create high/medium/low trajectories of supply and demand. The timber assessment included various scenarios associated with different policy and trade assumptions. These variations have primarily been focussed on socio-economic variables. In 2010, climate variables have been added to the set of common assumptions.

Land use projections are generally prepared by obtaining projections of independent variables and then simulating the impacts of projected conditions on future land uses. Projections can be implemented to contrast the potential effects of policy or market changes with historical usage (Lubowski, Plantinga, and Stavins 2006) or to project future land uses over a range of scenarios (Alig, Plantinga, Ahm, et *al.* 2003). Projection exercises have indicated that future land uses are especially sensitive to changes in population and income.

Lubowski (2002) developed a national-scale econometric model ofland use, using NRI panel data for land use and land characteristics on non-federal lands at five-year intervals from 1982 to 1997. The data included approximately 844000 plot-level observations, with three land use transitions over the periods 1982-87, 1987-92, and 1992-97 for six major land uses, namely, crops, pasture, forest, urban, range, and Conservation Reserve Program (CRP). Lubowski estimated the probabilities of transitions between six major land use categories as functions of net financial returns to the alternative uses, soil quality, and estimated parameters. The first step in the current research is to incorporate the econometric results into a land use projection model. The model is an algorithm that projects changes in land use, beginning with 1997 base year conditions. It treats crop and timber prices as endogenous, thereby accounting for feedback effects ofland use change on the prices of key commodities.

The dependent variable in the econometric model is the choice ofland use in year t+5 (t = 1982, 1987, and 1992) at each NRI plot. The independent variables are land use in year t, land quality rating of the plot, and proxies for the expected net returns from land use alternatives as of year *t*. By assembling data from a variety of private and public sources, Lubowski (2002) constructed county-level estimates of annual net returns (per acre) for crops, pasture, forest, range, and urban uses for all 3014 counties in the 48 contiguous states. The net returns to cropland and timber are weighted averages of net returns to specific crops and forest types, where the weights reflect current cropping patterns and forest type distributions (see Appendix for more details). The land quality measure is the land capability class (LCC) rating of the NRI plot. The LCC rating is a composite index representing 12 factors (including soil type, slope) that determine suitability of the land for agriculture. It also serves as a proxy measure for forest productivity. The LCC rating ranges from I-VIII, where 'I' indicates the greatest potential for intensive agricultural uses. For the econometric analysis, the eight LCC categories are combined to produce four land quality classes.

Landowners are assumed to have static expectations of future net financial returns, and allocate their land to the use generating the highest return net of conversion costs. Net financial returns are expected to have deterministic and random components. The deterministic component includes the county net return, land quality class dummy variables (LQ), and interaction between the two variables. This specification allows for plot-level deviations from the average county return. Certain distributional assumptions are imposed on the random components of net returns to yield a nested logit model for estimation. Three nests include land uses with similar land quality requirements-crops, pasture, and CRP; forest and range; and urban. Details on the econometric estimation and results are available in Lubowski (2002) and Lubowski, Plantinga, and Stavins (2006). The analysis yields probabilities for transitions between each of the six land uses. These probabilities are functions of independent variables and estimated parameters,

$$P_{ijkt} = P(\hat{\beta}_{jk}, NR_{it}, LQ_i), \qquad (1)$$

where
P_{ijkt} = probability that plot *i* transitions from use *j* to *k* during the interval beginning in year *t*;
$\hat{\beta}_{jk}$ = a vector of estimated parameters for the *j* to *k* transition;
NR_{it} = a vector of net returns to the six uses in year *t* and for the county where plot *i* is located; and
LQ_i = a vector of land quality class dummy variables for plot *i*.

Key inputs to the land use projection model are the transition probabilities in (1) and plot-level data on land use, net returns, and soil quality from the NRI. The projection model operates at the NRI plot level and has the base year 1997. To simplify notation, the years 1997, 2002, and 2007, and so on are denoted as t = 0, 1, 2, and so on. Based on the sampling design, each NRI plot is associated with a certain number of acres. A_{ijt} is the number of acres associated with plot *i* in use j in time t. In the initial period, each plot is in one of the six uses as indicated in the 1997 NRI data. Thus, A_{ijt} equals the acres represented by plot *i* ifthe plot is in use j in time 0, and equals 0 otherwise. Given a sequence of transition probabilities, Plantinga, Alig, Eichman, et *al.* (2007) show how this land will be distributed across the six use categories at each time in the future. They then express the area of land represented by plot *i* that transitions (transition acres) from use *j* to *k* during the interval beginning in *t* as $TA_{ijkt} = P_{ijkt} \bullet A_{ijkt}$. The acres of land represented by plot *i* in use *j* at time *t*+1 are given by,

$$A_{ijkt+1} = \sum_k TA_{ijkt} = \sum_k P_{ijkt} \bullet A_{ijkt}. \quad (2)$$

This expression reflects the first-order Markov structure of the Lubowski-Plantinga model.

The transition probabilities in the base year are computed with the 1997 values of the net returns (and the time-independent coefficients, B_{jk}, and variables LCC). With the initial acres A_{ijo}, one can estimate the acres in each use in time 1 by using the relationship in (2). The induced change in land use implies a change in the supply of land-based commodities and services, and hence, changes in related prices and the net returns from each use. Plantinga, Alig, Eichman, *et al.* (2007) modelled these endogenous price effects for forest and cropland and assumed the net returns to pasture, range, urban, and the CRP to remain constant throughout the simulation. Pasture and CRP account for a small share of the total land base. Rangeland is a major component of the land base (initially around 30%), but we were unable to find any information on markets (specifically, demand elasticities) for forage, which is the principal output of rangeland. Finally, the probabilities for transitions into urban uses were found to be insensitive to changes in urban rents, thereby indicating that these transition probabilities would tend to remain the same even with endogenous price effects.

Consistent with the model of landowner behavior underlying the econometric analysis, cropland and forest commodities are supplied inelastically. Thus, Plantinga, Alig, Eichman, *et al.* (2007) used crop and timber yields (measured in output per acre) to translate land use changes into output changes. After aggregating output changes to the appropriate level, they compute corresponding price changes by using own-price demand elasticities estimated in previous econometric studies. Changes in cropland area result in immediate changes in crop output because crops are assumed to be harvested in the same year they are planted. In the case of forests, timber harvests will be delayed for a period of years while the forestland grows to maturity. For afforested lands, they assume that harvests are delayed for the period of one optimal rotation, after which the forest is 'fully regulated' and provides a constant annual flow of timber. [8] Likewise, all land originally in forest (i.e. in t = 0) is assumed to have a fully regulated structure. When these lands are converted to non-forest uses, they assume that only a portion (20%) of the timber is merchantable.

Once Plantinga, Alig, Eichman, *et al. (2007)* computed the differences in prices resulting from land use changes between periods 0 and 1, they could then come up with new measures of net returns in period 1. Specifically, they apply national or regional percentage price change to the county-level prices used to compute net returns. With the period 1 net returns, they recalculate the transition probabilities and repeat the procedure. This stage of simulation ends when the crop and forest net returns have converged (i.e., period-to-period changes in prices are near zero). The converged net returns are equilibrium values that reflect all anticipated supply adjustments in agricultural and forest commodity markets. This process is atemporal-it represents an instantaneous adjustment to a new market equilibrium. For this reason, they hold urban land constant during this stage of simulation. Urban land will increase over time with factors such as population growth-as it does in the second stage of the algorithm discussed

[8] To account for alternative management objectives by NIPF owners (Alig, Lee, and Moulton 1990), Plantinga et al. (2007) assumed that a fixed percentage of forestland in each timber production region is never harvested, while the remaining forest is harvested in the manner described previously. The no-harvest percentages are determined by calibrating the model to regional timber harvest data for 1997. The no-harvest percentages range from 6% in the South-Central region to 62% in the Pacific Southwest region.

below-but should not affect the immediate adjustment in net returns to cropland and forests.

In the second stage of the algorithm, Plantinga, Alig, Eichman, *et al.* (2007) computed the time path of land use changes. Specifically, they recalculate the transition probabilities for the initial period by using the converged net returns for cropland and forests, and the observed net returns for other uses. Beginning with the initial acres in each use (A_{ijo}), we use (2) to compute the sequence ofland use transitions (TA_{ijkt}) through time. Unlike the first stage of the algorithm, the net returns remain at their equilibrium values throughout this stage.

Such econometric models project urban and developed uses to increase by 79%-in line with the projected US population increase of more than 120 million over the next 50 years-and higher average levels of personal income (Alig and Plantinga 2004, Alig *et al.* 2004, 2010a). This would raise the proportion of the US' developed land base from 5.2% to 9.2% (Alig, Kline, and Lichtenstein 2004). The projected developed and built-up area of about 70 million ha in 2025 represents an area equal to 38% of the current US cropland base, or 23% of the current US forestland base. In line with recent historical trends, the South is projected to continue to have the most developed area through 2025 (Alig, Kline, and Lichtenstein 2004). Developed land will also increase in other parts of the developed world aided by global increase in population (from 6-9 billion) by 2050.

Total non-federal forestland area in the US is projected to decrease on *net* by approximately 12 million ha between 2002 and 2062 (Alig *et al.* 2003, 2010a), implying a 7% reduction. The main reason for this fall in forestland area is the conversion to urban and developed uses. All three major landuse classes-crop, forest, and range-have lost area to urbanization, and this trend is expected to continue.

At the same time, additional housing density on remaining forestland is projected to be substantial (Stein, McRoberts, Alig, *et al.* 2005), with an increase from either rural or ex-urban to urban (8.9 million ha) or from rural to ex-urban (8.9 million ha). Continued development will also lead to further fragmentation of forests (Alig, Lewis, and Swenson 2005). Due to population surpassing 360 million individuals by 2030, abount 44 million additional housing units would be required (White, Morzillo, and Alig 2009). Previous modelling efforts have estimated that each additional housing unit equates to about 0.5 ha of newly developed land for residential, commercial, transportation, and industrial purposes.

Relatively fewer studies have projected forest fragmentation, especially at larger scales. One example of a broader scale study is the one by Wear, Pye, and Riitters (2004) that forecast changes in interior forest for each county in the South-a region where recent trends include significant land-use change. Wear, Pye, and Riitters (2004), who based forest fragmentation projections on population density forecasts for the year 2020, assumed that relative returns to agricultural and timber production would remain at current levels. In this context, the US South as a whole is forecast to lose 747000 ha (about 2.12%) of interior forest cover.

Policy implications

There have been long-standing concerns about reduction in forest area. Some of the earliest efforts in forest conservation were inspired by rapid loss of forests to agriculture and logging, the desire to protect timber and water resources, and to preserve unique and beautiful lands. The amount of developed land in developed countries has been increasing, and continued expansion is projected with increasing policy awareness (Society of American Foresters 2004). Tens of millions of hectares of US forest are at risk of being converted to non-forest area. A similar amount of hectares remaining under forest cover may have houses and other structures added over the next several decades. To the extent that this loss of forest land may have reduced the social values derived from forests, it seems reasonable to ask how changes in policy might affect this outcome. Next, I shall discuss several types of policies that could have some influence on the future of forests in the US.

Government policies that can contribute to development include federal/state expansion of highways, income tax subsidy for home ownership, and extension of public utilities. Policy responses to any perceived problem can involve local (zoning and development impact fees, conservation easements, and so on), regional (such as regional governance), state (for example urban growth boundaries), and national responses (such as the National Farm Bill) (Alig, Plantinga, Haim, *et al.* 2010b). Urban sprawl has been cited as one of the leading concerns of Americans (Pew Center 2000). According to the Report, approximately 1000 measures, aimed at changing planning laws and at making US development more orderly and land-conserving, were introduced in State legislatures in the late 1990S. Concerns about sprawl originate from both the dis amenities associated with increased congestion as well as loss of productive land for agriculture and forestry uses. Lands that are highly suitable for agriculture, forestry or urban expansion are often gently sloped, fertile valleys, and floodplains. Urban conversion is generally 'one-way'; the land is usually irretrievably lost for less intensive use within typical planning horizons.

Most land use protection programmes are designed to conserve open space in urban or nearby areas. Values exist for conserving most types of open space land uses, but these values .tend to vary widely with the size of the area, proximity of open space to residences, and type of open space (McConnell and Walls 2005). Value of open space amenity estimates, even for specific types of open space, appear to be site- or location-specific. One example of a US open space programme focussed on working forests is the Forest Legacy Program managed by the USDA Forest Service in partnership with state governments. The Program is designed to encourage protection of privately owned forestland and promote sustainable forestry practices by purchasing development rights, including use of conservation easements.

Conservation easements, in general, as a tool for encouraging protection of forests and other lands, have been increasing in popularity. They are also used by NGOs such as the Pacific Forest Trust. Landowners receive tax benefits or are paid a lump sum amount in exchange for signing a legal document that restricts use of their land. These restrictions include developmen as well as certain other forms of land use.

With the destruction caused by Hurricane Katrina and growing concern over possibility of occurrence of similar natural disasters, the relationship between human settlement patterns and vulnerabilities to such calamities has come under intense scrutiny in recent years. Natural disasters have varied consequences, including damage to ecosystems and human communities. Recent trends in land use and housing growth not only impose pressure on natural ecosystems, they also heighten society's vulnerability to natural hazards. Human communities are both a source-and victim-of calamities associated with natural hazards. Housing growth is perhaps the single most important factor behind increasing economic losses due to natural disasters. The threat posed by most natural disasters has not changed significantly over time. Wildland fire is an exception, to some extent. Many ecologists argue that forest management policies contribute both directly and indirectly to increasing the severity of wildland fires. Although scientific opinion is mixed regarding its role in current patterns, scientists agree that there is potential for significant climate change in the future. However, over the past 50 years, the likelihood of occurrence of natural hazards has been relatively stable. But, losses in the US have increased because our vulnerability to these disasters has risen. More houses and increased wealth have been concentrated in regions of the country facing significant hazard levels (Cutter and Emrich 2005; De Souza 2004; van der Vink *et al. 1998).*

Challenges in land conservation

Selective urban deconcentration, an overarching pattern of settlement change in the late 20th century (Johnson, Nucci, and Long 2005), has resulted in growth in several rural communities and suburbs distant from the urban core (Theobald 2005). This change from the centuries-long urban concentration pattern contributes to vulnerability in two ways. First, isolated communities, especially living in unincorporated areas, have less infrastructure (such as roads and water supply systems), and fewer resources for providing protection services (police and fire protection, and so on). Rapid growth exacerbates the difficulties of providing adequate infrastructure. Second, wildland fire is a considerable threat to homes in the wildland urban interface, which is typically located around the outer edges of metropolitan areas and throughout the countryside. These are the areas where housing growth has been most dramatic. The US society's response to natural disasters have been more reactive than forward-looking. When human losses are substantial, the outcome is often a new policy, reallocation of public spending, and regulation. To date, however, few incentives or policies have addressed the root cause, which is development of new housing units without regard to landscape patterns, ecological processes or hazard exposure.

Deforestation for conversion to developed uses can significantly reduce the US land base available for.such carbon sequestration (Alig *et al.* 2002, 2010b). Possible effects of urbanization on the US' potential to sequester more forest-based carbon to address climate change were examined by Alig, Latta, Adams *et aZ.* (200b). Less forestland can also impact timber markets. Land use changes affecting US forests since 1990 have been concentrated in the South-the region with more timber harvest than any country. Land base changes can affect the South's ability to continue its dominant role in softwood timber supply. Recent surveys and the USDA NRCS national resource inventory (2001) suggest that loss of timberland to urbanization is accelerating in key timber supply regions. For example, expansion of developed area and urban sprawl in the South has been described as a major issue for future natural resource management, especially for the region's forests (Wear and Greis 2002).

When an area is converted to urban and built-up uses, it is likely to be an essentially permanent conversion. Development also affects the quality of remaining forests due to fragmentation (Butler, Swenson, and Alig 2004; Alig, Lewis, and Swenson 2005; Wear, Pye, and Riitters 2004). More people on the forested landscape often means loss of open space, concern over loss of the amenity values generally associated with open space, and adverse effects on biodiversity. The growing apprehension about loss of forest land to development has also been reflected in public and private efforts to preserve forest land as open space (Kline, Alig, and Garber-Yonts 2004). Because much of the growth is expected in areas that are relatively 'stressed' with respect to human-environment interactions, implications for landscape and urban planning include potential impacts on sensitive watersheds, riparian areas, wildlife habitat, open space, and water supplies.

Private lands are important providers of recreation opportunities. Hence, changes in use and ownership of such land can affect the availability and quality of those recreation opportunities. Additionally, particularly in eastern US, public and private lands are interspersed. As a result, changes in private lands can also have an impact on recreation experience on public lands. This is especially true for trail-oriented activities such as hiking, snow-mobiling, and cross-country skiing. For example, the addition of private homes near public recreation land boundaries can alter viewsheds and wildlife behavior on public lands.

Wrap-up and research needs

The area of undeveloped rural land in the future in the US is largely dependent on the increase in developed land uses in the coming decades. The relatively low population density has allowed some latitude in use of land across major rural uses. However, the expansion of developed land in future will further constrain the country's flexibility in responding to changes in demand for land-based products and services such as climate change mitigation (for example, afforestation). Recent expansion was spurred largely due to demand for new housing from a rising population who desire to live in amenity-rich environments in ever-larger houses on ever-larger lots. The US Southeast and South Central regions are projected to experience the greatest percentage increases in developed land area. In the West, projected percentage increases in developed land area were greatest in the Rocky Mountain region. High projected increases in developed area in many western states reflect both significant projected increases in population and the small relative amounts of existing developed land area. Overall, this raises the question whether the trend towards less-efficient use of land is sustainable in the long term.

A major requirement for improving analyses of land use changes is data on land use change that are more up-to-date and universal. It is striking that the data available for this paper are not recent enough to cover the biggest land development and housing boom in the nation's entire history! Changes in land *cover* areas are provided by satellite and other remotely sensed devices, but there is a need to augment these with ground truth to determine actual land use, changes in ownership, and other attributes. Harmonized or reconciled land use definitions could also aid analyses. Development spans a broad range of population density associated with settlement patterns, and definitions of development can depend on the data source and purpose for which the data are analysed. Two major US data sources both show a steady increase in developed uses over recent decades. Estimates from the US Census Bureau reveal a 130% increase in census-defined urban area between 1960 and 2000. Census urban area consists of all territory units in urbanized areas, and in places of more than 2500 individuals beyond urbanized areas. Changes in rural land use have historically been, and remain, connected with changes in motor vehicle use, technology, and policy.

Some examples of research that could improve Analyses of Risk of Forestland Conversion include the following.

- Better information about expected benefits and costs regarding likelihood of land use conversion for a particular unit of land;
- Environmental impacts, losses in commodity production, and other costs that may arise if a unit of land is developed (such as increased costs due to fire suppression with houses in the wildland-urban interface); and
- Estimates of opportunity costs of retaining forestland (such as land values) to provide a sense of what it may cost to transfer development rights, implement a conservation easement, or undertake some other policy action.

Given the dynamics of changing population and social values, forest conversion can reduce provision of public goods by forests, such as the environmental service of storing terrestrial carbon to mitigate climate change, which falls outside the realm of private decision-making. Measuring and evaluating multiple forest benefits associated with public goods can be difficult owing to a general lack of information describing forest outputs and their values. This lack of information is especially true when it comes to valuing benefits accruing from ecosystem services-a set of values clearly needed for open space and other ecosystems services provided by private forests. Efforts to better align commercial uses of forests with conservation objectives have led to increased interest in what is being called 'sustainable forestry', although there are similar efforts tied to other major competing interests in land such as 'sustainable agriculture' or 'sustainable communities'. Land use will continue to change as private decision-makers and society examine options to adjust to changing demands for and supplies of renewable resources (for example, biofuels for energy security and to address climate change) and ecosystem services from the nation's forest and aquatic ecosystems. Sustainability analyses will be enhanced if both land use and land investment options are examined. Analyses should be explicit for timing of tradeoffs and market-level impacts, to help promote enhanced integrated macro analyses of land base changes using a balanced mixture of spatially explicit data and other information.

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Appendix: US landownership and regional descriptions of urbanization

About 0.16 billion ha of US land (18%) in the contiguous 48 states is owned by the federal government. The remaining 0.61 billion ha is owned by private individuals and entities, state and local governments, and Native American tribal governments. Private land accounts for the vast majority (about 85%) ofthe contiguous US non-federal land base (USDA ERS 2010). Because of settlement patterns, eastern US lands are mostly privately owned. Publicly-owned lands (primarily in federal ownership) are a prominent fixture of the western states. The contiguous western states contain about 8.5 times the federal land of eastern states. The West also comprises majority of the American Indian tribal government land. Many of the western federal lands are remnants of those gained by treaty from foreign governments (Gates 1971). The aggregate area of both federal land and non-federal land in the US has remained stable since 1982 (USDA NRCS 2001).

Privately-owned rural lands in crops, range, and forest uses are important providers of outdoor recreation opportunities. These three land uses account for the majority of non-federal land area in each US region. Regionally, undeveloped rural lands (forests, crops, and range) are most common in non-federal areas of the Great Plains, Rocky Mountains, and South Central regions of the US.

More urbanization: According to periodic surveys by the USDA Forest Service (Smith et *al.* 2004), from 1953 to 1997, a majority (26) of the US states experienced loss in forest area. Nine states recorded net losses of at least 1 million acres each, ranging up to 6.3 million acres. In descending order of net loss amount, the states were: Texas, Florida, California, Oklahoma, Louisiana, Washington, Alaska, Missouri, and Minnesota. Seven states had net gains of more than one million acres, ranging up to 4.1 million acres. In descending order of net gain amount, these states were: New York, Ohio, Pennsylvania, West Virginia, Mississippi, Alabama, and Kentucky. The only regions with net gain in forest area were the North, where a relatively large amount of pastureland reverted naturally to forests, and the Intermountain region, where many acres were reclassified from pasture or rangeland to forest over time.

According to the NRI, the North had three of the 10 states with the largest average annual additions of developed area. Areas of urban and developed uses steadily increased in the North since 1982. Between 1992 and 1997, the area of urban and developed area in the Northeast increased from 10-4% to 11.9% of the land base. Corresponding increases in the North Central subregion were from 6·7% to 7.3%.

More houses in woods: Most watersheds projected to experience the greatest amount of change were located in the East, although some were located in the Great Lakes area, California, and the Pacific Northwest. The largest change will occur in 12 states in the Northeast and South (Stein et *al.* 2005). The most affected private forested watersheds are generally found in the East, and along the West Coast. Overall, the US East is expected to be more heavily impacted by future increases in housing density than the West (White, Alig, and Stein 2010).

More houses burning in the woods: In the South, housing increased by 18%, almost as much as the rise in the Rocky Mountain region, and presented an even greater contrast between non-Wildland Urban Interface (WUI) housing growth (9%) and WUI housing growth (29%)· Over 3 million housing units were added to the WUI during this decade, and the WUI expanded to cover 17.1 % of the land area-a greater share than that in any other region.

Housing grew more slowly (just 9%) in the North than in any other region. However, the intermix WUI gained nearly 1.2 million new housing units-an increase of 21% over the decade. The area ofthe WUI also expanded by 2000, over 15% ofthe North was WUI.

The largest rise in housing (23%) was recorded for the Rocky Mountain region. Once again, WUI housing growth was even higher (37%), while intermix WUI housing grew by 75%. Although the 2000 WUI makes up just 1-4% of this region's land area, it contains 45.7% of the housing units in the state.

Housing growth in the West Coast region was 12% overall, with over 1 million new WUI housing units-an 18% increase in the number ofWUI homes. WUI area also expanded from 5.8% to 6.5% of the three-state area. Of the 16.1 million housing units in this region, over a quarter (4.5 million) are located in the WUI.

More land use changes: The Southeast region, followed by the Northeast region, is projected to witness the greatest percentage of non-federal rural lands converted to developed uses, while the Great Plains and Rocky Mountain regions are expected to record the lowest percentage changes. In the East, everything else being equal, forest is projected to be the greatest provider of newly developed land. In the West, range and cropland are projected to be the biggest providers of land for development.

The Great Plains and Rocky Mountain regions are projected to experience the lowest percentages of non-federal rural land converted. Increased developed land areas and associated residential housing can put increased pressure on natural resources for recreation opportunities and other services. At the national level, between 2000 and 2030, developed area is projected to increase by a little more than 50%.

Since most ofthe growth is expected to occur in areas (such as some coastal counties) already burdened by anthropogenic impacts, implications for landscape and urban planning include potential effects on sensitive watersheds, riparian areas.wildlife habitat, and water supplies. While providing additional living space and infrastructure, added development may also diminish agricultural output by reducing farmland and alter, ecological conditions by converting and fragmenting forests and other natural landscapes.

More forest fragmentation: Among the ecological sections in the South, the southern Appalachian Piedmont would lose the largest area of interior forest cover (173166 ha). The Gulf prairies and marshes in Texas, which have very little interior forest, would lose the highest proportion of interior forest (56.7%) (Wear, Pye, and Riitters 2004). In terms of rural versus urban locations, metropolitan statistical area (MSAs) counties contain 492 690 ha (66%) of the total forecast loss of 747744 ha. Heavily impacted MSAs are concentrated in Florida.

More assets at risk: Regional patterns of growth and decline in the US have shifted population and property value to more vulnerable areas (van der Vink, Allen, and Chapin 1998). By 1970, population and housing growth had shifted from cities of northeastern US to two regions facing considerable natural hazards-the Southeast, with its exposure to hurricanes from both the Atlantic and the Gulf; and the West, where a wide range of hazards are present. Colorado and California stand out as states where population and housing growth have been substantial (California earlier in the period, Colorado later). Both these states face the threat of catastrophic wildland fires. In California, earthquakes and landslides pose major threats to heavily populated cities. Coastal Oregon and Washington are exposed to tsunami risks; southwestern states (Arizona; and later, New Mexico and Nevada) have grown tremendously and have active fire regimes.

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