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ORIGINAL PAPER

Spatial and temporal residential density patterns from 1940 to 2000 in and around the Northern Forest of the Northeastern United States

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Abstract Over the past 60 years, housing growth has outpaced population growth in the United States. Conservationists are concerned about the far-reaching environmental impacts of housing development, particularly in rural areas. We use clustering analysis to examine the pattern and distribution of housing development since 1940 in and around the Northern Forest, a heavily forested region with high amenity and recreation use in the Northeastern United States. We find that both proximity to urban areas and an abundance of natural amenities are associated with housing growth at the neighborhood level in this region. In the 1970s, counterurbanization led to higher rates of growth across rural areas. The Northern Forest now has extensive interface between forest vegetation and residential development, which has the potential to profoundly alter the ecological and social benefits of these forests.

Keywords Housing density · Housing growth · Sprawl · Amenity growth · Cluster analysis · Northern Forest

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Introduction

Suburban sprawl first emerged as an environmental issue with the American public in the 1990s, popularized in part by then-Vice President Gore. But as the initial media attention faded and scientists had time to examine this phenomenon more closely, concern shifted from urban expansion in particular to residential growth more generally. Housing development across all landscapes, including urban, suburban, and exurban, has significant environmental impacts, although there remain major gaps in our understanding of this population-environment relationship (Brown et al. 2005; Radeloff et al. 2005a; Theobald 2001).

Interest in the environmental impacts of housing development emerged along with the realization that housing development has outpaced population growth in the United States since the 1940s. While population has roughly doubled since 1940, housing has tripled (Hammer et al. 2009). This divergence between housing and population growth rates means that land use per person is not constant, but is rising. Divergence results from decreasing household size, more widespread home ownership, and multiple-home ownership. Urban centers are still the dominant organizing force shaping settlement patterns in the United States and worldwide, but their influence has waned in the United States. Selective deconcentration, or movement out of dense urban areas, is one characteristic of recent settlement patterns in the United States (Johnson et al. 2005), resulting in a net decline in areas with very low-density and very high-density housing, and expansion of medium and low-density housing (e.g., Radeloff et al. 2005b). The environmental impacts of residential growth are extensive and somewhat independent of population density as many result from the removal and disruption of vegetation and the creation of impervious surfaces. Therefore, the same rate of population growth will have a greater impact on the environment when housing densities are lower, households are smaller, and more people own multiple homes (Brown et al. 2005; Theobald 2001).

Rural residential growth is of special conservation concern, because rural development typically occurs at lower densities with larger individual lot sizes, spreading the impacts of each house over a larger area and maximizing the cumulative footprint of housing development (Heimlich and Anderson 2001; Pejchar et al. 2007; Theobald et al. 1997). The genesis of rural housing growth in the United States is in the migration turnaround or “rural renaissance” of the 1970s, which represented the first reversal of longstanding rural-to-urban migration trends in the United States (Fuguitt 1985; Long and DeAre 1988). Preferences for small towns and natural amenities, together with affluence, portable pensions, and workplace flexibility, have spurred housing development in rural areas, driven by demand for seasonal homes, retirement homes, and permanent homes for telecommuters (Brown et al. 1997; Fuguitt and Brown 1990; Stewart and Johnson 2007).

There are growing concerns about the environmental impacts of this expanding housing development, as housing development is known to have prolonged and complex effects on biodiversity and ecosystem function (Hansen et al. 2005; Liu et al. 2003; McKinney 2002). New housing development affects natural systems in both direct and indirect pathways (Hansen et al. 2005). Housing and infrastructure construction remove vegetation directly, which fragments remaining habitat. Ecosystems are dynamic and complex, so that even small disturbances such as clearing a lot for construction of a home may initiate a cascade of changes in vegetation, with implications for wildlife populations and ecosystem functioning (Green and Baker 2003). Once developed, housing strongly influences transportation infrastructure and thus generates secondary impacts by shaping travel modes and patterns. Homeowner behavior is an additional factor in increasing or decreasing the effects associated with each structure. Homeowners pave driveways and patios; manage yards, pets, and bird feeders; and kill or remove "nuisance" wildlife, creating indirect environmental problems such as altered hydrologic systems, well-supported exotic plants, and predatory domestic pets, and light pollution (Gavier-Pizarro et al. 2010; Lepczyk et al. 2004; Longcore and Rich 2004). Even lacking a precise and comprehensive understanding of the impacts of housing on forest ecosystems, it is apparent that houses are a locus of many different effects of human presence and behavior on the ecosystem. Therefore, housing distribution is often considered a better, more spatially accurate indicator of human impact on ecosystems than population distribution (Liu et al. 2003).

Because the landscape ecological changes associated with residential development of forests and other wildlands occur over a long time period (Dupouey et al. 2002; Fraterrigo et al. 2005; Rhemtulla et al. 2009; Theobald et al. 1997), a record of when disruption occurred, such as in a land-use history, is an important tool for understanding ecological processes and conditions. Various sources of insight into land-use history have been developed and used, surveyors' notes (Rhemtulla et al. 2009), physical artifacts (Dupouey et al. 2002), historic airphotos (Gonzalez-Abraham et al. 2007), and remotely sensed images (Brown 2003), all of which are time-intensive to construct and limited in the extent of their coverage. As a result, land-use histories are not always feasible, and vary widely in their basis, extent, and time period.

The census of housing is a unique form of decadal social information that embeds land-use history; a house rarely moves from its original location, so its presence and age indicate when its lot and surrounding vegetation was disturbed. Fine-scale spatially detailed housing census data are available in the United States over a longtime period, providing insights into land-use history (Hammer et al. 2004). Most of the past studies of housing and land use in the United States have focused on areas where land is being converted to housing for the first time, often in the West or Midwest (Jackson-Smith et al. 2006; Nelson 2001; Radeloff et al. 2005a). In contrast, in the Northeastern United States, there is a long history of intensive land use and settlement, but also relatively low population growth over recent decades in comparison to other regions of the United States (Johnson 2008), suggesting that patterns of housing growth and land use might differ from other regions. Yet, there has been no large-scale investigation of housing patterns across the region.

Accordingly, we set out to study housing development across the Northeastern United States from 1940 to 2000, to both examine the spatial distribution and timing of housing development in the Northeastern United States, and to demonstrate use of historic housing data as a tool for land-use history. Our study area, which we refer to as the upper Northeast, includes Maine, New Hampshire, Vermont, and portions of New York (excluding the New York City/Long Island metro area). This is a region that currently combines high amenity and recreation use (Johnson and Beale 2002), a dense human population, and a small public land base. To better understand the relationship between housing and rural areas with natural amenities, we specifically examine housing development within the Northern Forest, the heavily forested northern sub-region of the upper Northeast, compared to the rest of the upper Northeast. In order to interpret our research findings, we also present data on current land cover and prevalence of seasonal housing inside and outside the Northern Forest. If the upper Northeast conforms to patterns found in national studies and studies of other regions, we expect to find widespread housing development in areas that were initially lower density (i.e., rural), with the 1970s emerging as a peak decade in housing growth, and significant housing development in the amenity-rich and more rural Northern Forest (Hammer et al. 2004; Johnson et al. 2005; Long and DeAre 1988; Nelson et al. 2004). Both the methods and data employed here are available for use in subsequent investigation of the environmental consequences associated with residential growth.

Background

The upper Northeast study area

The upper Northeast (Fig. 1) has a long history of intensive settlement including many cycles of population and land-use change. Starting in 1620, European settlers colonized this region, and 75% of the arable land in the region was cleared for agriculture by the early 1800s (Foster 1992). The remaining forests on less productive soils or steeper slopes were intensively logged (Cogbill et al. 2002). Large-scale logging accelerated in northern New England as southern New England and New York City developed, peaking in 1850. After 1850, agriculture declined rapidly as farms in the region were abandoned for more productive farmland in the Midwest (Foster 1992). As the Northeast's agriculture declined, loggers pushed further into its remote forests, exploiting Maine's woods for the first time (Foster 2002). Logging continued into the 20th century, with pulp and papermaking industries concentrated in the Northern Forest. After farmland was abandoned in the 1800s, forests entered a long period of regrowth. While virtually no 'old-growth' forest remains today in the Northeastern United States (Cogbill et al. 2002), current forests are older, more complex, and have higher wildlife densities than at any time in the previous two centuries (Foster 2002).

Fully understanding present-day trends in forest cover is made difficult by contrasting definitions and methods by which forests are inventoried. By Forest Service inventory measures, forest cover throughout the Northeastern United States was extensive in the 1990s, due to forest re-growth (McWilliams et al. 2000). A newer analysis using different methods finds evidence that a shift has occurred from decades of forest cover increase along the East Coast, to a net loss of forest cover during the period from 1973 to 2000 as urban areas expanded, land use intensified,

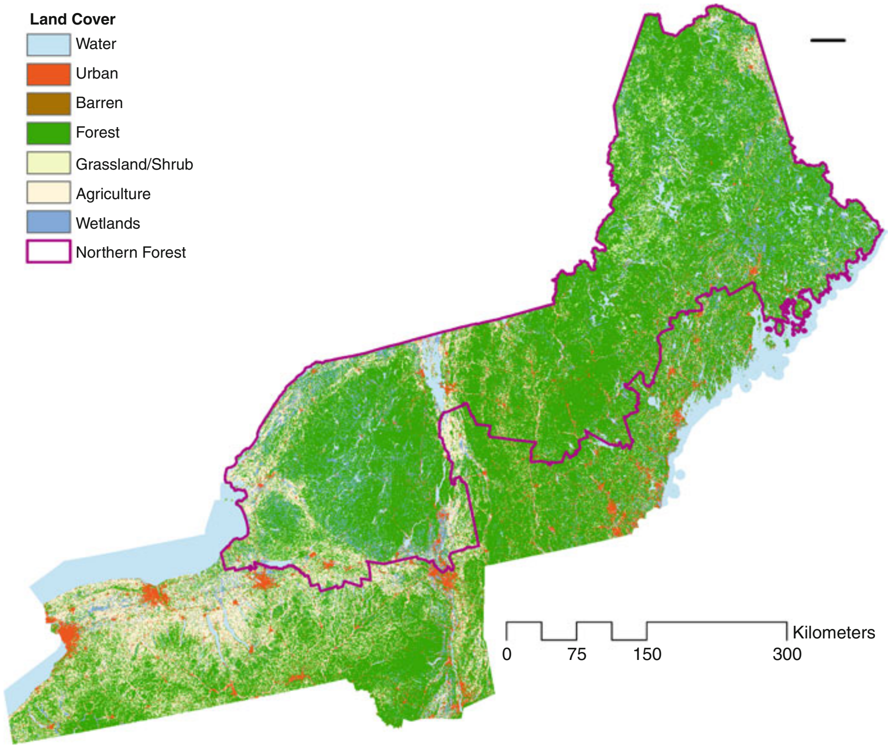

Fig. 1 National land-cover database for the upper Northeast study area and the northern forest

and the stock of former agricultural areas that can be recruited into forest dwindled (Drummond and Loveland 2010). Residential development has the ability to effect substantial land-cover changes because unlike the western states, where there are extensive Federally owned protected lands, the majority of forested lands in the Northeast are privately owned (up to 94% in Maine (McWilliams et al. 2005) and 75–76% in New Hampshire, Vermont, and New York (Morin and Tansey 2008)). Many parcels of nonindustrial private forest land are small and land management practices are heterogeneous, complicating landscape-scale planning and conservation (Kittredge 2005). Northeastern states also have extensive wildland-urban interface (Stewart et al. 2003), meaning that large areas with forest cover are either residential forest with houses under the canopy or are close to housing. Recognizing these potential threats, Foster et al. (2010) raise serious concerns about this region's long-term forest health and sustainability.

Residential development in the region stems in large part from population growth due to in-migration (i.e., amenity migration Stewart 2002), as the region as a whole shows only moderate population growth (Johnson 2008). In contrast, the major metropolitan areas further south (the Boston-New York City megalopolis) have stable or declining populations due to net out-migration and minimal natural increase (Johnson 2008). Housing development in a region like the Northeast, where rural community decline and metropolitan population loss have been prevalent, is not universally seen as a problem. In fact, to many, it may be seen as a real sign of improvement, a return of growth, and a source of local tax revenue and jobs (Pfeffer and Lapping 1994). Recreation tied to natural amenities also has a long history in this region. Intensive land use at the expense of forests helped inspire the first conservation movement in the 19th century (for example, Henry David Thoreau) (Foster et al. 2010) and nature-based tourism emerged as an industry in the 19th century as well (Brown 1995). Nature-based tourism remains economically and culturally important today. Northeastern states currently have some of the highest seasonal home concentrations in the United States: Maine with 15.6%, Vermont 14.6%, and New Hampshire 10.3% (Bureau of the Census 2001). These forests therefore hold substantial cultural, recreational, and environmental importance. Examining the pattern and rate of housing growth is thus an important first step in understanding the region's recent land-use history, and planning for a sustainable land-use future.

The Northern Forest

The Northern Forest is located within the upper Northeast, a swath of forested, largely rural land stretching from northern Maine through the Adirondacks (Northern Forest Center 2010) (Fig. 1). The Northern Forest is the largest remaining contiguous forest area on the East Coast. The region's distinct cultural identity stems from its forest-based economy and smaller rural communities removed from state policy centers. The economy and cultural identity of the Northern Forest region is undergoing significant changes with the declining importance of the forest products sector. The forest products industry has an ample timber supply but lacks cost competitiveness in the global market (Schuler and Ince 2005). Vertically integrated forest product companies that operated mills supplied by their own timberland have almost entirely divested their real estate holdings (Foster 2002; Hagan et al. 2005). Most large tracts of divested timberland have remained intact (particularly those in Maine), but there are growing concerns that these forests will be further fragmented and developed (Egan et al. 2007; Kluza et al. 2000). Social resilience is also a concern, as the largely rural communities in the Northern Forest work to both maintain the region's cultural identity and facilitate economic growth (Colocousis 2008; Northern Forest Center 2000). As more traditional economies wane, service economies built around tourism, recreation, and retirement are becoming prominent components of local economies, causing significant social and economic changes for local communities (Foster 2002; Johnson 2008; Northern Forest Center 2000).

Methods

Housing growth data are unique in its ability to capture the combined outcomes of demographic trends (population growth, migration, household formation, urban/rural settlement trends, urbanization) and to indicate the location and concentration of human impact on the environment (Hammer et al. 2004; Radeloff et al. 2005a). The persistence of housing through time makes contemporary housing counts particularly useful. It is possible to estimate historic settlement patterns based on houses that remain and to do so at a scale finer than that at which historic census records are kept (Syphard et al. 2009).

Not only do houses archive historic data regarding population, they also indicate the timing of series of environmental changes that result from the land-use and land-cover changes caused by housing construction. During construction, vegetative cover (whether farmland, field, or forest) is removed and is left permanently altered once housing is complete. When forests are partially cleared to make way for home building, new edge habitat is created and remaining forests experience changes in light, moisture, and exposure to wind (Pidgeon et al. 2007). Exotic plants introduced for landscaping purposes escape to adjacent wildlands but invade over a period of years or even decades (Gavier-Pizarro et al. in review) and hence areas adjacent to older neighborhoods should have greater concentrations. Conversely, urban vegetative cover often increases over time as newly planted trees mature and homeowners landscape their lots (Boone et al. 2010; Brown 2003). Hence, the ability of decadal housing data to indicate when the forest in each neighborhood began its response to housing development is valuable.

Another benefit of housing growth data is its relationship to urban/rural status, a widely used delineation of settlement types. In simplest terms, the distinction between urban and rural areas is based on the density of either population or housing. Definitions of urban and rural are subject to change, and the classification of a given area as urban or rural changes with the definitions, and as it grows (Redman and Jones 2005). Working from housing data itself makes definitions, classifications, and changes in status less significant, because housing is a direct indicator of settlement density and extent. In our Northeastern United States study area, the urban/rural distinction is not altogether meaningful or clear. Metropolitan areas encompass rural neighborhoods, and high-rise resorts and casinos are found in rural areas. Interstate highways string residential areas along vast corridors between small and medium-sized cities, and the major metropolitan areas have become a single megalopolis along the East Coast. Identifying an urban-to-rural gradient (e.g., McDonnell and Pickett 1990) is difficult because few vectors could originate in a rural area and progress monotonically (as the term “gradient” suggests) to an urban center. Housing data offers an alternative basis for research on anthropogenic effects on the environment, one without the encumbrances and vagaries of the urban/rural distinction (Hammer et al. 2004; Redman and Jones 2005) or the assumption of urban-to-rural gradients.

Data analysis

United States Census data can provide longtime series housing data at fine resolution. Digitized census boundaries at fine scales (block, block groups, and tracts) only became available nationwide in 1990, and boundaries of these units change so frequently that earlier data at these scales cannot be easily mapped. We used the partial block group (PBG) geography (Hammer et al. 2004), which are formed when block groups are subdivided into smaller spatial units by boundaries of incorporated places, legal and census-designated county subdivisions, and rural/urban areas. Block groups thus frequently consist of multiple "partial" block groups. Using partial block groups maximizes variations in housing density between PBGs and minimizes within PBG variation. Using PBGs, we can estimate historic housing density by decade, back to 1940 (Hammer et al. 2004). Estimates of historic sub-county housing counts are based on answers to the 2000 census long-form question "In what year was this housing unit built?"

For each decade, we summed responses by PBG for all prior decades (e.g., an estimate of a 1970 housing count sums housing units built before 1940 with those reported built in each subsequent decade through the 1960s). This method is likely to underestimate the true count because it misses housing units that did not persist to 2000 (and hence were not surveyed in the 2000 Census) due to demolition, destruction, or removal. To adjust for lost units, we summed the PBG-level estimated counts for each county by decade, compared them to historic county-level totals provided by the US Census Bureau, and distributed the difference proportionally across all PBGs in the county. Adjustment rates (proportion of a county's housing allocated by this process) were larger for earlier decades: 1940 $\bar{x} = 0.24$, SD = 0.09; 1950 $\bar{x} = 0.22$, SD = 0.07; 1960 $\bar{x} = 0.17$, SD = 0.07; 1970 $\bar{x} = 0.10$, SD = 0.05; 1980 $\bar{x} = 0.10$, SD = 0.03; 1990 $\bar{x} = 0.06$, SD = 0.03 ($n = 92$ counties). This pattern conforms to expectations, as older houses are more commonly subject to demolition.

To identify areas with similar housing growth trends, we used a two-stage clustering process to group PBGs from Maine, New Hampshire, Vermont, and New York that share similar housing attributes. This is very similar to the approach used in Hammer et al. (2004), but uses the 2000 PBGs, rather than the 1990 PBGs used in that study. We then clustered log-transformed values of housing density per km^2 over six decades, where log transformation limits the effect of large outliers. All analyses were conducted in R, version 2.13.1 (R Development Core Team 2011). Only PBGs with housing units present in 2000 were used in these analyses ($n = 12{,}123$, mean size = 17.2 km^2, SD = 62.4 km^2).

In the first step, we started with an initial random sample of 3,000 PBGs (sampled with replacement) and used hierarchical agglomerative clustering to create 25 unique clusters. The average-linkage rule was used to create distinct clusters with internal cohesion (Aldenderfer and Blashfield 1984; Kaufman and Rousseeuw 1990). We used a Euclidean distance measure for clustering, as it is the most commonly used distance measure in hierarchical clustering. Because the Euclidean measure is strongly affected by value differences, allowing large values to disproportionately affect cluster designation (Aldenderfer and Blashfield 1984), we log-transformed the housing density data. In order to reduce the effect of outliers, we dropped clusters with few PBGs as members, using a cut-off of less than five PBGs per cluster, resulting in 14 unique clusters for housing density. For the second step of the cluster analyses, we used the cluster centroids for a K-median partitioning of the full data set (Gordon 1999). K-median partitioning differs from the K-means method in that it uses a Manhattan distance measure (i.e., in attribute space) to limit the effects of outliers in assigning cluster status.

For each density cluster, we calculate an average housing unit density per decade, creating a trajectory of housing unit change over time, as well as the rate of change from each decade to the next (percent growth in housing units/km^2). We repeated the full clustering routine ten times and found that results were stable, with the majority (6/10) of the runs yielding 14 clusters with similar housing densities. Among the lower- and higher-density housing clusters, starting and ending housing densities were essentially the same in all six runs examined, and among the medium housing density clusters, we generally saw two similar local optima. To display housing clusters graphically, we then mapped the distribution of all clusters in ArcGIS 10. In order to better focus on housing growth in lower-density areas, we combined the five housing clusters with the highest densities (each starting with greater than 100 housing units per km^2 in 1940) and mapped these clusters together as 'very high-density' areas. The area and number of PBGs for each housing density cluster, as well as the total number of housing units per cluster in 2000, is shown in Table 1.

To examine residential development inside and outside the Northern Forest, we compared the total area occupied by each cluster and the proportion of 'wildland' vegetation cover for each cluster, both inside and outside the Northern Forest. We derived vegetation information from the US Geological Survey (USGS) National Land Cover Data (NLCD), classified 30-m resolution Landsat TM satellite data from 2001 (Homer et al. 2004) (Fig. 1). We estimated percent wildland for each cluster by calculating the ratio of combined forest, grassland/shrub, and wetlands relative to the total land area of the cluster, thereby excluding areas classified as urban, agriculture, water, and barren. We note that the term 'wildland' does not refer to the ecological status of the vegetation, but is used merely to refer to those

Table 1 Decade of highest growth, number of partial block groups, area, and housing units for each housing density cluster in the upper Northeast study area

	Decade of highest growth	n (PBGs)	Area (km^2)	% Study area	Total housing units (2000)	% Total housing units (2000)
No housing	NA	72,832	31,417	13.1	0	0
Low (D0-5)	80s	297	43,286	18.0	53,595	1.2
Low (D2-6)	70s	724	48,270	20.1	223,375	5.1
Low (D3-9)	70s	1,065	50,663	21.1	398,759	9.0
Med (D4-15)	70s	1,131	35,603	14.8	463,439	10.5
Med (D7-24)	70s	1,012	17,314	7.2	366,057	8.3
Med (D14-38)	50s	724	4,927	2.0	177,497	4.0
High (D30-89)	50s/70s	758	2,104	0.9	179,361	4.1
High (D9-156)	70s	369	1,139	0.5	152,680	3.5
High (D56-167)	50s/70s	1,126	2,335	1.0	388,728	8.8
Very high (>100 in 1940)	NA	4,917	3,468	1.4	2,012,126	45.6
Sum		84,955	240,525	100	4,415,617	100

areas with vegetative land-cover types that are not directly determined by human influence. Throughout the following discussion and figures, housing density clusters are named with "D", the average starting density in 1940, and the average ending density in 2000, so that D9-156 is a housing density cluster that started with an average density of nine housing units per km^2 in 1940 and had 156 housing units per km^2 in 2000. Lastly, to provide more social context on housing development in the upper Northeast, we calculated the number and proportion of seasonal housing units at the county level, inside and outside the Northern Forest, using 2000 Census data.

Results

Clustering housing densities over six decades grouped PBGs into nine distinct clusters throughout the study area, each with a unique trajectory (Fig. 2). Most clusters experienced a peak in housing growth in the 1970s (five clusters), with two clusters showing equal peaks in housing growth rates in the 1950s and 1970s, and one cluster growing the fastest in the 1980s. Except for the cluster that grew the fastest in the 1980s (D0-5), all clusters showed lower and declining rates of growth in the 1980s and 1990s (Table 1). Because the 'very high-density' clusters started at

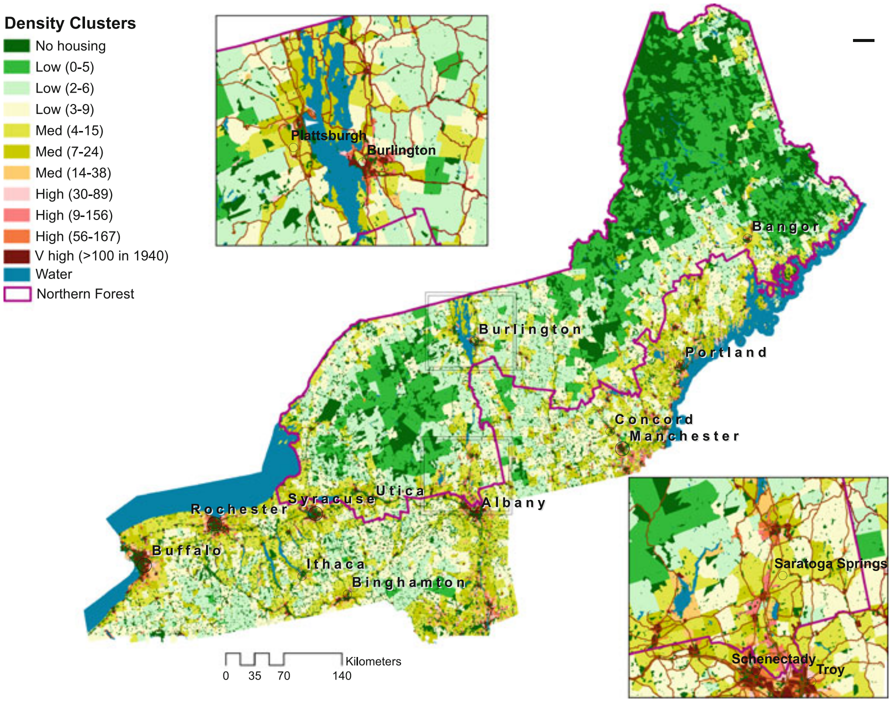

Fig. 2 Distribution of housing density clusters in the upper Northeast study area. Densities are divided among low, medium, and high final densities in 2000 and named by the average housing density in 1940-average housing density in 2000

high housing densities in the 1940s, and we do not have any information prior to this date, we do not include these areas in the discussion of housing growth rates.

Across the entire study area, 13% of the land area had no housing units, over half (59%) of the study area fell within the lower-density clusters (average of 9 or fewer housing units/km^2 in 2000), and over a third (24%) in the medium-density clusters (between 15 and 38 housing units/km^2 in 2000) (Table 1). Only a small portion of the study areas fell in the high-density and very high-density clusters (2.4 and 1.4%, respectively) (Fig. 4). Clusters were distributed unevenly inside and outside the Northern Forest, with most of the variation in distribution among the lower housing density clusters (correlation of proportion area by cluster between the two regions: $r = 0.27$, $p = 0.4$) (Fig. 4). Examining the distribution of the clusters by decade of highest percent growth revealed that clusters with peak growth rates in the 1970s made up the majority of the study area. Examining only these nine focal density clusters (excludes the no housing and 'very high-density' housing areas), 90% of the area occupied outside the Northern Forest experienced the highest growth rate in the 1970s versus 61% inside. The cluster that grew the fastest in the 1980s made up 2% of area covered by the nine main density clusters outside the Northern Forest, but 37% inside the Northern Forest. Clusters with maximum growth rates in the 1950s, and those with equal maxima in the 1950s and 1970s occupied relatively little area. Examining only the nine main density clusters, those with maximum growth rates in the 1950s were 1% of the area inside the Northern Forest and 4% of the area outside the Northern Forest (Fig. 4). Clusters with equal maxima in the 1950s and 1970s were similarly 1% of the area inside the Northern Forest and 3.6% of the area outside the Northern Forest (Fig. 4). Analysis of land cover showed that proportion wildland decreased across clusters of different housing densities (Fig. 4). There was no significant difference in proportion wildland by density cluster inside and outside the Northern Forest (correlation between proportion wildland by cluster between the two regions, $r = 0.97$, $p < 0.001$), so we report proportion wildland by cluster for the study area as a whole (Fig. 4). Below, we divide each group of housing density clusters by their final housing unit density in year 2000 (low, medium, and high-density clusters) and discuss each group in turn.

Much of the study area remains sparsely developed: Just over fifty percent of the study area fell into clusters with an average density of less than or equal to 6 houses/km^2 in 2000. The trajectory for the lowest-density housing cluster (D0-5) showed minimal growth in housing units until the 1980s, when a high-percentage increase resulted in part from the cluster's low starting base (Fig. 3). Growth in the number of housing units in the next clusters (D2-6, D3-9) peaked in the 1970s, although density of housing increased steadily through 2000 (Fig. 3). Examining the distribution of clusters over the landscape, areas with no housing or very low housing (D0-5) were overwhelmingly found in the Northern Forest, most prominently in Maine and in the Adirondacks of northern New York (Fig. 2). Sparse settlement and minimal growth are consistent with timberland management; changes in ownership may alter these patterns in coming decades. Cluster D2-6 was widespread over the entire study area (20%), but covered twice the area inside the Northern Forest than outside. The next highest-density cluster, D3-9, showed a similar trajectory over time to D2-6 and was also widespread throughout the study

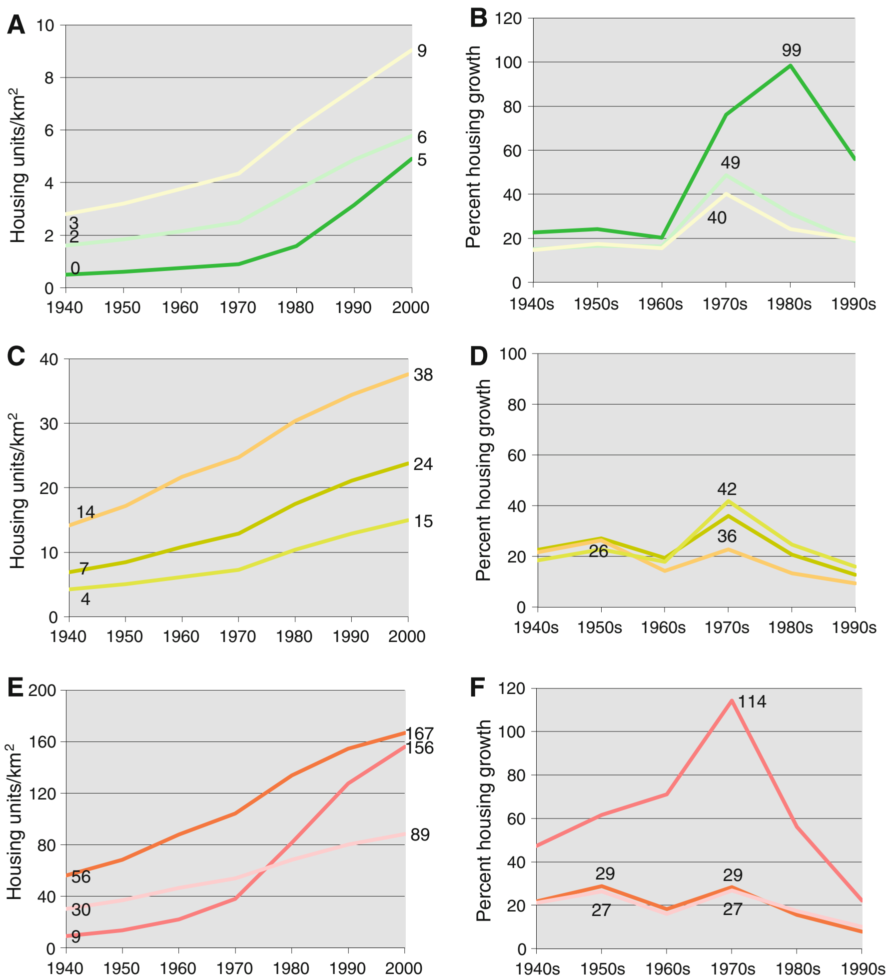

Fig. 3 Trajectories of housing density clusters over time (**a**, **c**, **e**), along with relative rates of change in housing densities, with the decade of highest growth labeled (**b**, **d**, **f**)

area (21%), but covered a greater area outside the Northern Forest than inside. When combined, areas with no and low-density housing covered nearly three-forths of the study area. The proportion wildland land cover was greater than 70% for each low-density cluster, with lower-proportion wildland vegetation in clusters with higher housing density (Fig. 4).

The three medium housing density clusters (D4-15, D7-24, D14-38) made up a combined 24% of the total study area. Each housing density cluster followed a similar moderate increase in housing over time (Fig. 3). The lower two density clusters (D4-15, D7-24) grew the fastest in the 1970s, but D14-38 showed the fastest growth in the 1950s. In New York, this moderate housing development followed the Hudson Valley north to the Albany area and continued west along the I-90 corridor

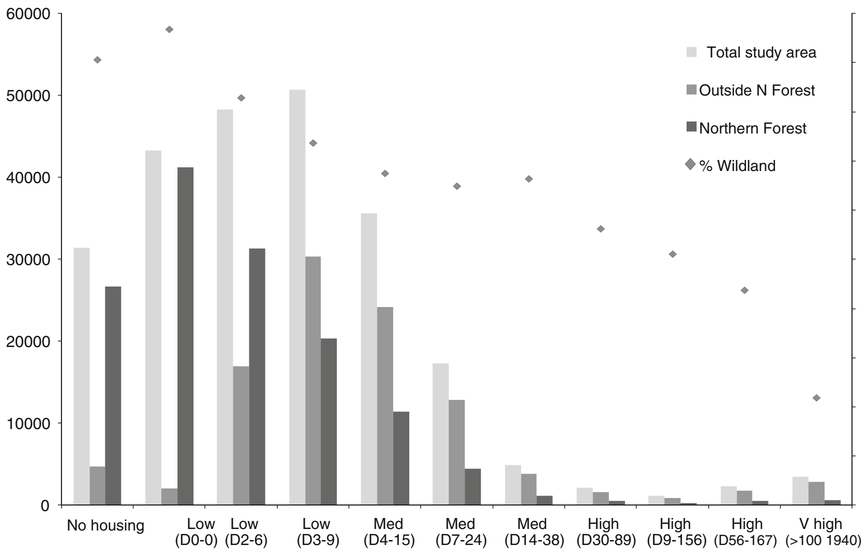

Fig. 4 Area and percent wildland vegetation for each housing density cluster, with area inside and outside the Northern Forest. Total area inside the Northern Forest was 138,460 km^2, area outside Northern Forest equal to 102,065 km^2

to Buffalo. Outside of New York, medium-density clusters occurred along the coast (southern New Hampshire and Maine), with some outgrowths along the Canadian border, and around Burlington, Vermont (Fig. 3). These clusters were predominantly found outside the Northern Forest (40,800 km^2 or 40% of total area outside the Northern Forest, as opposed to approximately 17,000 km^2 or 12% of the area inside the Northern Forest) (Fig. 2). Proportion wildland vegetation was stable across medium housing density clusters at just over 65%.

Those clusters with high housing densities in the year 2000 (D30-89, D9-156, D56-167) occupy a very small proportion of the total study area (2.4%). Two of the clusters (D30-89 and D56-167) showed fairly steady growth rates over time, with equal maxima in growth rates in the 1950s and 1970s. Cluster D9-156, however, showed a sharp increase in housing units beginning in the 1960s, peaking in the 1970s at a growth rate of 114%, with housing growth remaining high in the 1980s (56%), and further declining in the 1990s. This cluster's growth far surpassed other clusters with similar starting densities (e.g., D7-24, D30-89). As a group, these high-density housing clusters largely surround urban areas and are widely distributed along the eastern seaboard and around the older and bigger cities in New York, consistent with metropolitan spillover growth (Fig. 2). However, high-density clusters are also found in wider and patchy distribution over the landscape; for example, around the Finger Lakes region of New York, the northern reaches of Lake Champlain in Vermont and New Hampshire, and areas outside of Berlin, New Hampshire, and Montpelier, Vermont. The fast growing D9-156 cluster is most prominent along southern New Hampshire (Boston-Manchester suburbs) and southern Maine and is generally outside or between areas of very high density

(>100 housing units/km^2 in 1940) (Fig. 2). There are also small pockets of high-density clusters in less developed areas within the Northern Forest (e.g., Watertown in northern Jefferson County, NY or areas south of the White Mountain National Forest in New Hampshire). These high-density clusters are more common outside the Northern Forest boundaries (4.2% of total area outside the Northern Forest and 0.9% of total area inside the Northern Forest). Proportion of wildland declined steadily across these clusters, but even the highest-density cluster (D56-167) had 44% wildland cover.

The 'very high-housing-density' cluster (where housing densities were >100 units/km^2 in 1940) is mostly located on the coast north of the Boston area and along the Erie Canal and Hudson Valley corridors, with the largest concentrations found in the older cities of New York State (Fig. 2). While difficult to see on the larger map, this cluster is also found in more isolated developed areas within the Northern Forest (for example, in Saranac Lake and Watertown in New York; Burlington and Montpelier in Vermont; Berlin, New Hampshire; and Presque Isle and areas along 1-95 from Bangor to the Canadian border in Maine) (Fig. 2). Although high numbers of housing units are found here, this area occupies only a small proportion of the total study area (1.4% total study area). Area of these very high-housing-density clusters was greater outside the Northern Forest by a ratio of 4.5:1 (0.5% of the area within the Northern Forest, 2.8% of area outside Northern Forest) (Fig. 4). Wildland vegetation is the lowest here at 22% or half the level seen in next closest cluster (D56-167).

Seasonal homes are common throughout the upper Northeast, but are more prevalent within the Northern Forest region than outside. At the county level, an average of 20.2% (SD = 13.5) of all housing units are seasonal homes within the Northern Forest, while an average 9.5% (SD = 8.4) of homes outside the Northern Forest are seasonal homes ($t = -4.68$, $p < 0.001$, $df = 90$). Northern Forest counties have fewer housing units, so that the actual numbers of seasonal housing units per county are more similar within and outside the Northern Forest, but remain significantly higher within the Northern Forest counties (Northern Forest, $\bar{x} = 4{,}867$ housing units, SD = 3,062; outside Northern Forest, $\bar{x} = 3{,}372$, SD = 3,225; $t = -2.19$, $p = 0.03$, $df = 90$).

Discussion

Examining the spatial extent and trajectories of housing growth over the upper Northeast demonstrates that housing growth has been extensive in the region, both inside and outside the Northern Forest, but that the Northern Forest remains an area with slower housing growth. Like the rural areas in the North Central region (Hammer et al. 2004) and in many parts of the United States (Johnson et al. 2005; Long and DeAre 1988; Nelson et al. 2004), the upper Northeast experienced a peak in housing development in the 1970s. Much of this development occurred on the metropolitan periphery—that is, in rural areas proximate to large urban centers, but a significant portion also occurred in the Northern Forest, with 74 and 21% of the Northern Forest experiencing the highest rates of growth in the 1970s and 1980s, respectively (this percentage area excludes areas with no housing or 'very high' housing). This is consistent with the patterns seen in the North Central Region, where high-growth PBGs were often concentrated in remote natural resource amenity areas. Despite the 1970s/1980s growth, the Northern Forest has largely retained its regional identity as a rural landscape. The proportion of houses classified as seasonal homes in 2000 was substantially higher here than outside the Northern Forest, indicating that amenity-based migration and recreation are associated with the region.

Even with the surge of growth in the 1970s/1980s, housing growth in this region was not as heightened as patterns seen in rural housing development in the North Central Region (Hammer et al. 2004). Housing growth in the upper Northeast also took a different form; rural sprawl was not the only source of growth. Nearly, all areas across the upper Northeast (urban, suburban, exurban, and rural) grew during this period. We saw little evidence for a 1990s spike in growth, with nearly all clusters growing at rates equal to or less than 20% over this decade (D0-5 and D9-145 were the exceptions). This result varied from other regions with more intense growth in the 1990s (e.g., Radeloff et al. 2005a), and national data showing that the 1990s were an important period for population growth in newly developing, previously nonmetropolitan areas (Johnson et al. 2005). However, our findings are consistent with research by Johnson and Cromartie (2006), who report that in the rural Northeast population did not diminish as much as other rural areas during the 1980s nor did it accelerate as much as other rural areas during the 1990s. Having been widely settled a century earlier, migration in this region may not have had as much impact on the spread of housing, as existing housing stock may have absorbed migrants. Larger initial housing densities also result in lower housing growth rates. On the whole, the trajectories and spatial distribution of housing growth in our study area were more consistent with the outcomes expected across the country in the coming decades, a movement toward moderate density centers in both metropolitan and nonmetropolitan areas, but with an uneven spatial distribution (not all sparsely settled areas will grow in population) (Johnson et al. 2005).

Analysis of land cover by housing cluster showed that at lower densities of housing, land cover remained predominantly forest, grassland/shrub, or wetland. In part, our findings reflect the 30-m pixel resolution of the remotely sensed land cover. In satellite imagery at this resolution, moderate- and low-density housing are often effectively hidden under the tree canopy. For example, present-day land cover through New Hampshire and Vermont is classified as mostly forest (Fig. 1), but much of this area had average 2000 housing density of 6 housing units/km^2 (or about one house per 40 acres), suggesting the land use was low-density to medium-density residential. Even areas with high housing density in 2000 (D30-89, D9-156) retained over 50% land cover classified as forest, grassland/shrub, and wetland. These results conform with research from the North Central United States, where even PBGs with high housing densities retained significant wildland vegetation cover (Radeloff et al. 2005a). Future research on the relationships between land cover and land use (such as housing) on a finer scale will help refine our understanding of the circumstances under which wildland vegetation persists with housing development and how this relationship changes over time. The relationship between agriculture and land cover is also likely to be of interest in the upper Northeast, as high amounts of forest cover are often retained in the small-scale noncommodity farming practiced in this region (for example, in one study an average 57% of farm land was forested at the 1 m scale Lovell et al. 2010). In addition, our research shows that different areas on the landscape experienced variable maximum rates of housing growth and variable timing of these peak rates of housing growth. It is unclear how the intensity and timing of land-use change combine to alter ecological factors of interest, including land cover.

Despite the retention of wildland vegetation at a broad scale, there is concern about maintaining forest and other wildland resources with continued housing development in the region (Drummond and Loveland 2010). Continued expansion of housing into remaining high-amenity rural areas has the potential to significantly impact the forest resources that already serve some of the most dense and largest human populations in the country. Rural amenity areas that experienced particularly high rates or relatively expansive areas of housing development include the region around Burlington, Vermont; the area north of Albany, New York through Saratoga Springs to the Adirondacks; the area north of Utica, New York to the Adirondacks; and the area around the White and Green Mountains. Even moderate growth, especially in small communities, raises concerns about the community's capacity for change and accommodation, potentially including adequate planning, zoning, and enforcement of land-use statutes and regulations (Nelson 2001; Warner et al. 1999). The two largest remaining blocks of the Northern Forest (the Adirondacks and Northern Maine) are increasingly surrounded by urbanized or urbanizing regions. Isolation of protected area due to housing growth is a common problem in the United States and poses a significant challenge to biodiversity protection (Radeloff et al. 2010).

In short, the Northeast has a vast expanse of residential forest, where houses, streets, and associated commercial development coincides with forest vegetation. This extensive wildland-urban interface shares characteristics with urbanized regions in its human density and presence, automobile traffic, and extensive human manipulation of, and impacts on vegetation, hydrology, and airshed. But this wildland-urban interface also shares characteristics with wildland forests in its vegetative type, canopy cover, and wildlife habitat, particularly for synanthropic species (Radeloff et al. 2005b). Like urban forests, residential forests may be heterogeneous and unstable in time and space, but they may also fulfill many ecosystem services and continued development threatens these. Future conservation will require understanding the ecological and social benefits of different forest types and working to maintain them in configurations that assure the continued delivery of ecosystem services. Scientists and managers working in New England call for a recognition of five different types of 'woodlands': urban, suburban, rural, connected, and continuous, each with a different level of desired forest cover and different potential to deliver ecosystem services (Foster et al. 2010). For example, the most important benefits of urban forests may be their ability to reduce water runoff and provide cooling through shade (Pataki et al. 2011), while rural forests can support widespread wildlife populations. More research is necessary to understand how different landscape configurations alter social and ecological needs, and how these needs may combine, as the inhabitants of the Northern Forest try to preserve their traditional identity as a rural and forest-based place.

Identifying the desired landscape configurations and ecological benefits must also be accompanied by a better understanding of the policy instruments likely to effectively encourage the desired housing development patterns. Thus far, the policy responses to sprawl have been numerous, both in more urban and rural settings. Policy tools to manage growth (such as urban growth boundaries) or preserve undeveloped space and agricultural lands (such as zoning) have been used both in isolation and together (Bengston et al. 2004). However, no one policy instrument has emerged as most effective in constraining and shaping housing development on the landscape. A multi-faceted policy approach, with consistent implementation, appears to be most effective in preserving open space (Bengston et al. 2004).

Given that housing development in rural areas is certain to continue, some planners and researchers have promoted the use of ‘conservation’ housing developments, where houses are purposefully constructed on smaller lots and clustered together in order to retain open space (Arendt et al. 1996). While research suggests that some impacts of housing development can be mitigated through clustering houses or limiting density, there are still remaining questions about the ecological efficacy of conservation-oriented subdivisions (Hansen et al. 2005; e.g., Lenth et al. 2006; Milder et al. 2008; Pejchar et al. 2007). The impacts of housing stem not only from the physical structures of houses and roads interrupting flows and processes essential to ecosystem functionality, but also from the behavior and activities of those living in the homes and using the wildland that surround them. Even when homes are carefully placed and clustered, the people living in them will likely hike off-trail, let dogs run, use tools or machines that can start fires, let cats outside, landscape the yard, feed birds, and fertilize and water the garden. Planning and zoning to alter the placement of homes are a necessary first step, but routine chores, leisure behavior, and all manner of mundane activities the average person does not connect to ecological outcomes remain a significant source of stress on ecosystems. Thus, recommendations for changing the ecological effects of ongoing housing growth should include support for more ecological education and to make ecological homeownership a topic of widespread informal and ongoing discussion. The wildland-urban interface appears to be a permanent feature of life in America and other developed countries; if the health of the “wildland” part of the setting concerns us, we have to both learn and teach how to protect it.

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