Alternative Land Cover Scenarios for New Hampshire
NH EPSCoR Ecosystems & Society White Paper

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OBJECTIVE

Our primary objective is to produce narrative descriptions and simulate decadal maps of New Hampshire land cover from the present out to 2100 AD that represent a range of possible future conditions that reflect both stakeholder perspectives as well as existing landscape plans and visions. Each of the land cover narratives provides the basis for simulating land cover changes that are visualized in a series of maps that serve as inputs to process-based terrestrial and aquatic ecosystem models to explore how ecosystem services will change in the future under changes in land use.

RATIONALE

Land cover shapes ecological and physical processes that influence human well-being, and is itself shaped by human activities as well as ecological and physical processes. However, in landscapes managed predominantly by humans, decadal change in land cover is difficult to predict because of the difficulty in predicting human behavior over those time scales. Given this uncertainty, a scenarios approach is suitable for projecting land cover change over decadal to century time scalesand we have used a scenarios approach as the basis for modeling future land cover change in New Hampshire. Consistent with other global and regional projects (e.g., Bierwagen et al., 2010; Moss et al., 2010; Thompson et al., 2011, 2014; Sleeter et al., 2012) we employed a set of land cover scenarios to bound the plausible range of future land cover conditions. Scenarios can be a useful mechanism for addressing futures characterized by biophysical, ecological, and social uncertainties (Schwartz, 1991). In addition, they can serve important bridging functions with stakeholders.

METHODOLOGY

We combine key informant interviews (e.g., Marshall, 1996; Patton, 2001; Frey and Fontana, 1991) with review of New Hampshire focused surveys, plans and vision to inform a set of land cover change narratives for New Hampshire over the 21st century that reflect diverse stakeholder perspectives. These narratives serve as the basis for simulating a set of land cover change maps. Our approach allowed for: 1) production of a set of landscape narratives that capture the nuances and complexity of multiple stakeholder viewpoints; 2) identification of key landscape characteristics and the development of spatial data layers to represent these characteristics; and 3) presentation of alternative land cover scenarios in map and narrative forms. Maps offer an effective way for stakeholders to visualize alternative land cover futures and facilitate spatial analysis and modeling of interactions between land cover and other system attributes. Scenario narratives provide a mechanism for providing context for the simulated maps.

Key Informant Interviews

To maximize the usefulness of our land cover maps and ecosystem simulations for decision makers in the state, we included a broad collection of stakeholder perspectives from the beginning. To obtain representation from as diverse a group of perspectives as possible, we conducted key informant interviews with representatives from five key sectors in the state: environmental nonprofits, business and industry, timber interests, public sector agencies, and academics and natural resource management consultants (Table 1).

Table 1: List of organizations that were interviewed. Sectors represented include Academics and Natural Resource Management Consultants (A&C), Public Sector Agencies (Gov.), Environmental Non-Profits (Env.), Timberland Interests (Timber.), and Business and Industry (B&I). We also interviewed mixed stakeholder groups..

Organization	No.	Date	Sector
Neil & Louise Tillotson Trust Advisory Committee	10	Dec 2012	mixed
NH Energy and Climate Collaborative	12	Jan 2013	mixed
NH Water & Watershed Conference	30	March 2013	A & C
NH EPSCoR Ecosystems & Society Team	50	March 2013	A & C
NH EPSCoR Statewide Committee	12	March 2013	mixed
Commissioners, Regional Planning Commission	9	June 2013	Gov.
NH State Agencies (DES, HHS, DRED)	20	June 2013	Gov.
Granite State Futures	20	Sep 2013	Gov.
Society for the Protection of NH Forests, Board of Directors	9	June 2014	Env.
Society for the Protection of NH Forests, Staff	20	July 2014	Env
The Nature Conservancy (NH) & The Northern Forest Center	10	July 2014	Env.
Innovative Natural Resource Solutions LLC	3	Aug 2014	Timber.
NH Home Builders Association	3	Aug 2014	B & I

From each of these sectors a pool of stakeholders currently involved in land use management and/or specifically interested in how land use and land cover might change in New Hampshire was identified as potential interviewees by talking to people in leadership positions in each of these sectors. People from this list were contacted and asked about their willingness to participate in facilitated group interviews. Because the intent was to identify key informants (i.e., a group of people who were the most knowledgeable about, invested in, or involved in land use decisions, and that represented a range of viewpoints) no effort was made to create a sample that was numerically representative of each stakeholder sector or of the stakeholder community as a whole. We conducted interviews with between five and twenty representatives from each of these sectors.

Prior to the interviews, all key informants signed a UNH IRB-approved Consent Form which explained the purpose of the study, the nature of participant involvement, and the possible risks and benefits that could come from participation. During the interviews one or two NH EPSCoR researchers asked the questions and facilitated participants' responses while one or two researchers took detailed notes and/or recorded the responses. Where only one EPSCoR researcher was present and when the interviewees agreed, an audio recording of the interview was made.

The facilitator presented a brief overview of the NH EPSCoR Ecosystems and Society research initiative and this landscape alternatives project in particular; and asked participants to:

- Describe a picture of what you would like New Hampshire to look like in the future, two to four decades or more from now; and

- Describe a picture of what you expect New Hampshire to look like in the future, two to four decades or more from now.

These two statements were chosen to encourage a discussion of opposing views of the future. As a result, the key informants often described different views of the future landscape across New Hampshire that reflected their hopes verses their expectations.

Notes from the interviews were transcribed, shared, and compared for accuracy. These notes were then qualitatively analyzed, with participants' responses categorized by theme and the range of perspectives voiced within a given theme. Interviews were commonly 90 minutes long, although a few of the interviews ran a little longer.

Review of Plans, Visions, and Surveys

We also consulted existing plans, surveys, and visions relating to New Hampshire's and New England's current and future landscape produced by various stakeholder groups in New Hampshire (New Hampshire Climate Change Policy Task Force, 2009; Foster et al., 2010; Hamilton et al., 2013; Keirns et al., 2013; NH Fish and Game, 2005, 2013; Donahue et al., 2014; NH DOT, 2012; NH Office of Energy and Planning; 2014; Perschel et al., 2014) and by the Wildland Urban Interface (WUI) project (Radeloff et al., 2005) (Table 2). These reviews were conducted to confirm the themes discussed in the interviews, uncover additional perspectives that might not have been voiced during the interviews, and to provide concrete details to accompany qualitative narratives. New Hampshire county-based population projections (US EPA, 2009; NH Office of Energy and Planning, 2014) (Figure 1) also serve to inform our scenarios.

Table 2. Plans, surveys, and visions relating to New Hampshire's and New England's current and future landscapes.

Name	Author/Institution	Year
Ecosystems and Wildlife Climate Change Adaptation Plan	NH Fish and Game	2013
Granite State Future Survey	Keirns et al./UNH Survey Center	2013
Granite Staters Weigh in . . .	L. Hamilton and C. Wake/UNH	2013
New England Food Vision	B. Donahue et al./Food Solutions New England	2014
New England Forests: The Path to Sustainability	R. Perschel et al./New England Forestry Foundation	2014
NH Climate Action Plan	NH Climate Change Policy Task Force	2009
NH 10-Year Energy Strategy	NH Office of Energy and Planning	2014
NH State Rail Plan	NH Department of Transportation	2012
Wildlands and Woodlands	D. Foster et al./Harvard Forest	2010
Wildland Urban Interface	Radeloff et al./University of Wisconsin	2005

Putting it All Together: Developing Alternative Land Cover Narratives

Two main scenarios of the future emerged from the key informant interviews and from review of existing plans, visions, and surveys: one that is characterized by dispersed development, with a focus on traditional one- and two-acre lot residential zoning where most residents continue to live in houses adjoining private lawns, gardens, or small wooded lots *(Backyard Amenities)*; and a second vision that is characterized by concentrated development, with a focus on protection of public woods, open spaces, and waterways for local recreation *(Community Amenities)*. A third scenario represents a variation on the Community Amenities scenario combined with significant expansion of agricultural lands *(Agricultural Expansion)*. We also include a continuation of current trends in land cover change *(Current Trends)*. One way that the Current Trends scenario differs from the Backyard Amenities scenario in that population growth is more limited, so less land conversion occurs overall. Like recently published land cover scenarios for Massachusetts (Thompson et al. 2011, 2014), our scenarios capture a broad range of alternatives for land cover composition. The Backyard Amenities and Community Amenities scenarios represent different ends of a spectrum comprising the differences between 1) traditional zoning _and smart growth focused on compact urban planning and redevelopment (i.e., dispersed versus concentrated development) and 2) the degree to which ecosystem services are prioritized during development and land management. Thus, our land cover scenarios lie on a continuum from dispersed development that does not prioritize ecosystem services to concentrated development that does prioritize ecosystem services (Figure 2).

RESULTS: LAND COVER NARRATIVES

Broad narratives for each of the land cover scenarios we have developed (Backyard Amenities, Community Amenities, Agricultural Expansion, Current Trends) are provided below. For each, we describe changes in land cover with a focus on developed, forested, and agricultural lands. The narratives include descriptions of the spatial distribution of developed lands and associated spatial population distribution (e.g. concentrated versus dispersed), the degree to which ecosystem services are prioritized for each of land cover type, and regional variation across the state (i.e., focusing on differences between the northern, central, southeastern and southwestern regions of the state). Also included (where appropriate) are brief descriptions of other considerations, including population, economic development, policies and behavior, transportation, water and sewer development, changes in conserved lands and wetlands, and biomass and hydro energy development.

1. Backyard Amenities/Dispersed (Figure 3)

Developed Lands (Backyard Amenities)

In this scenario, development is driven by a combination of population increase, relatively weak regulatory environment, and robust economic growth. Development follows the path of least resistance. A robust house-building sector provides good jobs and fuels additional economic growth, which in turn leads to an increased demand for housing, promoting additional sprawl. Increased population is accommodated primarily in single-family homes on large lots (defined by current zoning in each municipality, commonly 1-2 acre lots; Table 3) built outside of urban cores where land costs are lower and municipal services are lacking. To accommodate development, new roads are built, opening additional fringe land for future development. Houses are built first on undeveloped land in Rockingham and Hillsborough counties (as this area provides easy access to the Boston-metro region (via NH Routes 16 and 101, and Interstates 95, and 93). Based on patterns of zoning change observed in more heavily developed municipalities in the southeast portion of the state, residential zoning changes when 50% of a municipality is filled with development, such that one acre of land must be conserved for every acre that is developed (Mitchell et al., in prep.). When 62% of a municipality is developed, residential zoning changes again such that three acres of land must be conserved for every acre that is developed . The result is that roughly 25% of developable lands in high-growth municipalities will ultimately be conserved.

Once south-east and south-central municipalities fill in with houses, housing development spills over into south-west and central regions of the state as pressure to expand transportation networks increases and more-affordable land becomes available and accessible. This expansion occurs northwest along the I-89 corridor from Concord and southeast from the Lebanon-Hanover region, as well as along the I-93 corridor north of Concord. Overall, 986,000 additional acres are developed between 2010 and 2100, an increase by a factor of 4.1 times the developed area in 2010. High amenity areas in the Lakes and southern White Mountains regions will see continued development of expensive second homes in the most desirable areas and a growth of spatially dispersed, low wage service provider homes in less desirable areas.

The total developed area of 1.3 million acres represents 22% of the area of the state. In urban centers, the availability of affordable upgraded housing will draw families into the new developments as they seek larger houses for new families. This will result in a reduction of in-fill development and mixed-uses in the urban cores and town centers that leads to decreased vitality in those areas from a lack of residents. Mono-cultural developments will emerge serving specific populations, increasing the likelihood of similar developments nearby, thereby facilitating even more sorting based on socio-economic factors and components.

Forests (Backyard Amenities)

Under the Backyard Amenities scenario, the primary driver of forest loss is development, with 351,000 hectares (763,000 acres) of forest land converted to development by the year 2100. An additional net 67,400 hectares (167,000 acres) are lost to agriculture (based on extrapolation of current trends; see below). Forestry and silviculture practices are similar to current patterns, but with less emphasis on ecosystem services, including the increased prevalence of pre-development liquidation harvests, primarily in the southern half of the state. In southern and central New Hampshire, undeveloped land is increasingly held by small land-holders that are focused on development (including second homes in lake country) and recreation. Forest management in those parts of the state is increasingly motivated by aesthetics and/or short-term profits rather than long-term forest management for either wood production or ecosystem services. This results in some wooded areas left unmanaged while in others the highest value timber is repeatedly removed (i.e., high-grading), resulting in increasing dominance of young, unhealthy trees of less commercially desirable species. Thus the forest becomes a patchwork of limited mature and relatively healthy forest, while other areas are low quality stands of wood with limited carbon sequestration or long term timber potential. In the north country, forest management continues to be driven by large private land-holders, often Wall Street investment companies (e.g., Timber Investment Management Organizations [TIMOs] and Real Estate Investment Trusts [REITs]). Management practices are selected based on short term profits (selling wood from the land, or reselling the land), and in contrast to current practices, impacts on local waterways and carbon sequestration are de-emphasized. Sustainable forestry practices are confined to the White Mountain National Forest, the Dartmouth Second College Grant (to be confirmed), and smaller areas of public and private land with a standing commitment to sustainable logging.

Agriculture (Backyard Amenities)

In the Backyard Amenities scenario, agriculture remains a relatively minor component of the New Hampshire landscape, although current trends of modest agricultural expansion continue at the same time that some farmland is lost to development. The net result is an increase of farmland by 18,400 hectares (45,500 acres) of new farmland by 2070, bringing the total agricultural land area to 146,100 hectares (361,000 acres). After 2070, farmland loss to development overtakes allocation of new land to agriculture, resulting in a modest decrease of 6,900 hectares (17,000 acres) by 2100, giving a final agricultural land area of 138,200 hectares (341,500 acres). Agricultural land continues to be dominated by pasture and hay fields. What agricultural land is present becomes an increasing source of pollutants (nitrate, phosphate) due to a weakened regulatory framework resulting in excessive fertilization, poor manure management, and removal of forest and wetland buffers along waterways.

Other Considerations (Backyard Amenities)

Population: We base projected population growth on the Integrated Climate and Land Use Scenarios (ICLUS) A2 population scenario (US EPA, 2009, Bierwagen et al. 2010). NH population grows from the current 1.3 million (2014) to 1.8 million by 2050 and 2.8 million by 2100. The vast majority of population growth occurs in Rockingham, Hillsborough, and Merrimack counties (Figure 4). We slightly modified the ICLUS A2 population scenario by adjusting allocation among counties to allow suburban sprawl in high density counties (i.e., Rockingham and Hillsborough) to spill over into municipalities in neighboring counties (i.e., Cheshire, Merrimack, Strafford) and northward along I-89, I-93, and NH Route 16. This reflects previous findings suggesting that the areas of most rapid growth tend to be progressively further from urban centers as buildout occurs (e.g., Jeon et al., 2014). In addition, all of the growth in Grafton county occurs around Hanover/Lebanon and Plymouth.

Economic Development: Economic growth is accelerated, but much of the added value of new businesses and jobs is siphoned away by the costs of the development pattern that continually demands new buildings and the expansion of infrastructure needed to reach and service them. Municipalities struggle to keep up with the spatial growth and therefore have few resources for strategic investments, such as educational improvements. While there are new jobs and new and growing businesses under this scenario, growth is focused in the service industry, as the workforce is ill-prepared to attract high technology and specialized manufacturing industries. Regionally, growth is concentrated in the southern half of the state.

Policies and Behavior: A variety of factors - including calls for more jobs and expanded economic development - shift public opinion toward supporting expansive land development with the jobs that create a short-term boost for the economy. Attitudes in support of a market-driven economy combine with lobbying from development interests to dominate the policymaking process at both state and local levels. Belief in local control over decision-making dominates the legislature. Fewer federal and state public funds are available for land protection or are directed toward initiatives and efforts in support of development of land for residential and commercial use. State agencies are left with a smaller number of less comprehensive statutes and regulations to implement or enforce. Conservation easements and other land protection agreements are challenged in court and are increasingly at risk (although no previously conserved land is developed in this or any of our scenarios). Landowners receive tax breaks and other financial incentives to make existing forested and agricultural land available for industrial parks and residential subdivisions.

Transportation: The automobile remains the primary form of transportation across the state and most goods move via trucks. The significant increase in population require more automobiles and more goods, leading to an increase in cars and trucks on the road, and much more time spent in traffic, especially in the more heavily populated southern and central regions of the state. There is also an increase in the number of roads and the width of major highways (Nh Routes 16 and 101; Interstates 89, 93, and 95); some intermediate road become four lane highways (e.g., NH Routes 13, 28, 9/202, 125, 11, 4), but road building does not keep pace with the increase in vehicle miles traveled and so does not alleviate the traffic problem.

Overall, there is an increase in impervious surfaces, Public transportation is focused on short trips in specific regions (e.g., Durham, Lebanon/Hanover, Manchester).

Water and Sewer Development: The expansive and dispersed development pattern makes investments in public water and sewer infrastructure impractical and unaffordable. Wells and septic systems associated with individual buildings expand across the state with little to no regulatory agency capacity to monitor and enforce water quality standards. Runoff from increased impervious surfaces flows directly into the state's water bodies.

Changes in Conserved Land and Wetlands: The strong pressure to develop combined with local resistance to private conservation by land trusts results in a significant reduction in the rate at which land is conserved. Legal protections for wetlands are rolled back, as are riparian buffer requirements near water bodies. In areas with high development pressure, marginal wetlands are drained, and construction occurs along the shores of waterways in floodplains and zones previously designated as riparian buffers.

However, within municipalities, as forest and open space are filled, local pressure to set aside conserved areas results in cluster zoning (Mitchell et al., in prep.). Conserved areas are generally managed for recreation and aesthetic values. Well-groomed trails are prioritized above habitat, carbon sequestration, and other ecosystem services. Logging on conserved land is permitted to improve viewsheds but generally not to improve habitat quality. Pests, pathogens, and invasive species are only managed where there is local pressure to do so, generally based on aesthetics, and pest management strategies may include liberal application of pesticides regardless of science-based recommendations.

Biomass and Hydroelectric Energy: Rapid conversion of forest land for residential, commercial, and industrial development leads to liquidation harvests in developed regions (primarily the southern half of the state); part of this harvest supports expansion of biomass for thermal energy and large scale (albeit low-efficiency) electricity production. Small scale hydro-electric stations remain difficult to permit as there is no focused state-wide energy plan.

2. Current Trends (CT)

The Current Trends scenario (Figure 5) is based upon linear extrapolation of trends in land cover change and conservation from 1996 - 2011 based on analysis of land cover data from NOAA C-CAP (for change in developed, forested, and agricultural lands) and NH GRANIT data on New Hampshire conservation and public lands.

<u>Developed Lands (Current Trends)</u>

Residential/commercial/industrial development from 2011 to 2100 follows a linear extrapolation of current trends (1996 - 2011) in development rates. The ratio of concentrated versus dispersed development remains similar to values of the period 1996-2011.

<u>Forests (Current Trends)</u>

Current trends in forest conversion to development and agriculture, as well as reversion of agricultural land to forest, continue as a linear extrapolation of current trends (1996-2011). By 2100, 93,000 hectares (230,000 acres) of forest land are lost to development, and another 49,000 hectares (121,000 acres) are lost to agriculture. Forest management practices remain similar to 2010 practices. Forestry remains highly mechanized, with little use of sustainable forestry practices outside of the White Mountain National Forest and other conserved areas with a sustainable timber mission. Silviculture continues to primarily occur in the North Country, particularly Coos and Grafton (FIA REF), although timber harvests occur throughout the state where land is being cleared in preparation for subdivision development. Wood harvests generally occur on a short harvest cycle (i.e., ?? - ?? years), and generally use uneven-age management, with selective cuts preferentially harvesting stands with high quality sawlogs. Lower quality wood within those stands is generally removed as well, for use as either pulp or fuel biomass. Stand regeneration is generally allowed to occur passively, without replanting or use of herbicide. Sustainable forestry practices do not dominate, but are nevertheless significant within the state. Currently, 863,000 of the state's 4,638,230 timberland acres certified through either the American Tree Farm System or the Forest Stewardship Council, and this proportion will remain similar in the future. Due to a combination of cultural norms, internal standards, and external certification, nearly all forest harvest adheres to Best Management Practices (BMP) for minimizing erosion and water quality degradation (North East State Foresters Association, 2013). The degree to which ecosystem services are prioritized for each of the forested lands remains similar to values of the period 1996-2011.

Agriculture (Current Trends)

Continuing 1996-2011 trends in forest conversion to agriculture and agriculture conversion to forest, there is a net increase in agricultural area in New Hampshire of 51,000 hectares (126,000 acres) by 2100, representing an overall increase from 128,000 hectares (316,000 acres) in 2010 to 179,000 hectares (442,000 acres) in 2100. Agricultural land continues to be dominated by pasture and hay fields. Agricultural practices, including the degree to which ecosystem services are prioritized, remains similar to current practices.

Other Considerations:

Population: The population of New Hampshire grows as a linear extrapolation of 1990-2010 rates based on U.S. Census data. The population increases by 103,608 people per decade, resulting in a state population of 2.2 million by 2100, up from the 2010 population of 1.3 million.

Economic Development: A continuation of Current Trends is essentially a slower paced Backyard Amenities scenario. Higher quality jobs continue to be concentrated in the southeast and south-central parts of the state, as well as some in the Hanover/Lebanon area, while remaining rare in the western, central, and northern parts of the state.

Policies and Behavior: Activities of the state legislature and private organizations continue to promote amenities, agriculture, and conservation, but the effectiveness of these policies and activities are constrained by the culture of individualism and local control. In recent years, land use policies enacted by the state government have reflected widespread public support for statewide protection of water and land resources based on shared beliefs in the value of ecosystem services such as recreation, agriculture, and tourism and concerns about unplanned and unregulated residential development. For example, the legislature passed comprehensive regulation of the state's water bodies through the Shoreland Water Quality Protection Act of 1991. In 2000 RSA 9-B was enacted, requiring state agencies to consider "smart growth" principles in their activities and the interagency Council on Resources and Development was created to ensure its implementation. The recent revival of agriculture in the state has led policymakers at both state and local levels to enact statutes broadening the definition of "agriculture" and discouraging unnecessary barriers to zoning and planning regulations. Nevertheless, New Hampshire is the only state in New England without a comprehensive environmental policy or regulatory program. As a consequence, state policies address issues incompletely or inconsistently. Strong cultural beliefs in the value of local control over decisions concerning property have resulted in state policymakers ceding many aspects of land use policy to local municipalities, albeit often providing model ordinances and other technical assistance to encourage policy development. The result is a patchwork of varied and inconsistent local land use plans, policies, ordinances, and programs tailored to the particular needs, circumstances, and politics of municipalities. Although there are examples of efforts toward more centralized coordination, collaboration, and integration of planning and policies (as exemplified by the recent Granite State Future initiative), management and use of land will continue to be decided by unique combinations of state, regional, and local policies that vary from one town to the next.

Transportation: Public funding for roads continues to lag behind actual needs. As a result, few new public roads are built. Instead, limited funds are spent on maintaining existing highway and road infrastructure, and widening roads where congestion is cause for concern (such as recent widening of I-93 south of Manchester and Rte 16 bridge over Little Bay in Newington/Dover). There is a modest increase of within-community public transit (e.g., UNH, Dartmouth, Manchester/Nashua). Otherwise, the automobile remains the primary form of transportation for most residents.

Water and Sewer Development: Modest increase in public water and sewer infrastructure takes place in large urban centers and new developments that are adjacent to existing services. Stormwater runoff continues to be a problem in some areas, but there is also modest expansion of low impact development technologies. Most residents of the state continue to get their water from wells and to use septic systems rather than sewers.

Changes in Conserved Land and Wetlands: The average rate of land conservation from 1996 - 2011 was over 8100 hectares (20,000 acres; 32 square miles) per year, and the Current Trends scenario assumes this rate continues into the decades ahead. However, we capped the expansion of conserved land in 2060 at 1.1 million hectares (2.8 million acres; 4334 square miles) equivalent to 46% of New Hampshire's total land area of 9,350 square miles.

Biomass and Hydroelectric Energy: There is a modest expansion of biomass for thermal energy in homes, and little to no increase in hydro power. Some dams - especially those down-river and close to the ocean, are removed.

3A. Community Amenities/Concentrated (Figure 6)

Developed Lands (Community Amenities)

No additional land is developed beyond what is already developed. Instead, urban cores and village centers are redeveloped to accommodate expanding populations. Instead of converting forests to new housing tracks and malls, development and redevelopment occurs within existing city and town centers. This scenario is aligned with several recommendations in NH's 2009 Climate Action Plan that clearly called for protecting existing natural resources - water, forests, and agricultural lands. Most redevelopment uses the principles of low impact design (LID; Roseen et al., 2011), which protects or enhances ecosystem services (e.g., through the use of permeable pavement and green roofs to minimize runoff and landscaping that minimizes disturbance to natural vegetation or promotes wildlife habitat). Population densities in NH's cities and villages increase, but so do the economic, social, and cultural vitality of town centers. More people would be able to walk to buy a gallon of milk and a cup of coffee and visit with friends and neighbors. This scenario reflects a recent demographic trend across America away from suburban sprawl and towards revitalized multi use pedestrian-friendly urban landscapes (e.g., Ehrenhalt, 2014)

Redevelopment may take various forms. One way to increase density is to transition to smaller lot sizes for houses, or allow more than one house to be built on existing one- and two-acre lots. Alternatively, increasing density via an increase in apartments, condos, or co-housing would likely result in lower property taxes. Increasing density attracts aging seniors and young professionals to urban cores and village centers, resulting in an increasing cultural shift toward "New Urbanism" (REF). Depending on shifting markets, rural housing may either become more or less expensive, as the cultural shift toward urbanism is balanced against the lack of supply of new housing in remote locations.

Forests (Community Amenities)

Total forest area decreases only slightly by 2100. The only source of change to forest area is a small amount of land lost to agricultural expansion in a continuation of 1996-2011 trends. By 2100, just 49,000 hectares (121,000 acres) of forest land has been converted to agriculture. Forestry across the state shifts toward more deliberate management for a combination of goals, similar to the goals that currently shape forest management in the White Mountain National Forest (USDA, 2005; Jones et al., ??); maximizing wood production, increased carbon storage, habitat connectivity, and habitat diversity, while continuing to work to avoid erosion and damage to waterways. These goals are not always aligned (for example, the goal of carbon sequestration is likely to favor longer harvest cycles than are recommended by current sustainable forestry practices, while the goal of habitat diversity dictates that some areas be fully cleared to maintain open space). To pursue all these goals simultaneously, a diversity of management regimes are maintained across the state based on different priorities.

Agriculture (Community Amenities)

Agricultural land area remains similar to 2011 areas, with modest expansion via the extension of trends from 1996-2011. By 2100, just 49,000 hectares (121,000 acres) will have been converted to agriculture. All agricultural land is managed with emphasis on ecosystem services.

Other Considerations (Community Amenities):

Population: We include two different population scenarios (Figure 1):
(1) high projected population growth based on the ICLUS A2 population scenario (US EPA, 2009, Bierwagen et al. 2010). NH population grows from current 1.3 million (2014) to 1.8 million by 2050 and 2.8 million by 2100. Under the high population growth scenario, the vast majority of population growth occurs in Rockingham, Hillsborough and adjacent counties. The ICLUS A2 population scenario is slightly modified by adjusting allocation among counties to allow suburban sprawl in high density counties to spill over into municipalities in neighboring counties (i.e., Cheshire, Merrimack, Belknap, Strafford) and northward along I-89, I-93 and NH Route 16 (e.g., Jeon et al., 2014). All of the growth in Grafton county occurs around Hanover/Lebanon and Plymouth areas.
(2) Extended NH Office of Energy and Planning (OEP) population projections for New Hampshire counties from 2010-2040 (NH OEP, 2014) were extrapolated out to 2100 (Bob Scardamalia, RLS Demographics, pers. comm.)

Economic Development: Under the Community Amenities scenario, economic growth takes place within urban cores and village centers, primarily in areas already served by existing infrastructure, thereby leaving municipalities with financial resources to improve the existing infrastructure and make strategic investments in education and workforce development. These investments raise the skill levels of the workforce, which in turn attracts new high technology and specialized manufacturing industries offering high paying jobs (Gittell and Orcutt, 2012). Growth within existing population centers is relatively uniform statewide. Depending on how the market evolves, however, there may also be accelerated economic inequality under this scenario: the inability to build new first and second homes in high amenity areas means that existing homes in these areas become ever more expensive and out of the reach of all but the extremely wealthy. If cultural shifts cause urban amenities come to be more highly valued than rural amenities, however, this inequity could be mitigated.

Policies and Behavior: In response to the effects of climate change, public attitudes shift toward valuing the collective needs of the state over the particular desires and needs of local communities. Extensive education and public engagement campaigns increase the general understanding of the value of ecosystem services. Elected officials enact laws that support statewide land protection and smart growth development, and rescind statutes encouraging sprawl and uncontrolled development. State agencies are funded to plan, implement, and enforce the new regulations. A public norm emerges that mobilizes local communities' support for the new policies. For example, communities become willing to develop and implement master plans with zoning and regulations consistent with state government land use policies while allowing for variation in local conditions.

Policies at both state and local levels support conservation and management of land and forests for their multiple uses and ecosystem services. More public land conservation is funded, particularly to create wildlife corridors and habitat. Tools such as tax incentives and matching funds programs support private landowners' efforts to conserve land for forests and agriculture under stewardship or other management plans. Similar policies and programs support growth of markets that support the development of renewable resource products, including those obtained from conserved lands. Local conservation of water resources is incentivized through tax breaks and other financial tools to ensure protection of watersheds. Universal buffer regulations protect all wetlands and surface waters across the state. Complete Streets policies that ensure safety, connectivity, and access regardless of age, ability, or mode of transportation are implemented in a coordinated and comprehensive way throughout the state. Governmental agencies are required to site buildings within population centers rather than at their edges. Performance zoning, which focuses not on a parcel's use but its performance and how it relates, interacts with, and impacts surrounding areas, replaces district zoning, encouraging smart, clustered development.

Taking advantage of financial incentives such as Payment for Ecosystem Service programs, business and industry moves from suburbs and sensitive areas to renovated spaces in city and town centers. The high numbers of single adult and multigenerational households preferring to live in urban communities combined with support for smart growth leads to policies encouraging construction of higher residential dwelling densities, and clustered, mixed-use, or re-use types of development with a broad range of housing choices. In particular, increasing numbers of ethnic and racial minorities and older people in the state push for and obtain requirements that developments include a high percentage of affordable housing. Resulting residential subdivisions and high-rise buildings are regulated to promote green site design and infrastructure, alternative storm water management, and livable, walkable communities.

Transportation: Substantial public funds are allocated to building and maintaining a fully integrated statewide transportation system connecting urban and rural communities that includes a variety public and non-motorized transportation options. For example, commuter rail connects: 1) the cities and towns of the Merrimack River valley with Boston (e.g., NH Capital Corridor); and 2) White River Jct. with Montreal and the NH Capital Corridor (NH DOT, 2012). As a result, there is a significant increase in public transit both within and between population centers. More freight also travels between urban centers on rail. Due to increased investment in public transit, and pedestrian and bicycle infrastructure, walking and riding miles increase while VMT decrease, resulting in less congestion even in growing urban centers. The number of roads therefore does not need to be increased; however the maintenance of existing transportation infrastructure becomes a priority.

Water and Sewer Development: Concentrated redevelopment creates opportunities and incentives to increase public water and sewer infrastructure. The opportunities come from the cost savings generated from fewer miles of pipes and the incentives come from having an increased number of paying users. Sewage managed by centralized facilities is converted to fertilizer for export or use within the state. Sustainable management of surface water runoff through low impact development techniques is the norm across the state.

Changes in Conserved Land and Wetlands: There is an expansion conserved areas and additional protection for all wetlands.

Biomass and Hydroelectric Energy: Use of biomass fuels in the state increases, primarily for heating, as well as co-generation facilities. Only sustainable harvest of biomass occurs. Hydroelectric energy increases in the form of run-of-river generators, even as dams removed to enhance habitat for fish and to improve flood management. The site evaluation committee sets aside large tracks of land (including conserved land) for renewable energy projects (wind, solar, geothermal, and wave).

3B. Community Amenities with Agricultural Expansion (Figure 7)

Same scenario as Community Amenities but with significant expansion of agricultural lands, mostly at the expense of forested lands.

<u>Agriculture (Agricultural Expansion)</u>

Agricultural land area increases linearly such that by 2060, there are 360,000 hectares (890,000 acres) of farmland in the state. This is the target for New Hampshire identified by the Food Solutions New England (FSNE) Omnivore's Delight vision (Donahue et al., 2014). This returns New Hampshire to the agricultural production of the late 1800s/early 1900s (CHECK THIS). New agricultural land area is exclusively developed on land identified either as “Prime Farmland”, as “Prime Farmland of Statewide Importance”, or as “Prime Farmland of Local Importance” in the Soil Survey Geographic (SSURGO) soils map for New Hampshire (GRANIT). By 2060, all Prime Farmland and Prime Farmland of Statewide Importance that is not already developed is used for agriculture. The remainder of the new farmland is Prime Farmland of Local Importance. The geographic distribution of these areas means that nearly all agricultural expansion occurs in the upper Merrimack River Valley, and along the Connecticut River.

All agricultural land is managed to maximize ecosystem services and minimize environmental impact. Specific agricultural land uses will be selected for each piece of land based on its biogeophysical context. Management goals include minimized fertilizer application, minimized runoff, promotion of carbon sequestration, and promotion of desirable wildlife, combined with promotion of high yields without soil degradation. Integrated Pest Management (IPM) and agroecological methods will be emphasized.

SIMULATION OF LAND COVER NARRATIVES

Overall Approach

In all scenarios, the spatial distribution of land change and land conservation was partially or entirely determined by regression tree analysis of historical land cover change based on enhanced land cover data generated from NOAA C-CAP 1996 and 2011 by Rubin and Justice (2014), and conservation land change between 1996 and 2011 estimated from the NH GRANIT Conserved. We assessed the probabilities of development of undeveloped land, forest conversion to agriculture or grass, agriculture or grass conversion to forest, and conservation as a function of a number of biophysical and social drivers. Drivers were selected based on their perceived value and availability of full-state coverage, while excluding drivers that would be likely to change over the simulated time interval without being explicitly included in our model. Drivers selected were: current land cover, elevacretion, slope, soil drainage classification, agricultural soils classification, distance from major roads (major roads identified by highest priority for plowing in NH Public Roads layer in GRANIT), distance from developed land, distance from conserved land, distance from surface water, and distances from populated places, and from the population centers of municipalities of different size classes (Table 4). Populated places were determined from the USGS Populated Places (PPL) from the Geographic Names Information System (GNIS). The same layer was used to identify the population centers of municipalities from the New Hampshire Political Boundaries layer from GRANIT. For most municipalities, the population center was defined as the PPL in New Hampshire with the same name. Where no such PPL existed, a PPL within the municipal polygon was selected, with preference for the most built-up PPL, or the polygon center-of-mass was used. Municipal population centers were then divided into size classes based on visual identification of natural breaks in a histogram of municipal census populations for 1990, 2000, and 2010 (Figure 8). Breaks were selected to remain fairly consistent across the three decades.

Population densities and population growth rates were deliberately excluded as possible driving variables because it is difficult to disentangle the degree to which population drives development from the degree to which development drives population growth. Our scenario approach also emphasizes the idea that high rates of growth are possible without increases in developed land area, so (with the exception of our Backyard Amenities scenario), rather than using population models as a driver of development, we combined population models with our simulation outputs to give population densities for each of our scenarios.

Regression trees produced zones of different probabilities of change, spread over the landscape based on the driving variables. For the Current Trends scenario, for each land change category, we calculated area of change within zone between 1996 to 2011, and assumed that land change was allocated among zones based on the percent of total land change that had occurred in each zone in 1996 to 2011, a protocol used in the Current Trends scenario for Massachusetts (Thompson et al. 2011). For the Community Amenities scenarios, conservation was spatially distributed based on the same regression tree as for Current Trends, but was constrained to specific areas targeted by conservation plans (NH Fish and Game, 2005; The Nature Conservancy, NH Chapter, 2013; Society for the Protection of New Hampshire Forests, 2014). Similarly, in the Community Amenities with Agricultural Expansion scenario, forest to agricultural conversion was determined by the regression tree but constrained by soils identified as prime agricultural land of national and statewide importance and farmland of local importance as defined by the SSURGO Database for New Hampshire (NH GRANIT, 2014) Allocation between these categories was prioritized such that all prime farmland and farmland of statewide importance was used for agriculture by 2060 and the rest of the New England Food Vision land area was composed of farmland of local importance.

Backyard Amenities

In the Backyard Amenities scenario, development rates are assumed to be driven by population growth, based on the EPA ICLUS scenario A2 for county-level population growth. Population within counties is distributed among municipalities based on current municipal population. Within municipalities, population is distributed over the landscape with 2.5 people per housing unit, and one housing unit per residential lot. Residential lot size for each municipality is initially set to the mean lot size based on 2014 zoning (Appendix A) but is allowed to change dynamically in response to development pressure, based on analysis by Mitchell et al. (in prep.). Specifically, when a municipality is 50% built out, it is assumed that municipalities adopt mandatory cluster development zoning. Lot sizes are halved, and for every acre that is developed, an acre of land is set aside for conservation. When a municipality is 62.5% developed, more extreme cluster zoning is adopted, with lot sizes halved again and 3 acres set aside for conservation for every acre that is developed. As municipalities become filled with land that is either developed or conserved, the excess population is randomly distributed over nearby municipalities, based on a gravity model. The gravity model is based on a simple transportation cost-distance map (generated using the R function costdistance()), in which the cost of travel along the major roads is assumed to be half the cost of travel elsewhere on the map. Minor roads are not included because new roads can be constructed to accommodapgte new development. Under the gravity model, the probability of spill-over population from a filled municipality going to each other municipality on the map scales with the inverse of the square of the cost-distance between the two. The excess population is then allocated by drawing from the resulting probability distribution across municipalities that are not yet filled.

For the Backyard Amenities scenario, development and conservation within municipalities was allocated according to regression trees generated for the entire state of New Hampshire, excluding the possible variables that primarily influenced larger scale geographical allocation that excluded variables (elevation, and distances from major roads, populated places, municipalities of different sizes, and surface water were excluded). No land is conserved except for the land set aside under cluster zoning. Other land conversion (forest to agriculture and agriculture to forest) in the Backyard Amenities scenario was allocated at the statewide level using the same regression trees as the Current Trends scenario.

Current Trends

Rates of land cover change (from forest to grassland or agriculture, from grassland or agriculture to forest, and from undeveloped to developed land) for the state as a whole remain fixed at their mean values between the years 1996 and 2011, based on the NOAA C-CAP Landsat-based 30-m resolution land cover change product for 1996 and 2011 (NEED UPDATED LINK) enhanced by Rubin and Justice (2014). C-CAP land cover categories were aggregated as follows: developed (high intensity, medium intensity, low intensity, and developed open space); forest (deciduous forest, evergreen forest, mixed forest, and shrub/scrub); agriculture and grass (cultivated crops, pasture/hay, and grassland/herbaceous); wetlands (palustrine forested wetland, palustrine scrub/shrub wetland, estuarine forested wetland, estuarine scrub/shrub wetland, unconsolidated shore, palustrine emergent wetland, and estuarine emergent wetland); surface water (open water, palustrine aquatic bed, estuarine aquatic bed); bare land (barren land). The time interval 1996 to 2011 included periods of low as well as high economic growth, so linear extrapolation of development over this period was deemed reasonable. For land conservation, however, the 1996 to 2011 time interval was characterized by particularly high rates of land conservation. To reflect the fact that current trends in land conservation are likely to be unusually high and not to be continued indefinitely, for the current trends scenario, we assume that rates of land conservation remain constant at 1996 to 2011 rates only until the year 2060, after which no additional land is conserved. In addition, we excluded the large Connecticut Lakes Headwaters property (conserved in 2001) from our analyses, including our calculation of conservation rates 1996 to 2011.

To model the geographical distribution of land change within the state, regression trees for geographic predictors of development and conservation were developed for each of four regions within the state: North (Coos and Carroll counties), Central (Grafton, Belknap, Merrimack, and Strafford counties), Southwest (Sullivan and Cheshire counties), and Southeast (Hillsborough and Rockingham counties), based on a randomly positioned uniform grid of sample points. For most of these regression trees sample points used for analysis were spaced as a 1 km grid, but for the development regression trees in the North and Southwest, a 500 m grid was used instead in order to accommodate low rates of development. Using the resulting regression trees, each region was subdivided into zones classified as having significantly different probabilities of development or conservation. The fraction of total development or total conservation occurring in each region was calculated, and land to be developed or conserved in each 10-year time step for the state as a whole was first allocated among regions, based on the fraction occurring in each region for 1996-2011, and then allocated among the zones within each region based on the fractions from the regression tree. As zones ran out of land area available for conservation or development, the amount of land area allocated to that zone is decreased to what is available. Within zones, newly developed or conserved land in each time step was randomly distributed within these zones as 30 m x 30 m pixels. In cases where regression trees included distance from development or distance from conserved land as a significant driving variable, zones were re-calculated each time step.

The distribution of forest land to be converted to agriculture or gtass and grass or agriculture to be converted to forest were also determined based on regression trees, but since these land conversion categories were small, the regression trees used were for the state as a whole. As with most regression trees for development and conservation, a randomly placed uniform 1km grid was used for sampling. Otherwise, the approach as the same as for conservation and development.

Community Amenities

In our two Community Amenities scenarios, all land development occurs as redevelopment, so the amount of developed land does not change. In the Community Amenities scenario without agricultural expansion, rates of conversion between forest and grassland or agriculture are the same as in the Current Trends scenario. In the Community Amenities with Agricultural Expansion scenario, forest is converted to agriculture and grassland at a constant rate such that by the year 2060 there are 500,000 acres of farmland and pasture in the state of New Hampshire, as described in the Food Solutions New England "Omnivore's Delight" scenario (Donahue et al. 2014). Agriculture and grassland are assumed not to turn back into forest. Conversion of forest into agriculture is constrained to areas identified as prime farmland, prime farmland of state-wide importance, or prime farmland of local importance. For both Community Amenities scenarios, conservation occurs at a constant rate such that by the year 2060, all high priority conservation lands identified by the New Hampshire Wildlife Action Plan, The Nature Conservancy New Hampshire portfolio plans, and The Society for Protection of New Hampshire Forests priority lands for conservation have been conserved.

Results - Decadal Land Cover Maps

Figures to be added once they are finalized

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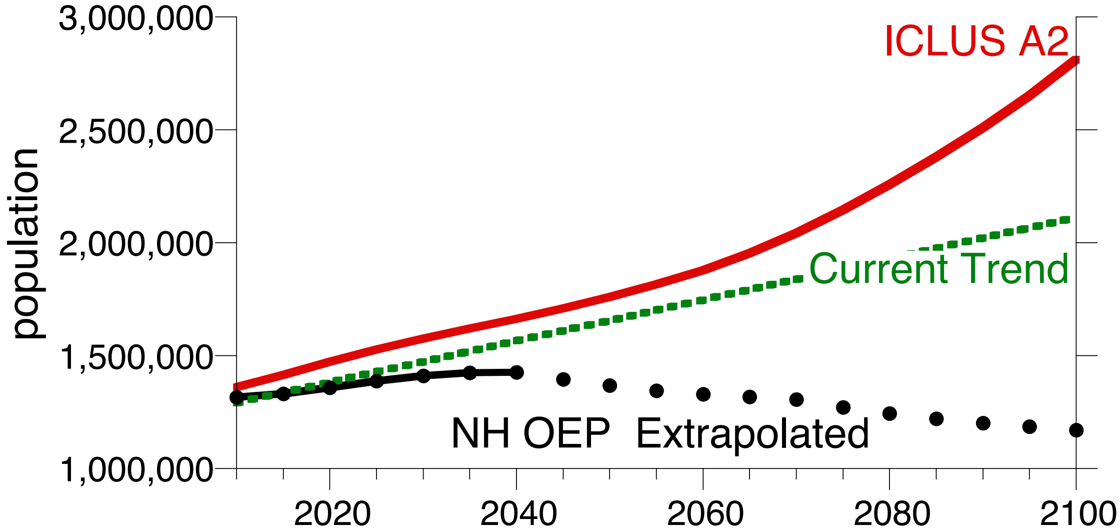

Figure 1. Population projections used in the this study include a high growth scenario from ICLUS (Integrated Climate and Land Use Scenarios [US EPA 2009] and from NH OEP (Office of Energy and Planning [NH OEP, 2014]). Also included was a "current trend" which represents a linear extrapolation of the trend in population growth in NH from 1990-2010.

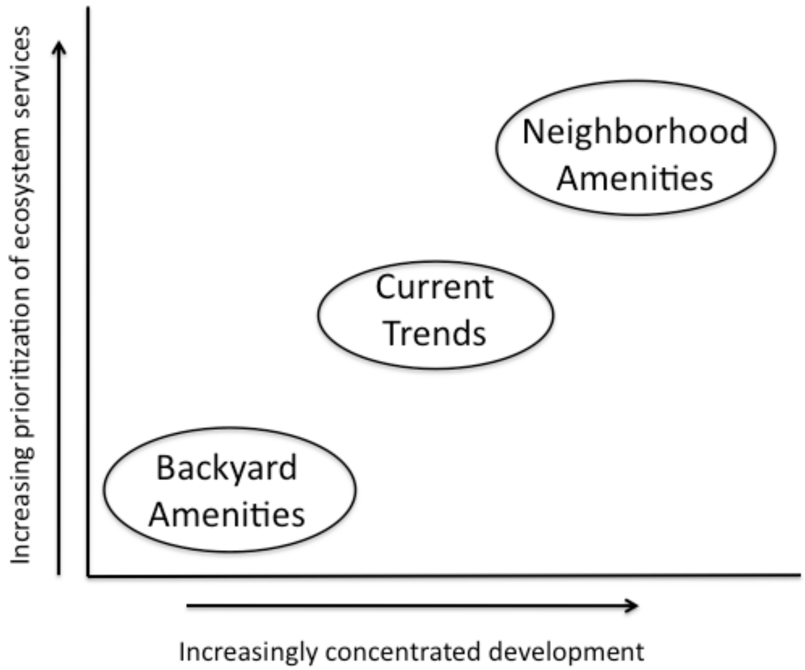

Figure 2. Conceptual framework used for development of land cover scenarios across New Hampshire. Note the land cover scenarios differ primarily by the degree to which development is concentrated (x-axis) and the degree to which ecosystem services are prioritized (y-axis) during development and in land management decisions.

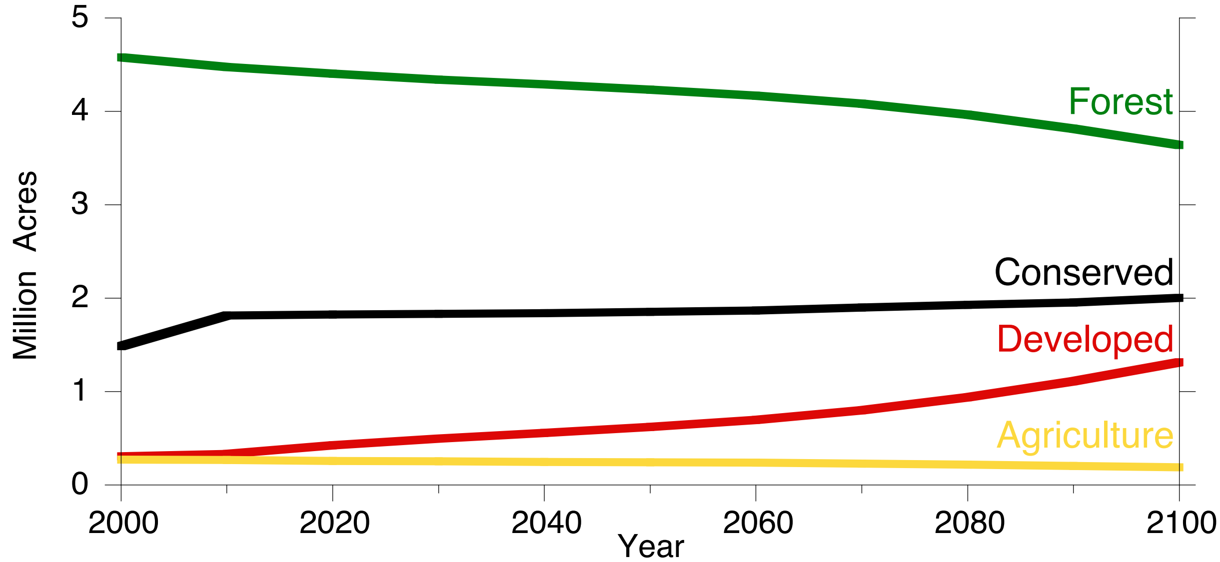

Figure 3. Trends in the area of forest, developed, agricultural and conserved land in New Hampshire for the *Backyard Amenities* land cover scenario.

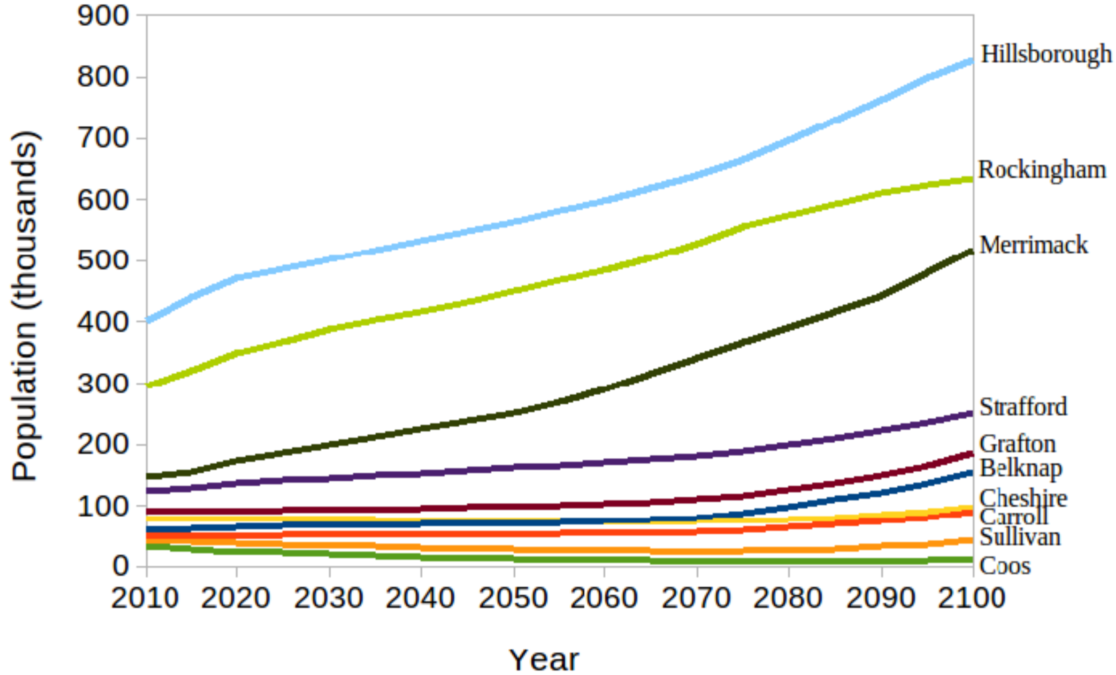

Figure 4. County-level trends in population growth for the *Backyard Amenities* land cover scenario.

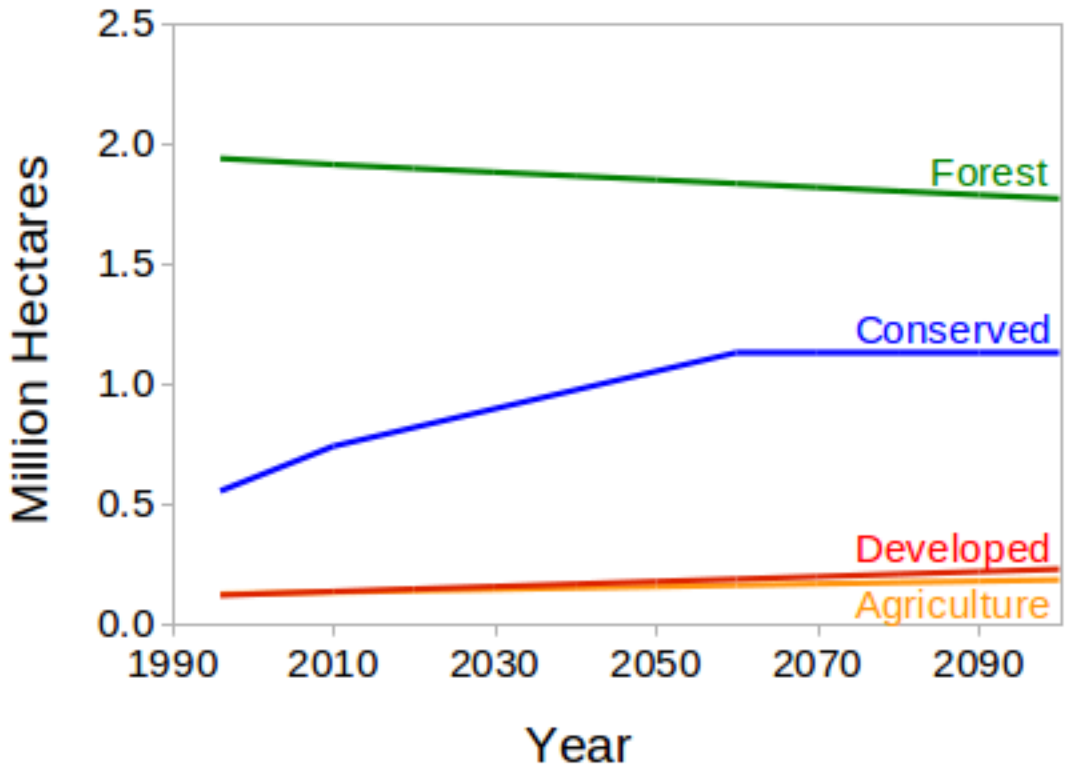

Figure 5. Trends in the area of forest, developed, agricultural and conserved land in New Hampshire for the *Current Trends* land cover scenario. (NOT FINAL)

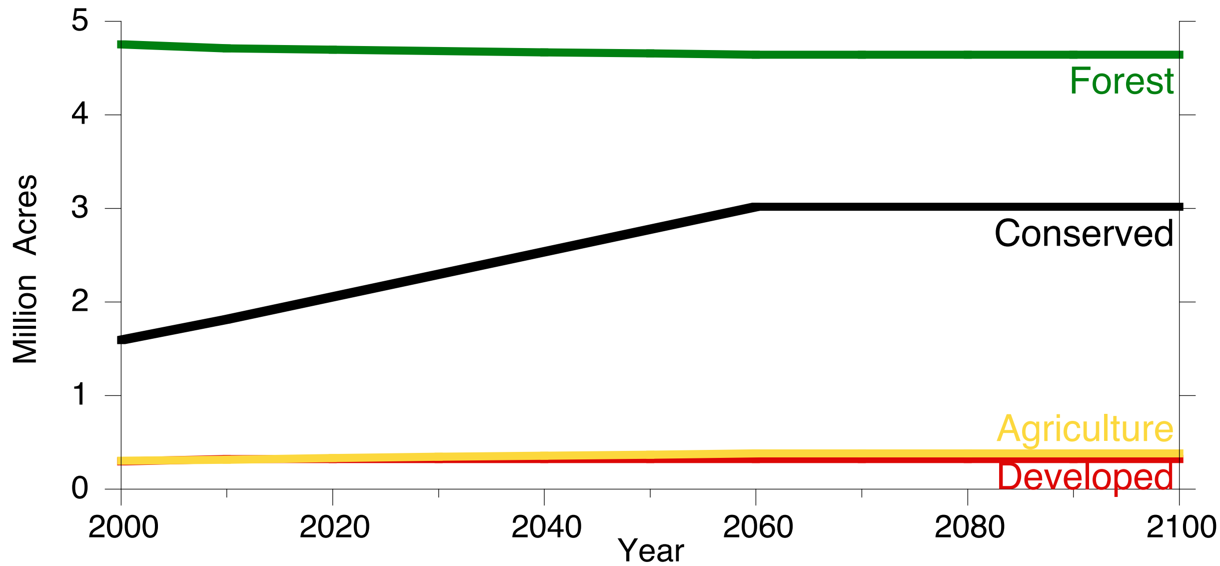

Figure 6. Trends in the area of forest, developed, agricultural and conserved land in New Hampshire for the *Community Amenities* scenario.

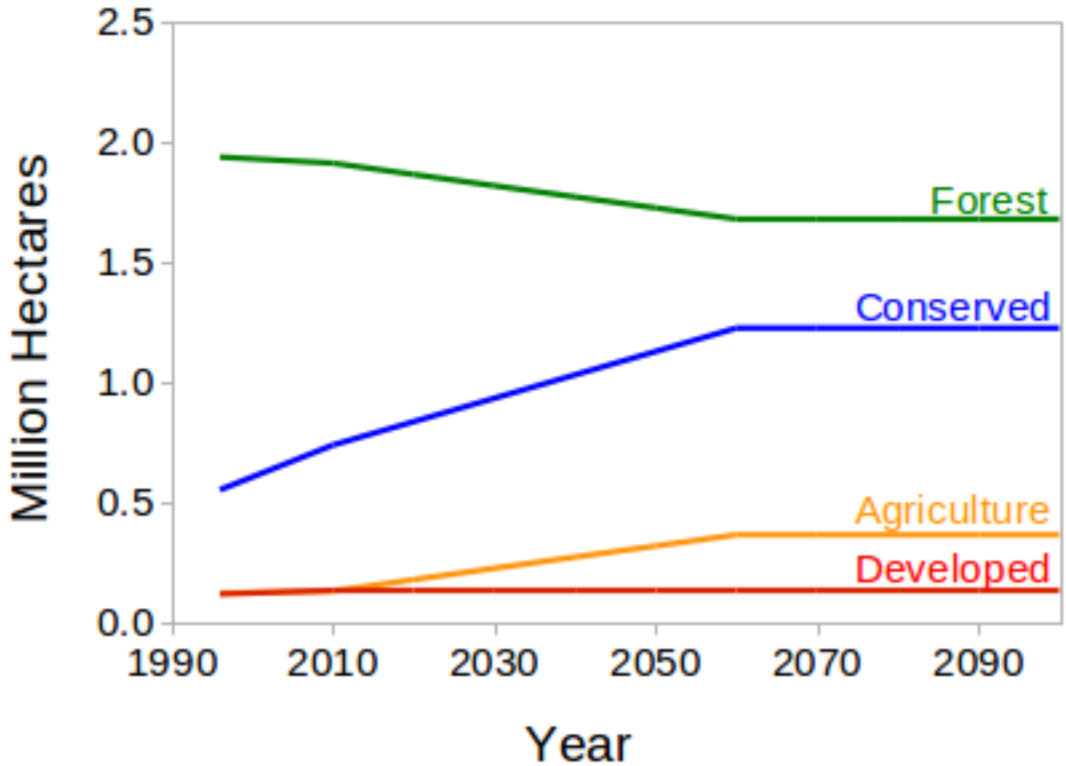

Figure 7. Trends in the area of forest, developed, agricultural and conserved land in New Hampshire for the *Community Amenities with Agricultural Expansion* land cover scenario.

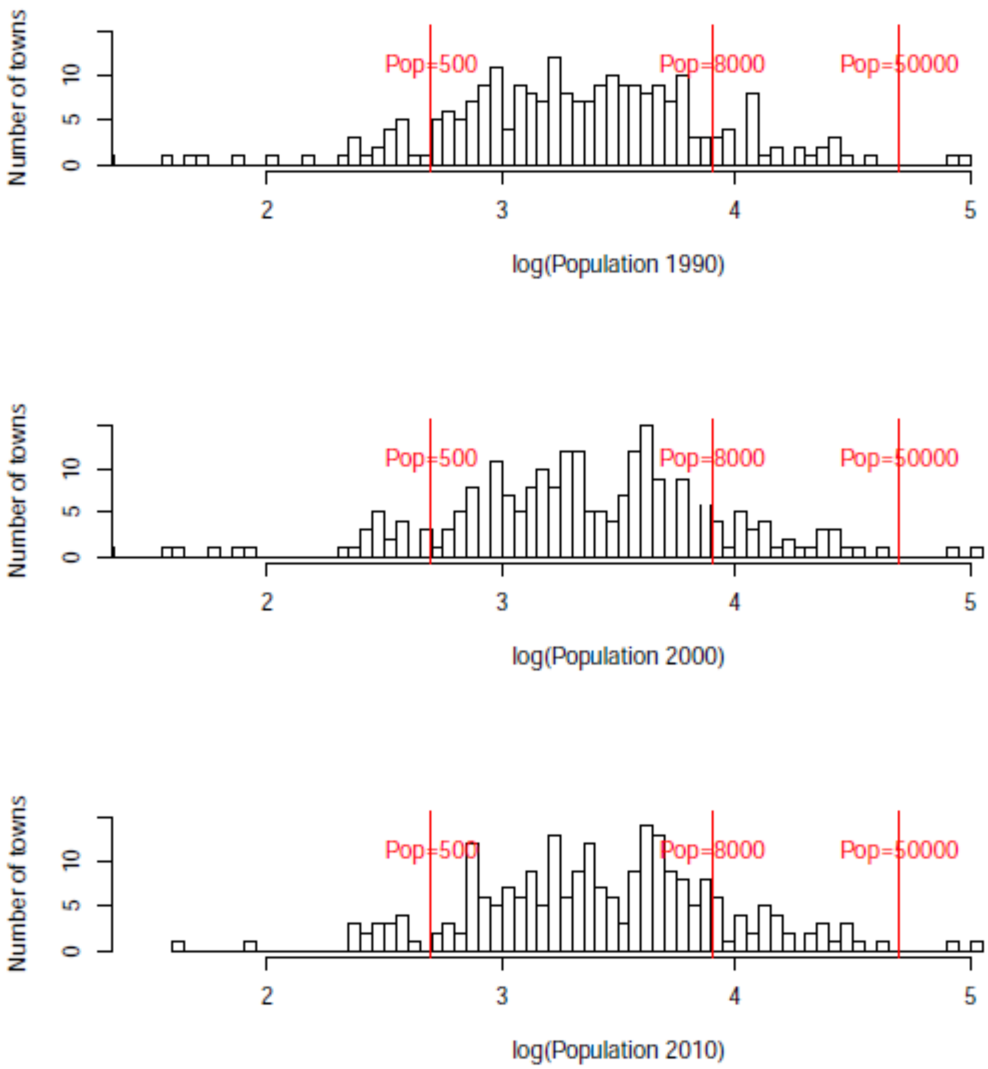

Figure 8. Histogram of the logarithm of populations for New Hampshire towns in 1990, 2000, and 2010.

Table 2: List of existing plans, surveys, and visions relating to New Hampshire's and New England's current and future landscape produced by various stakeholder groups in New Hampshire

Table 3. Current lot size zoning by NH municipality.

Table 4. GIS datasets and processing used to simulate maps of New Hampshire land use.

Data source(s)	**Processing**	**Range**
NOAA C-CAP 1996 and 2011 †	C-CAP categories aggregated as: Forest = 9, 10, 11, 12 Agriculture and grass = 6, 7, 8 Developed = 2, 3, 4, 5 Bare land = 20 Wetland = 13, 14, 15, 16, 17, 18, 19 Surface water = 21, 22, 23	Categorical
USGS National Elevation Dataset (NED)	Unmodified	0 to 1850
USGS National Elevation Dataset (NED)	Calculated from elevation using `gdaldem`	0 to 61
NH GRANIT: Soil Survey Geographic (SSURGO) database for New Hampshire*	Converted Attribute "HydrolGrp" to a consistent numerical code (11=A; 22=B; 33=C; 44=D; 14=A/D; 24=B/D; 34=C/D) Rasterized numerical code for state using `gdal_rasterize`	Categorical
Digital Flood Insurance Rate Maps	Rasterized numerical codes for flood insurance classifications for each county using rasterize() in R; Combined county rasters into single raster using map algebra in R; Note: Belknap county remains unclassfied because it does not have a current flood insurance rate maps	Categorical
NH GRANIT: Soil Survey Geographic (SSURGO) database for New Hampshire*	Converted Attribute "FrmlndCls" to numerical code (1=All areas are prime farmland; 2=Farmland of statewide importance; 3=Farmland of local importance; 4=Prime farmland if drained; 5=Prime farmland if protected from flooding or not frequently flooded during the growing season. Rasterized numerical code for state using rasterize() in R	Categorical
NH GRANIT: NH Public Roads	Generated map of major roads, identified as all roads with "Plow_Level" of 1; Rasterized map of major roads using rasterize() in R; Generated distance raster with `gdal_proximity.py`	0 to 122,486
NOAA C-CAP 1996 and 2011 †	Generated maps of developed land from aggregated land cover map; Generated distance rasters with `gdal_proximity.py`	0 to 10,882

NH GRANIT: New Hampshire Conservation/Public Lands	Extracted year conserved from attribute "DATEREC1" Added year conserved obtained from a DRED database query for Distances converted to meters from U.S. Survey Feet	0 to 6,229
NOAA C-CAP 1996 and 2011 †	Generated maps of surface water land cover from aggregated land cover map Generated distance rasters with `gdal_proximity.py`	0 to 7676
NH GRANIT: NH Political Boundaries, U.S. Census Populations (1990, 2000, and 2010), and U.S. Census Populated Places from USGS Geographic Names Information System (GNIS)	Populated places (PPL) point file joined with 1990-2010 U.S. Census population data for municipalities by PPL/town name Points for PPLs other than towns deleted from vector file Copies of vector file made and coverages of point subsets were computed for:	
	All populated places	12 to 19,722
	New Hampshire municipalities with:	
	Any population	12 to 36,940
	Population > 500	12 to 36,940
	Population > 8000	80 to 93,060
	Population > 50,000 (i.e. Manchester and Nashua, NH)	152 to 258,789
	Boston, MA	42,557 to 327,293