Alternative Futures Modeling in Maine's Penobscot River Watershed: Forging a Regional Identity for River Restoration

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Abstract

Maine's Lower Penobscot River Watershed (LPRW) has gained national attention for river restoration efforts and threats from rising development pressures. Here, we describe an alternative futures modeling approach for the 2.5-million-acre watershed designed to foster interdisciplinary research, stakeholder engagement, and on-the-ground solutions to complex sustainability challenges. We use focus groups and Bayesian Belief Networks to integrate expert knowledge and spatial data to arrive at land suitability rankings for four important land uses: development, conservation, forestry, and agriculture. We then overlay these uses to identify areas of future conflict and compatibility across the landscape in an effort to foster greater collaboration and improved land use. Future work includes the co-development of stakeholder-derived futures scenarios, and the identification of sub-watersheds where future development may degrade water quality and cross regulatory thresholds for urban-impaired streams, resulting in significant mitigation and compliance costs.

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Introduction

The Penobscot River rises from Maine's North Woods near Mount Katahdin in Baxter State Park, and flows over 350 miles before reaching the State's rugged "Downeast" coast west of Acadia National Park. The Penobscot drains 2.2 million ha (8,610 mi^2)—nearly 25 percent of the State—and throughout its long history has served as both cultural and economic mainstay for the people that have inhabited its banks. For the indigenous Wabanaki, the waterway was central to tribal culture, providing both transport and sustenance. Early European explorers, including Goma in 1525 and Champlain in 1604, navigated Maine's rocky coast and the lower reaches of the Penobscot. Their maps provided military intelligence as France and England vied for control of the region and its resources. Later, the maps would provide a blueprint for Euro-American settlement.

English settlement began in earnest after the French and Indian Wars of 1754–1763, and the region's vast resources were slowly opened to broader markets along the East Coast, Europe, and the Caribbean. Timber from the North Woods was driven down-river to be milled and loaded on ships along Bangor's many wharves. The extensive timber resources attracted the English monarch's attention via the "Broad Arrow" policy, which reserved the finest mast trees along major waterways for the Royal Navy. That policy was just one of many unpopular edicts that would fuel rebellions such as the 1772 Pine Tree Riot and, ultimately, the American Revolution.

By the mid-1800s, the Penobscot River sent more lumber to market than any other waterway in the world (Wilson 2005). That logging boom denuded the watershed of its pines. Later markets would exploit the region's others species, including spruce and hemlock. The river's vast fisheries, and those of Penobscot Bay along the coast, were also rapidly exploited as the region industrialized, creating a dual assault on the watershed's aquatic and terrestrial systems. Later years saw large integrated pulp and paper mills, textile mills, ship-building, and leather tanning operations. Many of these mills harnessed the power of the river as they converted raw materials to finished products. By the mid-20th century, the push for hydroelectric power had begun, and combined with its vast forest holdings, the Great Northern Paper Company operated on the Penobscot one of the world's largest hydroelectric systems.

As industry and commerce grew, the Penobscot increasingly became a source of industrial and municipal water and a conduit for wastes of all kinds. During the 1960s, the River's banks supported several pulp and paper mills, 22 leather tanneries, 25 textile plants, and a host of poultry processing facilities, many of which discharged waste directly into the river. In mid-century the River and its tributaries had over 100 licensed dams. Inevitably, these uses came into conflict. Bangor discontinued using the River for drinking water in 1959. By 1966, the last major shell-fisheries were closed due to contamination, and a 1972 study found the River unable to support most fish species.

River communities, once centered around vibrant working waterfronts, saw rail and then highway transport divert attention from the Penobscot as economic activities were re-oriented toward new modes of transport. By the latter half of the 20^{th} century, river communities along the Penobscot and elsewhere along the Eastern Seaboard had figuratively and literally turned their backs on their waterfronts. Across Maine and elsewhere, older downtowns near rivers like the Penobscot slipped into decline—a trend exacerbated by "urban renewal" efforts that obliterated block-after-block of historic downtowns in Maine and elsewhere (Kunstler 2005).

The decline of the Penobscot and its surrounding communities mirrored that of other major waterways—a process that would eventually give rise to environmental policies designed to reverse the cycle and restore health to America's waterways. On the Penobscot, the Federal Water Pollution Control Act of 1972—better known as the Clean Water Act—played the central part. Across the nation, other environmental statutes like the National Environmental Policy Act of 1969 and the 1973 Endangered Species Act (ESA) transformed our approach to managing natural resources. On the Penobscot, pollutants dropped an estimated 85 percent. At the state level, Maine's 1971 regulation of shorelands codified setbacks for new development and placed restrictions on the clearing of riparian vegetation. Under these regulations, water and scenic quality improved, and the river's significant bald eagle population saw a dramatic rebound. Nevertheless, some environmental problems remained. In 2000, the National Marine Fisheries Service and U.S. Fish and Wildlife Service listed populations of Atlantic salmon (*Salmo salar*) in several Maine rivers, including the Penobscot, as endangered. The shortnose sturgeon (*Acipenser brevirostrum*) had already been listed as endangered back in 1967 under a predecessor to the ESA. Those designations would further fuel efforts to restore the River.

Today, one navigating the Penobscot or traversing its banks witnesses a river repeatedly transformed. In 1604, Champlain's ships sailed amid old-growth forests. By the mid-1800s, those forests were gone, displaced by agricultural fields, but the pastoral landscape of the nineteenth century has since largely reverted to forest. On the river, additional changes are coming. In 2004, the Penobscot River Restoration Trust began planning one of the largest dam removal and river restoration projects in the world. The $30-million project seeks to maintain existing hydro-power capacity while removing two lower dams and modifying fish passages on another four dams. Dam removal under the project begins in 2012, and will reopen 1,000 miles of river habitat to 11 sea-run fish species, including Atlantic salmon and shortnose sturgeon.

The Penobscot still faces an uncertain future. Attempts to protect endangered fisheries can collide with renewed calls for alternative energy, including hydroelectric power. Efforts to assist Maine's struggling paper sector can conflict with efforts to improve water quality and diversify the region's economy though recreation and tourism. And residential and commercial development within the watershed's lower reaches threatens to transform the functioning of both human and natural systems. Indeed, a recent US Forest Service report entitled "Forests on the Edge" ranked the Lower Penobscot River Watershed 1^{st} in the Nation based on the projected loss of private forestland to residential development over the next 30 years (Stein et al. 2005). Two nearby Maine watersheds also made the Nation's "top 15" list.

Because of that development potential, the Penobscot River watershed provides a compelling

opportunity for coordinated efforts to understand and anticipate development and its impacts. But realizing a sustainable vision for the Penobscot requires interdisciplinary science and the capacity to work with diverse stakeholders to understand the social, economic, and bio-physical drivers of land use change, and the complex and coupled nature of human and natural systems. These challenges are representative of a wide range of emerging and increasingly complex environmental issues facing Maine as well as many other regions around the globe.
This chapter describes one ongoing effort to forge a regional identity for the Penobscot River Watershed. We focus on efforts at the University of Maine to realize this vision through an alternative futures modeling research project. That project is part of a 5-year, $20 million Sustainability Solutions Initiative (SSI) funded by the National Science Foundation, which seeks to identify and facilitate solutions to complex sustainability challenges through stakeholder engagement and interdisciplinary research.

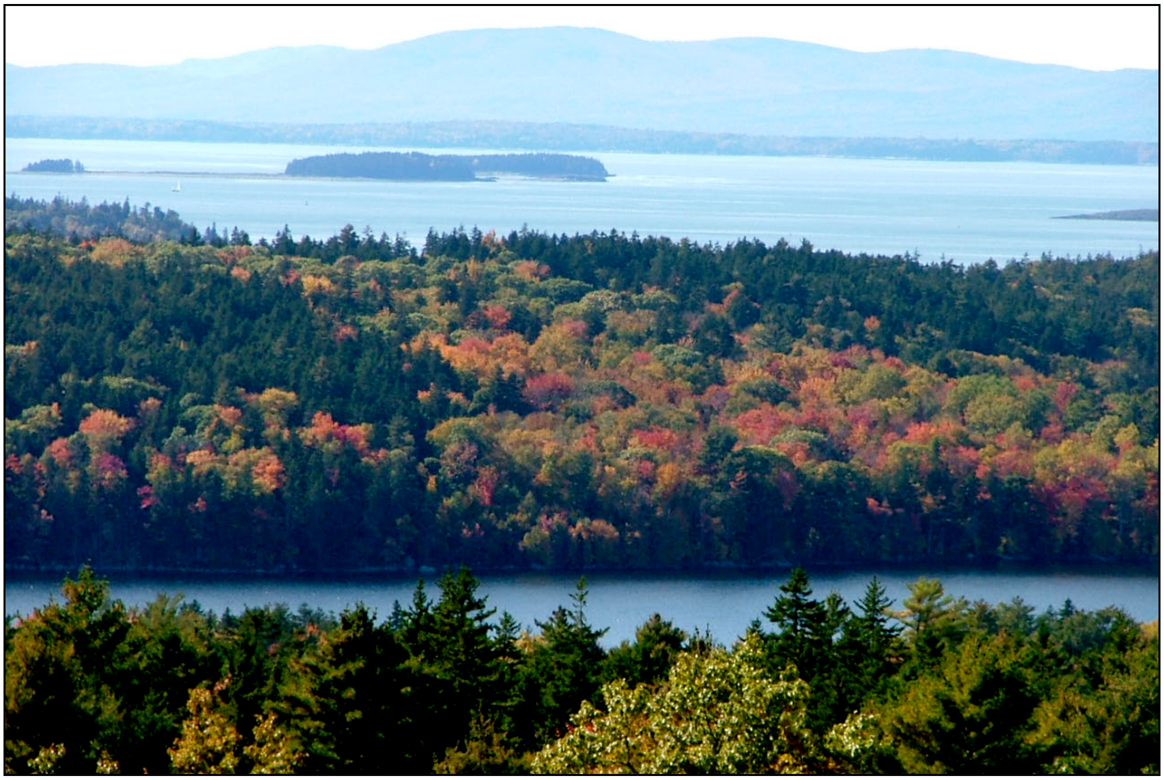
The alternative futures modeling approach described here provides an analytical framework for collaboration in identifying future challenges and opportunities facing the Penobscot River watershed. The approach is designed to provide policy makers and other stakeholders with the tools needed to assess social, economic and ecological trends, and develop a range of plausible futures for the region. The process is intended to foster a proactive approach to landscape-level management, and allow stakeholders to investigate a wide range of issues and policies affecting land use and the long-term sustainability of coupled human and natural systems.

Drivers of Landscape Change: Forest Management and Urbanization

Struggling Natural Resource-based Economies

Few regions in the eastern United States rival Maine's natural beauty (figure 1). Its coasts, forests, and mountains have earned the state a national reputation for quality of place and have played a formative role in the nation's environmental history. In the 1840s, naturalist Henry David Thoreau followed the Penobscot River's banks on his journey to the summit of Katahdin, witnessing the march of settlement as he moved northward himself. Later, the region would inspire young Theodore Roosevelt and help form his conservation ethic, thus influencing transformative conservation policies of his presidency.

Figure 1. Penobscot Bay, Maine (Photo by R. Lilieholm).



Today, 90 percent of the Maine's 20 million acres are forested—among the highest percentage for any state (McWilliams et al. 2005). And as the Nation's most rural state, much of this land is undeveloped, as readily seen from night-time satellite images (figure 2).

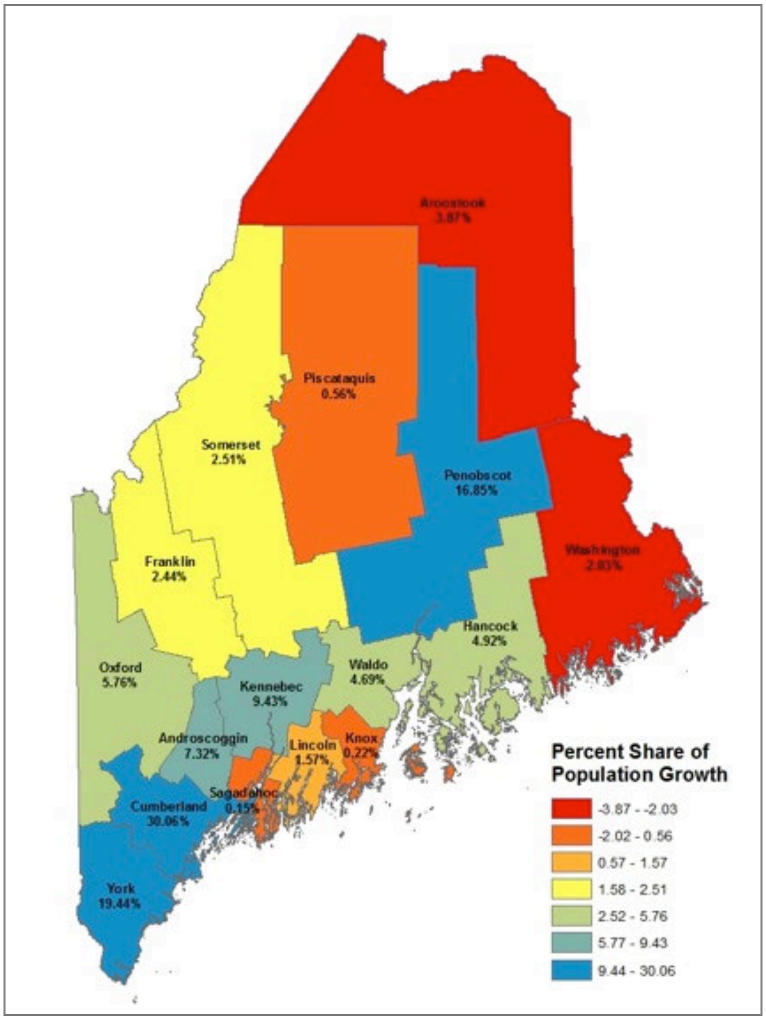
But appearances can be deceptive. Ninety-five percent of Maine's lands are privately owned, and the unsettled northern reaches of Maine are very much a working landscape traversed by logging roads and dotted with mills. Maine's forest products sector is one of the most diversified in the U.S., producing a wide variety of forest products including firewood and poles, hardwood and softwood dimensional lumber, wood composites, panel products like plywood and oriented strand board, and pulp and paper. Also important to the region are forest-based recreation and tourism, including hunting, fishing and recreational camps; guide and outfitting services; support industries for skiing and snowmobiling interests; and various nature-based education programs.

Yet these traditional engines of economic growth have faced challenges in recent decades. For example, while the forest sector continues to comprise 25 to 30 percent of total manufacturing jobs, the number of jobs has declined with overall declines in manufacturing. The greatest decrease in forest sector employment—45 percent since 1990—has occurred in Maine's high-paying pulp and paper sector. Many forms of recreation have also declined in popularity—especially as measured by visitation at well-known destinations such as Baxter State Park and the popular Allagash River canoe way.

Figure 2. Satellite image of the U.S. at night (NASA).

These losses have disproportionately affected Maine's rural communities—communities already reeling from manufacturing losses over the last several decades (Barkley 1995). Increasingly, younger residents find it difficult to secure meaningful employment and leave the region in search of better prospects. The results are an aging population and fractured social networks, both of which threaten the long-term vitality of many rural Maine communities. Indeed, the dichotomy between fast-growing southern Maine and the rural north and interior has led to the creation of "Two Maines"—one vibrant and moderately prosperous, the other struggling (figure 3).

Figure 3. Population change in Maine, 2000-2010 (U.S. Census).



Changing Landownership Patterns and Rising Development Pressures

In Maine and across much of northern New England, the housing boom of the 1990s and early 2000s, coupled with large sales of industrial forestlands, combined to substantially alter public perceptions of natural resources, land use, and development. Indeed, the greater Portland's region's rapid growth and low-density development led Senator Susan Collins (R-Maine) to dub the city the "Sprawl Capital" of New England. Similar conditions have affected large portions of York, Cumberland, and Knox counties along Maine's southern coast, where development proposals overwhelmed local planning boards and threatened the economic viability of historic town centers as businesses moved to outlying suburban areas.

While growth pressures are greatest in the south and along Maine's coast, second home and resort development proposals have the potential to significantly alter land use in virtually every corner of the state, especially along ecologically important streams, ponds, lakes and waterways.

Maine's preponderance of private land, low prices, and abundant amenities makes it an attractive target for second-home development, but that development also increasingly limits traditional access to the coast, rivers, and lakes. Foremost on many minds is a recently approved plan by Plum Creek Timber Company to build two resorts with nearly 1,000 house lots in the remote Moosehead Lake region of north-central Maine—the largest development proposal in the state's history. As evidenced by the Plum Creek proposal, large development proposals can now penetrate even far-flung regions of the State.

The stakes in these development controversies are high. An influential 2006 Brookings Institution report identified Maine's natural amenities and quality-of-life as key components of its economic base while noting the threat from haphazard growth and development. Between 1980 and 2000, the report noted, over 800,000 acres of rural land were altered statewide, with 650,000 acres converted during the 1990s alone. And while Maine added just 47,000 new residents during the 1990s, 65,000 new housing units were constructed, each with an average "footprint" of 10 acres. An earlier U.S. Forest Service entitled "Forests on the Edge" (Stein et al. 2005) drew similar conclusions, and listed three Maine watersheds on its "top 15" list of watersheds where private forestlands faced high development pressures.

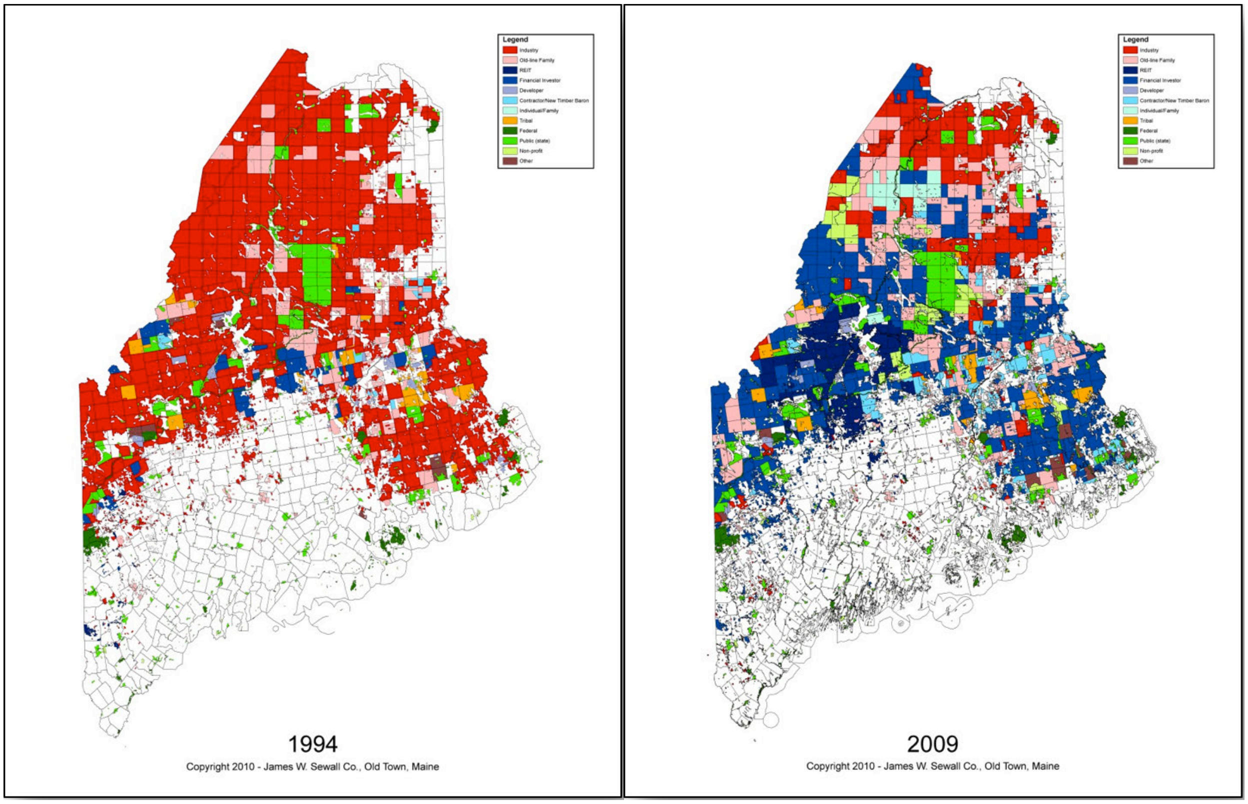
Haphazard development not only jeopardizes Maine's unique quality-of-life "brand," but also the long-term viability of the forest products sector and of many types of recreation. Despite an active industry, there has been a massive shift in forest land ownership in the sparsely-settled northern half of the state as the forest industry has largely divested itself of timberlands (figure 4). This transfer of land has precipitated a number of changes and challenges to forestry and recreational uses through:

- fragmentation of forest land and forest parcels, along with the conversion of forest to residential and commercial development;
- decreased access to recreational sites and timber for harvests;
- increased taxes as municipal budgets and demands for services rise;
- decreased landowner investment in stand improvement; and
- heightened concerns and regulation over timber harvests and recreational use.

(Egan and Luloff 2000, Shelby et al. 2004, Lilieholm et al. 2010.)

The impacts can be dramatic. For example, the Brookings Report documented how low-density residential development cost the state over $200 million in school construction costs even as overall student enrollments declined (Brookings Institute 2006).

Figure 4. Land ownership change in northern Maine, 1994–2009.



Amenity-based Economic Development

The Brookings Report noted that Maine's new-found growth was largely driven by the in-migration of residents from nearby states seeking improved quality of life, lower living costs, and a variety of scenic and cultural amenities. Such in-migration is critical to the state's economic future given its aging population and limited natural rate of increase. Indeed, Maine has the oldest median population in the country—a ranking exacerbated in part from the significant number of 25- to 34-year-olds that have left the state in recent decades (Brookings Institution 2006).

The Brookings Report energized an emerging view in the state. Indeed, the challenge—and opportunity—was to attract new residents and associated development while protecting the Maine "brand"—the combination of natural and social assets that increasingly attracts both visitors and new residents to the state (Reilly and Renski 2007). The view had some roots in older concepts of environmental protection, which had emphasized the preservation of Maine's natural resources as one method of preserving the state's quality of life. But the Brookings Report exemplified a partial shift away from a preservation-based view of environmental protection and toward a view more closely aligned with concepts of sustainable development. Under this view, the state's *working* forests and waterfronts, not just its relatively pristine natural areas, could play a central role defining the state's image and supporting economic growth and change.

Even before 2006, Maine was already transitioning toward this strategy. Over 100 land trusts—in partnership with landowners, recreationists, foresters, and state and federal agencies—have in recent decades permanently protected from development nearly four million acres, or 17 percent of the state's area, through a variety of means ranging from fee simple acquisition to conservation easements (Cronan et al. 2010, Lilieholm et al. 2010). The state itself protected many of these lands, using funding from several successful ballot initiatives under the Land for Maine's Future Program. The Forest Legacy Program, administered by the U.S. Forest Service, has allocated more funding to Maine than any other state. Private fundraising also has played a major role. Some of these acquisitions and easements precluded any industrial or agricultural use but many, while precluding future development, allow continued production of food and fiber. While agricultural preservation easements are common across the country, the prevalence of working forest easements is largely unique to the Northeast.

Collectively, these protected lands represent one of the Nation's most ambitious and successful public-private partnerships in land conservation. Yet while Maine had invested significant resources in protecting lands for ecosystem function, fiber production, recreation, and tourism, a recent assessment of conserved lands highlighted the need for a more strategic, proactive and coordinated approach to land conservation (Cronan et al. 2010). Ideally, that approach would be stakeholder-driven and strategically consider both the biophysical and the human dimensions of ecosystem protection. These concerns led to University of Maine efforts to promote a regional, strategic, long-term vision for the Lower Penobscot River Watershed.

The University of Maine's Sustainability Solutions Initiative

In 2006, researchers at the University of Maine began thinking about how the institution could better direct its efforts to meet stakeholder needs, foster cross-campus collaboration, and effect meaningful change. These discussions led to the creation of the Environmental Solutions Initiative or ESI, which eventually grew into a five-year, $20 million NSF-funded program now known as the Maine Sustainability Solutions Initiative (SSI).

SSI's overall goal is to study how forest management, urbanization, and climate change drive landscape change in coupled social-ecological systems (SES). SSI uses a portfolio of nearly twenty independent research projects, all of which attempt to address integrated ecological, social, and economic systems. The initiative attempts to greatly expand the university's interdisciplinary research, to embrace stakeholder involvement, and to focus on real-world solutions—or what we refer to as "knowledge-to-action." While pursuing these broad objectives, we are also studying how SSI affects researchers, students, and higher education institutions—a program we call "research on research."

SSI has nearly 100 scientists, 50 graduate students and roughly 100 undergraduates, all working on a wide variety of sustainability science issues in Maine. To provide a few examples, individual projects include research on forest management and urbanization, alternative energy technologies, and efforts to integrate Native American communities in the development of invasive species policies. SSI has also for the first time begun to harness the institutional power represented across the State's major colleges and universities, including UMaine's five campuses and private colleges such as Colby, Bates, and Bowdoin. SSI's efforts have catalyzed other units on the University of Maine-Orono campus as well. For example, the Center for Research on Sustainable Forests reorganized in 2010 to better address newly identified areas of interest by expanding its traditional focus on industrial timberlands to include two new research areas: (1) Family Forests and (2) Conservation Lands and Public Values.

One of SSI's projects—reported here—explores socio-demographic and land use challenges facing the Lower Penobscot River Watershed (LPRW). Our research approach seeks to understand past, current and future drivers of landscape change in order to better inform decision-making and arrive at landscapes that sustain both human and natural systems.

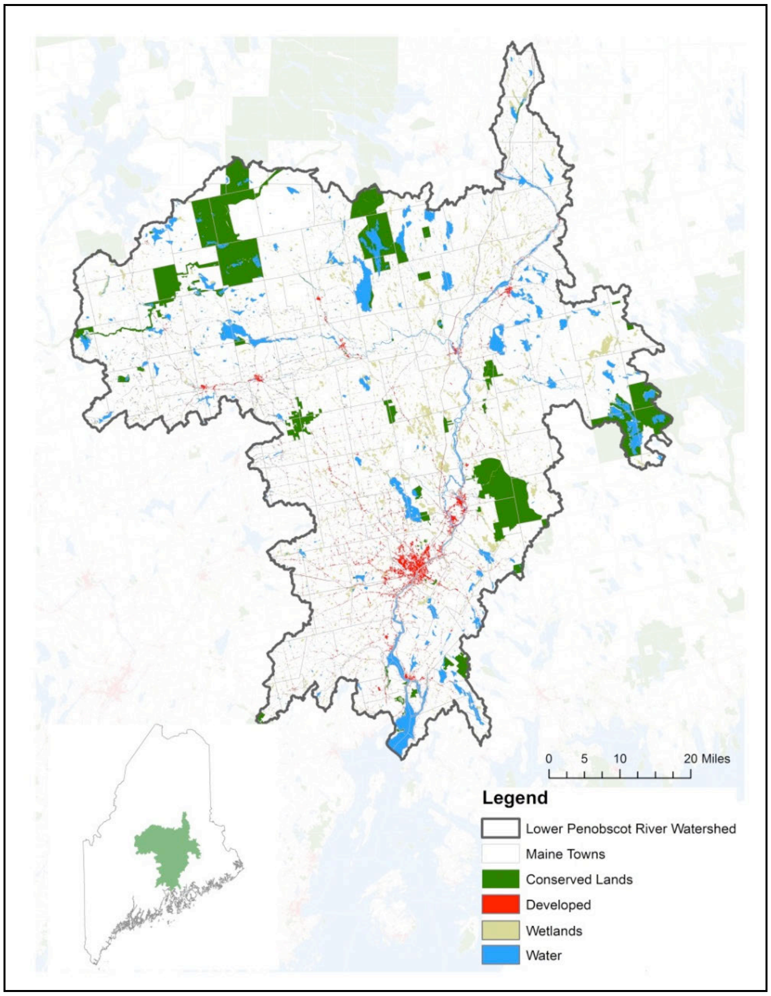
Alternative Futures Modeling in the Lower Penobscot River Watershed

Alternative futures modeling is an analytical framework that spatially integrates bio-physical, socio-demographic, and economic information into a GIS-based system of simulation models that can be used to assess the impacts of land use policies on a variety of social, cultural, and natural features (Theobold and Hobbs 2002, Hunter et al. 2003, Busch et al. 2005, McCloskey et al. 2010, Gomben et al. 2012). Researchers use these models to generate and evaluate alternative future scenarios depicting how landscapes are likely to develop under varying assumptions and conditions. The models may focus on single components of a landscape, like water resources, or the interaction among multiple components, like urban development and the loss of agricultural lands or sensitive species habitat (see Hunter et al. 2003).

We selected the 2.5-million-acre LPRW as our focal area for several reasons (figure 5). First, the Penobscot is Maine's largest watershed and New England's second largest waterway, draining nearly one-quarter of the state. The Penobscot's central location within the state is also an asset, along with the diversity of land covers and land uses. The watershed also allows us to study land use change across socio-economic and environmental gradients. Rising from the heart of Maine's North Woods—one of the most remote and undeveloped regions remaining in the eastern U.S.—the river winds through forests, agricultural lands, communities, and a series of dams on its way to Penobscot Bay. Also important is the river's proximity to UMaine's Orono campus. The campus sits on an island in the river, and thus provides an ideal place-based outdoor laboratory for both faculty and students.

The LPRW faces a number of significant challenges and opportunities. On the one hand, major improvements in water quality have transformed the river from a liability to an asset for many communities. As water quality has improved, communities are increasingly re-orienting their social and economic life towards the river. The Penobscot River Restoration Trust, described earlier, will probably accelerate this trend. Already, communities such as Bangor, Brewer, Hampden, Bucksport and others have begun to transform their waterfronts with parks and commercial development in an effort to attract new growth, aided by a state funding through a voter-approved Riverfront Community Development Bond.

Figure 5. The Lower Penobscot River Watershed.



Beyond the River's banks, the forests and farms that comprise the LPRW's working landscape face rising development pressures. These open space lands—which produce a host of private and public goods and services—are undergoing fragmentation and development at a rapid pace. For example, between 1990 and 2000, the LPRW's population increased just 2 percent while housing units increased 10 percent (White 2005). Seasonal homes increased by 14 percent during the same period (White 2005). The vast majority of new development was located outside of existing downtowns—undermining their economic viability and further challenging municipalities' ability to provide services (Brookings Institution 2006). Scattered, low-density development also fragments the landscape and compromises the economic viability of working farms and forests.

Study Goals and Objectives

Our research integrates spatial data and stakeholder knowledge to develop a decision support system for generating and evaluating alternative future landscape scenarios for the 2.5-million-acre LPRW. Our work is intended to foster proactive and strategic land use planning efforts by identifying lands suitable for human development activities, as well as lands suitable for the conservation of ecosystem services, working forests, and working agricultural lands. Our approach stems from the following hypothesis:

> A collaborative and strategic landscape planning process engaging a diverse range of stakeholder interests can: (1) identify and prioritize the suitability of lands for development and other uses; (2) build broader and more effective partnerships; and (3) result in a landscape that better meets social, economic and ecological needs for current and future generations.

Our research has three primary objectives:

1. Develop a set of stakeholder-derived models that integrate spatial and expert knowledge of biophysical and socio-economic variables that can be used to spatially identify land suitability for: (1) development; (2) ecosystem protection; (3) working forests; and (4) working farmlands.

2. Describe how high-value development lands intersect with other competing land uses, and explore the potential for future conflicts and compatibilities.

3. Based on stakeholder input, develop and evaluate a set of alternative futures scenarios that reflect a plausible range of demographic trends, land use policies, alternative development patterns, and conservation strategies.

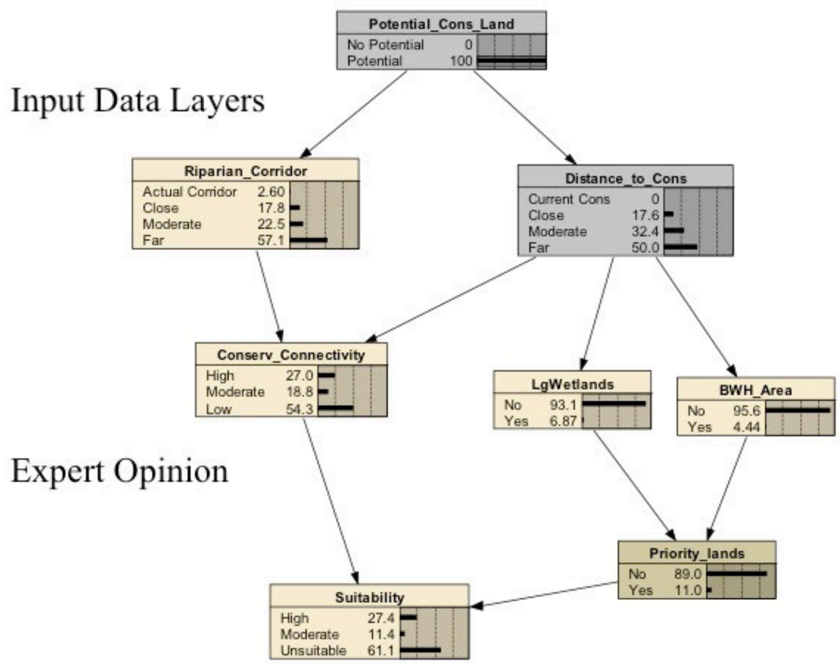
Stakeholder-derived Land Suitability Modeling with Bayesian Belief Networks (BBNs)

For the 2.5-million-acre LPRW, we used Bayesian Belief Networks or BBNs to integrate empirical GIS spatial data with expert knowledge. Our goal is to identify, on a 30x30 meter gridcell basis, lands important for development, ecosystem protection, working forests, and working farmlands.

BBNs are hierarchical, probabilistic models of that depict the relationship between random variables and their conditional dependencies (see example below). BBNs have been used to model drivers of urban land use change and explore stakeholder-derived alternative planning scenarios (Prato 2005, Kocabas and Dragicevic 2007, Ma et al. 2007, Pourret et al. 2008, Steventon 2008, McCloskey et al. 2011). Several factors have driven the increasing use of this methodology. First, BBNs are well-suited for integrating expert knowledge and empirical data—especially spatial data—using the Netica software package (Marcot et al. 2006, Chow and Sadler 2010). Second, BBNs are relatively easy to calibrate, validate, and update as new information becomes available (Steventon et al. 2008)—attributes that make them useful for conceptualizing and generating hypotheses, and assessing land use alternatives. Third, unlike statistical models that project the future based on past trends, BBNs can anticipate future changes that depart from past practices. In the wake of the 2008 financial crisis and the subsequent transformation of the real estate market, that feature is particularly important, for past data may be poor predictors of future trends.

We began our process by convening a series of four land-use specific focus groups, each composed of stakeholders with expertise in each particular land use. Our panelists began by identifying biophysical and socio-economic attributes that make land particularly suitable for their uses. Thus, for example, the development focus group identified factors such as slope, soils, road access, utility access, and nearby population density as important for residential and commercial development. We then worked with the expert panels to create BBN influence diagrams describing the connections between model variables (figure 6). Experts ranked the importance of their chosen variables by completing a set of conditional probability tables (CPTs) based on the influence diagram. We obtained feedback on the CPTs via email surveys with our focus group participants using Likert-scale responses. Through several rounds of communication, we: (1) fine-tuned the influence diagrams; (2) arrived at suitable thresholds for each BBN box or node (see figure 6); and (3) obtained CPT values.

Figure 6. Example Bayesian Belief Network for conservation lands (from McCloskey et al. 2011).



The process resulted in four land-use-specific BBNs designed to spatially identify lands suitable for each land use. We then used the Netica software system to apply each BBN to each 30x30 meter gridcell in the 2.5-million-acre study area. The result was a series of maps depicting the likelihood of suitability for each land use. Once these maps were produced, we reconvened all of our stakeholders as a single group to review models and output maps, and consider potential conflicts and compatibilities between the various land uses.

Identifying Areas of Potential Conflict and Compatibility

Figure 7 shows some initial results of our modeling efforts. Dark green lands portray existing conserved lands, while dark grey areas show lands already developed. Light grey areas show lands currently undeveloped, but highly suitable for development. Light green areas show unprotected lands highly suitable for conservation. In figure 7, areas shown in red depict lands highly suitable for both future conservation and future development. Based on our models, these areas are where the region is likely to experience future conflicts over land use. Much of the projected conflict is located near water bodies and existing conservation areas—areas of interest to both developers and conservationists.

Figure 7. Areas suitable for conservation and development, including potential regions of future conflict (from McCloskey et al. 2011).

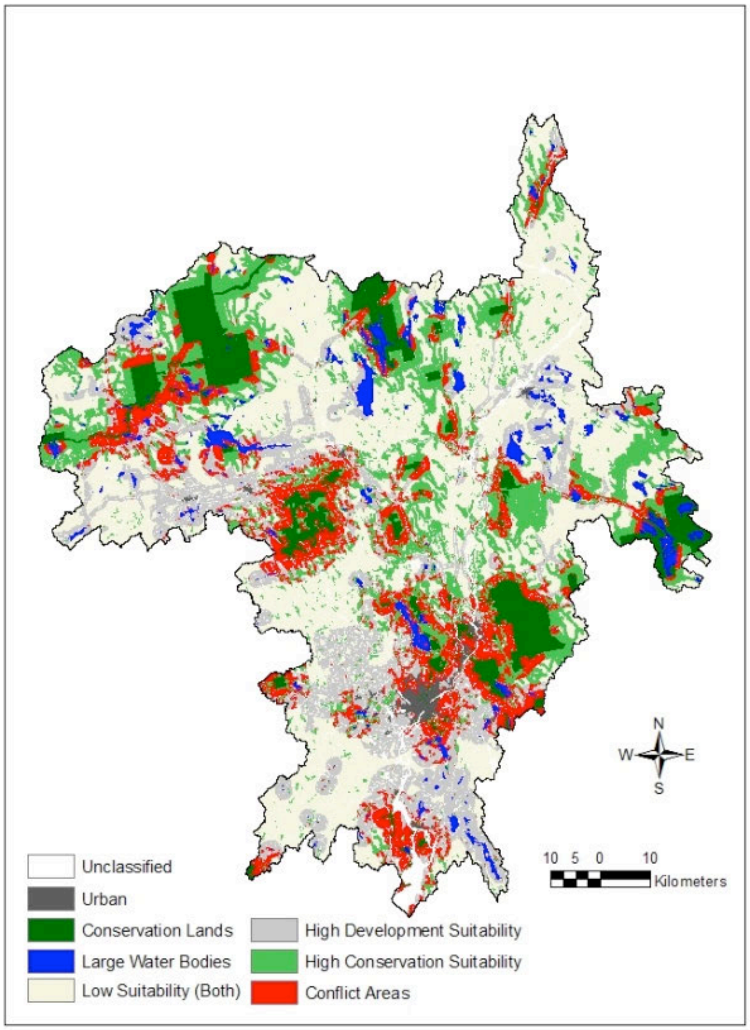


Figure 8 shows that the 279,532 ha of land highly suitable for development represents a seven-fold increase over the actual number of developed hectares in the study area. Similarly, the region's existing 81,575 ha of conserved lands represents less than one-quarter of the additional 305,268 ha of lands identified as highly suitable for conservation.

Figure 8. Areas suitable for conservation and development.

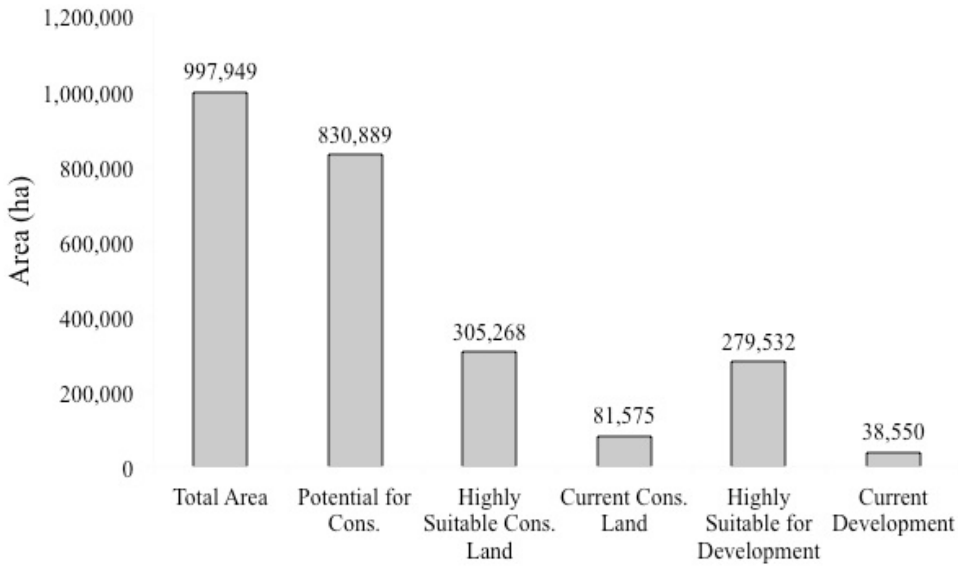
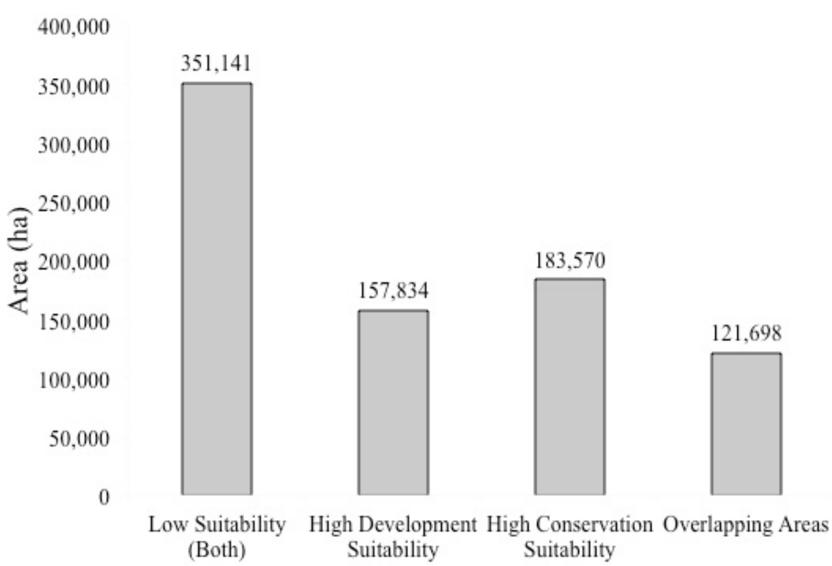


Figure 9 further breaks down these two land classes. It shows that there are 157,834 ha that are highly suitable for development but not highly suitable for conservation. Development could be targeted to these lands, where it would be less likely to compromise important ecosystem processes. Similarly, 183,570 ha are highly suitable for conservation, and not highly suitable for development. Here, conservation is unlikely to displace lands valued for development. Finally, the 121,698 ha identified as overlapping areas in figure 9 represent the red areas in figure 7—areas of likely future conflict over land use stemming from their high suitability for both conservation and development.

Figure 9. Area of potential conflict between conservation and development.



Next Steps and Future Directions

Scenarios of Future Development for the LPRW

The land use suitability maps described above give stakeholders an idea of how areas of future conflict and compatibility among land uses are distributed across the landscape. Yet not all of the areas we identified as highly suitable for development are likely to experience actual development pressure under reasonable futures scenarios. Demographic and economic projections for the Lower Penobscot watershed anticipate modest growth rates, and the watershed therefore is not like coastal southern California or Colorado east of the Front Range, where high growth rates ensure that development will likely occupy nearly every available parcel. As a result, we expect only a small portion of the red areas in figure 7 to experience conversion to development. That finding—to put it simply, that the supply of developable land greatly exceeds demand—is important.

Identifying a plausible range of future development scenarios is important in developing and evaluating the likely effects of alternative land use policies. Taking that additional step requires developing additional models that spatially depict future growth patterns based on socio-economic assumptions and explicit land conversion rules. The pace and location of development-induced land conversion is influenced by a wide range of factors, including population growth and housing demands, ownership, zoning, household size and income, the location of employment centers and existing infrastructure, land values and availability, public policies, overall economic conditions, and a host of site-specific features including access, slope, aspect, and drainage (Alberti 2008). These factors often interact in complex and uncertain ways.

To address challenges like these, researchers have developed a wide and expanding range of urban growth models (UGM) (see, e.g., Wu and Silva 2010). General approaches range from large-scale urban planning models like METROPILUS (Putman and Shih-Liang 2001), SPARTACUS (Lautso 2003), TRANUS (de la Barra 2001) and UrbanSim (Waddell 2005) that can assess the regional impacts of population growth and transportation policies, to rule-based models (see, e.g., Landis 2001, Klosterman et al. 2003), state-change models (see, e.g., Landis 2001), and cellular automata models (see, e.g., Clarke and Gaydos 1998, Battie and Xie 2005).

While modeling capabilities continue to advance, UGMs are not expected to predict with certainty the spatial distribution of future land uses (Ma et al. 2007). Instead, as Irwin (2010) notes:

> [T]he goal is not to predict the exact plots of land that will be developed, since such modeling accuracy simply isn't possible. Instead, the goal is to understand how various causal factors influence the qualitative aspects of the observed land use pattern (e.g., the degree of contiguity, fragmentation, concentration, density of various land uses) and changes over time in these pattern measures at a spatially disaggregate scale of analysis.

An important "next step" of our research is to use our land use suitability maps described and feedback from our stakeholders as foundations for generating a range of plausible future development scenarios. Our goal will be to identify, under varying scenarios, which of the areas determined to be highly suitable for development are likely to experience conversion over the next 20 to 30 years, and what opportunities and conflicts will arise from those projected changes. To achieve this goal, we will "populate" our development suitability maps to arrive at development footprints for 10-year intervals between 2010 and 2040 (figure 10). We will generate a wide range of scenarios by altering: (1) the projected number of new households; (2) settlement density; and/or (3) areas available for development. Each of the resulting futures maps will illustrate potential changes in development patterns of that might occur under various population projections and land use policies. Likely scenarios that could "benchmark" the range of possible futures for the region include the following.

- Trend: Projects past development trends under current zoning into the future.

- Smart Growth: Limits dispersed low-density development, and channels new growth into areas with existing infrastructure and services to lower the costs associated with unplanned growth.

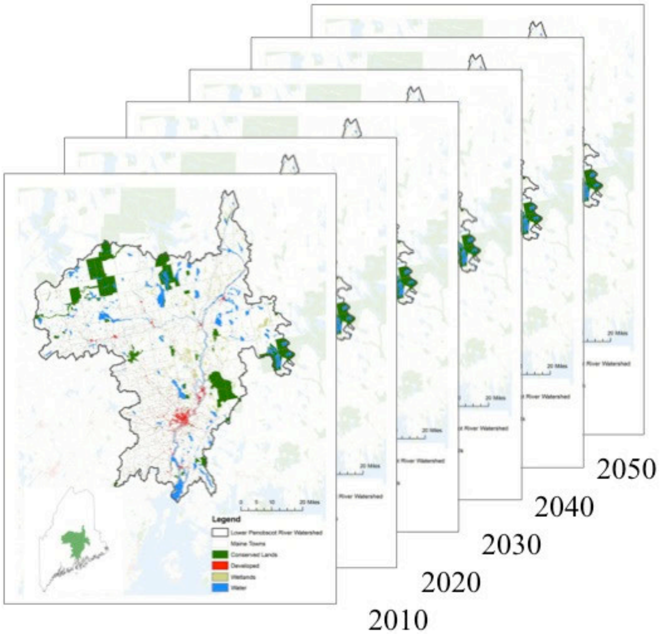
- Ecosystem Conservation: Channels future development away from ecologically sensitive areas (e.g., groundwater recharge zones, critical wildlife habitat, riparian areas, etc.).

- Public Health, Safety, and Welfare: Channels future growth away from areas essential to the protection of public safety (e.g., steep slopes, flood plains, areas of wildfire risk, etc.).

- Conservation of Working Landscapes: Channels future growth away from productive forests and agricultural lands.

These scenarios will result in easily understood spatial depictions of future landscapes, and we can use those spatial depictions to obtain feedback from a wide range of stakeholders. Our experience in other regions of the country suggests that this approach is effective in informing stakeholders about the potential consequences of alternative land use futures, and that it can help foster proactive land use planning that protects both human and natural systems. For example, concern over municipal water supplies or flood hazards could lead to the development of scenarios that encourage future development away from these zones. The resulting development footprint would then indicate the displacement of development under the new policies being considered—another important research output because development precluded from one area will often simply relocate to another.

Figure 10. Projecting future development through time.



Effects of Development on Ecological and Regulatory Thresholds

One potential land use conflict illustrates the potential applications of our mapping efforts, and also will form a central focus for our future work. Water is a key feature of the Maine landscape, and one important application of our suitability models and development scenarios will be to assess the implications of future growth scenarios on sensitive aquatic resources.

The negative influence of urbanization on hydrologic systems is well documented, and researchers now conventionally refer to "urban stream syndrome" as a pervasive condition of small watersheds in developed areas. Stream impairment results from a diverse set of physical and chemical drivers, including hydrology, chemical and nutrient pollution, and thermal stress (Meyer et al. 2005). Most of these drivers are closely linked to development, and researchers and regulators now use development levels as powerful, albeit imperfect, predictors of watershed stress.

Despite the close and inverse relationship between development and water quality, urban stream protection efforts generally emerge somewhat haphazardly, and often begin after development has largely occurred and water quality has been degraded (Owen 2011). But by applying our models at the municipal- and watershed-level, we hope to anticipate water quality issues likely to result from future development, and to facilitate more proactive efforts to balance communities' development goals with state and federal laws protecting water quality.

Such predictions could be quite valuable because proactive efforts to prevent or manage urban stream degradation are likely to produce positive environmental outcomes at much lower cost than restoration efforts begun after degradation has substantially progressed (Owen et al. 2011).

Fostering Knowledge-to-Action

While researchers and nonprofit groups have pursued many alternative futures modeling projects in recent years, the processes of conveying maps to stakeholders, and of turning maps into actual change on the ground, are still relatively understudied and undocumented. A final extension of our work therefore will be to explore how stakeholders and other end-users perceive and react to both models and futures scenarios. Here, we will use a variety of tools, including web-based interactive surveys, to determine the effects of background information on models, presentation formats (narratives vs. 2D vs. 3D representations), etc., on how stakeholders perceive models and their utility. Several specific questions are of interest to us. For example, we are interested in finding out whether stakeholders understand the inherent uncertainties of our maps, and how they address that uncertainty in their decision-making. Also of interest is whether spatial depictions of future scenarios motivate individuals to take action, and whether the magnitude of change is correlated with individual perceptions and motivations.

Lessons Learned

Communities, planners, businesses, advocacy groups and others often lack the time and resources needed to identify and evaluate the impacts of important land use decisions. These limitations oftentimes mean that important decisions regarding land use are made with incomplete information regarding current and future conditions (Pullin et al. 2004). As a result, approaches that can integrate spatial data with expert knowledge have the potential to improve land use decision-making processes for practitioners, policy makers, and the public.

This paper describes an alternative futures modeling approach designed to help stakeholders with varying land use interests build relationships, promote transparency, and better understand how land use decisions made today are likely to affect broader regions (McCloskey et al. 2011). By integrating expert opinion and spatial data, our aim is to engage broad interests and encourage long-term thinking when it comes to how land use policies are developed and implemented. As part of this modeling effort, we have worked with scores of individuals and dozens of agencies and NGOs to better understand existing landscapes and envision how landscapes may change in the future. Our modeling process is ongoing, but even at this preliminary stage, we have learned several important lessons.

Engaging Stakeholders and Forging Partnerships

Since its inception, the LPRW futures project has engaged a wide range of stakeholders, including governmental agencies at local, state, and federal levels. Examples include the Maine Department of Conservation, Department of Agriculture, Maine Forest Service, Land Use Regulation Commission, Department of Inland Waters and Fisheries, State Planning Office, Land for Maine's Future, U.S. Forest Service, and the USDA Natural Resources Conservation Service. Representatives from major businesses have participated in our focus groups and workshops, as well as trade groups and nonprofit advocacy organizations. A partial sampling includes the Maine Forest Products Council and Maine Pulp & Paper Association, to the Small

Woodland Owners Association of Maine, Maine Coast Heritage Trust, and the Maine Organic Farmers and Gardeners Association.

Through this work, we have learned much about engaging diverse stakeholders and sustaining their interest in the process. The challenges are substantial. Time constraints make it difficult to engage thoughtful, energetic and knowledgeable stakeholders. Sustaining these relationships over time is even more difficult. Managing expectations also is challenging. Given the scope of our work, many groups and individuals came forward with a desire to participate, and managing expectations about participation and resulting end products will always be a concern with projects such as ours.

Nevertheless, we have also learned many positive lessons. Virtually everyone engaged in our focus groups and workshops felt empowered by the experience. They seemed to enjoy working with university researchers, learning new tools, and exploring various “futures” for the LPRW. Our participants were clearly up to the intellectual challenge, and readily grasped the overall intent and value of our work.

Planning in an Anti-planning Environment

Fostering a proactive approach to land use issues can be a challenge anywhere, especially in states such as Maine with a long-standing deference to local home rule and private property rights. In 2010, Maine elected a highly conservative governor and many conservative legislators. They quickly set about challenging long-standing regulatory programs, scaling back the State’s already limited planning capacity, and pursuing policies thought to strengthen private property rights. A subset of our participants shared these policy preferences. Nevertheless, while some stakeholders expressed concerns over “where we were heading” with our land use planning and alternative futures work, their curiosity generally outweighed their concerns over possible increased regulation. In fact, we were surprised to find that many developers were highly supportive of zoning and other land use regulations because of their ability to reduce future uncertainties—especially the potential to reduce future conflicts over incompatible land uses. The preliminary lesson, we think, is that an alternative futures mapping process can divorce planning from some of its ideological overtones, and can facilitate a more pragmatic dialogue about future land use.

Conclusions

A core feature of sustainable development policies is the protection of sustainable economic activity, vibrant communities, and environmental quality. In Maine, protecting these assets is an important economic development strategy. Understanding landscape change drivers through interdisciplinary research therefore is critical to sustaining human and natural systems. Equally important is the process of engaging stakeholders in the research process, and understanding how scientific knowledge can be transformed into meaningful solutions.

Alternative futures modeling is an effective way to foster improved understanding of existing land use, and of the intricate and dynamic connections between human and natural systems. In Maine, the approach is particularly relevant given the close economic and social ties between the state's landscape and its people. Ensuring the health of these systems is not only important to quality-of-life, but also the sustained viability of the tourism and forest products sectors.

Our work engages stakeholders across a broad range of interests including conservation, government, business and real estate development. This breadth allows us to better understand the factors likely to drive future challenges and opportunities affecting Maine's landscape. Our stakeholder-derived models of land suitability provide the public with quantitative, spatially explicit depictions that not only inform key stakeholders of current land use and suitability, but also allow various interests to design and evaluate the effects of alternative assumptions regarding population growth and development pressures on current and future landscapes. Most importantly, our modeling is designed to facilitate the identification of locations where compatibilities and conflicts in projected land use are likely to exist across time in response to differing assumptions embodied in future land use scenarios.

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