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Eliciting expert knowledge to inform landscape modeling of conservation scenarios

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ABSTRACT

Conservation and land management organizations such as The Nature Conservancy are developing strategies to distribute conservation efforts over larger areas. Relative to fee-simple protection efforts, strategies that allow ecologically sustainable timber harvest and recreation activities, such as working forest conservation easements, should yield greater socioeconomic benefits (ecosystem services) with less investment per area without significantly compromising the conservation of biodiversity (ecological targets). At the same time, climate change may profoundly influence forest resilience to management strategies in the coming century. As a result, there are many possible scenarios for the future of our forests and significant uncertainty for practitioners and decision makers. Yet, monitoring efforts aimed at evaluating the effectiveness of conservation strategies span decades or longer, leading to a lag in knowledge transfer and delayed adaptive management.

To explore potential outcomes for biodiversity, provisioning of ecosystem services, and resilience of our forests resulting from various management strategies and climate change projections, we developed an approach that integrates quantitative, spatially explicit landscape modeling with scenario-building informed by expert knowledge. In this paper, we present our experiences applying this approach to two conservation project areas in the western Great Lakes region of the U.S.

For each project area, spatially explicit landscape simulations were performed using the VDDT©/TELSA© software suite (ESSA Technologies, Ltd.). At key points in the process, we infused the modeling efforts with expert knowledge via interactive in-person or web-based workshops and an online collaborative tool. Here, we capture our experiences applying the scenario building and modeling approach to forests in the western Great Lakes region and our efforts to make the process transparent and responsive to local and regional experts. It is our intent that this approach be transferable and implemented in future landscape scale conservation projects.

1. Introduction

Conservation strategies are shifting to distribute protection efforts over larger areas and a broader range of ownerships and management techniques. These 'distributed conservation strategies,' such as working forest conservation easements, are based on the premise that blending resource extraction and conservation should provide socioeconomic benefits without significantly compromising the conservation of biodiversity or the provisioning of ecosystem services (Silbernagel et al., 2011). While initially less costly per acre than fee simple ownership of land, these strategies are often complex to negotiate and implement and can be expensive to maintain over time (Merenlender et al., 2004).

At the same time, changes in some climate variables and their seasonal patterns are likely to influence the composition and dynamics of northern temperate forests (Opdam and Wascher, 2004; Scheller and Mladenoff, 2008; Mladenoff and Hotchkiss, 2009). While emerging conservation strategies are aimed at addressing development pressures and potential climate change impacts, the efficacy of these strategies compared to traditional, fee simple protection remains unclear, particularly in light of resource demand pressures over the coming centuries. Political, social, and economic situations further complicate conservation decision-making, where financial opportunities and public support often drive conservation actions in addition to ecological considerations (Pergams et al., 2004). Conservation planning could be greatly

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facilitated by the ability to compare strategies and understand the spatial aspects of strategy effectiveness.

Scenario analysis provides a way to visualize and compare the potential outcomes of a variety of conservation strategies and to develop more resilient conservation policies when faced with the irreducible uncertainty associated with applying new strategies under changing climate, ecosystem, and socioeconomic conditions (Peterson et al., 2003b). Rather than relying on predictions, which are quite uncertain under complex, dynamic conditions, scenarios "enable a creative, flexible approach to preparing for an uncertain future," and recognize that several potential futures are feasible from any particular point in time (Mahmoud et al., 2009). Landscape scenario analysis specifically refers to examination of the different possible conditions and factors that underlie landscape change (Nassauer and Corry, 2004). Development of landscape scenarios must incorporate the multidimensional drivers of landscape change, such as socioeconomic factors influencing the demand for natural resources, and site-specific ecological responses to these drivers. Inputs from a variety of disciplines and professional fields are required to capture these local dynamics. Such inputs are difficult to acquire from existing academic studies, because the scale and setting of previous studies are often not transferable to the scale and location of interest. In addition, the complex interactions of human and natural systems cannot be reliably anticipated by extrapolations from past trends (Coreau et al., 2009). Therefore, some degree of creative thinking is an asset when forming scenarios, especially when trying to capture rare but plausible events.

To form landscape scenarios that are plausible both ecologically and socio-politically, a collaborative process among various experts, practitioners, and stakeholders can be used (Peterson et al., 2003a; Hulse et al., 2004). Though the term *plausible* is not well defined in the literature, here it describes possible or believable, though not equally likely, alternative futures (Mahmoud et al., 2009). In the case of landscape scenarios, local experts, including foresters, business people (e.g. paper mill managers), land managers, wildlife biologists, and ecologists, can identify and define various potential drivers of landscape change and consider the contrasting, *plausible* alternative futures that might result.

To further strengthen this approach, landscape scenarios can be combined with quantitative landscape models. For example, in regional environmental applications, landscape scenario analysis is often integrated with landscape modeling to create spatially explicit landscape futures resulting from various land management, policy, climate change, and resource or energy demand conditions (Baker et al., 2004; Santelmann et al., 2004; Provencher et al., 2007; Sturtevant et al., 2007; Wilhere et al., 2007; Zollner et al., 2008; Low et al., 2010). However, limited guidance is available on the process of eliciting and integrating expert knowledge into scenario building and modeling efforts.

Here, we demonstrate the elicitation and integration of expert knowledge to develop, model, and analyze scenarios of landscape change in a collaborative project by the Wisconsin and Michigan Chapters of The Nature Conservancy (TNC) and landscape ecologists at the University of Wisconsin at Madison. This project aims to evaluate the effectiveness of various conservation strategies under conditions of climate change and demand for woody biomass for energy production. Expert knowledge was infused into the overall scenario-building and modeling process (Fig. 1) in three key stages – (1) scenario development, (2) model parameterization, and (3) spatial narrative building. We discuss how a variety of methods was utilized at each of these stages, including in-person workshops with local experts, web-based workshops with regional experts, one-on-one interviews, and an online collaborative tool. We articulate the direct and indirect benefits of each method as well as the many considerations associated with using expert knowledge in such instances. By providing examples of how and why we used these four elicitation methods, we enable readers to choose techniques appropriate for their project's unique goals, timeline, budget, and expert pool.

Such integration of scenario analysis and landscape modeling enables scientists and conservation practitioners to better understand the potential outcomes of the complex and simultaneous interactions of the diverse milieu of processes that influence landscape change, including ecological processes, climate change, and interactions of humans and the environment (Seidl et al., 2011). Ideally, this approach can be applied more broadly to consider new, high-risk strategies seeking to balance cost-effectiveness, biodiversity conservation, and maintenance of ecosystem services in other forest settings. By bringing together diverse experts such as landowners, foresters, and ecologists this approach aims to foster cooperation and yield more robust simulations and subsequent conservation adaptation.

2. Elicitation methods and outcomes

2.1. Study areas

This project focused on two study areas – the Wild Rivers Legacy Forest in northeastern Wisconsin and the Two Hearted River watershed in Michigan's Upper Peninsula (Fig. 2). The Wild Rivers Legacy Forest study area spans 218,792 ha of northern hardwood and hemlock-hardwood forests, interspersed with a complex of lakes, cedar swamps and other wetlands, rivers, and streams. Current ownership and conservation of this area results from collaboration between TNC, the Wisconsin Department of Natural Resources (DNR), and two timber management investment organizations (TIMOs). As a result, the area contains national forest; state forest lands managed by the Wisconsin DNR; county forests; lands owned by TIMOs under a state-held working forest conservation easement restricting subdivision, development, and forest management practices; and lands owned by the TIMOs without easement restrictions (Fig. 2a).

The Two Hearted River watershed (Fig. 2b) encompasses 53,653 ha and contains a mixture of forest types, including upland hardwood forests, pine stands, and coniferous forests, interspersed with a variety of wetland systems, including muskeg, bogs, and swamps (Swaty and Hall, 2009). Together, the Michigan DNR, a TIMO, and TNC own 80% of the watershed. All of the land controlled by the TIMO is managed under a working forest conservation easement. In both study areas, diverse owners have multiple management objectives, ranging from a focus on conservation of biodiversity (TNC) and improvement of forest condition for investors (TIMOs) to recreation, forest products, and reduction of fire risk (DNR). These areas exemplify the complex mosaic of ownership and management (Fairfax et al., 2005) and environmental pressures that must be considered in typical landscape scale conservation efforts in the U.S. today.

2.2. Selection of expert pool

In general, experts involved in scenario development and modeling can be divided into stakeholders, practitioners, and academic and agency scientists, separable by the scale at which they understand the study landscape and the level of their management responsibility (Fig. 3). We aimed to develop and model landscape scenarios composed of a set of three drivers of landscape change identified *a priori* by the project team – a conservation strategy, a level of demand for woody biomass for energy production, and selected climate change variables.

Development and modeling of these scenarios required local and regional knowledge, including the previous and current

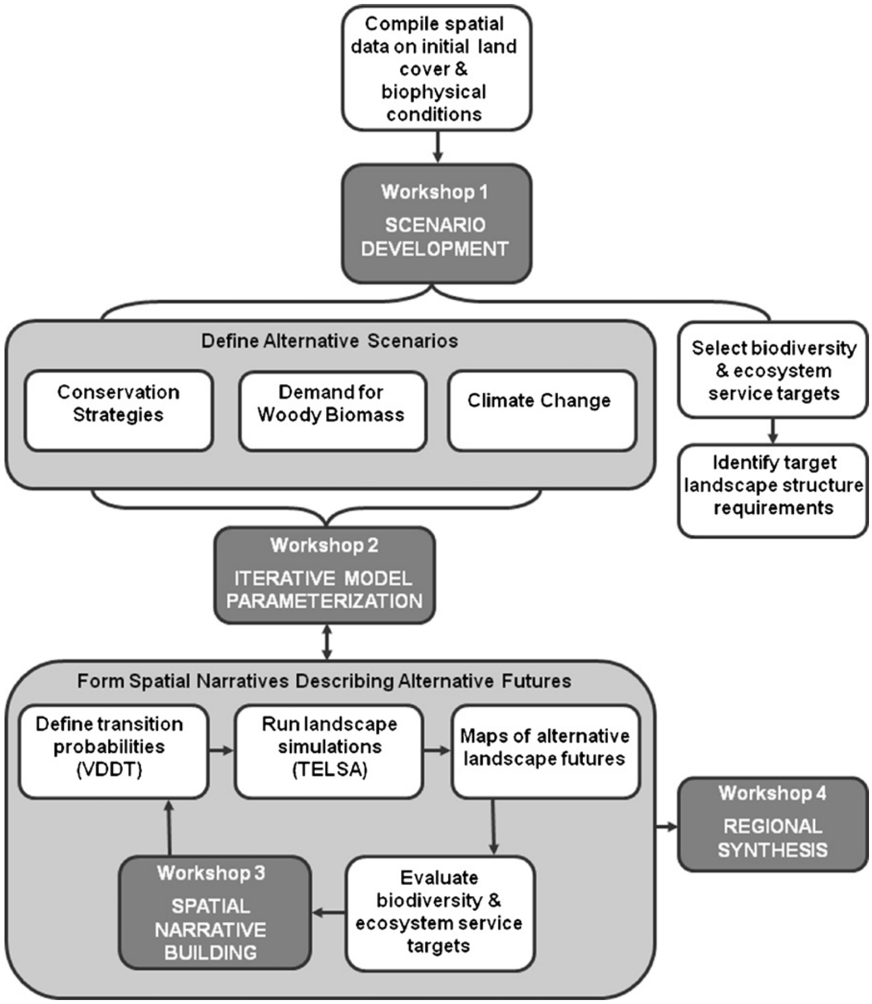


Fig. 1. Flow chart illustrating the collaborative process used to develop and model landscape scenarios. Expert input was elicited and integrated into the project via four workshops, indicated by the dark grey boxes.

conditions of each study area, the local biotic and abiotic processes affecting these areas, and their broader socioeconomic setting. Knowledge of forest succession often stems from forestry practitioners and is not formally documented in peer-reviewed literature (Drescher et al., 2008). Local experts were primarily practitioners (Fig. 3), chosen for both their knowledge base and their affiliation with the agencies and organizations responsible for the management of the study areas, including the Wisconsin and

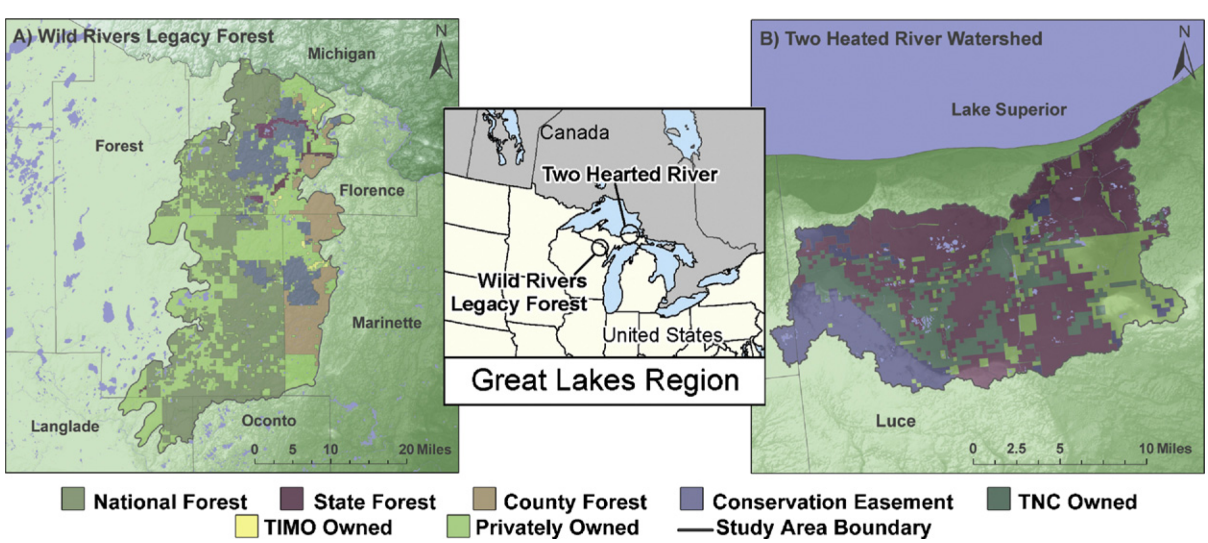


Fig. 2. Maps of the study areas – the Wild Rivers Legacy Forest in northeastern Wisconsin (A) and the Two Hearted River watershed in Michigan's Upper Peninsula (B).

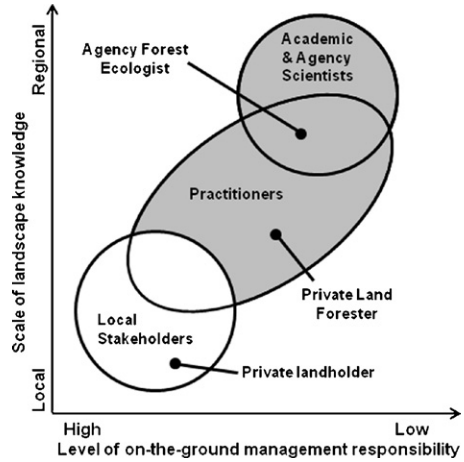


Fig. 3. A conceptual diagram of the different types of experts – local stakeholders, practitioners, and academic or agency scientists – who can provide input for scenario-building and modeling approaches. The project team fell within the academic or agency scientists bubble, having broader scale expertise and little or no on-the-ground management responsibility. Experts fell within the shaded area, ranging from forestry practitioners to agency scientists with local and regional knowledge.

Michigan DNRs, TNC, and TIMOs. Regional experts were primarily academic and agency scientists (Fig. 3) capable of considering the project within the context of broad-scale forest management and monitoring in the western Great Lakes region. Stakeholders, in this study, refer to local landowners or others with a local, non-professional land interest.

This composition (1) increased the likelihood that experts would view the resulting scenarios and simulations as valid and incorporate them into their management decisions and (2) decreased the likelihood that the resulting scenarios would be biased toward a particular point of view or set of goals or values. While selecting broadly across agencies, it was also necessary to ensure knowledge gaps identified by the project team could be addressed by at least one participating expert. For example, local experts were selected to achieve a representation of subject-specific expertise, such as wildlife biology, forestry, recreation management, landscape modeling, and the effects of disturbance processes in the western Great Lakes region.

2.3. Scenario development

2.3.1. In-person workshops

In-person workshops with local experts, one near each study area, were used to facilitate collaborative development of locally tailored landscape scenarios (Fig. 1, Workshop 1). This format enabled gathering information from many experts simultaneously and provided a venue for expert discussion, crucial for capturing the uncertainty and variability inherent in scenario analysis. In advance of the workshop, experts were provided with descriptions of the project's motivation, aims, and approach. By considering the experts' prior experiences with conservation planning, the project team clearly communicated the utility of the scenario building and modeling approach, discussed how the approach and its results can complement conservation planning efforts, and anticipated and answered questions.

Workshops began with an introduction to the project designed to complement and elaborate upon the pre-workshop materials. This introduction emphasized the anticipated outcomes of the project, including resources to pre-assess and compare conservation strategies, complement long-term monitoring, adjust strategies to anticipate future conditions, and inform ongoing and future conservation opportunities. The necessity of expert input and the role of experts in the scenario building and modeling process were also explicitly addressed to both inform experts of what to expect and encourage them to develop a sense of ownership and value their personal investment in the project.

Because no prior landscape scale modeling efforts existed for these study areas, experts were first asked to characterize the current state and functioning of local forest ecosystems. Next, experts were assembled into a single group, and discussion time was devoted to each of the three scenario components in turn – climate change, demand for woody biomass for energy production, and possible conservation strategies.

To start the discussion, the project team presented climate change projections for the study area (TNC, 2009b; WICCI, 2010), and experts discussed the climate variables they thought were the most important drivers of local landscape change. Second, experts were asked to describe the potential future of woody biomass harvest for energy production in the study area. The future of woody biomass harvest will be determined by a complex interaction of ecological, economic, and sociopolitical factors, and it is expected that these factors will be highly dependent on location. Therefore, local impressions of this market and its future are crucial for informing scenarios. Third, to elicit current and possible future conservation strategies and their geographic distribution in the study area, experts reviewed current, ground-truthed land cover maps of the study areas. These initial landscape maps provided the baseline from which alternative future landscapes diverge during the modeling process.

The full elicitation process was conducted separately with Wisconsin and then Michigan experts. The project team then reviewed the two sets of information to identify common alternatives for each of the three scenario components to formulate a single set applicable to both study sites (Table 1). To build complete scenarios, one alternative from each of the three components – a conservation strategy, a level of harvest of woody biomass, and climate change – were combined to generate a set of 10 landscape scenarios.

2.4. Model parameterization

Landscape scenarios were modeled using the VDDT®/TELSA® software suite developed by ESSA technologies Ltd. (Kurz et al., 2000; Beukema et al., 2003; Provencher et al., 2007). Non-spatial, state and transition models of probabilistic disturbance, succession, and management in each land cover type in the study areas were developed in VDDT (Vegetation Dynamics Development Tool) by modifying vegetation models previously developed by LANDFIRE, the Landscape Fire and Resource Management and Planning Tools Project (LANDFIRE, 2007; TNC, 2009a). VDDT models, along with spatial data, serve as an input for TELSA (Tool for Exploratory Landscape Analysis) to simulate land cover change at multiple time steps under each scenario. We refer the reader to Forbis et al. (2006) and Provencher et al. (2007) for a full description of VDDT and TELSA methodology.

Model parameters, including ecological pathways of disturbance and succession, influences of projected climate variables and resource demand, and conservation strategies, were defined and incorporated into the model interface by the project team (Table 2). Though these parameters are based on the principles of forest and landscape ecology, expert knowledge of local and regional dynamics was crucial to define and refine model parameters, ensuring that model results were plausible (Fig. 1, Workshop 2). This input was gathered through two web-based workshops and a series of one-on-one interactions.

Table 1
Landscape scenario descriptions and illustrative maps developed through collaboration with local experts for the Two Hearted River Watershed. The same resource demand and climate change conditions and similar alternative management strategies were simulated for the Wild Rivers Legacy Forest.

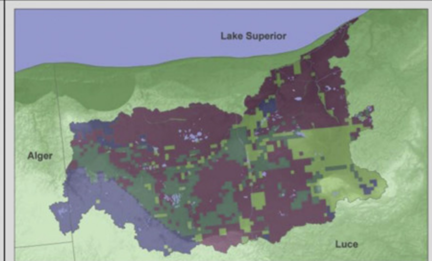
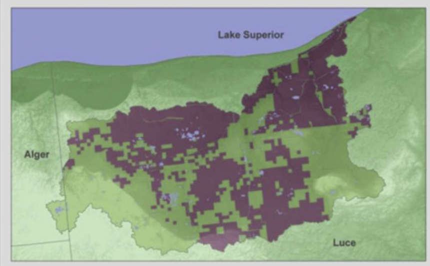
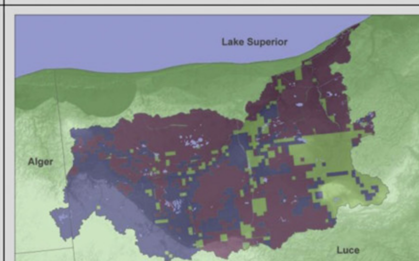
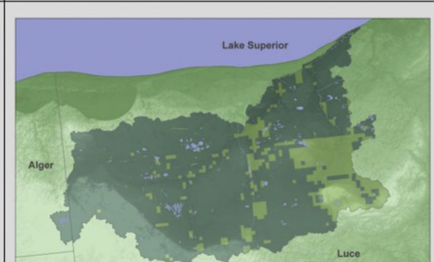
<table>
<tr><th colspan="2">Scenario components</th></tr>
<tr><th>1. Management strategies</th><th>Alternative Management Areas</th></tr>
<tr><td>a. Current Management.
Landscape dynamics are simulated under today's management boundaries and regimes.
In maps of alternative management areas, lands managed by the Department of Natural Resources (DNR) are shown in maroon (■), under a working forest conservation easement in blue (■), by The Nature Conservancy as a forest preserve in dark green (■), and by private owners in light green (■).</td><td>
</td></tr>
<tr><td>b. No Conservation Action.
Lands unowned by the state's Department of Natural Resources (DNR) are acquired by private, industrial timber interests and managed for maximum timber productivity (green). To simulate timber harvest by multiple, private owners acting independently, management activities are not spatially aggregated within the privately owned zone. Current management is simulated on state DNR owned lands (maroon).</td><td>
</td></tr>
<tr><td>c. Easement.
In this alternative landscape, area originally purchased by TNC is placed under an easement instead. Today's management strategies are applied in this larger easement area (blue) and the DNR management area (maroon). Management in the easement area is spatially aggregated to reduce fragmentation.</td><td>
</td></tr>
<tr><td>d. Ecological Forestry.
This scenario simulates cooperative, ecological forestry across the whole study area except privately owned lands. TNC management (dark green) is expanded to include the current easement and DNR management areas, including restoration forestry to reduce the area of uncharacteristic land cover and promote old growth characteristics. Management was spatially aggregated.</td><td>
</td></tr>
<tr><th colspan="2">2. Resource Demand</th></tr>
<tr><td colspan="2">a. No harvest of woody biomass.
b. Harvest of woody biomass for energy production on a 25 year time horizon.</td></tr>
<tr><th colspan="2">3. Climate Change</th></tr>
<tr><td colspan="2">a. A gradual increase in the probability of fire over the duration of the simulation, culminating in a 50% increase over today's conditions at year 100.
b. A gradual increase in the probability of both fire and wind over the duration of the simulation, culminating in a 50% increase over today's conditions at year 100.</td></tr>
<tr><th colspan="2">Scenario development</th></tr>
<tr><td colspan="2">32 landscape scenarios were constructed by combining one alternative of each component—one management strategy, one resource demand condition, and one climate change condition. For example, one scenario combines current management, harvest of woody biomass for energy production on a 25 year time horizon with an increase in only fire under climate change conditions.</td></tr>
</table>

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Table 2
Model parameters incorporated into each component of the modeling interface.

Parameters	VDDT	TELSA	Source
Stand development			
Seral stages – defines ecological succession in each modeled cover type	Define age and structural characteristics; assign deterministic succession pathway		Existing LANDFIRE models (LANDFIRE, 2007b), current land cover maps
Natural disturbances			
Fire, wind, flooding, and insect infestation	Define intensity and transition pathways; assign return interval through a combination of probability and proportion	Define size and spatial distribution	Existing LANDFIRE models (LANDFIRE, 2007b), state records, scientific literature, local and regional experts
Management			
Timber harvest – thinning, selection cutting, clear cutting, plantation management	Define transition pathways	Define stand age and size limits, return interval, and spatial distribution for each cover type and management unit	Local experts
Restoration forestry	Define transition pathways	Define stand age and size limits, return interval, and spatial distribution for each cover type and management unit	Local and regional experts

2.4.1. Web-based workshops

The first web-based workshop (Fig. 1, Workshop 2) began with an explanation of the modeling process, carefully prepared to match the level of technical detail to the experience and knowledge of the participating experts. For example, to overcome the potential barrier of experts' unfamiliarity with the modeling platform, the project team provided a simple conceptual diagram of each VDDT model and explained how expert knowledge would be integrated into that model as specific parameters. Fig. 4 shows a VDDT 'box' diagram and a corresponding conceptual diagram of the Alkaline Conifer Hardwood Swamp land cover model. Such conceptual diagrams make the dynamics of succession, disturbance, and management easier to visualize, communicate, and discuss.

To target expert discussions and narrow the potentially overwhelming set of possible model variables and parameters, the project team defined the information needed from experts in two ways. First, we developed very specific questions that were manageable in breadth, each phrased as relevant to only one of the many modeled cover types, e.g. how well can forestry practices restore species and structural diversity to northern hardwood forests? Second, we provided initial parameter approximations for each scenario to serve as a starting point. Importantly, information not useful for model parameterization may be useful for forming spatial narratives to explain model outputs. For example, experts may provide information pertinent to stand-level dynamics, such as the potential loss of tree or herbaceous species currently at the northern edge of their range due to climate change. However, the VDDT and TELSA modeling captures dynamics at a landscape scale. While such stand-level details cannot be captured within the model, spatial narratives can synthesize spatial model outputs with expert input and previous research to illuminate the characteristics within and between stands in possible future landscapes. Expert input elicited during this workshop was integrated into models after the workshop, and each scenario was modeled with this set of initial parameters.

After initial modeling runs, a second web-based workshop (Fig. 1, Workshop 2) was held to gather local and regional expert input on the maps of possible future landscapes resulting from the current conservation scenario. During the workshop, maps of possible land cover resulting from each scenario 25, 50, 75, and 100 years into the future were presented. Maps of natural disturbances and of management activities over this time period were also presented (Fig. 5). Output maps were also available to experts through an online collaborative tool described in Section 2.4.3. For each set of maps, experts were asked if the outputs were reasonable and, if not, how the models could be improved to more accurately capture the landscape dynamics in the study areas. Specifically, experts were asked to comment on the location and magnitude of each disturbance type and management activity while considering both the land cover type and ownership.

2.4.2. One-on-one interactions with experts

Because refinement of model parameters requires detailed and often quantitative inputs too narrow or technical to be adequately addressed in workshop format, expert input was also elicited through one-on-one interactions. These interactions consisted primarily of informal phone conversations and email exchanges with experts individually. In general, these questions focused on defining specific model parameters necessary to accurately simulate the spatially and technically varied management regimes employed in different scenarios.

Remote one-on-one interactions were often supplemented by the use of information sharing technology. Online meeting technology (e.g. WebEx, www.webex.com) allows sharing of visuals during a phone conversation. For example, during these meetings we viewed and demonstrated VDDT models, inspected spatial data, and opened websites. While it is often possible to share documents ahead of time via e-mail, this method is more interactive and flexible.

2.4.3. Data Basin as an online collaborative tool and data repository

To supplement workshop and one-on-one interactions, expert input on modeling results and parameters was also elicited using Data Basin, an online collaboration tool developed by the Conservation Biology Institute (www.databasin.org). Data Basin enables remote workgroup communication and feedback, sharing of spatial and non-spatial data, and interactive mapping without the need for GIS experience or software. Conceptual diagrams and descriptions of ecosystem models were posted to enable experts to review and comment on model parameterization. We encouraged use of discussion space for comments, textual discussions, and "at your leisure" review of materials.

2.5. Narrative building

Spatial scenario output alone, in the form of classified maps and summary statistics, can still be abstract and difficult to interpret, particularly by those working on the ground. For example, end-users may want to explore how projected land cover change will affect target conservation species, or what compounding factors may or may not lead to changes in the pattern of wetland ecosystems. Thus, a second set of in-person workshops (Fig. 1, Workshop 3) were held for each study area, in which experts worked with

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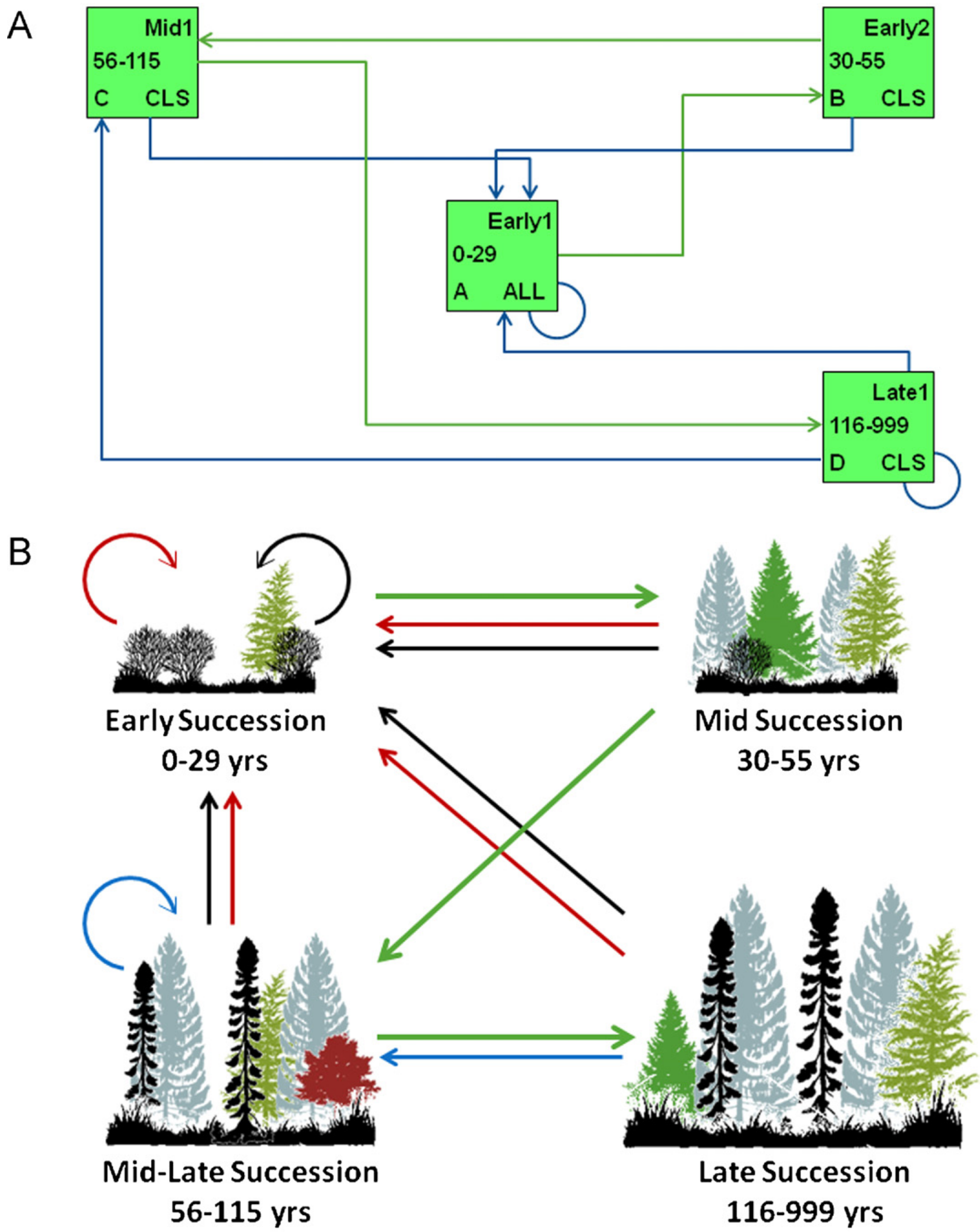

Fig. 4. A 'box' diagram of the state and transition model developed in VDDT to simulate the dynamics of the Alkaline Conifer Hardwood Swamp ecosystem (A) and the corresponding conceptual diagram developed to explain the same model to experts (B).

the project team to build spatial narratives, or storylines, around the projected landscape futures. These narratives describe hypothesized human-ecological dynamics behind the simulated landscape change and impart place-specific meaning to otherwise neutral map outputs (Silbernagel, 2005).

The format and contents of spatial narratives should be tailored to both the project and target audience. While the narratives resulting from this project will be reported in a future publication, they follow a general sequence beginning with a socio-ecological description of the study landscape from pre-European settlement through present day, answering the question 'how and why did today's landscape come to be?' For example, previous forest managers perceived mixed northern hardwood stands on sandy soils as unproductive for sugar maple (*Acer saccharum*), a historically highly valued timber species, and chose to liquidate sugar maple from those areas to capture its economical value, leaving lower value American beech (*Fagus grandifolia*) and red maple (*Acer rubrum*). This historical management has left two important legacies on today's landscape – (1) areas of mixed northern hardwoods in which sugar maple was removed now have an unusually high beech component, increasing their susceptibility to beech bark disease, and (2) tree biodiversity has been lost in areas previously targeted for sugar maple production as the species grew to dominate these stands by repressing regeneration of shade-intolerant northern hardwood species. This portion of the narrative is shared by all scenarios and explicitly acknowledges that present day forest conditions and patterns, the starting point for modeling future scenarios, is a result of the area's land use legacy and underlying geologic history. As one expert explained during Workshop 3, "You have to think about where we've been to figure out where we're going."

Next, the narratives of alternative future scenarios diverge to explain the landscapes resulting from differing scenario conditions.

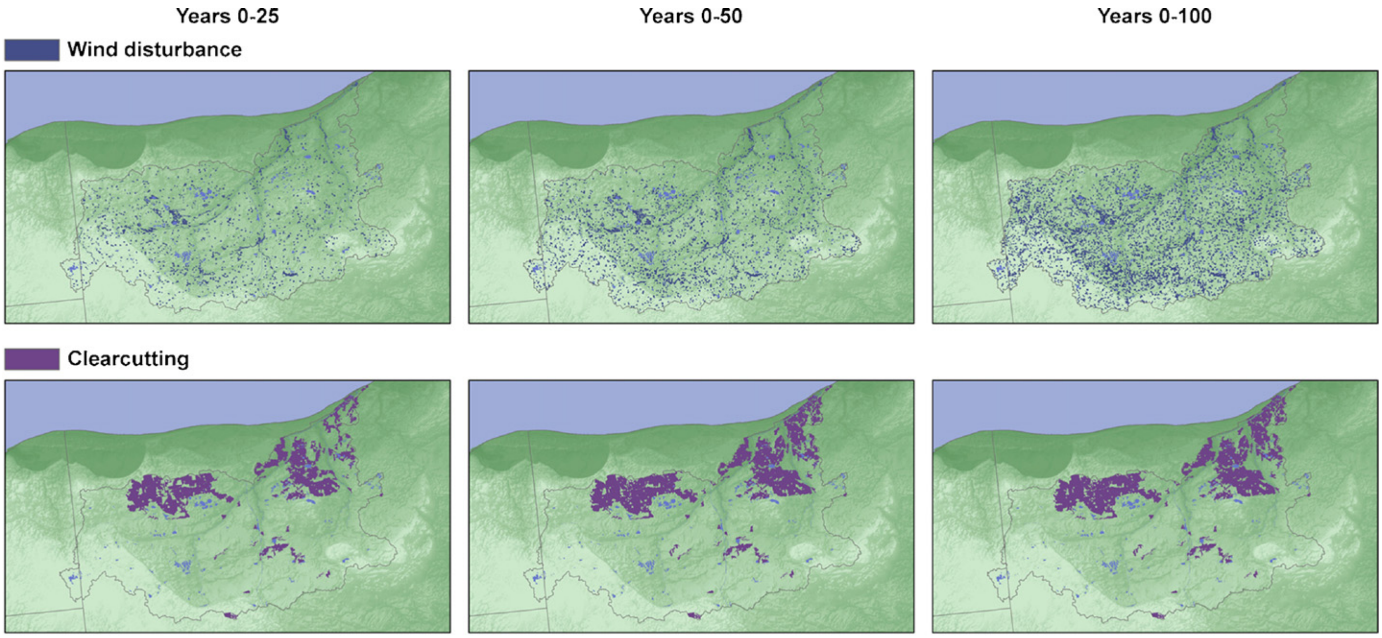

Fig. 5. Time series maps of simulated wind disturbance and clearcutting in the Two Hearted River watershed under the "Current Management" scenario. For each scenario, time series maps of land cover and management as well as fire, wind, flooding, and insect and disease pathogens were generated.

Here, the question 'how and why did this landscape come to be?' is answered from a future vantage point. By way of example, we can continue to focus on specific areas dominated by an unnaturally high proportion of sugar maple. Under the No Conservation Action scenario, the market value for timber and pulp are assumed to drive management decisions, and the stumpage price for sugar maple is expected to remain high. Model results show areas of sugar maple dominated forest expanding, causing a loss of diverse mixed northern hardwood. Under the Ecological Forestry scenario, management is aimed at restoring diverse or characteristic structure and composition, with economic gains a secondary concern, and model results show a reduction in the total area of sugar maple dominated forest. The narrative focuses on explaining the economic, social, and small-scale ecological repercussions of these mapped, spatially explicit differences, and highlights tradeoffs. For example, the higher level of harvest under the No Conservation Action scenario may provide more forestry-related jobs and income to the area and increase habitat suitable for game species such as deer. However, production oriented harvest may also lead to a loss of biodiversity and increase the vulnerability of the forest to insect and disease pathogens. Also, private, industrial ownership of forested areas may limit public access to recreation, hunting, and non-timber forest products, all of which are culturally significant to the residents of the area. In contrast, the Ecological Forestry scenario may increase forest biodiversity and provide more habitat for species sensitive to anthropogenic disturbance while providing fewer forestry-related economic benefits. Importantly, the increased expense of restoration forestry practices may inhibit its application over time.

As the simplified example above illustrates, spatial narratives provide a multi-disciplinary and locally relevant analysis of scenario results, bringing in economic, social, and ecological drivers and consequences. They also provide an opportunity to capture important landscape dynamics not handled by the modeling software, such as changes in species composition and nutrient cycling. In our case, we supplemented stand level model results with information from the Tree Atlas (Prasad et al., 2007-ongoing; Iverson et al., 2008), other modeling efforts (Scheller and Mladenoff, 2008), and analyses (Swanston et al., 2011; WICCI, 2011a,b; Birdsey et al., unpublished report) to explain possible future changes in tree species composition and its influence on biodiversity and ecosystem service targets. Experts are key sources of information regarding the past, present, and future human-ecological dynamics on these landscapes. With expert input and spatial narratives, we can more fully capture the feedbacks between management decisions, economic drivers, natural disturbance dynamics, and the possible effects of climate change.

Also during this stage, experts helped distinguish plausible from implausible scenarios and helped identify the most likely origin of implausible results by considering such contributing factors as human error, poor input data, poor match of software to issues, and technical difficulties. In this way, expert input from Workshop 3 guided model revisions to produce more realistic simulations of possible future landscapes.

3. Insights and implications

3.1. Recommendations for selection of experts

Experts should represent the agencies and organizations involved in the management of the study area and provide insights into subject areas identified by the project team. To widen the expert pool, experts can recommend peers who could contribute to the project. While there is no ideal number of experts or spatial scale of information, consultation of multiple experts and sources of quantitative data at both local and regional scales increases the likelihood of compatibility and provides insight into the range of variation across the landscape. Whether one or many experts are consulted, project teams should be cognizant of expert uncertainty and quantitatively evaluate within and between expert uncertainties when possible. Differences in expert opinion may be the result of differing professional experience, and sub-sampling of expert groups representing many fields may be necessary (Czembor et al., 2011).

Importantly, the locally tailored scenarios and modeling outcomes resulting from expert input are only applicable to the study areas under consideration. Therefore, the scenario-building and modeling process, including selection of an expert pool, must be repeated for each area of interest. Such specificity can be seen as an advantage or a disadvantage depending on time and funding

Table 3
Benefits and considerations associated with each method of expert knowledge elicitation.

Project stage and elicitation methods	Benefits	Considerations
Scenario development		
In-person workshop	Gathers input from many experts at once; establishes rapport among researchers and experts; provides opportunity to visit study areas.	Supports multi-media presentations; time consuming and expensive to plan and host; may require travel by project team and participants resulting in a larger carbon footprint.
Model parameterization		
Web-based workshops	Easier to schedule than in-person workshops; gathers input from many experts at once; inexpensive; good for gathering general or 'ballpark' figures for parameters; ideal for presenting results, such as model outputs, that are easily conveyed in digital format.	May need to hold multiple workshops for model parameterization; participation is limited; requires access to and comfort with web conferencing technology; should follow in-person interactions if possible.
One-on-one interactions	Greater flexibility in scheduling, location, and discussion topics; facilitates gathering detailed information for parameterization, especially capturing specifics not included in peer-reviewed or agency publications; lack of formal agenda is conducive to gathering unanticipated input; builds rapport with experts.	Time consuming; relies on a single expert as the source of reliable information.
Spatial narrative building		
In-person workshop	Conducive to sharing map outputs; enables discussion and debate among experts.	See above.
Data Basin	Facilitates continued expert participation; allows experts access to project information and results; no need for access to or experience with expensive, complicated GIS software.	Requires time investment for startup and maintenance, perhaps third-party help; maintaining expert interest and participation is challenging; best used as supplement to other elicitation modes.

constraints as well as the availability and willingness of local experts and practitioners to participate in the process.

3.2. Recommendations for utilizing each mode of expert input

Below we describe the benefits and considerations associated with each method of expert knowledge elicitation employed at each stage of the project (Table 3). Given the varied types of expert input required for collaborative scenario-building and modeling, we anticipate a hybrid approach that employs multiple modes of interaction in concert will be most effective. While the need for effective mediation of expert discussions seems obvious, the open-ended nature of both workshops and one-on-one interactions and the need for elicitation of unanticipated knowledge makes this point worth emphasizing. The basic tenets of good meeting facilitation apply in all interactions (e.g., advance preparation, facilitator impartiality, conflict resolution, and solicitation of input from all attendees). In workshop settings, facilitators should be cautious to avoid forcing consensus among experts, especially with regard to model parameters, and take precautions to avoid dominance by one or a few group members as well as groupthink (Janis, 1972), as both can result in over-confidence and biased models (Czembor et al., 2011). For example, all experts involved in this study were given the opportunity to review alternative scenarios, model parameters, and results independently during one-on-one interactions and using the online collaborative tool.

It is essential to clearly define the expectations of the project team at the start of each meeting to minimize misunderstandings and maximize the amount and quality of information received. While advanced preparation on the part of the project team can ensure that discussions stay on-topic, care should be taken to remain flexible, as unanticipated input may alter how the interaction, a particular stage, or the entire project proceeds. Flexibility can also give the experts a sense of ownership and further engage them in the project.

3.2.1. In-person workshops

In-person workshops provide input from multiple experts on several topics in a setting conducive to discussion and interaction. Situating in-person workshops near study sites provides the opportunity for field visits in which experts can familiarize the project team with the study area and provide examples of different landscape features, management regimes, and ecosystem responses to specific drivers of landscape change. This is especially helpful when local experts and practitioners use local references and language during the workshop. In-person interactions promote familiarity and trust between project team members and local experts, and increase the likelihood of continued expert involvement and support. Therefore, we suggest planning in-person workshops early in the project timeline if possible. However, in-person workshops require significant planning, demand a greater time commitment from both planners and participants, have a greater carbon footprint, and are more costly than remote communication.

3.2.2. Web-based workshops

Alternatively, web-based workshops excel when time is tight, travel budgets are slim, and experts are geographically distributed. A variety of web-based and telecommunications software are available to host remote workshops, and project teams should consider the clarity in which they are able to present information and the ease in which expert participants are able to log on, view project information, and provide feedback. Special consideration should be given to the types of visual information to be shared and the accessibility and ease of use of sharing technologies to experts. In our experience, web-based workshops are more successful once rapport with experts and familiarity with project study areas have been established. Therefore, we recommend holding web-based workshops after in-person interactions with experts and field visits, if possible.

3.2.3. One-on-one interactions

While in-person and web-based workshops offer a format for efficient and focused discussion among a group of experts, one-on-one interactions can delve more deeply into specific questions or detailed information. Here, specificity is gained while the ability to brainstorm or collaborate with a group is lost, and there can be a tendency to rely on one expert for reliable information, though the project team can subsequently check facts as needed. However, one-on-one interactions provided greater flexibility in scheduling, location, and discussion topics, as well as a more relaxed setting, than in-person or web-based workshops. In the absence of a formal

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agenda, experts are more likely to provide unanticipated but useful information. In our experience, a personal relationship with the expert increases the odds of a successful one-on-one interaction and subsequent interest in project outputs. The project team can build trust and rapport with experts by meeting in a location and atmosphere that is comfortable for the expert.

3.2.4. Online collaborative tool

A major challenge to collaborative projects is obtaining continued involvement of participants. Data Basin is one of several online, GIS-based tools available to display two dimensional maps or three dimensional landscape visualizations of alternative landscape futures (Lovett, 2005) to aid in both urban and natural resource planning. When choosing and employing such tools, project teams must be cognizant of the strengths and weakness of the approach (Pettit et al., 2011) and should clearly communicate the assumptions underlying each alternative landscape and the limitations of the visual material (Monmonier, 1996; Sheppard, 2001).

These tools allow continued review and discussion of project materials at experts' convenience outside of scheduled workshops or meetings. The Data Basin project gallery was effectively used during and after web-based workshops and to supplement one-on-one interactions. However, the natural resources experts we engaged tended to prefer discussing forest conservation issues in the field, and efforts were made to engage these experts through one-on-one interactions. The project team may need to regularly send announcements and project updates to keep experts involved in the online collaboration. At this time, access to this project on Data Basin is still 'by invitation only' to workgroup members but will be publically accessible.

3.3. Implications

Integrating expert knowledge into scenario analysis and landscape modeling provides a mechanism for managing uncertain futures, allowing us to imagine future landscapes for which there may be no past analogues. This approach presents unique challenges – coupling technology with experts' imagination and creativity to produce useful outcomes can be difficult and sometimes infeasible with the available modeling tools. Some limitations are unavoidable; some situations simply cannot be modeled. Alternatively, software capable of modeling such situations may be available, but its use could be prohibitive due to intensive input requirements, platform limitations, applicability to end-users, or other constraints. Project teams should explicitly communicate with experts the rational for their choice of approach and modeling platform as well as the strengths and weaknesses of these tools (c.f. Scheller and Mladenoff, 2007; Sturtevant et al., 2007).

In addition, there can be a conflict between model complexity and expert input. As model programming and parameters become more complex, more effort may be needed to frame issues, questions, and processes for experts. Many practitioners do not think in terms of parameterization, disturbance probabilities, or algorithms. Therefore, model transparency is paramount (Mendoza and Prabhu, 2005; Sturtevant et al., 2007). From our experience, it was worth our time to produce schematics, visuals, and explanations of our modeling concept at the front end of an expert workshop so that professional, non-modeling experts are on the same page. This allowed the project team to collect expert knowledge in formats more familiar and accessible to local experts (e.g. fire return interval) and convert to another format required by the model (e.g. annual probability of fire).

Furthermore, spatial modeling outputs (e.g. maps and indices) of landscape futures alone do not explain why conditions changed from time step to time step. Instead, spatial narratives derived through collaborative interactions with experts with place-based knowledge (Silbernagel, 2005) provide a richer, more complete understanding of the drivers underlying landscape change. With so many variables in a natural system, there will be important drivers or responses of landscape dynamics that cannot be addressed by the quantitative modeling process as well as they can in qualitative spatial narratives. Thus, a spatial narrative approach can be a way of filling in gaps and making the project useful to a wider audience (Carpenter et al., 2006).

However, a project team may be tempted to push difficult modeling questions to the spatial narratives for convenience, especially in the face of a challenging effort to learn modeling software, select parameters, and adapt spatial data. Construction of a valid and insightful narrative involves equivalent effort by the project team and experts. Relevant spatial narratives result from a rigorous collaborative effort to search notes, recordings, and output, and to think about and discuss the plausible stories that led to the futures indicated by the modeling output.

Our approach recognizes and handles an uncertain future but does not reduce such uncertainty. The likelihood of one scenario over another cannot be measured, and results should not be considered predictions. As Scheller and Mladenoff (2008) explain, scenarios should be regarded as experiments and interpreted in context with and comparison to the alternative scenarios examined.

Landscape models informed by expert opinion are also uncertain. While a complete discussion of model uncertainty is beyond the scope of this work, we provide a brief overview below to summarize current thought. Uncertainty in these models is commonly divided into three components – modeled ecosystem stochasticity, uncertainty of an individual expert, and between expert uncertainty (Czembor et al., 2011). Natural ecosystem stochasticity is often captured by multiple Monte Carlo simulations or similar methods in which values are sampled from distributions for specific parameters, which can be based on historical data or future projections.

The uncertainty of individual experts can be estimated through self-assessment techniques (Drescher et al., 2008), bounded sensitivity analysis (Czembor et al., 2011), and other statistical methods. Kuhnert et al. (2010) suggest eliciting a quantitative confidence interval or probability distribution rather than a single parameter value from single experts. However, individual confidence intervals are often overestimated, and the degree of overestimation is influenced by the format of questions used to elicit the interval (Speirs-Bridge et al., 2010).

Between expert uncertainty results from disagreement between experts and is often overlooked by methods that reduce the opinions of many experts to a singular parameter value, such as forced consensus among experts, Delphi methods, or averaging expert responses. However, between-expert uncertainty should be explicitly considered when parameterizing models and interpreting results. Drescher et al. (2008) suggest that uncertainty of expert knowledge of forest succession is generally high, especially for systems with high species diversity and moderate site conditions, implying that an acute awareness of uncertainty is necessary when modeling these systems. Failure to consider model uncertainty may result in overconfidence in model results and undermine the reliability of decisions based on those results.

While the use of expert knowledge introduces additional sources of model uncertainty, published research alone often does not provide the detailed, site-specific information necessary to develop alternative landscape scenarios or to fully parameterize spatially explicit landscape models. As noted previously, forestry practitioners are often the only source of information about forest succession and dynamics, especially at local scales (Drescher et al., 2008). In addition, experts are the only source of information regarding the current and future management strategies employed on these landscapes, especially on private lands. As a result these models are, by necessity, a synthesis of previous research (e.g. LANDFIRE and peer reviewed literature), empirical data (e.g. fire data from the DNR), and expert knowledge. The iterative process of eliciting expert feedback on model results is crucial for refining models and scenarios and producing reasonable results. In addition, failure to engage experts affiliated with the agencies and organizations responsible for the management of the study areas could reduce the perceived credibility and subsequent utilization of project results.

4. Conclusions

To be effective, the conservation community must constantly seek innovative means to protect lands and waters, manage natural resources, and match public policy with conservation goals. The working forest conservation easements described here provide one example of such innovation, allowing for the distribution of limited conservation funds across larger landscapes (i.e., "distributed conservation," Silbernagel et al., 2011) than would be possible with more traditional, fee-simple protection. Careful planning, rooted in scientific literature, generally precedes such conservation work. However, because the pace of conservation is driven by ephemeral alignments of opportunity and funding, the development and application of conservation strategies is rapid and often outpaces the availability of supporting information from peer-reviewed publications. While outcomes of these strategies will certainly become evident over time and through long-term monitoring efforts, the ability to envision possible futures resulting from untested strategies provided by this approach is crucial to evaluate, adapt, and inform ongoing and future conservation efforts. Furthermore, cost–benefit analysis similar to the approach described by Low et al. (2010) can be used to capture the budgetary considerations that also underlay decisions about how conservation strategies are arranged on the landscape.

Where conservation practices step beyond the support of peer-reviewed publications, information from experts can provide helpful data and insights that have not yet been published. In addition, a wealth of information can be gained from those experts whose knowledge base is not typically found in publications. Likewise, if the insights resulting from collaborative scenario building and modeling efforts are to be considered and adopted by decision-makers, researchers must reach beyond academic publications to present their findings in outlets focused on practitioners and decision-makers. For example, the results from this study will be presented at a regional conference focused on sharing tools for sustaining western Great Lakes forests. Ideally, conservation practitioners, land managers, and scientists in attendance at the conference can integrate this and other techniques into their own forest management efforts. Careful planning and preparation for interactions with experts, as examined in this study, combined with a spirit of adaptability and a willingness to follow unexpected leads and insights, can lead to a more thorough understanding of the implications of conservation actions. Indeed, successful collaboration increases the validity and transfer of results to those involved in making management and policy decisions affecting landscape conservation.

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