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ALCES Online: Web-delivered Scenario Analysis to Inform Sustainable Land-use Decisions

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Abstract: Simulation models are yet to reach their potential to inform environmental sustainability, in part due to inaccessibility. ALCES Online (www.online.alces.ca) addresses this deficiency through web-delivery of high quality scenario analysis to individuals lacking a modeling background. The simulator is available for the province of Alberta, Canada, and efforts are underway to create versions for additional jurisdictions. The underlying scenario analysis is holistic through incorporation of a diverse set of drivers and indicators. Simulated land uses include energy, agriculture, mining, forestry, and human settlements; natural drivers such as fire are also included. Environmental and socioeconomic consequences are conveyed by tracking indicators related to landscape composition, wildlife, ecosystem services, and the economy. Dynamics are simulated spatially, and indicator performance presented using maps and regional summaries. Simulations span three time periods: pre-industrial, past century, and next 50 years. The pre-industrial phase informs baselines from which to assess land-use impacts. Simulation of the past century reconstructs changes caused by historical land use, thereby demonstrating capacity for land use to alter ecosystems over meaningful time. A range of future (50 year) simulations allow the user to assess potential consequences of decisions related to development rate, management practices, and ecosystem protection. To facilitate application across diverse initiatives, ALCES Online is customizable through user-defined study areas, indicators, and land-use strategies.

Keywords: land-use planning, integrated modelling, scenario analysis, stakeholder engagement, web application.

1. BACKGROUND

Planning land use to balance the often competing objectives of economic growth and ecological integrity is a complex undertaking due to the diversity of factors and interests involved. Reductionist approaches that seek to manage individual land uses or issues in isolation are ill-equipped to manage problems such as environmental degradation that emerge as the result of multiple activities unfolding over large regions and long timeframes. Recognition of the multifaceted nature of land-use issues motivated the development of integrated approaches to planning such as integrated environmental management (Cairns and Crawford 1991). Such approaches adopt a holistic perspective, requiring assessment of the cumulative effects of multiple land uses on socioeconomic and environmental values over large temporal and spatial scales (Carlson and Stelfox 2009). Land-use planning is also multifaceted with respect to participants and, from an operational perspective, integrated planning requires interaction among the numerous agencies and stakeholders influenced by regional land use (Margerum 1999).

Cumulative effects assessment and stakeholder engagement required for integrated planning are both aided through computer modeling. Computer models offer a formalized process for synthesis and application of knowledge when assessing the multitude of interacting variables relevant to cumulative effects. In addition to integrating knowledge, computer models can facilitate integration among planning participants by fostering a common understanding of system dynamics, thereby informing objective debate during decision making. The utility of modeling to integrated planning is well recognized and many examples exist. Its use is not as prevalent as it should be, however, and several challenges are preventing full realization of modeling's potential as a land-use planning tool. Perhaps chief among these challenges are the need for increased stakeholder involvement and more integrated and holistic modeling approaches (Laniak et al. 2013, Moore and Hughes 2013, Gaber et al. 2008).

In this paper, we describe ALCES Online (www.online.alces.ca), an initiative that seeks to deliver holistic scenario analysis in a format accessible to planning participants lacking a computer modeling background. Our approach is to simulate the long-term consequences of land-use scenarios to diverse indicators across very large regions, but in sufficient spatial detail to be meaningful at local planning scales. Simulation outcomes are then used to populate a web application that allows stakeholders to view historical and potential future environmental and socioeconomic changes associated with the scenarios, and also investigate customized scenarios and indicators of interest. We present ALCES Online in the context of Alberta, a 660,000 km2 province in western Canada. Alberta was selected as the first jurisdiction for ALCES Online development due to the diversity of land use issues facing the province (Stelfox 2010) and the presence of numerous promising integrated planning initiatives. ALCES Online is now presented by explaining the approach for simulating past and future land-use impacts, describing the ALCES Online web application, and outlining priorities for future ALCES Online development.

2. MODELING APPROACH

Three types of simulations were completed for ALCES Online: predisturbance, hindcast, and forecasts. The predisturbance simulation demonstrates plausible landscape dynamics in the presence of natural ecological processes prior to the emergence of industrial development. The hindcast simulation approximates how land use, landscape composition, and related indicators have changed over the past 100 years, from 1910 to 2010. A suite of forecast simulations explore potential future changes over the next 50 years in response to development rate, management practices, access management, and protection. The simulations were completed using ALCES Integrator and Mapper. Described in greater detail elsewhere (Carlson et al. 2010), these models achieve a synoptic view of cumulative effects by including a wide-range of land uses and ecological processes as drivers. Energy, forestry, mining, agriculture, human settlements, and fire were included in the simulations completed for ALCES Online. Using an annual time-step, ALCES Integrator simulates regional land use and natural disturbance trajectories and their consequences to the area, edge, and age of natural and anthropogenic land cover. ALCES Mapper is then applied to spatially distribute the consequences of regional land use trajectories, using information related to the likelihood of development and expected levels of aggregation. Spatially explicit changes in landscape composition in response to simulated trajectories are tracked, and applied to assess implications to indicators related to wildlife, ecosystem services, and the economy.

Where possible, simulations were parameterized using publicly available data to promote transparency. The current composition of the province was based on 2010 land cover and footprint data derived by the Alberta Biodiversity Monitoring Institute (ABMI) from various sources. Natural land cover classes spanned a number of forest, grassland, wetland, and aquatic types, whereas anthropogenic land cover included a number of footprints related to energy development (wells, seismic lines, pipelines, industrial plants, roads), mining (pits, roads), forestry (cutblocks, roads), settlements (towns, rural residential, recreational features), and agriculture (crops, pasture, feedlots). Forest age was not included as an attribute in the ABMI data, and instead was derived from a national forest age dataset (Pan et al. 2011) and corrected to incorporate more detailed information regarding the location and date of timber harvest and wildfire. The 2010 land cover data was then used in simulations as an end-point from which to hindcast historical land use and as a start-point from which to simulate future changes in response to land-use scenarios. Prior to application in simulations, the polygonal land cover data was intersected with a grid to calculate the area of each anthropogenic and natural land cover type within each 6.25 km2 cell. Simulations then tracked changes to each cell's composition in response to disturbance and reclamation.

A hindcast simulation created maps at decadal intervals depicting the historical transformation of Alberta's landscape over the past century (1910 to 2010). The hindcast provides important context during planning by illustrating how land-use issues have emerged and emphasizing that current conditions often differ substantially from pre-industrial conditions. The general approach was to start with today's (i.e., 2010) landscape composition and remove anthropogenic footprints at rates consistent with available historical land-use and fire data. Energy sector footprint expansion was based on the drilling dates of hydrocarbon wells. Farmland expansion was based on dates of first cultivation recorded in historical soil scientist reports. Town growth was based on historical population data and aerial photographs, whereas rural residential growth was based on drilling dates of water wells. During the hindcast, area removed from current anthropogenic footprint was converted to natural land cover types in a manner consistent with the estimated preindustrial composition of a given cell. Historical change in forest age was approximated using cutblock and fire data, and by assuming a gradual shift from an estimated natural to current age-class distribution.

Forecast simulations were 50 years in length, and required derivation of plausible trajectories for each land-use sector over that period. Trajectories for most sectors, including forestry, agriculture, mining, and human settlements, were based on recent trends. Trajectories for the production of various hydrocarbons (conventional gas, coalbed methane, shale gas, conventional oil, bitumen) were informed by projections developed by the province's energy regulator (ERCB 2013). In addition to the rate of development, assumptions were required regarding the intensity and lifespan of associated footprints. Where possible, these assumptions were based on existing patterns such as the average amount of energy sector footprint (seismic lines, pipelines, industrial plants) created per production well. Fire was also simulated using the average burn rate over the past 80 years. The location of fire was random, except that burn rates differed between the southern and northern portions of the province to reflect the observed pattern of substantially less fire in the south, presumably in response to higher fire suppression effort. The size of individual fire events varied according to the observed size-class distribution in recent decades.

In the forecast simulations, the spatial distribution of footprint reclamation was based on footprint age (i.e., older footprints reclaimed first). Future land use was spatially allocated using a random process guided by assumed spatial differences in the relative likelihood of each land use. For example, energy exploration was distributed relative to hydrocarbon reserves and expected regional differences in development rates, whereas timber harvest was distributed relative to annual allowable cut. Across all land uses, footprint expansion was not permitted in protected areas and, in some cases, other land-use designations such as military reserves and First Nation reserves. In addition to spatial differences in the likelihood of development, allocation of land use was influenced by the expected distribution of disturbance intensity across cells. For a given type of disturbance (e.g., oil well), current land cover data were analyzed to calculate the frequency of different footprint intensities across cells (e.g., percent of cell covered by oil wells). The relative frequency of the footprint intensities were then used as a guide when distributing development across the cells.

A suite of forecast scenarios incorporated four types of levers: development rate, management practices, access management, and protection. Simulated development rates included low, moderate, and high, with the moderate scenario parameterized to represent a plausible trajectory. Sectors that have exhibited relatively stable production in recent years (i.e., forestry, agriculture, coal) were simulated to remain at current levels of production throughout the moderate scenario. For the more volatile energy sector, the moderate scenario was based on projections developed by government agencies (ERCB 2013, NEB 2011) and other experts (CERI 2011). Human population, on the other hand, was simulated in the moderate scenario as a continuation of recent (i.e., past 15 years) trends. The high and low development scenarios were ±25% relative to moderate, with the exception of the agricultural sector which maintained the current level of production across all three development rate scenarios. After growing rapidly throughout much of the 20th century, growth in farmland in the province plateaued in recent decades as land with agricultural potential became scarce. Due to the scarcity of suitable land, the expansion of farmland in all scenarios was limited to that which was required to compensate for the loss of existing farmland to competing land uses such as settlement expansion. Scenarios also assessed three levels of management practices: basic, improved, and optimistic. The basic scenario reflects minimal effort to reduce environmental impacts, the improved scenario reflects a concerted but realistic effort, and the optimistic scenario reflects an aggressive effort. The scenarios involved strategies that alter environmental impacts without changing the development rate, such as urban intensification, coordinated development of industrial footprint, accelerated reclamation of industrial footprint, nutrient conservation on farmland, water conservation, and emission intensity reduction. Access management was also simulated at basic, improved, and optimistic levels, which influenced the extent to which hunters and anglers were assumed to use industrial footprints to access fish and wildlife populations for harvest. An additional scenario assessed the consequences of preventing future expansion of land use, as could occur through expansion of a protected areas network.

Total footprint area during the hindcast and forecast of the moderate development scenario is summarized in Figure 1. During the first half of the 20th century, much of southern Alberta was converted from natural land cover to farmland, causing a rapid expansion in anthropogenic footprint. The second half of the 20th century saw a slowing of farmland growth but continued expansion of settlements in south-central Alberta and accelerated industrialization of the forested region for timber and hydrocarbon production. Over the next 50 years, footprint was simulated to increase at the same rate as in recent decades, with industrial development focused in those regions containing unconventional hydrocarbons such as bitumen in northeastern Alberta and shale and tight gas in the foothills of the Rocky Mountains.

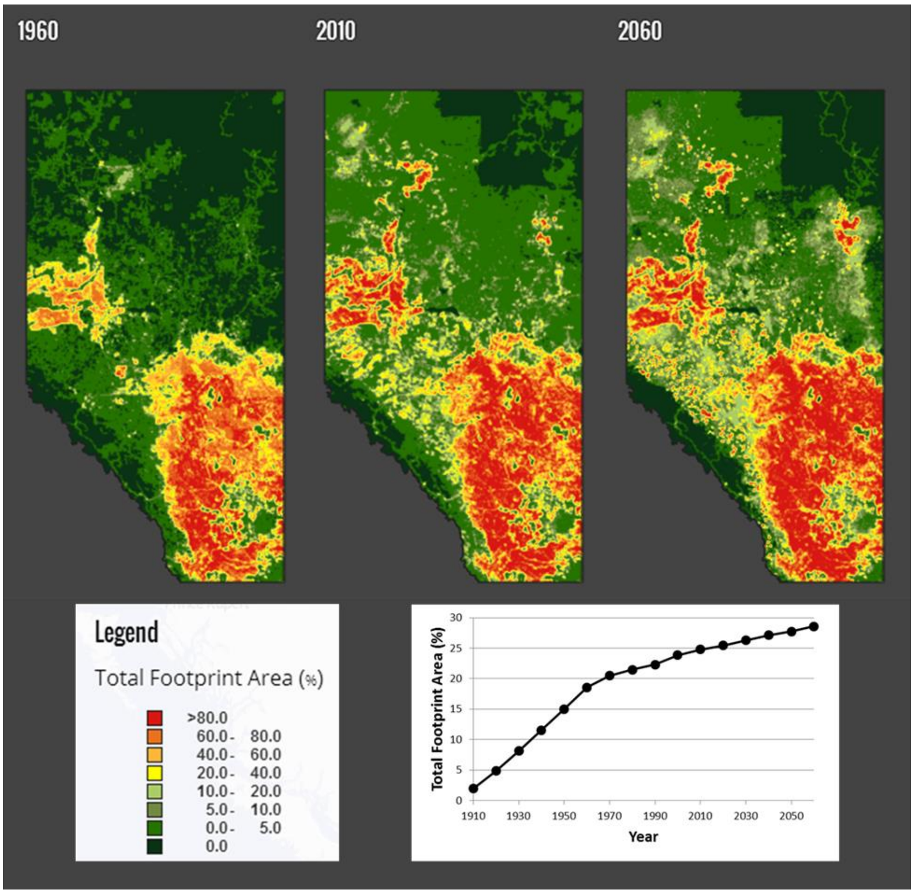

Figure 1. Total footprint area in Alberta during the hindcast and moderate development rate forecast. For brevity, spatially explicit output is only shown for three of the sixteen reporting years (1960, 2010, and 2060).

Indicator models were applied to simulated past and future changes in landscape composition, resource production, and human population to explore consequences to the economy, wildlife, water, and air emissions. Employment, gross domestic product, and royalties associated with natural resource production were estimated using coefficients derived from recent economic data. Wildlife indicators included habitat indices for biota targeted by hunting (moose), trapping (fisher), gathering (edible berries) and angling; empirically derived indices conveying risk to the threatened grizzly bear and woodland caribou; and an old forest bird index based on bird density relationships provided by the Boreal Avian Modeling Program. Water use was calculated from simulated patterns in land use by applying water use intensity coefficients derived from provincial water use data, whereas water quality was calculated from simulated landscape composition by applying nitrogen, phosphorous, and sediment runoff coefficients that varied by land cover type, natural region, and management practice. Emission of greenhouse gases, sulphur oxides, and nitrogen oxides were calculated from simulated land-use patterns by applying emission intensities derived from greenhouse gas and pollutant release inventories.

The index of native fish community integrity provides an example of indicator response to historical and potential future land-use dynamics. The index ranges from 1 (natural) to 0 (highly disturbed) and applies relationships derived from expert opinion to incorporate impacts of expanding anthropogenic footprint such as angler access and fragmentation of stream habitat (Sullivan 2009). The INFI declined during the hindcast as anthropogenic footprint expanded, a pattern consistent with fish population declines that have been witnessed in the developed portion of the province (Post et al. 2009). As land use continues to expand into the forested portion of the province during the forecast, so too does the region exhibiting depressed INFI levels. Integrity of the fish community can be marginally improved by implementing improved management practices and access management (Figure 2).

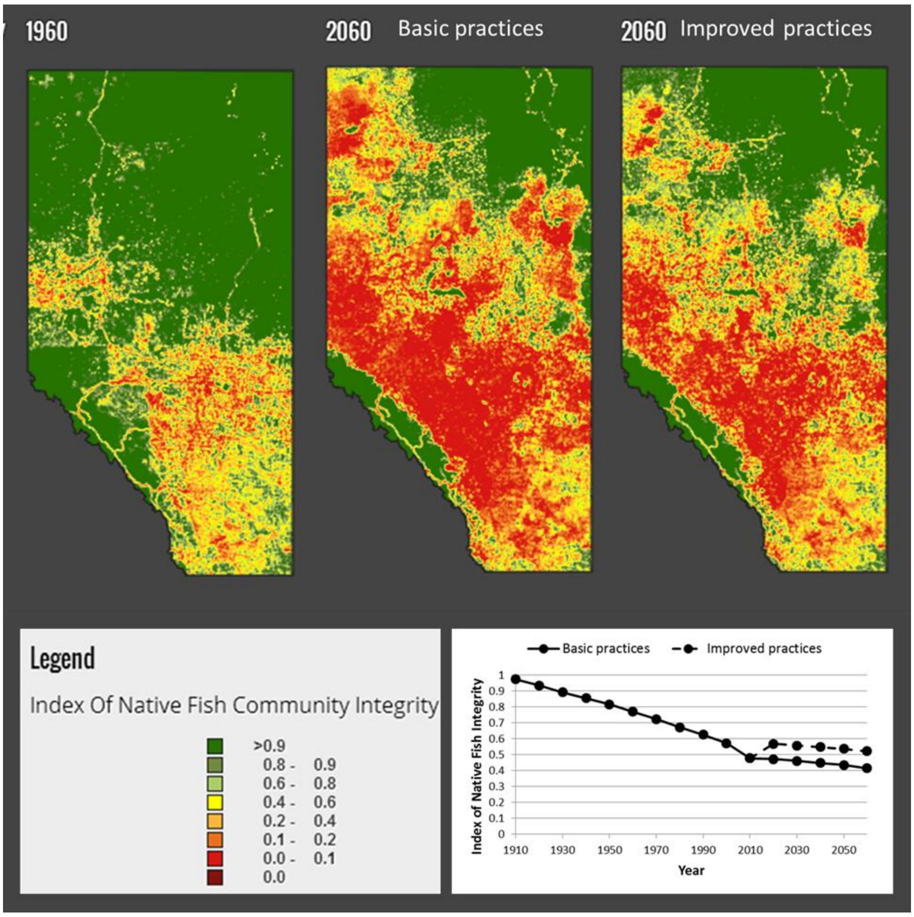

Figure 2. Index of native fish community integrity response during the hindcast and two forecast scenarios, basic and improved practices. For brevity, spatially explicit output is only shown for two of the sixteen reporting periods (1960 and 2060).

3. WEB-DELIVERY OF SIMULATION RESULTS

As discussed previously, computer models are an effective medium for holistic assessment of the consequences of land use. By integrating diverse knowledge to assess potential futures, computer models help users make sense out of otherwise overwhelming complexity. Further, by permitting iterative exploration of land-use options, computer models provide an interactive environment within which to test strategies. Too often, however, active use of simulation models is limited to scientists armed with the time and expertise to apply software that is typically complex and poorly suited for dissemination to non-experts. Outcomes of simulation exercises are instead conveyed to planners and stakeholders through other mediums such as reports and presentations, which struggle to provide the same level of synthesis and interaction. As a result, the full potential of simulation modeling is not realized where it matters most, i.e., informing those responsible for making future land use decisions.

ALCES Online is a web application designed to allow non-experts to visualize, customize, and compare land-use simulations. The application provides an intuitive interface from which to access simulations, requiring just three basic steps: selecting the study area of interest; selecting the indicator of interest; and selecting the scenario of interest (Figure 3). These commands are used by ALCES Online to query a database of simulation outcomes stored on a server. The results of the query are used to create a series of maps showing indicator behaviour prior to industrial development; over the past 100 years; and during the next 50 years in the presence of the selected land-use scenario. Maps are provided for the user-defined region at a resolution of 6.25 km^2. Alternatively, coarser resolution maps can be created that summarize indicator performance across political (e.g., municipalities) or ecological (e.g., watersheds) units. Outputs are also reported as graphs or scatterplots, including an option to create graphs that compare indicator performance across multiple scenarios. Outputs can be exported as an ESRI shape or comma-separated values (CSV) file for spatial output, and as a CSV file for regional summaries. Through the use of a customized database management system, ALCES Online is able to rapidly (i.e., seconds) access data and render maps and graphs, providing a seamless environment within which to explore the consequences of numerous simulations to a diverse set of indicators. An online tutorial provides guidance on how to use ALCES Online to access and explore land-use scenarios, and customized training workshops can also be arranged.

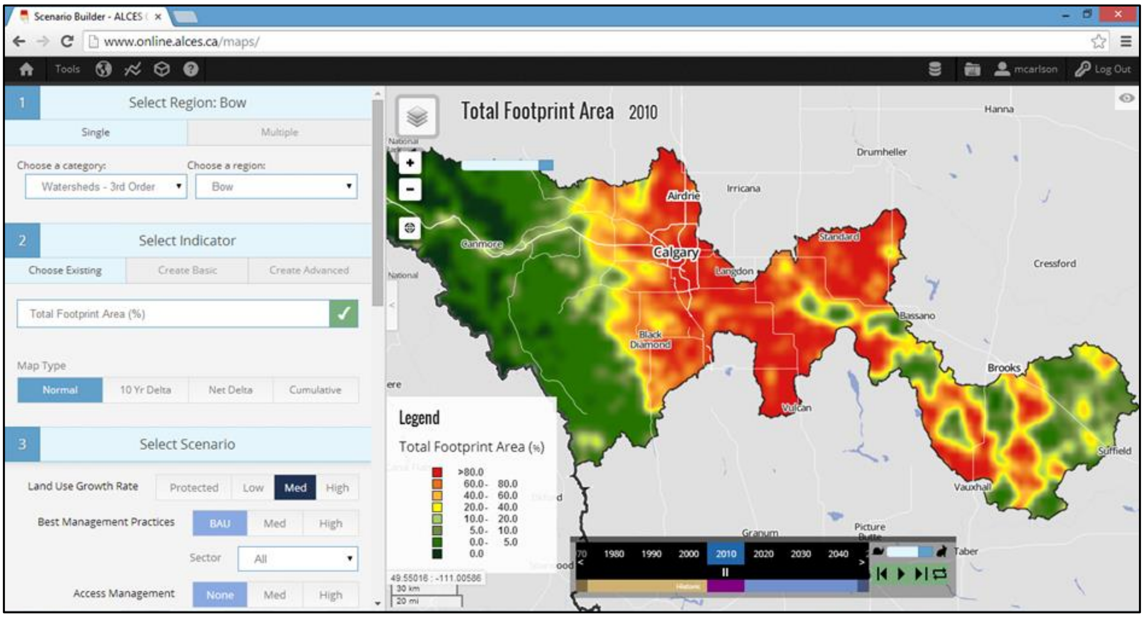

Figure 3. The ALCES Online interface. The three steps for accessing simulations are shown to the left: 1) select the study region, which in this example is the Bow River watershed; 2) select an indicator, which in this example is total footprint area; and 3) select a scenario, which in this example is moderate development rate with basic practices and no access management.

Although assessment of cumulative effects is a common land-use planning need, specifics invariably differ across initiatives. Examples include which indicators (e.g., wildlife species) are of interest, and scenario details such as the location of proposed protected areas. ALCES Online allows users to develop customized indicators and scenarios in order to satisfy their planning needs. Customization is achieved through the integration of simulation outputs, thereby providing flexibility while also maintaining accessibility through the ALCES Online interface. A customized indicator is created by defining its relationship with one or more attributes tracked by ALCES Online (e.g., landscape composition, forest age, resource production, human population, etc.). Two calculators are available within ALCES Online for defining indicator relationships. Using the basic calculator, synthetic indices are defined that integrate multiple attributes through the application of weights. The advanced calculator can be used to define more complex relationships involving nonlinearities such as habitat thresholds, coefficients that modify through time such as a gradual reduction in water use intensity, and interactions between explanatory variables such as a habitat attribute that is only beneficial if other conditions also exist. Once an indicator is defined, its response to historical and potential future scenarios can be explored. Customized scenarios can also be created by establishing zones that differ with respect to which land use strategies (i.e., protection, low/moderate/high development, basic/improved/optimistic practices or access management) are applied. A simple example is exploration of a series of protected area networks that differ with respect to the areas removed from development. Once a zoning strategy has been defined, ALCES Online can assess consequences to indicators by integrating simulation outputs and rendering outcomes as maps and graphs.

Other features available within ALCES Online add to its utility for exploring land use and its consequences. High resolution satellite imagery allows users to view landscapes that vary with respect to land-use patterns, and numerous overlays are available that depict the current spatial distribution of features such as anthropogenic footprint types. Users can save multiple way-points at different spatial scales to efficiently recall key site locations important to land use discussions. Quantitative exploration of relationships is provided through scatterplots, which can be used to visualize the relationship between two to four variables, and how the relationship changes in response to simulated historical and future land use.

ALCES Online is made available to organizations through subscriptions, whereby access to the internet software and underlying analyses is provided for an annual fee. The annual fee funds ongoing revision of the simulations as better information becomes available, expansion of the suite of scenarios and indicators, and improvements to the web interface. This organizational model, whereby subscriptions are pooled to fund research beneficial to a multitude of organizations, is far more efficient than repeating customized but similar analyses for individual clients. Beneficial implications include reduced cost for organizations to access cumulative effects scenario analysis and more rapid improvement in scenario analysis capacity. The subscription model has also facilitated collaboration with organizations (i.e., clients) whose diverse expertise has contributed to improvements such as revised trajectories that reflect local knowledge, and whose diverse demands have shaped the evolution of ALCES Online to better serve a range of needs. Improvements are typically made available to all clients, although in some cases access to customized indicators or scenarios is restricted to respect data-sharing concerns. Another benefit of ALCES Online is that, by reducing the need for repetitive scenario analysis, the tool has increased our availability to assist organizations with the interpretation and application of scenario analysis outcomes, for example by leading stakeholder workshops to inform the development of a land-use plan for a military base in southern Alberta.

4. NEXT STEPS

After two years of development, ALCES Online became available for Alberta earlier this year. Early applications include regional planning led by the provincial government, assessing the consequences of land use to First Nation traditional territories, exploring alternative land use trajectories in Alberta's East Slopes, and aiding the development of a land-use planning for a military base. In the coming months, we expect application of ALCES Online to expand to also include municipalities, watershed councils, and natural resource industries.

Early application of ALCES Online has been useful for identifying priorities for enhanced functionality. A number of initiatives are underway to expand the suite of indicators tracked by ALCES Online. Examples include integration of ALCES Online with a hydrological model; incorporation of population census data to explore relationships between land use and social attributes; and parameterization of additional wildlife models in Alberta's prairie region using relationships derived from biodiversity monitoring data and expert opinion. We are also working to expand the suite of scenarios that are available, most importantly by adding capacity to explore climate change impacts through shifts in plant communities and agricultural potential, changes to precipitation and temperature, and altered natural disturbance rates.

Early evidence suggests that ALCES Online's strategy of disseminating holistic scenario analysis through a web application is achieving the objective of increasing involvement in the modeling process. Individuals lacking a modeling background are using ALCES Online to explore the consequences of land use, including in workshop settings. With the advent of the tool, we have witnessed a rapid shift in our role from that of providing land-use planning recommendations based on simulation outcomes, to instead providing planners and stakeholders with modeling tools that they use to investigate opportunities for balancing land use benefits and liabilities. This is a welcome development, as it delivers insight directly to those involved in the decision making process. Based on the success of ALCES Online in Alberta, versions are being developed for additional jurisdictions including the provinces of British Columbia and Manitoba, as well as jurisdictions in India and Australia. We encourage others to undertake similar initiatives to disseminate their modeling tools to allow computer modeling to more fully meet its potential for informing sustainable land-use decisions.

6. ACKNOWLEDGMENTS

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