Representing Ecosystem Services:
Three Perspectives on Modeling the Benefits from Nature

June 2013

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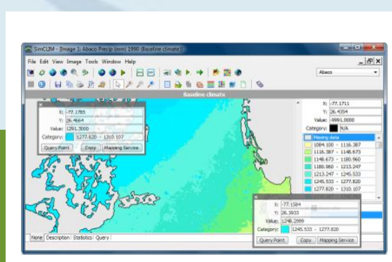
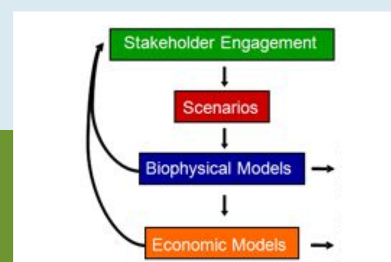
MIISTAKIS INSTITUTE





Prepared for the:

Ecosystems Services for Environmental Innovation and Competitiveness project

Preface

This report is a project milestone document provided under the agreement between the Miistakis Institute and the Alberta Biodiversity Monitoring Institute (ABMI), lead agency of the *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* (ESA) project.

The purpose of ESA project is to establish relevant and credible systems for assessing ecosystem services and biodiversity across Alberta. These systems include the biophysical and socioeconomic information used to map biodiversity and ecosystem services across the province, internet-based services to distribute these maps and supporting documentation, and tools that allow people to apply this new capacity to land-use and management decisions. By creating economic and regulatory incentives for conservation and stewardship, markets for ecosystem services can guide people's behaviour in directions that support desired environmental and socioeconomic outcomes. The ESA project goals are to establish systems for assessing ecosystem services in Alberta, and to evaluate tools for applying the information derived from these systems to environmental markets and land-use management.

The Miistakis Institute became involved in the *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* (ESA) project, when the joint Miistakis/ABMI *Understanding Landscape Value* (ULV) project was rolled into the ESA project recognizing the complementary goals, the value in streamlining multiple Alberta-based projects, and the opportunity to leverage resources.

EXECUTIVE SUMMARY

The ecosystem services approach is fast becoming the dominant paradigm when considering the sustainable use of the world's natural resources. As resource managers in Alberta seek more frequently to adopt the ecosystem service paradigm, key challenges arise regarding inaccessibility of models, lack of data, poor understanding of regulatory applications, inadequate value measures, supply-side bias, disconnected ecological research.

In 2011, Miistakis partnered with the Alberta Biodiversity Monitoring Institute (ABMI) to launch the *Understanding Landscape Value* (ULV) project in recognition of the lack of methods for measuring the values of ecosystem services. The ULV project rolled into the larger ABMI-led *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* project.

The Miistakis Institute's role in that larger project includes four roles, one of which is a higher-level review of ecosystem services mapping and modeling. This report represents the results of that review focused on three key concepts/questions:

- How do ecosystem services, biodiversity and climate change link conceptually;
- What ES mapping and modeling tools are available that would be usable by local decision makers; and
- How applicable is a given tool (in this case, InVEST) to the existing data and policy context of Alberta.

To guide efforts in making connections between climate change, biodiversity, local communities, natural capital, resilience and ecosystem services, Miistakis developed a simple conceptual model. The ecosystem, or natural capital, is characterized by a stock of capacity, and by a flow of advantages that enrich humans at multiple levels ("human well-being"). Those flows were characterized to begin as a series of ecological functions, ecosystems services were represented as a utilitarian view of ecosystems (the human-defined benefits associated with ecological function), and biodiversity not as an ecosystem service, but "a necessary condition for ecosystem services to be delivered" (Scholes et al 2010).

Human activity has an impact on ecosystems and the services they provide, a feedback flow that was characterized as land and resource management. Natural resilience approaches are characterized as increasing the self-regenerative capacity of the ecosystem, tending to be proactive, comprehensive, and less expensive over time.

Mapping ecosystem services (ES), climate change adaptation (CCA), and biodiversity is an important step in visualizing, analyzing and identifying knowledge gaps of both current and projected landscapes. The second perspective reviewed the use of ES mapping tools to determine current activity, lessons to be learned, and limitations.

Mapping tools were divided into the three major areas of use: 1) process, 2) analysis, and 3) education and delivery. Examples of process-based mapping tools reviewed were DataBasin, and the Wildlife Observation Mapping Tool; analysis-based tools were SimCLIM, InVEST, ARIES, the Developable Lands tool; education and delivery tools reviewed were Ecosystem Services Carbon Calculator, NatureServe Explorer, and Environment Canada's Scenario Maps.

An important distinction was found between *online tools* (used largely through a web browser), and *GIS-based tools* (used either stand alone or through a GIS software application), with advantages and disadvantages to both. A significant issue identified with providing tools to a large user group is dealing with the different (and often low) levels of capacity.

A review of the InVEST ecosystem services modeling suite created a third perspective on representing ecosystem services, assessing its modeling capacity, and technical and data requirements with respect to Alberta. A tiered structure makes InVEST flexible with regard to the quality of available data and desired modeling outputs. Inputs include spatial and thematic data and expert opinion, producing spatial and tabular outputs.

The model was reviewed against the five ecosystem services chosen by the ESA project (rangeland production, forest production, pollination of agricultural crops, water purification, and biodiversity) as InVEST has modules for all of these services except rangeland production.

The authors drew the following conclusions:

- Ecosystem services may be the best way to connect biodiversity and local decision making, as the 'utilitarian' character of ES resonates with Albertans.

- Climate change, biodiversity, local communities, natural capital, resilience and ecosystem services have intuitive conceptual linkages; framing these connections conceptually illustrates how management can be proactive and resilience-based.

- The quality and availability of data is not uniform across the province, with access to spatial data in Alberta a perennial challenge.

- Mapping ecosystem services with reference to biodiversity and climate change adaptation is important but complex, requiring expert knowledge, and a tool that will need to distill information in a manner that is clear to decision makers.

- The InVEST modeling suite is robust, scalable, and credible due to widespread meaningful use and may have great utility for addressing questions and research objectives of the ESA project.

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INTRODUCTION

Context

The ecosystem services approach is fast becoming the dominant paradigm when considering the sustainable use of the world's natural resources. This approach firmly roots humans within ecological systems, making us explicitly conscious of the ecosystem services on which we broadly rely for human well-being. For this reason, the Miistakis Institute has undertaken a number of ecosystem service-based projects, seeking to better understand, and better utilize this approach in promoting natural resource conservation work.

Key challenges in the adoption of this paradigm include (in no particular order):

- Inaccessibility of academic data and models for management-level decision makers;
- Lack of data to support ecosystem service-based decision making;
- Limited understanding of the regulatory-based ecosystem service applications;
- Difficulties in measuring the human well-being benefits associated with given ecological features and functions;
- Prevalence of dialogue around the supply side of ecosystem services (who is selling) at the expense of the demand side (who is buying);
- Research measuring ecological structure and function being disconnected from associated benefits and human well-being;

In 2011, the Miistakis Institute partnered with the Alberta Biodiversity Monitoring Institute to launch the *Understanding Landscape Value* (ULV) project. This project arose in recognition of the increasing deference to ecosystem service-based management approaches, but the lack of associated methods for measuring the values of ecosystem services. As described below, the ULV project rolled into the larger ABMI-led *Ecosystem Services for Environmental Innovation and Competitiveness* project.

The Miistakis Institute's role in that larger project includes four roles, one of which is a higher-level review of ecosystem services mapping and modeling. This report represents the results of that review.

Goal of this Report

Applying the ecosystem services approach to the policy and management realms of resource use and conservation in Alberta requires an understanding of factors ranging from 'high-level conceptual' to 'on-the-ground' applied. More importantly, it requires stitching these different scale perspectives together.

As the Miistakis Institute was also working on the ABMI-led *Biodiversity Management and Climate Change Adaptation* project, this created an opportunity to cross-pollinate the research, and recognize synergies between the two projects' need to develop a deeper understanding of this challenging conceptual-applied dynamic of ecosystem services.

Recognizing the challenges with the ecosystem services paradigm listed above, Miistakis undertook a pre-scoping exercise regarding how ecosystem services could be represented conceptually, cartographically, and pragmatically in the Alberta context. This report is intended to review three key concepts/questions aimed at connecting the conceptual and the applied in terms of representing ecosystem services:

- How do ecosystem services, biodiversity and climate change link conceptually;
- What ES mapping and modeling tools are available that would be usable by local decision makers; and
- How applicable is a given tool (in this case, InVEST) to the existing data and policy context of southern Alberta.

Structure of this report

The structure of this report follows the above three questions directly[1].

- As the heading describes, *Ecosystem Services, Biodiversity and Climate Change: A Conceptual Model* provides a conceptual model for how the ecosystem services concept interrelates with biodiversity management and climate change adaptation.

- *Approaches to Mapping Ecosystem Services, Climate Change Adaptation and Biodiversity* generically describes "on-line" and "GIS-based" approaches to ecosystem services mapping, and reviews several applied tools, both process-based and analysis-based.

- *A Feasibility Assessment for Using InVEST to Model Ecosystem Services in Alberta* provides an overview and assessment of the InVEST modeling suite, and its application to Alberta.

The conclusions summarize how each perspective sees viable avenues to addressing the ecosystem service dilemmas identified in the introduction.

[1] Note that both *Ecosystem Services, Biodiversity and Climate Change: a Conceptual Model* and *Approaches to Mapping Ecosystem Services, Climate Change Adaptation and Biodiversity* first appeared in a similar form in a Miistakis Institute report for the *Biodiversity Management and Climate Change Adaptation* project (Miistakis 2012).

Detailed Project Background

Ecosystem Services Assessment for Environmental Innovation and Competitiveness project

Ecosystem services are the benefits that people receive from ecosystems that contribute to human well-being[2]. A key component of ecosystem services is biodiversity, or the variety of species, their genes, and the ecological complexes they comprise[3]. In the context of this project, biodiversity is the distribution and abundance of species. Understanding the spatial distribution of biodiversity and ecosystem services, and how they change in response to natural processes and human activity, is critical to balancing the often-competing goals of economic development, environmental integrity, and human well-being.

The *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* project is a key element of the *Ecosystem Services Research and Innovation Roadmap*, a province-wide initiative led by Alberta Innovates - Bio Solutions. The capacity to assess ecosystem services in a consistent manner across Alberta's diverse geography is a key prerequisite to successful implementation of the *Roadmap*. The *Roadmap* charts a course for the effective use of market-based instruments and institutional collaboration to capitalize on emerging opportunities, and fill key gaps in capacity and knowledge. By providing a forum for collaboration on the design and evaluation of conservation offsets and other market-based instruments, the *Roadmap* addresses key questions relating to technical feasibility, economic viability, and stakeholder acceptance.

The purpose of this project is to establish relevant and credible systems for assessing ecosystem services and biodiversity across Alberta. By advancing this capacity, this program supports the *Roadmap's* vision of Alberta as an internationally recognized jurisdiction for world-class management of ecosystem services, green growth and sustainable development incented through market-based instruments. These systems include the biophysical and socioeconomic information used to map biodiversity and ecosystem services across the province, internet-based services to distribute these maps and supporting documentation, and tools that allow people to apply this new capacity to land-use and management decisions. By creating economic and regulatory incentives for conservation and stewardship, markets for ecosystem services can guide people's behaviour in directions that support desired environmental and socioeconomic outcomes. Our goals are to establish systems for assessing ecosystem services in Alberta, and to evaluate tools for applying the information derived from these systems to environmental markets and land-use management.

[2] Millennium Ecosystem Assessment 2005 (MA 2005)

[3] www.iucn.org

Understanding Landscape Value

Project Background

Ecosystem services are fast evolving to be a core consideration in our use and conservation of the landscapes we inhabit in Alberta. Ecosystem services represent the benefits people get from ecosystems, and those contributions may be recognized as supporting (e.g., soil formation, wildlife habitat), regulating (e.g., water and air purification, flood regulation), provisioning (e.g., food and fibre, fuel, water), or cultural (e.g., aesthetic, recreation). By creating economic and regulatory incentives for conservation and stewardship, markets for ecosystem services can guide people's behaviour in directions that support desired environmental and economic outcomes.

There is growing interest among governments at all levels, environmental NGOs, resource industry companies, landowners and others in the development of market and regulatory systems for ecosystem services such as water supply and quality, wildlife habitat, and others.

An accepted, science-based, systematic way of assessing ecosystem services underpins ecosystem service-based regulatory and market systems. In the past several years, the Miistakis Institute and the Alberta Biodiversity Monitoring Institute (ABMI) have both been involved in several Alberta initiatives which inform our conclusion that there is value in exploring the need for a ecosystem services valuation tool to support these systems and their associated initiatives.

Though the goal of this first stage of the project is to develop an understanding of which circumstances/situations individuals and organizations would use this type of tool/approach, examples of potential uses might include conservation offsets, land trust conservation planning, on-farm planning, and municipal conservation strategies.

The growing interest in ecosystem services, combined with greater access to environmental data and knowledge, has created an unprecedented opportunity to develop a world-class ecosystem services assessment system for Alberta. This is a significant undertaking that will require the support of appropriate experts and stakeholders. A common vision for such a process will promote cooperation and efficient use of limited resources.

Project Summary

Understanding Landscape Value was conceived as a two-stage project, the first being a feasibility and design phase, the latter a development phase. The objectives for the first phase include:

- Develop an understanding of the complementary ecosystem services initiatives already in place

- Identify a set of potential end users, and develop an understanding of the nature, features, etc. of an ecosystem services valuation tool most desirable to a representative subset of those users
- Develop a preliminary understanding of what data limitations/opportunities exist relative to a tool for valuing ecosystem services
- Connect with potential users (and funders) of an ecosystem services valuation tool, providing potential implementation partners
- Arrive at a feasibility assessment the value of, and prospects for, an ecosystem services valuation tool in Alberta
- Articulate what an effective decision-support tool for valuing ecosystem services would look like
- Develop an implementation plan for Phase II

Project Synchronization

Recognizing the complementary goals, the value in streamlining multiple Alberta-based projects, and the opportunity to leverage resources, the Miistakis/ABMI *Understanding Landscape Value* (ULV) project was rolled into the ABMI *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* (ESA) project. The Miistakis Institute has undertaken a handful components of the larger ESA project which relate directly to the ULV project goals.

These include:

Ecosystem Service Scorecards

The knowledge assembled and created in this project will be used to create ecosystem service scorecards that assess the yield of ecosystem services for a given landscape, graded against an ecologically-defined baseline, in support of a defined resource management decision-making need. Scorecards will include information on the rangeland-related ecosystem services as well as biodiversity.

Initial tasks will focus on identifying an appropriate scorecard structure, balancing between creating a broadly-applicable method and localized effective applications due to the wide variety of potential scorecard audiences and purposes. The approach therefore initially has a twin focus on a higher-level methodology and a localized proof-of-concept.

This involves a scan of existing resource management scorecarding initiatives, identifying/working with scorecard applications to determine needs (focusing on scorecards for cattle producers, reporting on rangeland health and associated ecosystem services), clarifying the necessary ecosystem services and modelling/data supports, and drafting a conceptual scorecard structure. Future tasks may include refining the scorecard structure and interface, exploring methodologies to incorporate derived data from ecosystem service and biodiversity models and other relevant information, testing scorecards with target users, and identifying web-delivery options.

Miistakis will deliver a report on the scorecard structure for rangeland-related ecosystem services, summarizing the pre-scoping, scorecard consultations, and case reviews, and presenting a draft scorecard and then final scorecard structure.

Web Portal

All spatial data and maps developed in the ESA project are being made publicly available via a web portal. The goal of the portal is to facilitate interactive use of the derived data and models, interactive use of the project applications' information and associated tools, and access to the associated data and information resources.

An explicit understanding of the audiences for the portal will evolve, but initial target audiences include decision makers identified in the user-needs assessment , other ecosystem service academics, other ecosystem service modellers, and targeted Government of Alberta agency staff.

Miistakis will develop a conceptual web portal structure, a mock-up of the web portal, structure, and a final web portal structure for providing public access to ES data and maps.

User Needs Assessment

To ensure that the derived ES information and tools are in fact used by decision makers, there must be clarity around the circumstances under which decision makers could and would apply that information. The scorecard application and the web portal will be supported by a user needs assessment. The goal of the user-needs assessment is to derive targeted feedback from a selection of representative decision makers (*i.e.*, "users" of ES information) and use that to inform the design and delivery of the web portal and scorecard application.

The user needs assessment for the web portal will focus on understanding how portal visitors are likely to use the web site, what interactivity is required, and the necessary model-web interfaces, with the intent of informing the portal design and function. The user needs assessment for the ES scorecards will focus on understanding how cattle producers are likely to use ES scorecards in support of maintaining healthy rangelands and the ecosystem services they provide, and subsequently as a potential marketing tool to promote beef produced under ES-friendly management. A review of peer-reviewed and grey literature will be undertaken to scan user needs on the assumption that several potential Alberta-based "users" will not identify themselves as such, given the limited experience with ES-based decision-making in Alberta. This parallel task would create conceptual characterizations of ideal users.

Miistakis will then create a User Needs Assessment Summary Report summarizing the pre-research, framing of assessment for the ES scorecard and web portal, listing identified ES decision makers consultations, and presenting a final user needs assessment for the scorecards and web portal.

Ecosystem Services Mapping and Modeling

(NB: this information is repeated above under 'Goal of this Report')

Applying the ecosystem services approach to the policy and management realms of resource use and conservation in Alberta requires an understanding of factors ranging from high-level conceptual to on-the-ground applied. More importantly, it requires stitching these different scale perspectives together.

As the Miistakis Institute was also working on the ABMI-led *Biodiversity Management and Climate Change Adaptation* project, this created an opportunity to cross-pollinate the research, and recognize synergies between the two projects' need to develop a deeper understanding of this challenging conceptual-applied dynamic of ecosystem services.

To these ends, Miistakis will undertake a pre-scoping exercise regarding how ecosystem services could be represented conceptually, cartographically, and pragmatically in the Alberta context. This review will be a summary presentation of their consideration of three key concepts:

- How do ecosystem services, biodiversity and climate change link conceptually;
- What ES mapping and modeling tools are available which would be usable by local decision makers; and
- How applicable is a given tool (in this case, InVEST) to the existing data and policy context of southern Alberta.

ECOSYSTEM SERVICES, BIODIVERSITY AND CLIMATE CHANGE: A CONCEPTUAL MODEL

Climate change, biodiversity, local communities, natural capital, resilience and ecosystem services are common terms in the field of conservation science and design, and they have intuitive conceptual linkages. However, developing applied programs that promote ecological conservation by effectively employing these concepts is challenging without explicitly articulating the connections between them.

To help guide the authors' efforts in making these connections – and in making these connections clear for the communities who will be engaged – the Miistakis team developed this simple conceptual model.

Nature and people

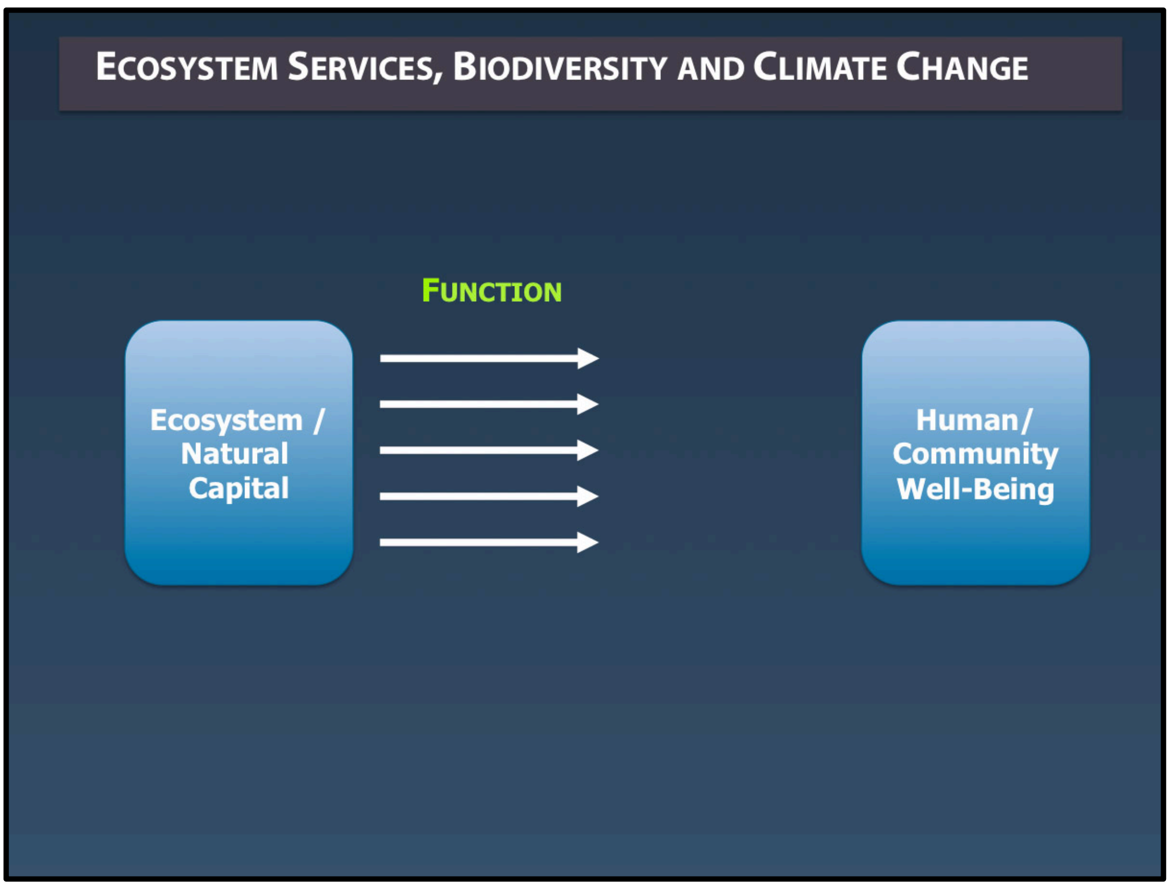

Figure 1: Ecosystems / natural capital and human/community well-being

The concept of nature as apart from humans has long since been refuted, and modern discussions of conservation tend now to focus on the fundamental reliance humans have on ecological systems. The generator or 'stock' of ecological capacity is often referred to as 'natural capital', given its ability to provide a wealth of value to humans.

That ecosystem, or natural capital, is characterized not only by a stock of capacity, but also a flow of advantages that enrich humans at multiple levels, and has been extensively described and defined as "human well-being" by the Millennium Ecosystem Assessment (2005). Those flows, or 'interest' on the natural capital, begin as a series of ecological functions (see Figure 1).

Ecosystem services

Ecosystems services, or the benefits humans derive from nature (Costanza et al 2012), represent an intentionally utilitarian view of the earth's ecosystems – "what's in it for me" as opposed to an intrinsic or moral view of nature's value. The critical piece in viewing ecosystem services as the conceptual link between *ecosystems* and *human well-being* is that an articulation of ecological function is not enough; there must also be a human-defined benefit associated with that ecological function (see Figure 2).

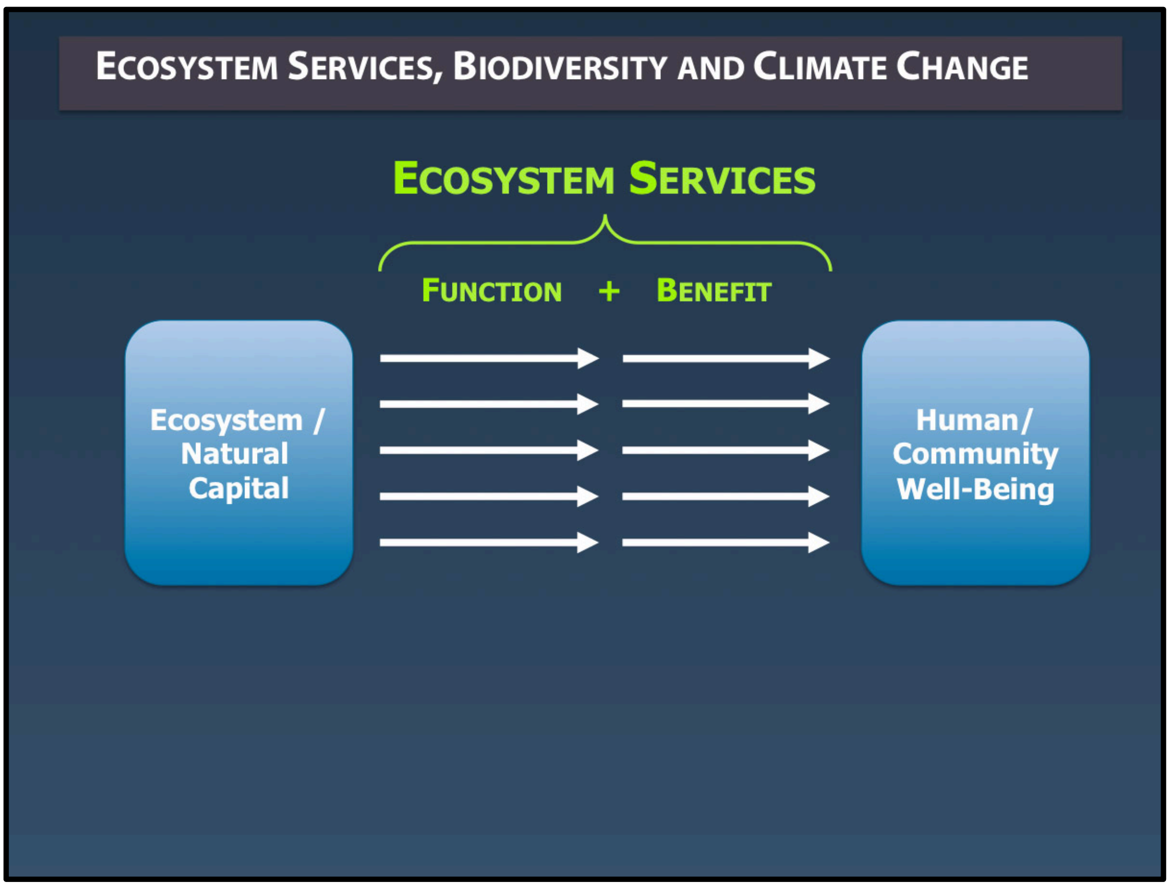

Figure 2: Ecosystem function + benefit = ecosystem services

For example, the fact that ecosystem components such as wetlands retain storm water describes an ecological *function*, but not an ecosystem *service*. From an anthropocentric perspective, the flood water control that comes from that function is the benefit (protects people from property damage, human health and safety risk, etc.). The *function* plus the identified *benefit* constitute an ecosystem service.

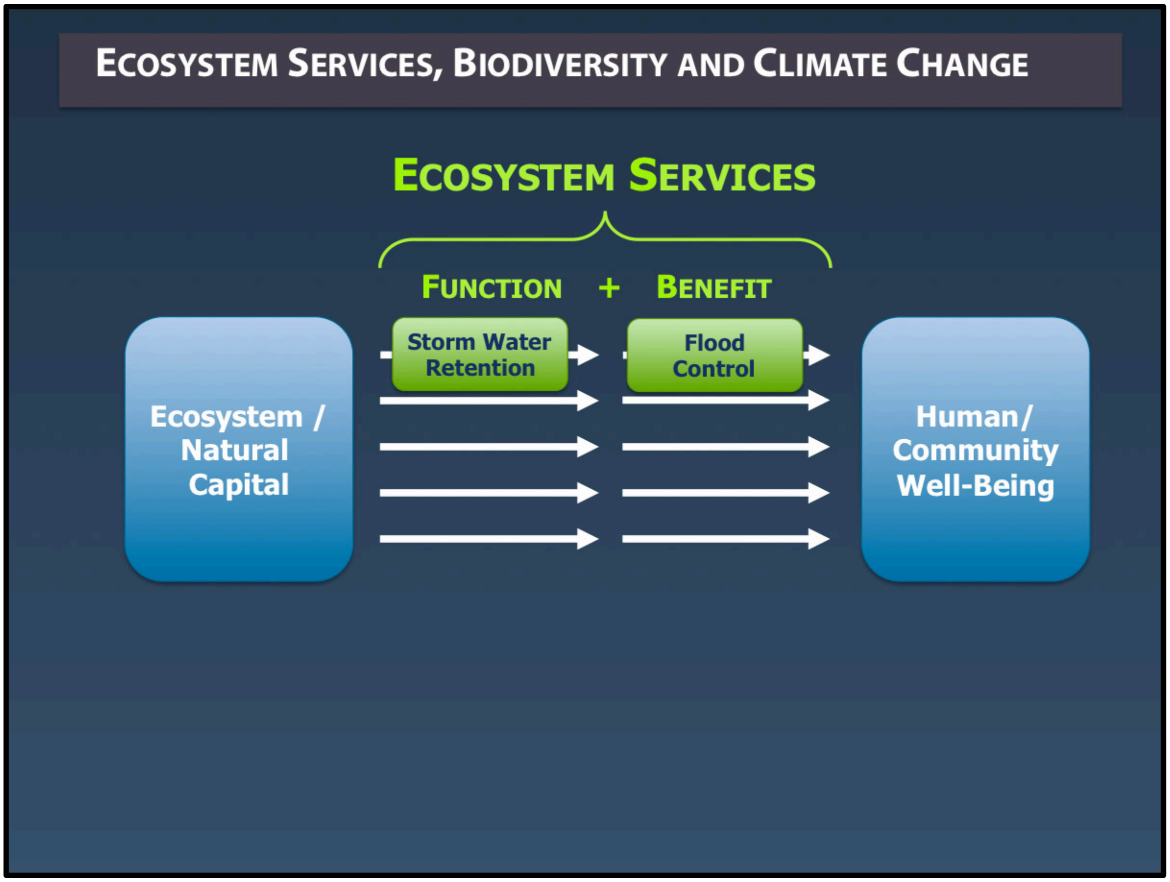

Figure 3: Ecosystem function and benefit example

Ecosystem services and biodiversity

The Millennium Ecosystem Assessment (MEA 2010) was a global effort to clarify the emerging literature and policy around ecosystem services (also known as 'ecological goods and services'). Perhaps the two greatest contributions of that effort were 1) the clear articulation of the connection between ecosystems and human well-being, and 2) the synthesis of ecosystem services research to create a standardized list of ecosystem service areas. This list, and its wide acceptance, served to expand the stunted conservation beyond simply food and fibre all the way to broad social and cultural services (see Table 1).

Table 1: Ecosystem services identified by the Millennium Ecosystem Assessment (2010)

Provisioning	Regulating	Cultural
Food and fiber	Air quality maintenance	Cultural diversity
Fuel	Climate regulation	Spiritual & religious values
Genetic resources	Water regulation	Knowledge systems (traditional & formal)
Biochemicals, natural medicines, pharmaceuticals	Erosion control	Educational values
Ornamental resources	Water purification & waste treatment	Inspiration
Fresh water	Regulation of human diseases	Aesthetic values
	Biological control	Social relations
	Pollination	Sense of place
	Storm protection	Cultural heritage values
		Recreation & ecotourism

Supporting
Primary production
Photosynthesis (production of oxygen)
Soil formation & retention
Nutrient cycling
Water cycling
Provisioning of habitat

The services are divided into three main categories: *provisioning*, *regulating* and *cultural*. Underlying all of those are a set of indirect services, categorized as *supporting*, in that the first level ecosystem services could not exist without these support functions.

It is noteworthy that “biodiversity” is *not* an ecosystem service. Scholes et al (2010) explain this relationship as being indirect where biodiversity is “a necessary condition for ecosystem services to be delivered”. In terms of ecosystem valuation approaches, they suggest that the “key value of biodiversity may be in reducing the variability of ecosystem services, (equivalently, reducing the uncertainty or risk), especially in the face of disturbances or changes in the environment.”

However, the connection between biodiversity and some ecosystem services is still distant enough that it is arguable that not all ecosystem services derive from biologically diverse landscapes; the scenic value of rolling fields of canola crops is derived from natural processes, but is an ecological monoculture (see Figure 4). This makes it incumbent upon scientists, conservationists, and policy makers to identify the most *proximate* connections between biodiversity and ecosystem services.

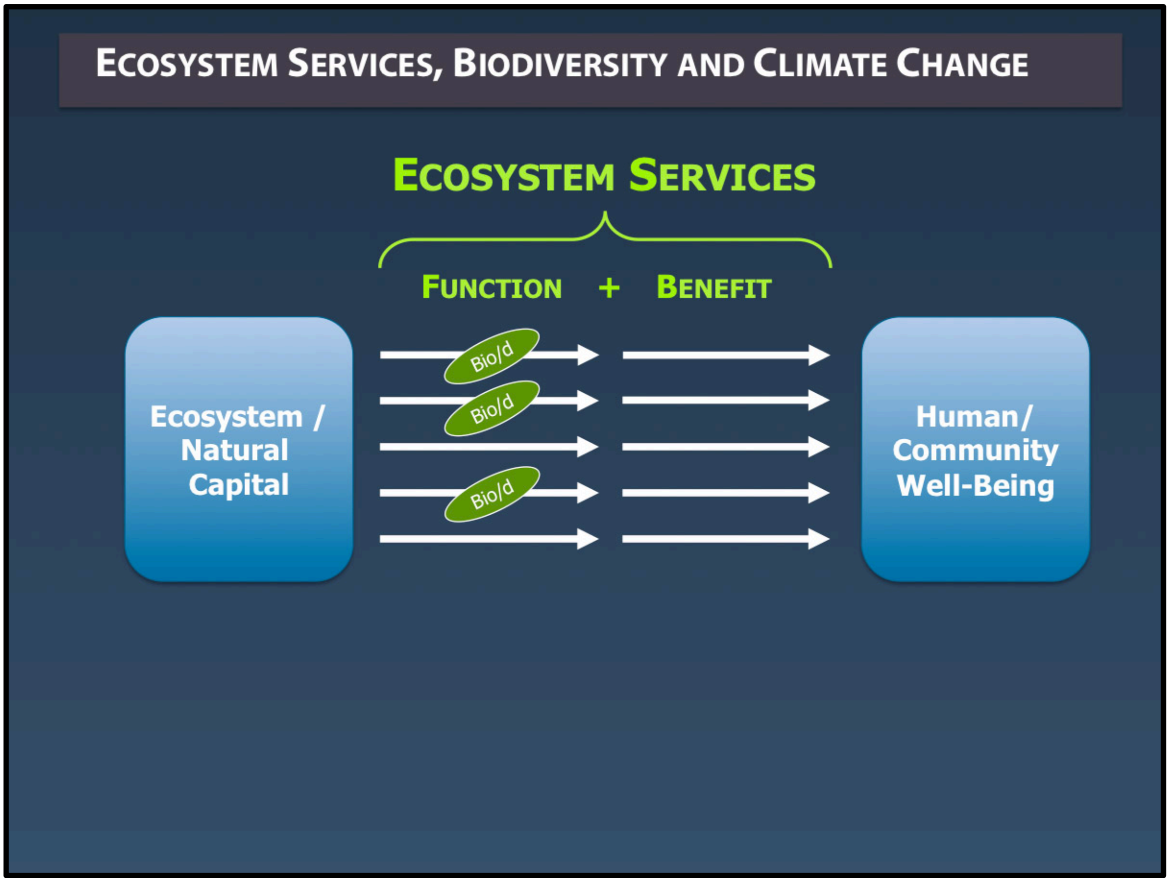

Figure 4: Biodiversity and ecosystem services

Management of ecosystems, functions and benefits

The relationship between human communities and ecosystems is, of course, not unidirectional; human activity has an impact on ecosystems and the services they provide. This feedback flow can be characterized as land and resource management; the collective actions humans undertake in maximizing the benefits they seek from ecosystems (see Figure 5).

These effects can occur at three levels. First, they can impact at the 'natural capital' level, where the activities of humans can affect the stocks of ecosystem capacity. Management actions can –

and increasingly, do – decrease the ecosystem capital, but they can also serve to maintain, or even enhance those stocks by protecting their capacity to regenerate.

Second, human activities can impact the function of ecological systems, directly or indirectly interrupting the flow of ecological activity. Again, these actions can impair, but can also work to sustain those flows.

Third, and finally, human activity can affect the benefits people derive from ecosystems and their functions, supporting or deceasing them.

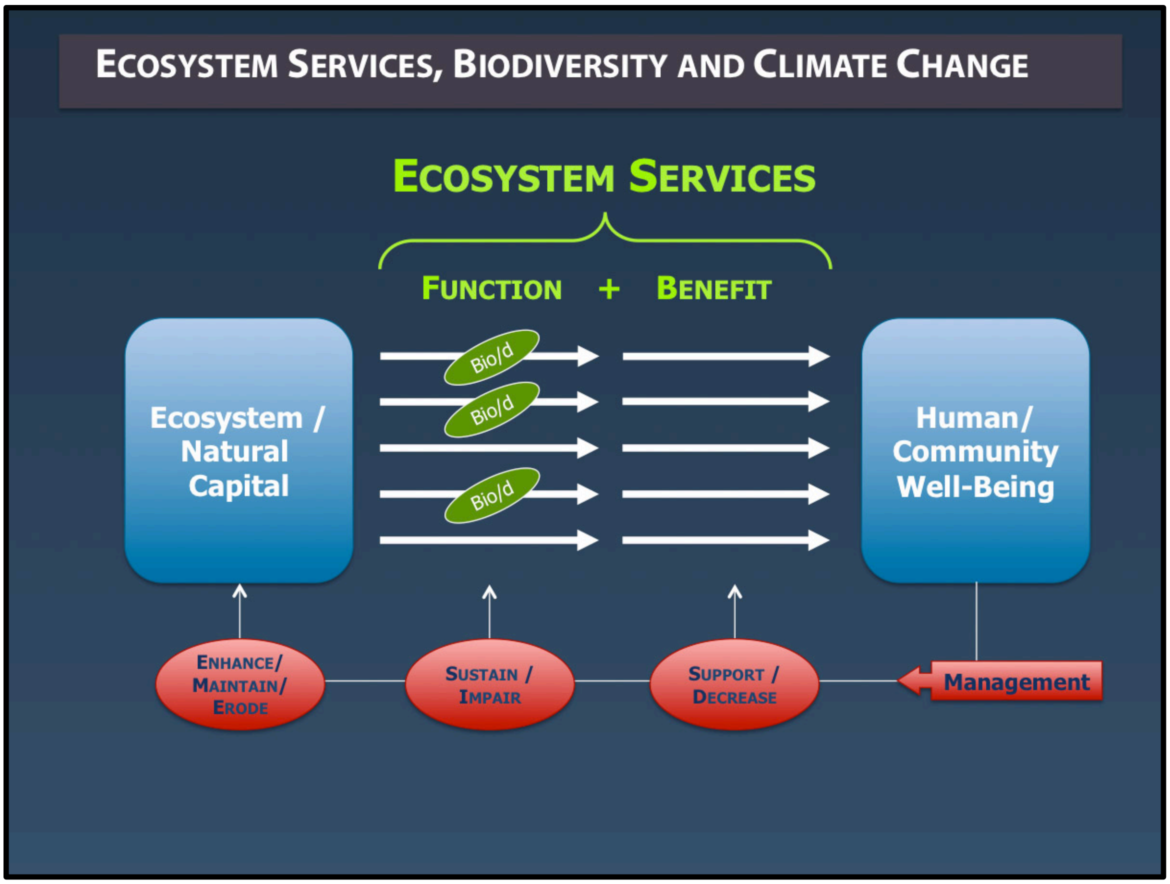

Figure 5: Management impacts of ecosystems, functions and benefits

The following example gives more detail on these interactions.

Climate change and ecosystem services

Climate change offers a strong example of how a perturbation to this system affects the stock and flow of ecosystem services, and illustrates conceptually what are the opportunities and limitations of adaptation.

As with any strong perturbation, climate change affects this system at the *function* level, having a variety of impacts. The model conceptually represents that a given ecological function may be unaffected, altered, or interrupted (see Figure 6). In terms of the resultant benefits to humans, they can be similarly unaffected, positively or negatively altered, or eliminated.

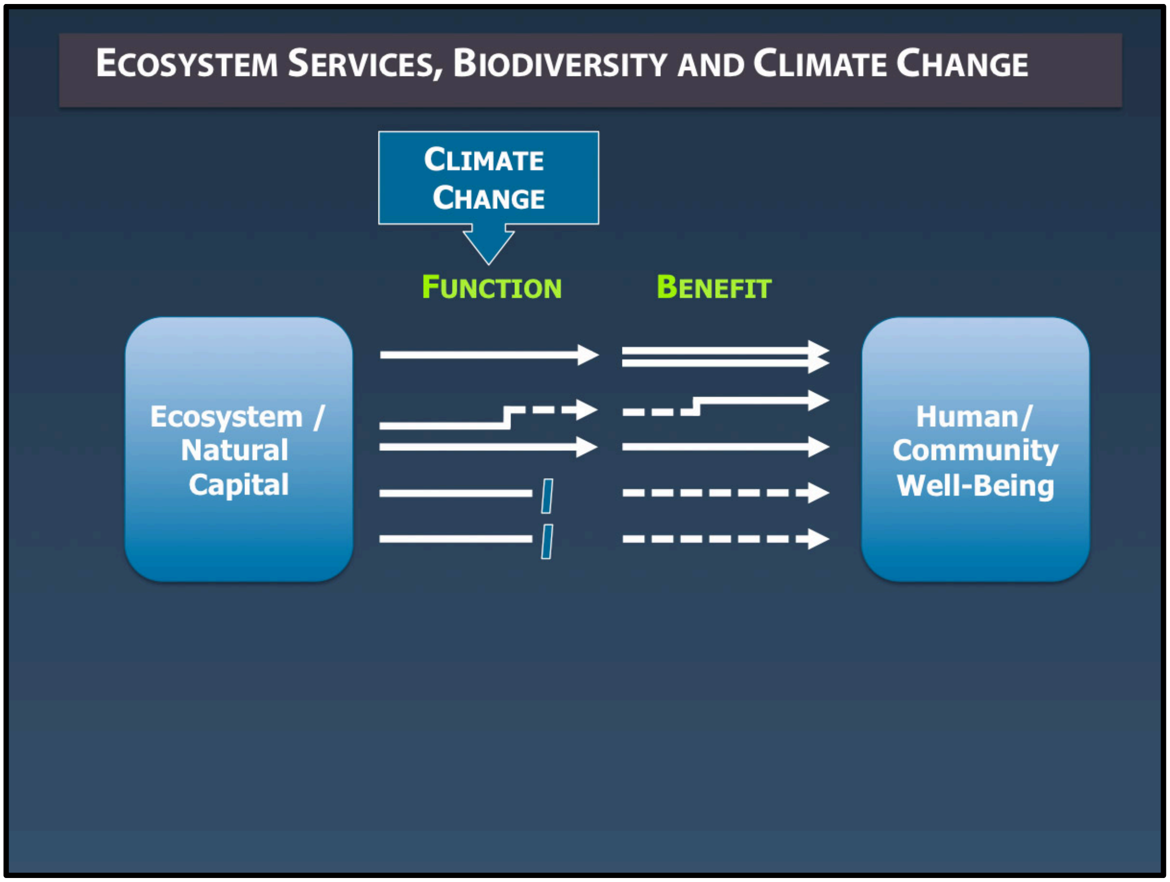

Figure 6: Conceptual impact of climate change on ecosystem function

Climate change adaptation and ecosystem services

In terms of the feedback loop described above, management action in this case can be termed 'adaptation.' And similarly, that adaptation to climate change can be characterized as being directed or having an impact at the ecosystem, function or benefit level (see Figure 7).

At the ecosystem level, human adaptation to climate change can be to 1) maintain or build the ecosystem asset that provides multiple ecological functions, 2) maintain or build the ecological function, 3) replicate the ecological function, and/or 4) modify expectations around the benefits humans derive from those ecological functions. For example, establishing reserves around biodiversity hotspots could be an example of maintaining the self-regenerative capacity of an ecosystem (1), and limiting timber harvest in watershed headwaters could be an example of maintaining the erosion control function in extreme storm events (2). Creating an engineered wetland could be a way of replicating the storm water retention function (3), and focusing recreational hunting and fishing on climate-shifted habitat areas could be an example of changing human expectations around the benefits anticipated from a properly-functioning ecosystem (4).

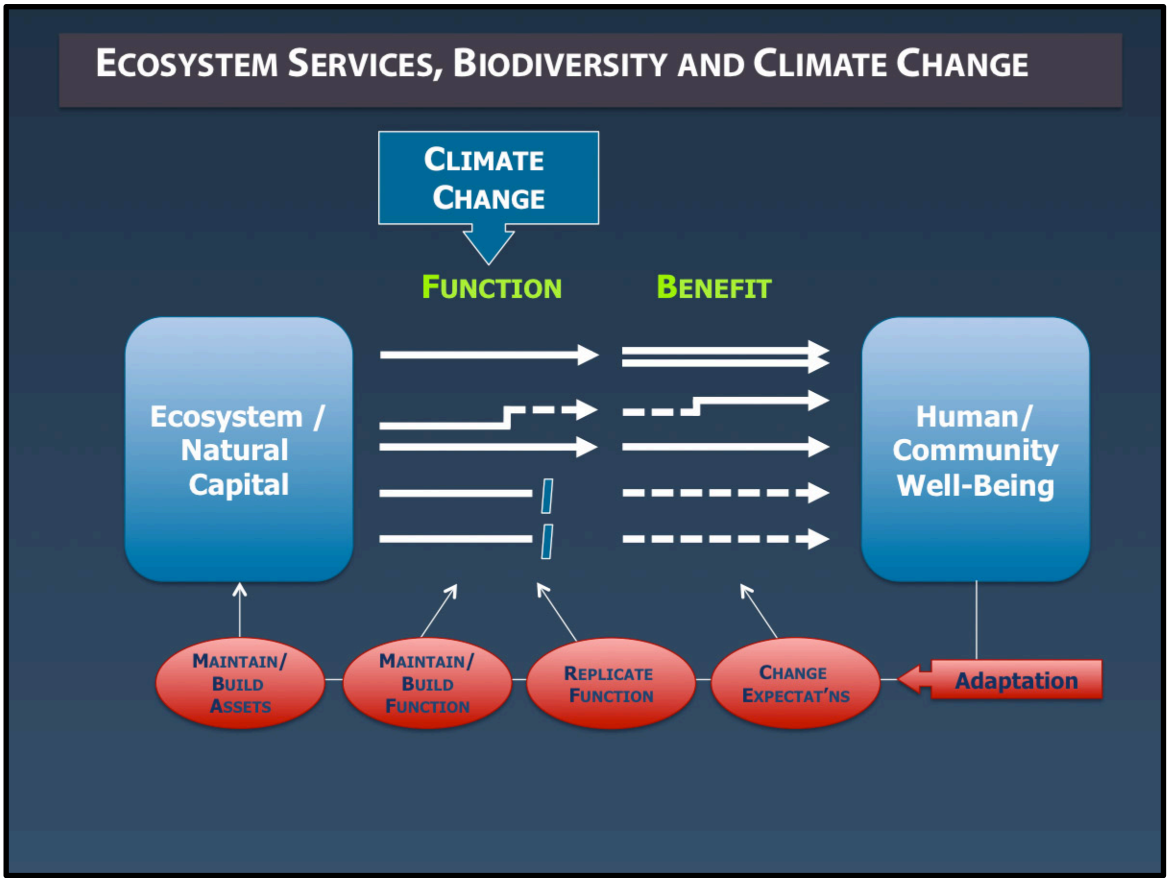

Figure 7: Adaptation to climate change at several levels

Natural and engineered resilience

In each of the cases described above, the goal is to create greater resilience – resilience in the ecological systems, resilience in the human communities that rely on those systems. The adaptation approaches described above can be split into two broad categories of resilience: natural resilience and engineered resilience (see Figure 8).

Natural resilience approaches are those that seek to increase the self-regenerative capacity of the ecosystem (or natural capital stocks), or seek to protect or enhance specific ecological functions. These actions recognize that doing so likely enhances a variety of benefits to human well-being, but perhaps does so without a direct intent to protect the flow of a given benefit.

Engineered resilience approaches seek to replicate a given function specifically with the intent of providing a particular benefit(s), or promote the resilience of a community by re-defining the expectations humans have of nature (e.g., lowering potable water expectations, so there is no anticipation one could drink from natural streams).

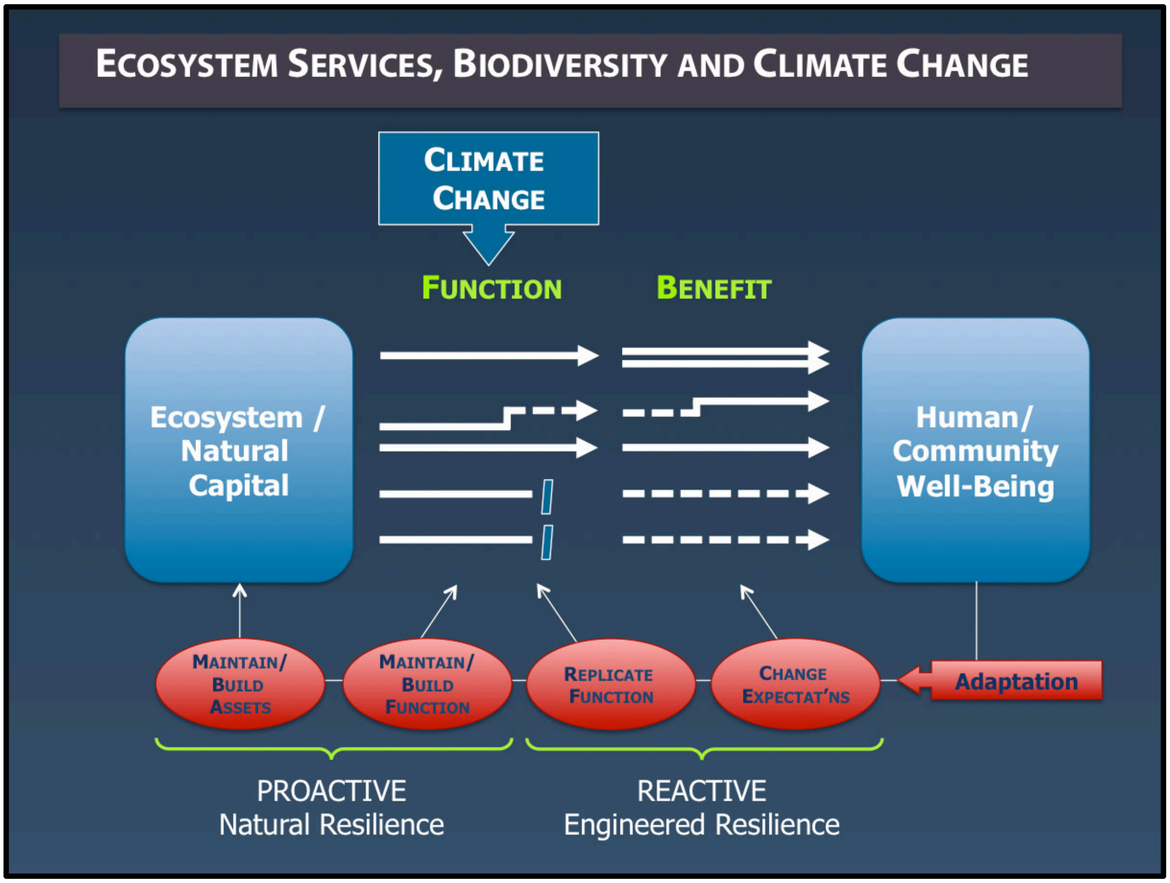

Figure 8: Proactive and reactive resilience approaches

In general, there are three defining characteristics of each approach. First, natural resilience approaches tend to be proactive, whereas engineered resilience approaches tends to be reactive, arising in response to the loss of a desired ecosystem service benefit. Second, natural resilience approaches tend to be more comprehensive and systems-based. Engineered resilience approaches tend to reduce systems to their component parts and parse out discrete benefits. Third, natural resilience approaches tend to be less expensive over time, primarily because the 'work' is being done by a self-organizing ecological system rather than through expenditures of human and built capital.

APPROACHES TO MAPPING ECOSYSTEM SERVICES, CLIMATE CHANGE ADAPTATION AND BIODIVERSITY

Introduction

Mapping ecosystem services (ES), climate change adaptation (CCA), and biodiversity is an important step in visualizing, analyzing and identifying knowledge gaps of both current and projected landscapes. The purpose of this section is to review the use of mapping tools in a broad sense to determine what is already being done, what lessons can be learned and what limitations exist.

Mapping tools, for the purposes of this section, can be divided into the three major areas of use: 1) process, 2) analysis and 3) education and delivery. Overlap exists across these areas, but in general most mapping tools fit within these uses.

An important distinction is also found in the type of mapping tool for the purposes of this section: *online tools* (used largely through a web browser), and *GIS-based tools* (used either stand alone or through a GIS software application). Online tools tend to be more publicly orientated with a reduced need for specific skills. GIS-based tools tend to be built for and by people with specific skill sets and/or knowledge.

Review process

The internet and literature were reviewed, coarsely, to look for a variety of mapping tools being used in the areas of ecosystem services, climate change adaptation, and biodiversity, with a particular interest in any that worked in one or more of these areas.

The goal of the review was to identify tools the Miistakis team can use, build or learn from in moving forward with our community level approach to biodiversity management and climate change adaptation in Alberta (see Miistakis 2012). Given that the end focus is a community level approach, tools were looked at for their applicability for that purpose.

Given the vast amount of tools available and the preliminary nature with which each tool was reviewed, the authors opted at this stage to compare each tool against a vision of a 'perfect tool.' While it is unlikely there is such a thing, conceptually, the perfect tool is defined as one which will:

- Work at a variety of local scales, specifically at a community level in Alberta;
- Be accessible, both financially and technically, to a wide assortment of capacity levels that mirror the realities of communities within Alberta;
- Require data that is readily available and simple to compile;

- Provide what the local community needs, while utilizing what they bring to the table, such as local knowledge;
- Be visually appealing with a friendly and intuitive user interface; and
- Incorporate the needs of ecosystem services, biodiversity management and climate change adaptation

Mapping tools were broken into general types based on observed trends during the review process. The roles of process, analysis and education or delivery were identified and are detailed further below. Further, the difference between online and GIS based mapping tools is considered at a broad level.

Mapping tools

A mapping tool in it's simplest form is any tool that creates a map. Most of these tools will have the ability to view the map interactively with common functionality such as zooming in and out, panning, and identifying features. Mapping tools designed to generate static inputs for analysis may provide no functionality for interactively viewing the output, instead focusing on providing interaction with the decisions driving the analysis.

The use of computers to interactively work with maps and spatial data has been around almost as long as computers, but Geographic Information Systems (GIS) did not gain wider use till approximately 15 years ago. In the last 8 years, since the release of Google Maps API, the increased access to spatial data, reduction in required technical capacity, and an increasing availability of free desktop and online mapping tools, has created a dramatic increase in the use of spatial data in decision making. As a result, the internet contains many examples and approaches on how to use mapping tools, both effective and ineffective.

Online and GIS-based mapping tools

In a broad context the authors differentiate between online and GIS based mapping tools.

Online tools are those that largely use a web browser for interaction and delivery of the mapping tool. GIS based tools are those that utilize a GIS application for the interaction and delivery of the mapping tool.

Online tools tend to be more user friendly for the average user as they are intended for a wider distribution in most cases. Online tools contain less functionality to learn and understand, but as a result, there are fewer ways to utilize the map.

GIS based tools are those that use full spatial tool sets provided by one of the many GIS software applications and toolkits. These tools generally contain the many features required to widely use and manipulate spatial data. They tend to be more complicated and thus not as user friendly for the average user, and typically they are often designed for wide distribution.

As technology continues to progress there is an increasing number of ways to merge Online and GIS based tools, blurring the differences between them, the important goal for the Miistakis team's work with local communities is achieving this while keeping the application user friendly to a wider audience.

Process based mapping tools

Process based mapping tools are those that facilitate the process being undertaken by the local community and often blend the lines between analysis and education and delivery. These mapping tools help facilitate the discussion primarily through data gathering or visualization.

Two common forms include community-based mapping and citizen science. Community-based mapping is the combined use of GIS tools and facilitated discussion to capture the knowledge of a community spatially. Citizen science is the process of using all interested local citizens to capture specific pieces of spatial information.

Very few tools were found that were specific to the roll of facilitating a process. Community-based mapping is largely done within a GIS environment and as such few tools have been developed. Citizen science on the other hand has many, though very similar, mapping tool examples. Two have been highlighted for further review as they best meeting our ideal criteria.

DataBasin

URL: http://databasin.org/

The DataBasin website describes itself as:

> *Data Basin is a free system that connects you with spatial datasets, non-technical tools, and a network of scientists and practitioners. You can explore and download a vast library of datasets, connect to external data sources, upload and publish your own datasets, connect to experts, create working groups, and produce customized maps that can be easily shared.*

While the DataBasin toolset can easily and effectively be used for education and delivery as well, it is more unique in its roll as a process tool by providing several tools to assist with community-based mapping.

The DataBasin works at any scale, providing the ability to upload your own data or access data shared by others. While available data for Alberta is limited, this is not an unusual situation. Capacity requirements for a local community are low with the tool being free and easy to use with a simple and friendly user interface. Data requirements would depend greatly on the process within which you are working, and be more dependent on the local community than the tool itself.

The DataBasin has a Climate Change Center where information and tools related to climate change have been collected. Ecosystem Service tools are also mentioned as being in development and a wealth of bio-diversity information is available, though often not at an Alberta specific scale.

The tools specific to community-based mapping are somewhat limited at this time. While you can draw features on the map, there are no tools to add information to the feature or export it.

DataBasin is a great tool for its purposes and depending on future needs, this tool should be considered for further investigation.

Wildlife Observation Mapping Tool

URL: http://www.rockies.ca/lib_tools.php

The Wildlife Observation Mapping Tool is a web mapping application created to capture user observations of wildlife related events on a highway, trails, within communities or any landscape where a group wants to monitor wildlife.

This tool was created by the Miistakis Institute and while it does not specifically relate to climate change or ecosystem services, it is a process related tool for the collection of biodiversity and contains the bulk of the features used in the many similar web based applications, many of which were created based on the original version created for Road Watch in the Pass.

The tool works at any scale and was developed in Alberta. It uses readily, and freely available data, with no limits on what local data that a community would wish to add. It is free and easy to use, with a minimal first time install of about 15-30 minutes for someone with basic web programming skills. The interface is simple and friendly to use, with many changes to refine the user experience made over the years.

The success of this tool with the Road Watch in the Pass program (www.rockies.ca/roadwatch) was directly related to the accompanying support, specifically a local community coordinator that was instrumental in the successful use, delivery and promotion at the grass roots level.

This tool and the lessons learned from the Road Watch in the Pass project provide a stable foundation for many possible process related applications.

Analysis based mapping tools

Analysis mapping tools are those that assist a local community with evaluating spatial and spatially-related information. These tools put that information in a local context considering priority, what to include / exclude, and any other required decisions. The outputs of this analysis then become a data source that is used as part of the process, or for education and delivery.

Analysis tools are largely more complex and require a greater understanding of the different issues being considered and the technology being used to run the analysis. These tools often work best in a collaborative and facilitated environment, allowing for a wide use of the application by the stakeholders, while at the same time limiting the technical and informational requirements to just what is needed to run the analysis, based on the feedback of the stakeholders.

Analysis tools are more commonly GIS-based tools that run within specific software applications. This better facilitates the complex operations required to run some analyses.

There was a moderate number of tools available that provided support in this area for one or more of climate change adaptation, biodiversity and ecosystem services.

SimCLIM

URL: http://www.climsystems.com/simclim/

The SimCLIM website describes itself as follows:

> *SimCLIM is an integrated modeling system for assessing climate change impacts and adaptation. SimCLIM is designed to support decision making and climate proofing in a wide range of situations where climate and climate change pose risk and uncertainty.*

As SimCLIM is a purchasable, GIS based, software program it is hard to review, beyond what could be found on the website and the user manual. Overall, the tool seems very interesting in regards to modeling, however there are a number of issues when compared to our ‘perfect' tool.

The price tag and technical capacity to run the model would certainly be an issue with some local communities. Scalability is unclear at this point, it appears that users can edit the climate change data, but spatial data is treated as an overlay and not used by the analysis unless you create a custom build of the application for your area. If it is possible to change the underlying data sources to something more locally specific, it is unclear what that data would be and if it is readily available. There was no immediate indication that there was any component in SimCLIM that considered biodiversity.

Overall while this tool looks very interesting from an academic standpoint, there is likely little of value for a program aimed at local communities.

InVEST: Integrated Valuation of Environmental Services and Tradeoffs

URL: http://www.naturalcapitalproject.org/InVEST.html

The InVEST website describes itself as follows:

> *"InVEST is a family of tools to map and value the goods and services from nature which are essential for sustaining and fulfilling human life."*

InVEST is a GIS-based mapping tool that takes spatial and thematic data as inputs, and estimates the value of ecosystem services. While not specific to climate change, the tool integrates biodiversity and ecosystem services.

While InVEST does require a lot of local data and values to run, it is very scalable and will work at the Alberta local community level. The data and technical needs required to run InVEST do create a capacity issue for some local communities. However, it is designed to run in a stakeholder-driven decision support process and as such not everyone involved would be required to understand and use InVEST as long as they understood the outputs.

InVEST is a great tool for its purposes and depending on future needs, this tool should be considered for further investigation.

ARIES: ARtificial Intelligence for Ecosystem Services

URL: http://www.ariesonline.org/

The ARIES website describes itself as follows:

> *"**ARIES** is a web-based technology offered to users worldwide to assist rapid ecosystem service assessment and valuation (ESAV). Its purpose is to make environmental decision making easier and more effective. ARIES helps users discover, understand, and quantify environmental assets and the factors influencing their values, for specific geographic areas and based on user needs and priorities."*

ARIES looks very promising and incorporates all three themes of climate change adaptation, ecosystem services and biodiversity. The online mapping tool on preliminary view looks user friendly and easy to use. The application however is still in alpha stage of testing and has no Canadian – let alone Alberta – case studies. Further all attempts to use the mapping application resulted in an error, making it hard to evaluate to any level of detail.

This application is worth looking at again in more detail, depending on future needs, though it may be this application will not be ready to be used in time.

Developable Lands Mapping Tool

URL: http://www.rockies.ca/files/reports/Developable%20Lands%20Mapping%20Tool%20Report.pdf

Developable Lands is a GIS-based application developed by the Miistakis Institute, to facilitate a stakeholder decision support process in the Crowsnest Pass to determine where best to develop when evaluating a set of economic and environmental priorities.

While this tool was not designed with relation to climate change adaptation or ecosystem services, it is an excellent example of a mapping tool designed for use at the local community level. Simple and easy to use, with a friendly and appealing interface, the application was designed to use with stakeholders to analyze a series of input layers based on the priorities of the group. The data requirements are low, with a small amount of technical capacity required to setup the data for use by the mapping tool.

Originally developed for use within ArcGIS, a future version of the application was built in a free and open source application, Quantum GIS. This allowed the application to be shared freely with all stakeholders. A web version was determined to be feasible, but not developed.

While this tool will not be directly useful for the future needs of this sub-project, the lessons learned and the underlying structure will provide a solid foundation if any new tools need to be developed.

EDUCATION AND DELIVERY MAPPING TOOLS

Education and delivery mapping tools make up the most common and often used type of online mapping tools, and the most widely-used form of maps in general. These tools allow data to be displayed in a way that allows for the visualization of complex spatial themes in a manner that is easily observed and understood by a user group. They come in many forms, either as printable or electronic maps and images and interactive mapping applications. They tend to be easy to use, understand and share.

In general these mapping tools are all very scalable and used in a wide variety of ways. The technical and financial capacity requirement is very low, with little more then basic internet required. Data requirements are specific to the data you wish to share and as such assumed to be readily available. To be useful and serve their purpose these tools are required to be visually appealing and user friendly, though not all of them succeed at this goal.

Most of these tools are fairly straight forward, often allowing the user to view the important data in relation to other data. However some provide interactive interfaces by asking a series of questions about the data, and then tailoring the data to the user's needs.

Very few tools served the needs of more then one of ecosystem services, biodiversity, and climate change adaptation.

A few examples of related sites are:

Ecosystem Services - Carbon Calculator

URL: http://www.carbon-biodiversity.net/Interactive/CarbonCalculatorNotes

The website describes itself as follows:

"This innovative tool provides users with initial estimates of carbon values for existing protected areas or any polygon drawn on a global map."

NatureServe Explorer

URL: http://www.natureserve.org/explorer/

The website describes itself as:

"an authoritative source for information on more than 70,000 plants, animals, and ecosystems of the United States and Canada. Explorer includes particularly in-depth coverage for rare and endangered species."

Environment Canada Scenario Maps

URL: http://www.cccsn.ec.gc.ca/?page=viz-maps

This is not a particularly visually appealing or user friendly interface, but it displays the variety of climate change information available and creates map outputs based on the users inputs.

Local community capacity

A significant issue with providing tools to any large user group is dealing with the different levels of capacity. ArcGIS for example is a powerful and commonly used GIS application. It is also propriety, expensive, and relatively complex to use. Many smaller local communities would not be able afford or use ArcGIS.

In order to ensure a tool is useful to all levels of capacity, it may be desirable to stick with free and open source based applications. It is entirely feasible to use propriety software to create information to deliver to local communities. For example, on might use a proprietary software to create climate change data that is shared with communities, but the community would not need to purchase or use the software unless they wished to make their own modifications.

Many of the issues surrounding climate change adaptation, ecosystem services and biodiversity are complex and require expert knowledge to fully understand. A mapping tool will need to distill that expert knowledge and provide the result in manner that is clear and concise to the average decision maker.

Summary

Mapping tools are most widely used to deliver results or educate the user by providing a means to visualize the results of the overall process it was designed for. Mapping tools availability and focus varied based on the topic, as outlined below.

Biodiversity mapping tools are largely educational in nature, providing the user with access to information about the spatial distribution of species. This could be for specific species like NatureServe, or it could be models that calculate species richness or hotspots. Biodiversity tools are common in both online and GIS based forms. There are more biodiversity tools than climate change or ecosystem services tools.

Ecosystem Service mapping tools seem to be in their infancy with a much smaller volume of available examples. This could be the newer nature of the topic of Ecosystem Services, but also because it is a harder concept to convey easily in a mapping tool. Data requirements of Ecosystem Services are fairly high, specifically on valuing services on the landscape. Most Ecosystem Service map tools are GIS based at this time.

Climate change related mapping tools were largely focused on displaying complex climate data in various ways that impact the user. As the topics are complex, the mapping tools themselves were very complex. Simple online mapping tools were mostly limited to displaying climate data back in various forms, with GIS based mapping tools predicting change and climate change adaptation risks. For the most part, climate change adaptation referred to the adaptation of humans and society to the risks of climate change, not the adaptation of the natural world.

A FEASIBILITY ASSESSMENT FOR USING INVEST TO MODEL ECOSYSTEM SERVICES IN ALBERTA

This section provides a brief overview of the InVEST modeling suite. It includes a description of InVEST and its modeling capacity and technical and data requirements. It highlights those InVEST modules that address the ecosystem services being considered in this project, and suggests possible approaches to running these modules for Alberta. As a case study it examines the biodiversity module more deeply, suggesting useful input data sets and other components, and connecting InVEST outputs to the broader ESA project.

Unless otherwise noted, all description of the InVEST modeling suite refer to the InVEST v.2.5.4 User Guide (Tallis et al, 2013).

A Review of InVEST

InVEST - or Integrated Valuation of Environmental Services and Tradeoffs - is a free Ecosystem Services modeling suite, designed to run within ESRI ArcGIS or as a stand-alone application. It is a constantly evolving application, developed by the Natural Capital Project, based at Stanford University in California.

InVEST models multiple ecosystem services (ES) through a tiered, modular approach. Modules divide ES models into general groups of Marine and Terrestrial services, and then subsequently into individual ES.

The tiered approach allows InVEST to be flexible to the quality of available data, and also to the desired outputs of the modeling. Tier 0 models are the most basic, assigning relative or qualitative values to ES. Tier 1 models are more complex, measuring ES more precisely and incorporating a temporal aspect to the ES analysis. Tier 2 models are the most advanced, allowing for expression of ES in financial terms, and incorporation of temporal dynamics into the modeling process. The outputs from tier 2 models are suitable for use in conservation planning that involves market-based instruments, such as conservation offsets, transferable development credits, or payment for ES programs. In earlier versions of InVEST a third tier of models was developed; however, tier 3 models were thought to be too specific to individual cases to be of general utility, and therefore were discontinued in the InVEST modeling suite. Figure 9 presents a schematic of the tiered approach.

TIER 0 Models	TIER 1 Models	TIER 2 Models	TIER 3 Models
Relative values	Absolute values	Absolute values	Absolute values
No valuation	Valuation done through a suite of approaches	Valuation done through a suite of approaches	Valuation done through a suite of approaches
Generally not time-specific, or annual average	Annual average time step, no temporal dynamics	Daily to monthly time step, some temporal dynamics	Daily to monthly time step, temporal dynamics with feedbacks and thresholds
Appropriate spatial extent ranges from sub-watershed to global	Appropriate spatial extent ranges from sub-watershed to global	Appropriate spatial extent ranges from parcel to global	Appropriate spatial extent ranges from parcel to global
Good for identifying key areas (relatively high risk or environmental service provision)	Good for strategic decisions with absolute values, can be good for tactical decisions with calibration	Good for tactical decisions with absolute values	More precise estimates of environmental service delivery
Some environmental service interactions	Some environmental service interactions	Some environmental service interactions	Sophisticated environmental service interactions with feedbacks and thresholds

Figure 9: InVEST Model Tiers (Tallis et al 2013)

Like many modeling applications, InVEST sits at the centre of a broader process. It is a spatially explicit model that produces both spatial and tabular data outputs. For inputs, it relies on both spatial and thematic data, expert opinion, and other resources. Creating and acquiring suitable inputs to an InVEST model can be time-consuming, and the quality of the information that comes out of InVEST is heavily dependent on the quality of the data that goes in. InVEST is most effective when it is part of a broader process that involves up-front and ongoing stakeholder consultation to frame questions, determine which ES's to model (i.e. which modules to apply), identify plausible future scenarios, and offer knowledge that may be used as valuable inputs to the modeling. Figure 10 (p.34) illustrates the broader process to which InVEST is designed to contribute.

There is a diverse, global, and growing community of users of InVEST. The Natural Capital Project web site hosts detailed documentation on how to use InVEST, case studies from a broad range of applications, and a user forum. The Project has also published a book of notable case studies (Kareiva et al 2011).

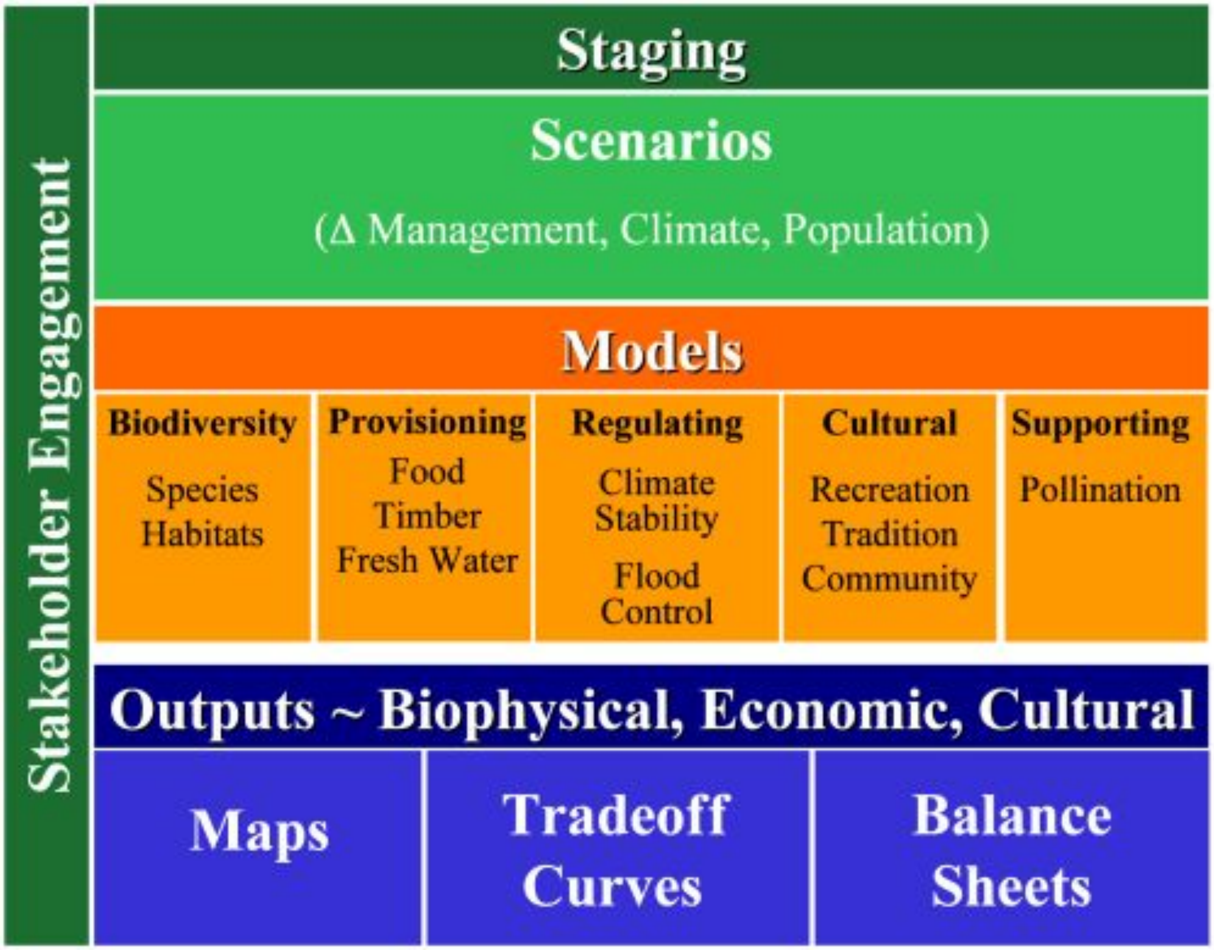

Figure 10: InVEST Model Process (Tallis et al 2013)

InVEST in the Alberta Context

The *Ecosystem Services Assessment for Environmental Innovation and Competitiveness* project is interested in estimating and mapping five ecosystem services for the province of Alberta: rangeland production; forest production; pollination of agricultural crops; water purification; and biodiversity.

InVEST has modules for the assessment of all of these services except rangeland production. The following section briefly examines the modules and input requirements of the other four ecosystem services.

Forest Production

InVEST includes a Managed Timber Production Model, which accounts for the ecosystem services provided by natural and plantation forests through the generation of merchantable timber harvests. The model assumes that an entity or entities have the legal right to harvest timber from a forest. In the case of Alberta the majority of these rights would be administered through Forest Management Agreements (FMAs) between the Government of Alberta and forestry companies.

The Managed Timber Production Model maps the net present value of the planned harvesting of a forest over a user-defined time period. Inputs include a polygon vector GIS layer representing the planned harvest of timber for the study area, and various data related to economic valuation (anticipated volume of harvest, harvest schedule, market value of timber to be harvested, etc.). The model assumes that the market value of timber will not change over the duration of the analysis. Factors related to the harvest of each individual parcel, such as frequency and cost of harvest, are also held constant.

This is a Tier 1 InVEST model, and is relatively simple. But it is capable of providing a general assessment of the value of merchantable timber contained in a forested landscape. Running this model in Alberta would rely on the cooperation of the FMA-holding companies, or at least the Provincial agents that administer FMAs, in order to gain access to the required input data. The outputs of this model could be compared to those of another InVEST model - the Carbon Storage and Sequestration Model[4] - in order to compare the value of ecosystem services associated with harvest to those of preserving natural forests. This might facilitate improved understanding of the tradeoffs between two extremes of the forest management continuum, and lead to more sustainable forestry practices.

Lastly, it may be possible to modify the Managed Forest Production Model in a way that accurately captures the ES values associated with productive rangeland.

Pollination of Agricultural Crops

The InVEST Crop Pollination Model is a Tier 0 model; the only valuation it provides of the ecosystem service associated with crop pollination is a relative index of additional crop yield generated through natural pollination. This is achieved through modeling the relative abundance of pollinators over an agricultural landscape.

The Crop Pollination Model is based on an estimation of relative abundance of wild bees, a predominant pollinator of agricultural crops. The model can accommodate a variety of pollinator species or species guilds if their habitat requirements are sufficiently different. Required input data includes a model of potential wild bee nesting sites, and a map of available food (nectar and pollen) sources. The latter is obtained through a detailed land use / land cover (LULC) raster data layer. For each LULC type the user must estimate an indexed value for both nesting suitability and flower availability. These are used to calculate a pollinator abundance raster layer, as well as a

[4] The Carbon Storage and Sequestration Model is not discussed in this report, as it is not one of the ES mentioned in the ESA Project Terms of Reference. Please consult the InVEST User's Guide for these details.

subsequent Farm Abundance Index - a relative measure of the pollinators available for visiting each farm parcel. Lastly, the ES value associated with each agricultural parcel is attributed back to the nesting habitat that is the source of the pollinating bees.

Clearly, some knowledge of the behavioural ecology of bees is essential to the creation of a useful Crop Pollination Model, which would require consultation with experts. Although sophisticated LULC data - specifically the provincial Grasslands Vegetation Inventory (GVI) - exists for some regions, it is not exhaustive and does not cover all agricultural regions of the province. The structure of GVI also presents a challenge as it is not a "flat" data layer; there are instances of overlapping polygons which would need to be resolved before the data could be used as an InVEST input. Lastly, GVI and all other known data sources lack any description of the crops being grown on individual parcels. A source for this information would need to be identified, or a suitable generic crop distribution map would need to be proposed. The ABMI Terrestrial Habitat Data could also be useful in helping identify non-agricultural sources of nectar and pollen.

The results of a Crop Pollination Model could be used to demonstrate the ES value of wild bees as crop pollinators, but they also could be used to demonstrate the value of conserving bee habitat within agricultural landscapes.

Water Purification

InVEST estimates the value of ecosystem services related to water purification through the tier 1 Water Purification Nutrient Retention model. This model calculates the ability of soil and land cover to intercept runoff and purify water, and compares this to the cost of engineering similar services as water treatment facilities. Results are reported as on aggregate, summarized over a watershed or sub-watershed scale. It works best in areas that are dominated by saturation excess or runoff hydrology, which comprises most of Alberta.

This model focuses on the abilities of vegetation and soils to retain pollutants and purify surface water as it moves through a drainage basin. It was designed to account for non-point-source, nutrient pollutants like nitrogen and phosphorus, but can be modified to incorporate consideration of other contaminants as well.

Required inputs for this model include a digital elevation model (DEM) and watershed (or sub-watershed) boundaries, climate data (precipitation, evapotranspiration, etc.), soils data (as contained in the provincial AGRASID data set), a LULC layer from which to estimate pollutant export levels and nutrient filtration coefficients, and information related to the cost of building water treatment infrastructure. The DEM is used to calculate hydrological flow models, which in turn allow for the modeling of both the movement and retention of pollutants.

Most of the data sets required to run this model are available in Alberta. Expert opinion would be required in order to parameterize the model and estimate the costs associated with engineered water treatment. Water purification seems to be one of the most popular ecosystem services to model; the concept of deriving this benefit from nature is more intuitive, and the costs associated with removing this ES and manufacturing purification instead are easier to estimate than the foregone opportunities from the destruction of other natural capital.

Biodiversity

InVEST has the capacity to evaluate biodiversity through the tier 0 Biodiversity: Habitat Quality and Rarity model. This model allows for the calculation of relative habitat rarity and susceptibility to degradation, under both current and possible future conditions.

Since the next part of this section is dedicated to exploring this model in greater detail, further discussion will be deferred to the following paragraphs.

Modeling Biodiversity in Alberta Using InVEST

InVEST estimates the value derived from biodiversity by calculating metrics for relative habitat quality and rarity across a landscape using the tier 0 Biodiversity: Habitat Quality and Rarity model. The InVEST model suite does not consider biodiversity as an ecosystem service, but rather as an inherent characteristic of natural systems with its own intrinsic value. Therefore InVEST deliberately avoids the monetization of biodiversity; instead, assessment is relative to the magnitude and threat of disturbance on the landscape. In essence, the model views intact, undisturbed landscapes as more valuable, and altered landscapes as less valuable.

Biodiversity metrics are derived from LULC and human use spatial data layers and are governed by several factors: the threat of human use to native land cover; the sensitivity of different land cover types to disturbance; the distance between native land cover and the nearest human activity; and the extent to which landscapes are legally protected from development. Biodiversity and the quality of landscapes is typically assessed in the InVEST model through a habitat-based, or non-species specific approach.

Figure 11 (p.38) provides an overview of data requirements, process, and outputs for the Biodiversity: Habitat Quality and Rarity model.

The model requires LULC and human footprint spatial data, and thematic information related to the biodiversity value of different cover types, and the threat to these values presented by different types of human activity. Optionally, the user can generate and input a LULC layer that represents a possible future land use scenario, as the basis for longitudinal comparison of biodiversity values across the landscape. Or one could use the model coupled with historic LULC data in a backcasting exercise, to improve understanding of the value of biodiversity that has already been lost.

InVEST Data and Model Inventory				
	Step	**Data requirements**	**Process**	**Outputs**
Biodiversity: Habitat Quality and Rarity (Tier 0)				
Required	**Supply**	Current Land use/land cover Threat impact distance Relative threat impact w eights Form of threat decay function Threat maps Habitat suitability (optional: by species group) Habitat sensitivity to threats Half saturation constant	Calculate habitat quality and degradation based on threat intensity and sensitivity	Habitat degradation index; Habitat quality index
Optional	**Supply**	Protected status		
		Baseline land use/land cover	Calculates rarity of current and/or future habitat types relative to baseline; calculates quality and degradation of baseline based on threat intensity and sensitivity	Relative habitat rarity index for current and/or future land use/land cover; Degradation and quality for baseline
		Future land use/land cover	Calculates quality and degradation of future scenario based on threat intensity and sensitivity; optionally calculates habitat rarity relative to baseline	Habitat degradation, quality and optionally rarity for future scenario

Figure 11: InVEST 'Biodiversity' module data requirements, process and outputs (Tallis et al 2013)

Inputs

The primary spatial data input for this model is a raster LULC data set for the area of interest. The model has the flexibility to accommodate coarsely defined LULC types or very specific ones. For the study area of Alberta, the best LULC input data would likely be the ABMI c.2000 Alberta Land Cover Map. More detailed data may be available for specific regions of the province, but this is likely the best province-wide resource.

For modeling habitat quality, the user must create a table which specifies the quality or suitability of habitat (values range from 0 (least suitable) to 1 (most suitable)) for every LULC type in the input raster data set. Obviously, assignment of habitat suitability/quality is highly dependent on the conservation objective. For example, the habitat requirements of migratory songbirds will be markedly different from those of endemic prairie reptile species. It is therefore important to respect the broader process in which InVEST is embedded, and to consult with stakeholders to identify appropriate and meaningful conservation objectives. As with LULC types, the conservation objectives can also be coarsely or very precisely defined. In a recent effort to understand the broad-scale ecological function and connectivity of the entire contiguous United States, Theobald et al (2012) elected to assess habitat quality based on the general requirements of all terrestrial species. This might not allow for answering questions related to specific populations, but it affords the opportunity to understand the more general ecological value of the landscape, and may be a worthwhile exercise in the Alberta context.

The model also requires an assessment of the threat imposed on each natural land cover type by each type of human footprint. Each threat must be mapped as a separate raster layer, and threats can be binary (0 if the threat is present, 1 if it is not) or continuous (e.g. the proportional density of a threat within a raster grid cell). The best province-wide source for mapping many of these threats would be the ABMI c.2010 Alberta Human Footprint Map.

The model considers the comparative impacts of different threats through the required input of a threat table. This allows the user to specify the weighting (or impact - continuous values ranging from 0 to 1) and range of influence/impact (specified as a distance) for each threat. Again, these impacts must consider the conservation objective of the analysis. The threat table can be populated through a Delphi approach with stakeholders or experts, or depending on the conservation objective, may make use of information that has already been tabulated through other provincial conservation planning initiatives (e.g., the province-wide ALCES model developed by Brad Stelfox and Forem Technologies).

Using the above inputs, the Biodiversity model calculates Habitat Quality as a function of threat impacts, the proximity of quality habitat to threats (calculated based on a distance-decay function), the distribution and effectiveness of protected areas, and the relative sensitivity of habitat types to different threats. Habitat Quality is one of two raster grids that are output from the InVEST Biodiversity model.

The other raster grid output is a relative measure of Habitat Rarity. Calculation of Habitat Rarity is dependent on having a minimum of two time-slices of the LULC map of the landscape - a current LULC raster layer (required for this model), coupled with either a historic (baseline) layer, or a layer that represents a possible future scenario. The estimate of Habitat rarity is obtained by comparing the distribution of natural LULC types between the two time-slices of the landscape.

To meet the objectives of the ABMI ESA Project, it may be worthwhile to employ the InVEST Biodiversity model. This model could assist in mapping habitat rarity across the province, and could also improve our understanding of the impacts on biodiversity (habitat quality) associated with historic and anticipated future patterns of land use. To make the best use of this model, one would need to generate both historic (baseline) and forecasted future LULC raster data layers for the province. Such analysis has been used in the Willamette Valley in central Oregon to successfully influence conservation and land use planning decisions see Willamettepartnership.org 2008).

Mapping the baseline conditions would first require a precise identification of what "baseline" means. Depending on the answer to this question, a baseline data set could be generated through obtaining an older LULC data set, using spatial analytical techniques to "delete" human footprint from the landscape, or potentially using the output of backcasting approaches like ALCES (ALCES.ca 2008) to model historic conditions.

Generating LULC layers for possible future scenarios could be done through the use of multi-agent modeling software like NetLogo (ccl.northwestern.edu 1999), or through spatially explicit, dedicated land use change and environmental modeling platforms like Dinamica EGO (csr.ufmg.br n.d.).

As with any of the InVEST models described above, the Biodiversity model is highly scalable to varying levels of data quality and analytical effort. Better data and more concerted effort may produce better outputs, but there may nevertheless be great value in using the Biodiversity model as an instrument for conducting a rapid assessment of the habitat quality and rarity conditions within our province.

CONCLUSIONS

As resource managers in Alberta seek more frequently to adopt the ecosystem service paradigm, key challenges arise regarding inaccessibility of models, lack of data, poor understanding of regulatory applications, inadequate value measures, supply-side bias, disconnected ecological research.

To help address these challenges, Miistakis approached them from three perspectives: making the conceptual links between ecosystem services and two applied conservation issues (climate change and biodiversity management); understanding the range of tools available to decision makers for mapping ecosystem services; and assessing the practical data challenges of applying an ES tool in Alberta.

The authors arrived at the following conclusions.

Ecosystem services and climate change

Ecosystem services may be the best way to connect biodiversity and local decision making. The 'utilitarian' character of the ecosystem services approach resonates with the majority of Albertans (who do not consider themselves active conservationists). This characteristic also resonates with local decision makers, and they can more readily equate existing plans and policies with ecosystem services. Though relatively new, the concept is already well ingrained in provincial policy discussions.

Climate change, biodiversity, local communities, natural capital, resilience and ecosystem services have intuitive conceptual linkages. Framing these connections in a conceptual model that shows the flows from natural capital to human well-being, illustrates the need to have clarity on the benefits we derive from specific functions, and how management action can be proactive and resilience-based, not just reactive.

Many communities are already taking actions that promote maintaining/restoring biological resilience (conservation plans that protect key linkages, riparian restoration projects, etc.), but adapting to climate change is not the reason. Linking biodiversity data to the ecosystem services (ES) that they provide increases the potential for practical conservation action.

Data and information

The quality and availability of data is not uniform across the province. Some regions have exceptionally high-quality data, whereas others has only the most basic, provincial- or national-scale data. Access to spatial data in the Province of Alberta has been a perennial challenge, as data sets that are free and accessible in neighbouring jurisdictions are sometimes challenging to discover in Alberta, and often come at a prohibitive cost. In general, the spatial data that is available in Canada is inferior to that of many other regions of the developed world. In some cases, the decision support tools that have been developed in other regions have a heavy bias towards, and reliance on, this higher-quality data.

Ultimate decisions on the data needed, and thus the extent to which these challenges will be a factor, will be dependent on the decision and mapping tools chosen.

Mapping tools

Mapping biodiversity, climate change adaptation and ecosystem services is an important step in visualizing, analyzing and identifying knowledge gaps of both current and projected landscapes. However, many of the issues surrounding climate change adaptation, ecosystem services and biodiversity are complex and require expert knowledge to fully understand. A mapping tool will need to distill that expert knowledge and provide the result in manner that is clear and concise to the average decision maker.

Biodiversity mapping tools are largely educational in nature, providing the user with access to information about the spatial distribution of species. This could be for specific species like NatureServe, or it could be models that calculate species richness or hotspots. Biodiversity tools are common in both online and GIS based forms. There are more biodiversity tools than climate change or ecosystem services tools.

Ecosystem service mapping tools seem to be in their infancy with a much smaller volume of available examples. This could be the newer nature of the topic of ecosystem services, but also because it is a harder concept to convey easily in a mapping tool. Data requirements of ecosystem services are fairly high, specifically on valuing services on the landscape. Most ecosystem service map tools are GIS based at this time.

A significant issue with providing tools to any large user group is dealing with the different levels of capacity. ArcGIS for example is a powerful and commonly used GIS application. It is also propriety, expensive, and relatively complex to use. Many smaller local communities would not be able afford or use ArcGIS. As well, very few tools were found that were specific to the roll of facilitating a community-based process.

InVEST in Alberta

This report has reviewed four models, comprising part of the InVEST ecosystem services modeling suite, that are designed to assess the values associated with ecosystem services identified as priorities in the ABMI ESA Project. A fifth priority (rangeland production) is not represented in the current InVEST toolkit, but the suite is constantly evolving and it is likely that an existing model could be modified to this purpose.

The InVEST modeling suite is robust, scalable to varying levels of input data quality and other available resources, and credible due to widespread use and meaningful contributions to land-use and conservation planning. There may be great utility in adopting an InVEST-based approach to help answer some of the questions and address some of the research objectives of the broader Project.

The authors anticipate these three perspectives, collectively, and the resulting conclusions illustrate both issues and routes to potential solutions regarding the identified ecosystem service application dilemmas.

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