New Business Decision-Making Aids in an Era of Complexity, Scrutiny, and Uncertainty

Tools for Identifying, Assessing, and Valuing Ecosystem Services

BSR's Ecosystem Services, Tools & Markets Working Group

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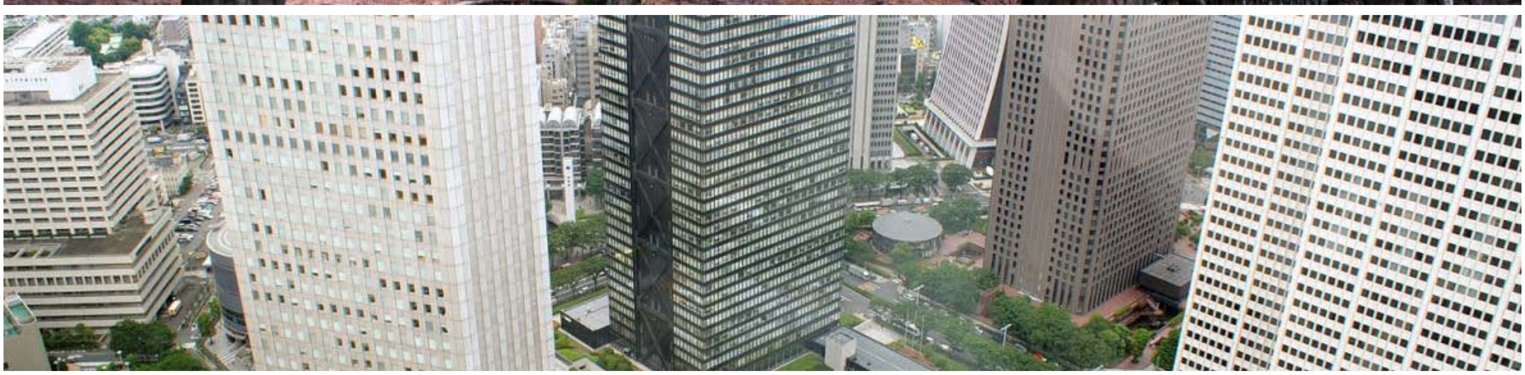

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About This Report

This report was written by Sissel Waage, Kit Armstrong, and Linda Hwang, with contributions from Ken Bagstad. It is based on work both prior to, during, and following an October 2010 roundtable that focused on emerging ecosystem services tools and included analytical work, as well as comments on drafts, by (in alphabetical order): Ken Bagstad, University of Vermont, Gund Institute for Ecological Economics; Kevin Benck, Parametrix; Pieter Booth, Exponent; Chris Colvin, The Natural Capital Project; Kenna Halsey, Parametrix; Kevin Halsey, Parametrix; John Finisdore, World Resources Institute; Gary Johnson, University of Vermont, Gund Institute for Ecological Economics; Sheryl Law, Exponent; Doug MacNair, Cardno ENTRIX; Mary Ruckelshaus, The Natural Capital Project; David Saah, Spatial Informatics Group; and Austin Troy, University of Vermont and Spatial Informatics Group. We are grateful to all of these individuals for the time they invested.

This report draws upon discussions about emerging ecosystem services tools during the October 2010 roundtable with the individuals listed above as well as (in alphabetical order): Brian Bellew, U.S. Bureau of Land Management (BLM); Greg Biddinger, ExxonMobil; Roberto Bossi, Eni; Sarah Connick, Chevron; Amanda DeSantis, DuPont; Craig Duxbury, The Walt Disney Company; Sofie Gudum Faaborg, DONG Energy; Ann George, Freeport-McMoRan Copper & Gold; Sachin Kapila, Shell; Jasper Lament, BC Hydro; John Lin, U.S. Environmental Protection Agency; Mark Nechodom, U.S. Department of Agriculture; Anne Neville, Rio Tinto; David Norris, Freeport-McMoRan Copper & Gold; Shirley Oliveira, BP; Malka Pattison, U.S. Department of the Interior; Mark Rekshynskyj, BLM; Darius Semmens, U.S. Geological Survey (USGS); Carl D. Shapiro, USGS; Manuel Winograd, European Environment Agency; Robert Winthrop, BLM; and Richard Wood, ExxonMobil. We are deeply appreciative for the strong participation and level of engagement during the roundtable discussion.

Finally, we would like to thank the corporate members of BSR's Ecosystem Services, Tools, and Markets (ESTM) Working Group, including BC Hydro, BP, Chevron, DONG Energy, DuPont, Eni, Exxon Mobil Corporation, Freeport-McMoRan Copper & Gold, GlaxoSmithKline, Merck & Co., Rio Tinto, Shell, and The Walt Disney Company.

Any errors in the report are those of the authors alone. Please direct comments or questions to Sissel Waage at swaage[at]bsr.org.

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ABOUT BSR

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Executive Summary

Business today occurs in an increasingly complex world characterized by intense scrutiny and uncertainty. Every year decision-makers must consider new parameters when managing ongoing projects and planning new ones, and must understand each project's impacts and opportunities. Carbon emissions (and sequestration), water availability (and natural filtration capacity), and biodiversity are but a few of the relatively new areas attracting more and more scrutiny. The guiding concept that ties all of these areas of corporate impact assessment together is ecosystem services.

Although it may sound like an esoteric scientific concept, ecosystem services will likely become a standard category of corporate performance metrics in the coming years. A shift is under way, as evidenced by multiple factors, including:

» Multilateral organizations are increasingly focusing on ecosystem services issues.

» National governments are exploring ecosystem services applications and potential value.

» Investors and stakeholders are demanding broader corporate impact measurement, assessment, and disclosure related to ecosystem services parameters.

» Companies, across industries, are issuing corporate policies that name ecosystem services and are launching new initiatives focused on understanding corporate impacts on ecosystem services.

Recognizing this context, BSR's Ecosystem Services, Tools, and Markets (ESTM) Working Group undertook a comparative assessment of emerging ecosystem services tools in 2010. These decision-making aids seek to offer an ecosystem-oriented approach to considering corporate actions within the broader landscapes—both literally (in terms of effects on and across watersheds) and figuratively (in terms of ripple effects across economic and sociocultural contexts). We applied seven ecosystem services tools to the U.S. state of Arizona's San Pedro Watershed, with the case study question of where to site a hypothetical residential housing development.[1] We offered each tool a common set of data

[1] The tools, discussed in detail with tool developer names and websites (see Table 1), included: ARIES, EcoAIM, ESR, ESValue, EcoMetrix, InVEST, and NAIS. We chose the San Pedro Watershed because it is an ecologically diverse area with past mining operations, cultural significance to 11 Native American tribes, and robust, longitudinal data sets. In addition, it was the site of a USGS and BLM joint study of several ecosystem services tools, which was made available for insights into this effort. Therefore, this site was ideal for comparing additional tools.

Box 1: Ecosystem Services

Ecosystem services are the benefits provided by functioning ecosystems for people's health, jobs, and safety. The Millennium Ecosystem Assessment (MEA) offered four categories:

» **Provisioning services**: Goods or products produced by ecosystems
» **Regulating services:** Natural processes regulated by ecosystems
» **Cultural services:** Nonmaterial benefits obtained from ecosystems
» **Supporting services**: Functions that maintain all other services

(gathered from public agencies) and asked it to respond to the same questions, with a focus on four key parameters: water provisioning, carbon sequestration, cultural services, and biodiversity.

The process of applying the ecosystem service tools to the San Pedro Watershed varied, because of differences in how the tools are applied and what parameters each one uses. In addition, all but two of the tool developers voluntarily engaged in this comparative test, without dedicated funding.[2] For these reasons, the scope of the work varied among tools to ensure that it was appropriate for the tool as well as feasible for the participating personnel. Throughout the process, we encountered challenges with data availability, model applicability in arid and groundwater-dominated systems, lack of direct funding, and associated time constraints.

The assessment resulted in several key insights, including:

» Comparing tools side-by-side is difficult, given their very different definitions of ecosystem services, as well as their distinct analytical "architectures."
» Ecosystem services tools offer insights that can be relevant to corporate decision-making processes, particularly in terms of dependencies on natural resource–based inputs that most businesses have not traditionally considered. None, however, readily mesh with key existing corporate processes and thus do not appear to be ready for immediate, widespread, off-the-shelf business application without considerable effort and cost.
» These tools have been applied to corporate decision-making processes infrequently to date, and these new business tools have not yet been compared to the current corporate processes. It is not yet clear what additional value ecosystem services tools provide when compared with existing approaches companies use to assess performance.

Aids and tools to support ecosystem services decision making, particularly in terms of proof of concept within corporate decision-making processes, are still emerging. Looking forward, ecosystem services concepts and tools will continue to mature, though the arena will likely become crowded and confusing as newcomers develop more tools. At the same time, policy initiatives and stakeholder pressure to consider ecosystem services impacts are growing.

Corporate decision-makers have an opportunity to engage with ecosystem services thought leaders and tool developers to explore cost-effective approaches to integrating these concepts into their decision-making process. They can also begin to understand the expectations emerging around corporate performance and ecosystem services.

[2] Only ARIES and InVEST applications were funded, through the BLM- and USGS-funded project led by a technical analyst, Dr. Ken Bagstad. A BLM and USGS contractor for this project, Bagstad had worked previously on the ARIES tool development team. He applied both ARIES and InVEST within this project. Although he consulted the InVEST team at key intervals, they neither directly funded, nor directly participated in the process. Though outside the BSR study, the USGS and BLM tools assessment also included the Defenders of Wildlife value transfer tool, as well as primary valuation and value transfer (function transfer) approaches from established literature. For further details, please contact Ken Bagstad.

Box 2: Ecosystem-Informed Approach

An ecosystem-informed approach is one that considers the combined interactions of:

(1) biological or living components (plant, animal, and microorganism communities) of environment, and
(2) physical or nonliving components (air, water, soil, and the other basic elements and compounds of the environment).

This approach considers the *structure* of ecosystems (in terms of elements present within the systems) that in turn affect the *function,* which relates to both the flow of ecosystem services, as well as the resilience of these systems.

Introduction

Imagine a corporate manager under pressure to continually add metrics to track and analyze performance. The number of parameters, complexity of processes, and cost to the company would constantly rise.

Many companies already face this dynamic. In response, many business leaders seek integrated approaches to track a multitude of metrics concurrently within a broader system performance. Some companies have begun to consider whether the concept of ecosystem services (see Box 1) might be a useful lens through which to view their environmental and social performance.[3] Other businesses have begun to explore the potential for incorporating an ecosystem-informed approach into their activities (see Box 2).

The reason for business consideration of ecosystems and ecosystem services is that a growing number of players are now engaging with ecosystem services, such as:

» Multilateral organizations, including the International Finance Corporation (IFC)
» Leading academic institutions, such as Stanford University[4] in the United States, Wageningen University[5] in the Netherlands, and Fundação Getulio Vargas[6] in Brazil
» Environmental organizations, such as Flora and Fauna International, the International Union for Conservation of Nature, The Nature Conservancy, and World Resources Institute
» National governments (such as India, Colombia, Mexico, the Philippines, the U.K., and Norway) and subnational governments (such as Brazil's State of Acre) through the Global Partnership for Wealth Accounting and the Valuation of Ecosystem Services[7]

These trends will likely continue to build. If they do, companies will face expanded corporate management and performance expectations, as well as new challenges and opportunities. For example, companies may need to employ new ecosystem services-related risk- and impact-assessment protocols to identify potential effects of new projects and possible disruptions to supply chains based on changes in ecosystem services flows. At the same time, businesses will have new opportunities to create, measure, and capture value by investing in activities that enhance ecosystem services.

In response to this emerging area of work, BSR's ESTM Working Group convened and facilitated a roundtable discussion in 2010—that included industry, tool developers, and government—focused on preliminary findings from a comparative tool application of emerging ecosystem services–focused tools. This application aimed to help corporate decision-makers, tool developers, government officials, and other interested entities to better understand how to apply these tools in

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[3] For an introduction to ecosystem services for businesses, please see BSR's publications on the topic at: www.bsr.org/consulting/working-groups/environmental-markets.cfm. For further scientific background on the topic, please see the MEA at: www.maweb.org/en/index.aspx.
[4] www.naturalcapitalproject.org/about.html.
[5] www.fsd.nl/esp/77468/5/0/30.
[6] www.fgv.br/ces.
[7] http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,,contentMDK:22811907~pagePK:210058~piPK:210062~theSitePK:244381,00.html.

Box 3: BSR's Ecosystem Services, Tools & Markets Working Group

To help companies track emerging ecosystem services issues and assess new decision-making aids, BSR together with corporate members formed a working group on environmental services, tools, and markets in January 2007. In the group's first year, BSR collaborated with corporate members to develop a business-focused report on environmental services and markets.

Between 2007 and 2010, the ESTM Working Group convened a series of roundtable discussions with member companies, ecosystem services tool developers and public sector representatives to explore the current and emerging state of ecosystem services tools that may be applicable to the private sector.

decision-making processes, cost, and what value they may add. The comparative tool assessment sought to compare the tools through applications at a common study site, using the same data sets and the same technical analyst to oversee the process.

This report documents the comparative tool assessment's process and findings. It discusses potential applications of tools within corporate contexts and the following:

- Key trends driving the business case for attention to ecosystem services
- The 2010 comparative tool assessment's approach and methodology
- Assessment results
- Key insights from the assessment
- Conclusions and a look forward

This report's companion supplementary materials contain additional detailed information on the tools and the comparative assessment. BSR's ESTM Working Group hopes this report will inform and facilitate the broader conversation around ecosystem services, which will likely grow in scope and intensity in coming years.

Box 4: Illustrative Government Activity on Ecosystem Services

United States
- U.S. Environmental Protection Agency Office of Research and Development research agenda and projects
- U.S. Department of Agriculture Office of Environmental Markets strategic agenda
- BLM and USGS funding of ecosystem services tool testing and development
- Relating concepts within Natural Resource Damage Assessments (NRDAs)

European Union
- Research agenda around ecosystem services, with "white box" modeling and analytical approaches in response to policy makers
- TEEB

Australia
- Various environmental markets established

England
- Engaged with the Global Partnership for WAVES with the World Bank

Vietnam
- National legislation on payments for ecosystem services

Key Trends

Several trends are contributing to an emerging business case for consideration, and even integration, of ecosystem services concepts within corporate decision-making processes.

TREND #1: Multilateral attention to ecosystem services is on the rise.

The pace of developments has increased in 2010 and early 2011, including:

» Release of The Economics of Ecosystems and Biodiversity (TEEB) reports[8]

» Discussions linking biodiversity and ecosystem services at the UN Convention on Biological Diversity Conference of the Parties (COP) 10 meeting in Nagoya[9]

» Establishment of an Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[10]

» Proposed expansion of requirements relating to ecosystem services in IFC's updated Social and Environmental Sustainability Performance Standards[11]

»

The question is no longer *if* ecosystem services will be a key framing of environmental issues among multilateral institutions in the coming years, but exactly *when*, *where*, and *how* it will occur. Overall, we appear to be moving toward a paradigm shift in thinking that centers on ecosystem services concepts, metrics, and valuation.

TREND #2: Governments around the world are exploring new accounting and valuation methodologies related to ecosystem services.

A growing number of government agencies around the world are supporting new initiatives and policies that relate to ecosystem services (see Box 4).[12] While government action on ecosystem services remains emergent and exploratory, the pace and scope of exploration has increased in recent years. This interest has been particularly clear in such areas as biofuels, agricultural conservation subsidies, and environmental markets. In light of recent developments, policy adoption of ecosystem services appears to be a key area for businesses to track in the coming years, particularly given the newly launched project Wealth Accounting and the Valuation of Ecosystem Services (WAVES) between various national governments and the World Bank.

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[8] www.teebweb.org/.
[9] www.cbd.int/cop10/.
[10] http://ipbes.net/.
[11] www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/pol_PerformanceStandards2006_PS6/$FILE/PS_6_BiodivConservation.pdf.
[12] NRDAs in the United States consider "[d]amages to natural resources . . . by identifying the functions or 'services' provided by the resources, determining the baseline level of the services provided by the injured resource(s), and quantifying the reduction in service levels as a result of the contamination" (excerpted from www.epa.gov/superfund/programs/nrd/nrda2.htm). For further information on NRDAs, see sites such as: www.epa.gov/superfund/programs/nrd/nrda2.htm, http://oceanservice.noaa.gov/facts/nrda.html, and www.nrdarpracticeexchange.com/activities.htm.

Box 5: The Natural Value Initiative

The Natural Value Initiative (NVI) is an example of this new wave of stakeholders' assessment of corporate performance from an ecosystem services approach. The NVI was established to:

"(1) demonstrate the business case for understanding, avoiding, minimizing, and compensating for impacts on biodiversity and ecosystem services using strong science and sound financial analysis,

(2) improve corporate performance and management of impacts and dependence on biodiversity and ecosystem services through the application of the Ecosystem Services Benchmark developed in the first phase of work, and

(3) mainstream biodiversity and ecosystem services into investment analysis."

The result so far is a beta version of a benchmarking approach that assesses corporate processes on biodiversity and ecosystem services issues.

Source: www.naturalvalueinitiative.org/content/006/600.php.

TREND #3: Investor and stakeholder demand for broader and more explicit corporate performance and disclosure relating to ecosystem services is rising.

Investors are likely to consider ecosystem services in the near future, as illustrated by risk assessments of palm oil in the European Union. To accelerate activity in this area, NGOs are developing approaches to influence and evaluate company performance with respect to ecosystem services (see Box 5).

As companies track biodiversity issues and disclose information on carbon and water, such as for the Carbon and Water Disclosure Projects, single-issue environmental assessment processes will continue to proliferate *concurrent* with expanded links among issues. For example, the Carbon Disclosure Project has already linked carbon and water in the Water Disclosure Project.

Many other stakeholder groups have linked carbon and water in the context of sustainability reporting. This dynamic highlights the need for an integrated perspective that can show what individual metrics add up to in terms of overall corporate performance. Companies should consider tracking ecosystem services as they relate to investor interest in three areas:

» Corporate risk assessment protocols
» Implementation of the IFC's performance standards
» Due diligence of supply chain management

TREND #4: Businesses are engaging with ecosystem services through corporate policy, impact assessment, and decision making.

A growing number of diverse industries and companies are publicly stepping into the ecosystem services domain. For example:

» The Dow Chemical Company has committed US$10 million to establish a new approach to resource management, with Dow President and CEO Andrew Liveris asserting that: "Going forward, the businesses that are best positioned to get ahead will be the ones that truly build a full approach to ecosystem management and biodiversity economics into all of their plans."
» Puma is launching the first-ever Environmental Profit and Loss (EP&L) statement to measure "the full economic impact of the brand on ecosystem services."
» The Walt Disney Company has set a corporate goal of "net positive impact on ecosystems."

The opportunity is ripe for engagement between public, private, academic, and NGO players to explore both how to integrate ecosystem services concepts and tools into existing corporate decision-making processes and how to clarify what added value an ecosystem services "frame" offers companies.

Both these trends, as well as open questions related to corporate applications of ecosystem services concepts, are the underlying rationale for BSR's ESTM Working Group's activities and our 2010 comparative tool assessment.

Box 6: The San Pedro Assessment's Hypothetical Scenario

Several large-scale residential development projects were proposed for communities in the San Pedro Watershed prior to the collapse of the real estate bubble in the U.S. These projects would likely have accommodated retirees or long-distance commuters to places, such as Tucson or Sierra Vista. Although commercial development would likely have followed large-scale residential development, the San Pedro valley's sparse population would probably not support large-scale commercial ventures.

We asked participating tool developers to apply their products to this hypothetical case, in which these communities would disturb the Chihuahuan desert scrub, the primary existing vegetation. They considered a proposed 500-acre and 1000-unit housing development. We estimated water use as 312 gallons per capita day for 2.56 people per home in unincorporated areas. This figure represents 894.5 acre-feet per year in new demand from 1000 new housing units, plus induced commercial demand.

Comparative Tool Assessment Process

The objective of the 2010 tool assessment was to compare and assess seven ecosystem services–focused tools through a test application within the U.S. San Pedro Watershed, in Arizona, a site targeted for a hypothetical residential housing project (see Box 6 for details). The study focused on four parameters: water provisioning, carbon sequestration, cultural services, and biodiversity. (Even though biodiversity is not an ecosystem service, its role in ecosystem structure and function makes it a significant parameter.) The study also tracked the time, cost, level of expertise, and other factors associated with applying each tool to this case study. The intent was to gather information that would help assess the feasibility of tool applications within corporate settings.

The study area was initially chosen by the U.S. Bureau of Land Management (BLM) and the U.S. Geological Survey (USGS) for an Ecosystem Services Valuation Pilot study, which included, among others, the ARIES and InVEST tools (described in Table 1). We chose this site because it is a data-rich, ecologically diverse area with a history of mining activity and cultural significance to 11 Native American tribes.[13]

The BLM and USGS agreed to include BSR in their review. Technical analyst Dr. Ken Bagstad[14] served as a contractor to the BLM and USGS, as well as BSR, to collect data and feed it into these tools. Parallel to the agencies' assessment, BSR engaged directly with the developers of five additional ecosystem services tools (described in Table 2). These developers applied their tools using the same data sets as the BLM and USGS assessment, insofar as those data sets meshed with the tools' data demands.

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[13] For further details on the BLM and USGS project and the site, consult the supplementary materials.
[14] Dr. Ken Bagstad did his doctoral work at the University of Vermont and participated on the ARIES development team.

Table 1: Ecosystem Services Tools Included in BLM and USGS Assessment

Tool	**Description** (Excerpted from tool websites and descriptive materials)	Developers and Websites
ARIES (ARtificial Intelligence for Ecosystem Services)	"ARIES is a web-based technology offered to users worldwide to assist rapid ecosystem ervice assessment and valuation. Its purpose is to make environmental decisions easier nd more effective. ARIES helps discover, understand, and quantify environmental assets nd what factors influence their values, in a geographical area and according to needs and riorities set by its users. ARIES can accommodate a range of different use scenarios, ıcluding spatial assessments and economic valuations of ecosystem services, optimization f payment schemes for ecosystem services, and spatial policy planning."[15]	» University of Vermont's Gund Institute and Ecoinformatics Collaboratory (United States) » Basque Centre for Climate Change (Spain) » Conservation International (United States) » Earth Economics (United States) » Instituto de Ecologia (Mexico) www.ariesonline.org/
InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)	"InVEST is designed to help local, regional, and national decision-makers incorporate cosystem services into a range of policy and planning contexts for terrestrial, freshwater, nd marine ecosystems, including spatial planning, strategic environmental assessments, nd environmental impact assessments. InVEST models are based on production functions ıat define how an ecosystem's structure and function affect the flows and values of cosystem services. The models account for both service supply (e.g., living habitats as uffers for storm waves) and the location and activities of people who benefit from services ɜ.g., location of people and infrastructure potentially affected by coastal storms). Since ata are often scarce, the first version of InVEST offers relatively simple models with few ıput requirements. These models are best suited for identifying patterns in the provision nd value of ecosystem services. With validation, these models can also provide useful stimates of the magnitude and value of services provided."[16]	» The Natural Capital Project, including: » Stanford University (United States) » University of Minnesota » WWF (World Wildlife Fund) » The Nature Conservancy www.naturalcapitalproject.org/

[15] Excerpted from www.hd.gov/HDdotGov/detail.jsp?ContentID=573.
[16] Excerpted from www.naturalcapitalproject.org/pubs/NatCap_InVEST_and_Case_Study_Summary_TEEB_2010.pdf.

Table 2: Additional Ecosystem Services Tools Included in BSR Assessment[17]

Tool	**Description** (Excerpted from tool websites and descriptive materials)	Developers and Website
EcoAIM (Ecological Asset Inventory and Management)	A new tool "to (1) inventory ecological services and help in making decisions regarding development, transactions, and ecological restoration; (2) develop specific estimates of ecosystem services in a geographically relevant context, and (3) offer the means for evaluating tradeoffs of ecosystem services resulting from different land or resource management decisions."[18]	Exponent » http://conference.ifas.ufl.edu/aces/Presentations/Wednesday/Coyote-B-E/PM/Yes/0135%20P%20Booth.pdf
EcoMetrix	"An environmental measurement and modeling tool that supports sustainable infrastructure, restoration projects, and enterprise-level program decision-making. EcoMetrix models and quantifies changes within an ecosystem, enabling users to evaluate the positive or negative effects of different scenarios and alternative designs on ecosystem services."[19]	Parametrix www.parametrix.com/cap/nat/_ecosystems_ecometrix.html
ESR (Ecosystem Services Review)	"A structured methodology for corporate managers to proactively develop strategies for managing business risks and opportunities arising from their company's dependence and impact on ecosystems."[20]	» World Resources Institute (WRI) » Meridian Institute » World Business Council on Sustainable Development (WBCSD) www.wri.org/project/ecosystem-services-review
ESValue	"A strategic decision support tool that integrates scientific and economic information to show the impact and value of alternative environmental management strategies on ecosystem services. The objective of the tool is to integrate existing information and expert opinion with stakeholder values to efficiently and effectively identify the key site-specific ecological effects and resulting change in economic value for different management strategies."[21]	Cardno ENTRIX www.entrix.com/

[17] Developers of the *Habitat Estimation Toolkit* and *MEASURES* tool were approached for inclusion in this study, but they declined due to time and cost constraints.
[18] Excerpted from Exponent materials for the 2010 BSR roundtable.
[19] Excerpted from Parametrix materials for the 2010 BSR roundtable.
[20] Excerpted from www.wri.org/project/ecosystem-services-review.
[21] Excerpted from Cardno ENTRIX materials for the 2010 BSR roundtable.

NAIS (Natural Assets Information System)	"The Natural Assets™ Information System (NAIS) was developed by Spatial Informatics Group (SIG) to estimate Ecosystem Service Values (ESV) using "state of the art" value transfer methods and geospatial science. Value transfer involves the adaptation of existing valuation information to new policy contexts where valuation data is absent or limited. For ESVs, this involves searching the literature for valuation studies on ecosystem services associated with ecological resource types (e.g., forests, wetlands, etc.) present at the policy site. Value estimates are then transferred from the original study site to the policy site based on the similarity of ecological resources at the policy site. Value transfer is a 'second-best' approach for gathering information about the value to humanity of ecosystem goods and services. However, the alternative, primary valuation research is extremely costly and is rarely feasible in the context of the policy and planning process. Therefore, value transfer integrated with geospatial science has proven to be a critical tool in decision making and planning."	Spatial Informatics Group www.sig-gis.com/pg-services-eco.php

Box 7: Nontechnical Tool Assessment Considerations

The process of applying the ecosystem service tools to the San Pedro Watershed varied because of the differences among the tools (in terms of needed inputs and ideal applications), as well as the reality that tool developers engaged in this comparative test voluntarily, often without direct project funding. Only Ken Bagstad, the technical analyst and ARIES tool team developer, was paid directly; he applied both ARIES and InVEST in the BLM-USGS project. For both of these reasons, we defined each tool's application to ensure that it was appropriate, as well as feasible within the *pro bono* budget.

The assessment process asked each tool developer to apply their tool to the hypothetical scenario to answer the same set of questions, specifically:

1. New Project Siting and Project Development: Where would be the ideal site for a new residential project that would have the least impact on ecosystem services? Why?

2. Existing Infrastructural and Project Expansion: Where (and if possible how) would you expand growth of residential units on the U.S. side of the border? Why?

3. Land Management: The questions concerning land management are threefold:

» In what areas would focused ecosystem services-related investments offer potential benefits? What are the recommended investments?

» What return on investment (ROI), quantitative or qualitative, would be realized and on what time frame (e.g., payments from environmental market transactions, real estate sales, etc.)?

» How might developers avoid regulatory exposure in light of: endangered species habitat sites, indigenous peoples, Native American claims, and other concerns

All of the tools except EcoAIM and EcoMetrix looked at the San Pedro Watershed as a whole to identify the site (or sites) that would have the least impact on all four parameters (water provisioning, carbon sequestration, cultural services, and biodiversity). Despite a common set of overarching questions, the approaches were distinct due to significant differences among tools, as well as other considerations (see Box 7). For example:

» ARIES and InVEST are GIS-enabled computer simulation tools.

» The ESValue tool incorporates stakeholder preferences and ecological analysis in the GIS impact analysis.

» The ESR is a structured approach to setting priorities among experts (and/or stakeholders).

The two least comparable approaches were the EcoAIM and the EcoMetrix tools. Their noncomparability was due to the decision to scope tool application to the San Pedro Watershed differently, as well as to the inherent nature of the tools. Specifically, the EcoAIM tool team focused only on one ecological parameter: minimizing biodiversity impacts, as a proxy for habitat-provisioning services of the landscape. The EcoAIM team also narrowed the geographic scope to built-up areas with impervious surfaces to select the site of the hypothetical housing development. Since the EcoMetrix tool is designed for parcels or sites rather than landscapes, it would be more useful when applied to the sites selected by landscape-level assessment tools, such as ARIES and InVEST. However, at the time of the BSR assessment, the BLM and USGS assessment was not yet complete. The EcoMetrix team instead selected field sites with the objective of ensuring a diverse set of sites and accessibility for fieldwork teams.

Table 3 summarizes how each tool's team applied it within the San Pedro comparative application. The supplementary materials contain additional details.

Table 3: Tool Parameters and Boundaries of the San Pedro Application

Tool	All Four Parameters Examined?	Other Boundaries Placed on Analysis
ARIES	Yes	None. It examined the whole landscape for hypothetical development.
EcoAIM	No, biodiversity only	This assessment focused on privately-owned parcels with existing infrastructure (e.g., road access) as constraints to development. Note that the tool is *not* limited to biodiversity; rather this parameter was selected as the best for illustrating the tool.
EcoMetrix	Yes	This tool selected five study sites—each 20 acres, projected to 500 acres—in consultation with technical analyst Dr. Ken Bagstad who oversaw all tool applications and based on a set of heterogeneous sites accessible for field research. The study's timing did not allow for the preferable process of examining sites identified by other tools, since those findings were not available in time for the fieldwork period prior to the roundtable.
ESValue	Yes	None. This tool examined the whole landscape for hypothetical residential development within context of ecological impact and stakeholder values.
ESR	Yes	This tool conducted the strategic priority setting exercise (the tool's focus) with one technical expert, Ken Bagstad, in consultation with WRI tool developers.
InVEST	Yes	None. Technical analyst Dr. Ken Bagstad examined the whole landscape for hypothetical development.

Overall, the comparative test uncovered important distinctions between the tools and ideal contexts for their application, including:

» ESR provides a structured but relatively high-level approach to understanding and prioritizing the relevance of ecosystem services in the business context defined by a tool user.

» ARIES and InVEST are landscape-level computer models for conducting detailed, spatially-explicit analyses and simulations. ARIES is an online modeling platform that integrates data with probabilistic and deterministic models to map ecosystem service flows, and InVEST is based on land use land cover (LULC) data, corresponding ecological attribute data for each LULC type, and generally accepted ecological-process models, applied in an ArcGIS environment.

» EcoAIM and ESValue integrate stakeholder preferences in consideration of ecosystem services impacts. EcoAIM in this instance focused on a modified risk-analysis approach. ESValue used stakeholder input to assess the relative social value of ecosystem services and scientific input to assess the ability of the ecological landscape to provide those values.

» EcoMetrix, a field site tool, is intended to be used once a broader landscape-level assessment has identified the parcels where ecosystem services are least likely to be affected. It helps define an approach to design that minimizes impact.

» NAIS was not applied because of time constraints, a *pro bono* budget, and a lack of primary economic valuation studies to apply to arid and semiarid ecosystems. However, NAIS's developers presented their tool's approach and participated in the roundtable discussions.

The distinctions and complementarities among tools is further laid out in Table 4 and Figure 1.

Table 4: Ecosystem Services Tool Distinctions Noted within the San Pedro Watershed Case Study

Ideal Scale	Application Approach	Time Required for Application[22]	Tool
Landscape to Watershed	» Computer modeling with a probabilistic basis, reporting uncertainty levels, as well as with artificial intelligence enabling work in areas with less data » Accounts for spatial flows of ecosystem services from provision to beneficiaries	200–300 hours of senior technical expert with GIS capabilities *Note: Time noted is to develop and parametrize a new case study, which currently can only be done by working with the ARIES team. In the future, applications in areas where models have already been developed will require substantially less time.*	ARIES
Landscape to Watershed	» Designed to run present and future scenarios of LULC's changing conditions and their effects on the flow of ecosystem services » Computer modeling based on data sets, generally accepted process models, and (if desired) public input	160–260 hours of senior technical expert with GIS capabilities *Note: The time it takes to use InVEST varies dramatically by site and according to the technician's level of expertise. The bulk of the time needed to run InVEST is to review literature and parameterize the models. Time used can be substantially reduced if literature is assembled beforehand.*	InVEST
Landscape to Site-Level	» Expert ecological input identifying and weighting project variables that determine the degree of ecosystem change » Stakeholder preferences associated with ecosystem services in an area » Ecological science and social preferences integrated to identify relative effect on ecosystem service values of different alternatives	Approximately 200 hours of a company's staff time, including: » 60 hours gathering input from stakeholders (not including about eight hours of each stakeholder's time individually) » 100 hours preparing the GIS data, meeting with scientists, and collecting expert opinion, as well as setting up the ecological relationships » 40 hours running the tool and analyzing the results	ESValue

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[22] Times are based on this single case study and may not be broadly applicable, but this first concurrent application of the tools allows us to begin to compare them.

Watershed to Site-Level	» GIS optimization model analysis of rare species with a risk-analysis basis, including metric weightings of stakeholder preferences	25 hours reviewing, identifying, downloading, converting, and uploading data, with administrative staff spending eight hours downloading and scientists' work accounting for the remainder *Note: For an application* ***limited to biodiversity***	EcoAIM
Watershed to Site-Level	» Priority setting	Fewer than 40 hours were needed to complete the ESR worksheet and document assumptions, strengths, and weaknesses of the approach. A "real-world" ESR application would require more time. It would bring together corporate representatives from different business units, inform them about ecosystem services, and seek their input and then have an analyst synthesize it. The time requirements may not be trivial, depending on the scope of the analysis and baseline knowledge about ecosystem services within the organization.	ESR
Parcel- and Site-Level	» Ecological field site data collection on presence and status of ecosystem services at a particular site	Field data collection, data entry, and data verification can range from 15 to 60 minutes per acre, depending on the site's complexity.	EcoMetrix

Figure 1. Distinctions and Complementarities Among Tools

Certain strengths and limitations inevitably influence assessment results and conclusions. Table 5 offers an overall summary of the pros and cons of the approach for the comparative tool assessment.

Pros and Cons of San Pedro Comparative Assessment

PROS

- » This case study helped us begin to examine these tools and to develop a sense of the time and expertise necessary for their application.
- » Site selection and other details associated with applications were flexible to ensure that the application was feasible within the time and cost constraints and tool capabilities.

CONS

- Most tool developers had no direct funding to participate in this study, which limited scope and personnel time, as well as level of detail in applications.
- Application of ARIES and InVEST within the context of the BLM- and USGS-commissioned study were delayed. Therefore, only very limited findings from both were presented at the October 2010 roundtable discussion, which informs this report.
- The study was not set up to compare current corporate environmental assessment approach (of environmental impact assessments, EIAs) to new ecosystem services–based assessments (as well as their potential merger). This comparison would have provided a more complete picture of the costs and benefits of a new ecosystem services–based approach.
- The data available about the San Pedro Watershed was not always comprehensive enough for these tools—noteworthy since we selected this site for its data richness—thus pointing to the high data demands of many tools.
- Many tool developers were unable to show full tool functionality because of time, cost, and other limitations (such as in terms of time series assessments, back-casting, etc.)
- The assessment could not explore inter-tool interactions given the time limitations.
- It also could not examine the broader context because of time constraints.

Overall, the San Pedro comparative study did not allow for side-by-side results of all tools. Nonetheless, it offered new insights and findings about all of the tools, as well as side-by-side results for ARIES and InVEST, as discussed below.

Assessment Results

Table 5 summarizes the results of applying each tool to the three sets of questions posed. Following the table is a more detailed discussion of specific results for the ARIES and InVEST applications.

Table 5: Responses to Tool Assessment Questions

Tools	New Project Siting	Existing Infrastructure Project Expansion	Land Management
ARIES	Produced maps of potential and actual service provision based on each service's spatial dynamics, to answer questions, including maps of: » Provisioning services where an ecosystem provides a direct benefit to beneficiaries (e.g., to identify areas of high carbon sequestration, high biodiversity for recreational values, high-quality views, and areas of high precipitation, infiltration, and groundwater recharge) » Detrimental sinks of ecosystem services where landscape features deplete the quality of an ecosystem service benefit for beneficiaries, such as highways, visual blight, and areas of increased high-intensity fire risk » Preventive services where an ecosystem mitigates a negative carrier's access to beneficiaries, such as areas absorbing floodwater, absorbing detrimental nutrients, or promoting sediment deposition Overall, model results identified sites that minimize impacts to: » Sources of key ecosystem services (e.g., areas of high carbon sequestration, high biodiversity for recreational values, high-quality views, and areas of high precipitation, infiltration, and groundwater recharge) » Beneficial sinks of ecosystem services (areas of infiltration and groundwater recharge) and avoid new detrimental sinks of ecosystem services These sites generally include avoiding disturbance to areas of high carbon storage, avoiding creation of additional road infrastructure, and minimizing additional water demand (i.e., requiring as few new wells and groundwater extraction requirements as possible).	Answers to this question are nearly identical to those for the development of new projects (see column to the left). Although not explicitly considered in the ARIES models, existing expansion near currently developed areas would reduce the landscape and habitat fragmentation resulting from highly dispersed development.	Investments should be considered in terms of their ability to: » Maximize carbon sequestration and storage » Minimize water demand in the watershed, which reduces groundwater pumping and can affect biodiversity and associated ecosystem services Regulatory exposure may be reduced by reconsidering water withdrawals from the San Pedro's riparian ecosystem, increasing water conservation, and bringing the San Pedro's water budget into balance. Given the complex nature of the San Pedro's groundwater and the way ARIES deals with groundwater, its value to support decision-making about groundwater will probably remain limited until it can incorporate existing groundwater models (i.e., local applications of the MODFLOW model). ARIES can couple with other tools, in particular those that scope ecosystem services–based decisions (e.g., ESR), to estimate economic values (e.g., Defenders of Wildlife's Wildlife Habitat Benefits Estimation Toolkit) or to map potential impacts to biodiversity (e.g., IBAT).

EcoAIM	» This tool's application to this case study focused only on biodiversity impacts—as defined by metric weightings generated through stakeholder preferences—and generated maps for four metrics, including species richness and special protection status, distance to impervious surfaces, distance to wildlife corridors, and vegetation type. » Results showed a combined biodiversity score for a region. Then the tool looked at the average biodiversity score of four potential development sites to guide developer choice. » Tool enables user to drill down into each metric for information by parcel (e.g., number of endangered species with known distribution in the parcel).	» Restoration siting assumptions focused on preservation (e.g., preserve corridors, join parcels, explore vegetation type, and consider species richness). » Results, in the form of tables, identified seven restoration projects, from which stakeholders can choose the optimal one. » ROI was based on restoration costs, land acquisition costs, license to operate benefits, and credit market benefits.	» Specific evaluation factors depend on stakeholder preferences. Stakeholders choose the best sites for restoration from the seven sites the tool identified. » Architecture allows user-driven sensitivity analysis to reveal the relative effect of stakeholder preferences on modeled outcomes. » ROI was based on restoration costs, land acquisition costs, license to operate benefits, and credit market benefits.
EcoMetrix	» Results identify whether or not potential actions will make a contribution to meeting larger goals at a landscape level, which led to selection of the southernmost site. » The tool assumed standardized lot design for all sites and identified alternative design features to improve performance and impact minimization (e.g., cattle removal, lot design changes, pavement material, roof type, existence of pool, etc.). » Approach allows for cost-benefit evaluation of alternatives (e.g., effect of removing swimming pools at each hypothetical residence for water provisioning vs. marketability of lots). *Note:* The tool examined landscape attributes, but not external variables like residential water use.	» This tool did not answer this question directly because it is not a project-level question—the level on which it focuses. Yet, EcoMetrix could contribute to assessing incremental impact to cumulative impacts questions.	Site-specific benefits include: » Decreased impacts and facilitated project approval » Decreased supply chain dependencies (in this case, water) » Decreased site management costs » Strengthened social license to operate » Opportunities to create PES Future mitigation needs were identified in terms of opportunities for off-site habitat restoration (and possible eco-asset credits for banking, markets, etc.). The tool also enables understanding where investments get the biggest ecosystem return. Expected ROI: » Improved project delivery » Decreased infrastructure costs » Decreased residential utility bills » Increased residential quality of life » Credit generation
ESValue	Model results indicated that a southernmost site would be best for development based on the ecosystem services that stakeholders valued and on the ecological impacts of development. Drivers of differences in scores and	Not considered	Clearly demonstrated that stakeholders favored strong land management practices that protect key ecosystems services. Developments that protect aquatic habitat,

<table>
<tr><td></td><td>ecological impacts across alternatives were given.</td><td></td><td>stream flow, water quality, and recreational access are much more likely to receive stakeholder approval.</td></tr>
<tr><td>ESR</td><td>The ESR relies on expert advisors to answer questions about project siting and to follow general guidelines that minimize site impact (e.g., reducing project footprint, acres of land disturbed, acre-feet of water withdrawn, degree of site fragmentation, avoidance of more valuable land cover types, etc.).</td><td>See column to left for response.</td><td>Not applicable</td></tr>
<tr><td>InVEST[23]</td><td>An ideal project site would have the following attributes:
» Carbon: Seek to avoid areas of high carbon storage (e.g., forests, riparian areas, oak woodland, and mesquite). Focus on ecosystems, like grasslands and desert scrub, that store less carbon.
» Biodiversity: New development should be accompanied by minimal additional road infrastructure (i.e., be located near roads) and minimal additional water demand (i.e., requiring as few new wells and groundwater extraction requirements as possible).
» Water: For arid areas, instead of predicting water availability, this model combines surface and groundwater into a single flow (“water yield”), which, along with some other factors, raised some problems with model outputs, worth noting here. First, increases in water yield may not always be beneficial, and may actually be detrimental. Results for each scenario show that water yield increases with new development because impervious surfaces are added. But, in arid systems where precipitation and runoff are flashy and evapotranspiration is high, additional impervious surfaces increase runoff speed and quantity, which lead to problems with erosion and lower dry-season flows. So, development should minimize the increase in water yield from pre- to post-development conditions.
» This interpretation of the model outputs (increase in water yield is detrimental) may, however, not be useful beyond this application because it includes</td><td>See column to the left; the answers to this question are nearly identical to those for the development of new projects.

Although not explicitly considered in the InVEST models, siting existing projects near currently developed areas would reduce the landscape and habitat fragmentation resulting from highly dispersed development.</td><td>» Similar to the answers in the column to the left, investments might be made to maximize carbon sequestration and storage, minimize threats to biodiversity, and reduce water demand in the watershed (which also reduces the threat brought on by excessive groundwater pumping).
» A key issue is to consider dewatering of the San Pedro’s riparian ecosystem, and thus consider increasing water conservation and bringing the San Pedro’s water budget into balance.
Given the complex nature of the San Pedro’s groundwater and the simplistic way InVEST deals with this matter, this tool will have limited value until it can incorporate existing groundwater models (i.e., local applications of the MODFLOW model). Perhaps the InVEST Tier 2 models will address these concerns.</td></tr>
</table>

[23] This material on InVEST was jointly written by Dr. Ken Bagstad, who applied the InVEST tool to the San Pedro Watershed case study, and Chris Colvin of the InVEST tool team and the Natural Capital Project.

expert information about locally important hydrological processes that are not included in the model parameters (erosion, flooding, and infiltration zones). For example, if the area drained into a reservoir (not present in the San Pedro Watershed), erosion was not a problem, and additional water demand from the new development could be met, an increase in water yield may be beneficial.

» While it might at first appear counterintuitive to minimize increases in water yield, this application provides an important illustration: Water yield model outputs must be examined carefully in the local context and along with other hydrologic ecosystem services to assess whether water yield changes are beneficial, detrimental, or if more information is needed. This assessment requires local expert knowledge, will be related to the timing and location of runoff and presence or absence of reservoirs, and may require additional information about tradeoffs or feedback loops with other processes and services or disservices (erosion, flooding, etc.).

Another part of the model that posed some problems was the second step, water consumption. Since new developments mean increases in groundwater use to meet the new residents' needs, changes in yield need to reflect increases in water consumption. However, the water consumption model was not applied because of difficulty translating urban-growth model data to the LULC coefficient tables in InVEST. Instead of adding a new LULC for the new development and using InVEST, water consumption was estimated by simply multiplying the number of new residents by the average volume of water consumed per capita per year, which would be the same across all scenarios, regardless of the location of the development. These values are presented in Table 8. While they were not calculated using InVEST and cannot be used to assess the ecosystem service impacts of the new development scenarios on water resources, they serve as an example.

Box 8: ARIES and InVEST Pilot

The InVEST biodiversity, carbon, and water-yield models were run for baseline conditions, plus each of the five development scenarios. Water consumption was estimated outside of InVEST by multiplying the number of new residents by the average volume of water consumed per capita per year, which would be the same across all scenarios, regardless of the location of the development (see Table 6 for an explanation).

The ARIES carbon sequestration and storage, water supply, and aesthetic viewshed, and open space proximity models were run for the same baseline and five development scenario conditions.

ARIES and InVEST[24]

As part of the comparative tool assessment, BSR requested that technical analyst Dr. Ken Bagstad run the InVEST and ARIES models[25] as developed for the BLM-USGS Ecosystem Services Valuation Pilot study to a series of housing scenarios comparable to those run for the EcoMetrix, EcoAIM, ESR, and ESValue tools. Five hypothetical development sites as mapped by the ESValue tool were chosen for ARIES and InVEST. Each 500-acre site was located across the entire watershed—from immediately adjacent to the river, to the foothills of the Whetstone Mountains—and thus were more likely to give varied results for the ecosystem service models used in the tools than smaller or more closely clustered sites would.

The goal was to identify a hypothetical preferred site, to see if they came to a consensus. (Using a stakeholder-based approach, the ESValue developers had identified site 5 as the preferred site for development in discussions with local stakeholders.[26])

The exercise did *not* provide a direct comparison, primarily because the model outputs do not always have the same units. With this caveat, Tables 6 and 7 present the results regarding the change in each ecosystem service predicted by the InVEST and ARIES tools, respectively. Table 9 offers managers guidance about how to minimize the effects of ecosystem services for each of the InVEST and ARIES model outputs.

Middle San Pedro Watershed

[24] This section was written by Dr. Ken Bagstad, with input from the InVEST tool team.
[25] Details of the InVEST and ARIES model applications to the San Pedro Watershed are described in a separate article: K. J. Bagstad, D. Semmens, R. Winthrop, D. Jordahl, and J. Larson. *Ecosystem Service Valuation to Support Decision-Making on Public Lands: A BLM Case Study for the San Pedro River, Arizona.* Reston, VA: USGS Professional Paper, forthcoming. The respective InVEST and ARIES users guides describe the models and modeling processes: K. J. Bagstad, F. Villa, G.W. Johnson, and B. Voigt. *ARIES—Artificial Intelligence for Ecosystem Services: A Guide to Models and Data.* Version 1.0 (beta). The ARIES Consortium; H. T. Tallis, T. Ricketts, E. Nelson, D. Ennaanay, S. Wolny, N. Olwero, K. Vigerstol, D. Pennington, G. Mendoza, J. Aukema, J. Foster, J. Forrest, D. Cameron, E. Lonsdorf, and C. Kennedy. *InVEST User's Guide.* Version 1.005 (beta). Stanford: The Natural Capital Project, forthcoming.
[26] Site numbers are shown in the InVEST and ARIES results figures that follow.

Table 6: InVEST Results for Housing Development Scenarios

This table denotes changes in each service, with definitions included in each map.

Scenario	Carbon Storage (tons)	Water Yield, 2007 (wet year, m^3 per year)	Water Yield, 2002 (dry year, m^3 per year)	Water Consumption[27] (m^3 per year)	Biodiversity Quality (percent)
Site 1	-10,288	*513,558*	*408,139*	271,532	-0.5
Site 2	**-6,924**	**380,215**	**315,427**	271,532	**-0.4**
Site 3	-7,315	416,244	315,798	271,532	*-0.6*
Site 4	*-11,556*	409,388	353,879	271,532	-0.5
Site 5	-10,118	416,125	359,974	271,532	*-0.6*

Note: The site that minimizes each ecosystem service impact is in **bold**. The site that most heavily impacts each ecosystem service is in *italics*.

Table 7: ARIES Results for Housing Development Scenarios

Scenario	Carbon (tons)		Water (m^3)	Open Space Proximity (relative values)		Viewsheds (relative values)	
	Carbon Sequest ration	Potential Stored Carbon Release	Surface Water Sink	Source	Use	Source	Sink
Site 1	*-68*	-147	-91	-22,761	**170,001**	*-4,183*	51,786
Site 2	**0**	**-158**	**0**	*-24,431*	144,528	**611**	51,786
Site 3	-1	*-131*	-1	**-20,374**	164,578	-470	51,786
Site 4	-2	-155	*-28,236*	-24,271	143,461	**611**	51,786
Site 5	**0**	-155	**0**	-21,752	*142,947*	0	51,786

Note: The site that minimizes each ecosystem service impact is in **bold**. The site that most heavily impacts each ecosystem service is in *italics*.

The application of InVEST and ARIES produced maps for each service for the hypothetical sites. Figures 2 and 3 present side-by-side maps of selected comparable results for hypothetical development site 4. Figure 2 compares carbon storage calculated by InVEST to potential carbon sources identified by ARIES. (None of the InVEST nor ARIES carbon model outputs are in the same units, which shows distinctions in how the two tools define and measure this parameter.) Figure 3 compares water yield calculated by InVEST to potential surface water sinks identified by ARIES. Maps showing other results for carbon, biodiversity, and aesthetics can be found in the supplementary materials.

[27] Water consumption was estimated outside of InVEST by multiplying the number of new residents by the average volume of water consumed per capita per year, which would be the same across all scenarios, regardless of the development's location (see Table 6 for an explanation). The output numbers are included in this report to show an example, even though they cannot be used to assess how the new development scenarios would affect water resources.

Table 8: ARIES and InVEST Model Outputs

Model Output	Units	Interpretation and Conditions for Minimizing Development Impacts on ES
InVEST Carbon Storage	Tons of carbon	A “snapshot in time” of carbon storage that estimates sequestration. It uses land cover maps depicting two different times to estimate the difference in storage. Development should minimize lost carbon storage from pre- to post-development conditions.
ARIES Carbon Sequestration[28]	Tons of carbon per year	Annual uptake of carbon in vegetation and soils. Development should minimize lost carbon sequestration from pre- to post-development conditions.
ARIES Potential Stored Carbon Release	Tons of carbon per year	The potential release of stored carbon from vegetation and soils to the atmosphere via fire or deforestation. Development should minimize lost carbon sequestration from pre- to post-development conditions.
InVEST Water Yield	Millimeters of water on the landscape per year (converted to cubic meters for comparing tradeoffs and valuation)	The total surface and groundwater flowing from an area. Development should minimize the increase in water yield from pre- to post-development conditions. However, this interpretation cannot be generalized; the InVEST water yield estimates come with some important caveats. See Table 6 for a complete discussion.
ARIES Surface Water Sink	Millimeters of water on the landscape per year (converted to cubic meters for comparing tradeoffs and valuation)	Summed infiltration (which can lead to groundwater recharge) and evapotranspiration. In arid systems where groundwater is highly valuable, development should minimize the loss of groundwater recharge from pre- to post-development conditions.
InVEST Biodiversity	Relative value for habitat quality	Relative habitat quality, based on the type of ecosystem and its relative value, along with drivers of ecosystem change and the system’s susceptibility to these

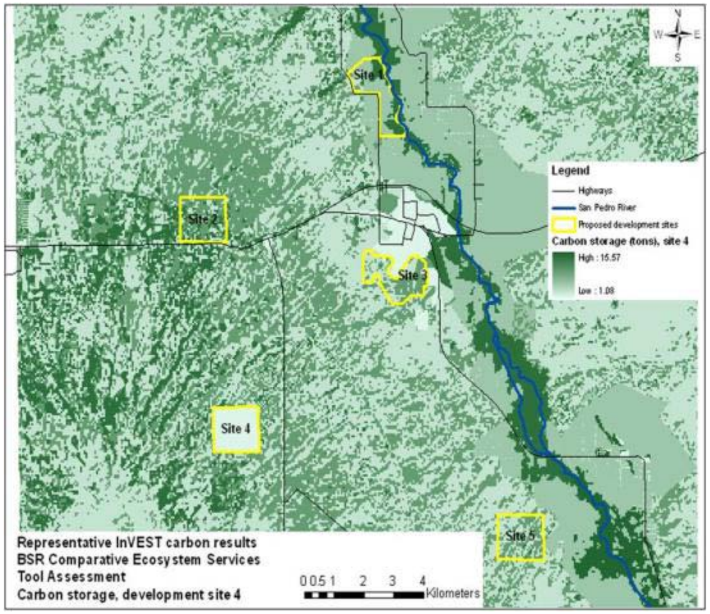
[28] The ARIES carbon model (which uses Monte Carlo simulation) and all ARIES models using probabilistic (Bayesian) models also generate uncertainty maps. Uncertainty is reported as the coefficient of variation (mean, or standard deviation) for each cell. The choice of how to best incorporate uncertainty information into decision making is typically at the discretion of stakeholders.

		changes. Development should minimize reductions in habitat quality from pre- to post-development conditions.
ARIES Open Space Proximity (source value)[29]	Abstract units for the quality of open space values	The potential value of living near open space of a given type, based on the types of land cover valued locally and the factors that influence its quality (e.g., fire or public access). Development should minimize reductions in open space quality from pre- to post-development conditions.
ARIES Open Space Proximity (use value)	Abstract units for the amount of homeowners using open space	The number of users and potential value they derive from open space proximity. To maximize this value, more housing could be located near valuable open space types.
ARIES Viewshed (source value)	Abstract units for the quality of viewsheds	The potential value provided by views, based on locally valued land cover types. Development should minimize reductions in high-value land cover from pre- to post-development conditions.
ARIES Viewshed (sink value)	Abstract units for the degradation of viewsheds by aesthetically unappealing land use	Visual blight or features that reduce view quality (e.g., development, roads, mines, and transmission lines). Development should minimize the creation of new blight from pre- to post-development conditions.

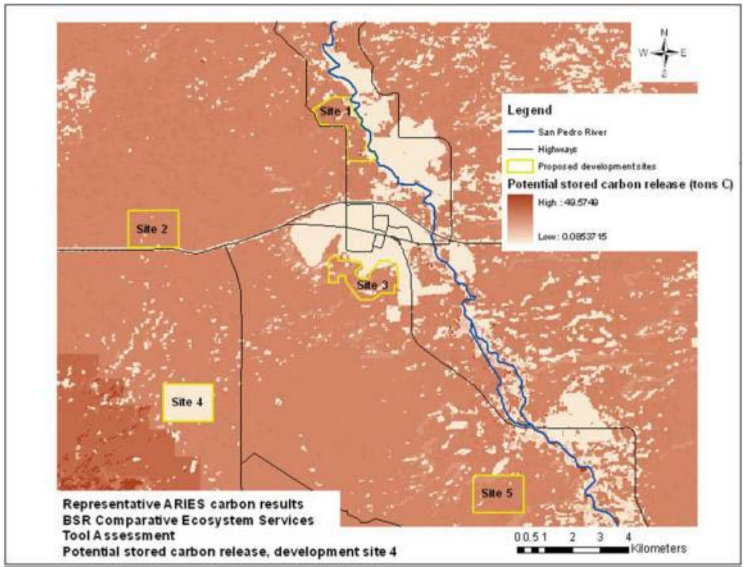
[29] For the ARIES open space proximity and view models, the results of flow models, which simulate the spatial connection between homeowners and open space or viewsheds, provides more useful information for decision making than estimates of potential open space proximity or view quality would alone. Flow models were not available at the time of analysis, but are available as of April 2011 as part of the forthcoming ARIES beta release.

Figure 2: Carbon: InVEST Carbon Storage Versus ARIES Potential Carbon Sources

InVEST
Carbon Sequestration and Storage



ARIES
Atmospheric Carbon Sources and Uncertainty



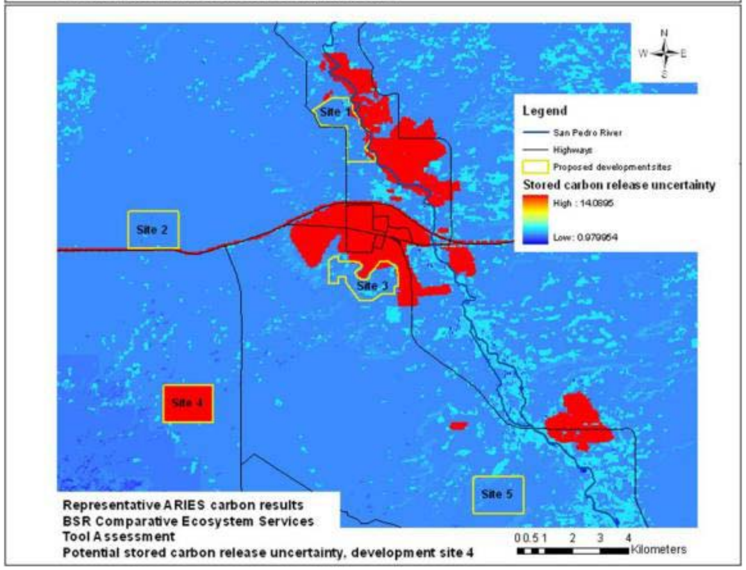
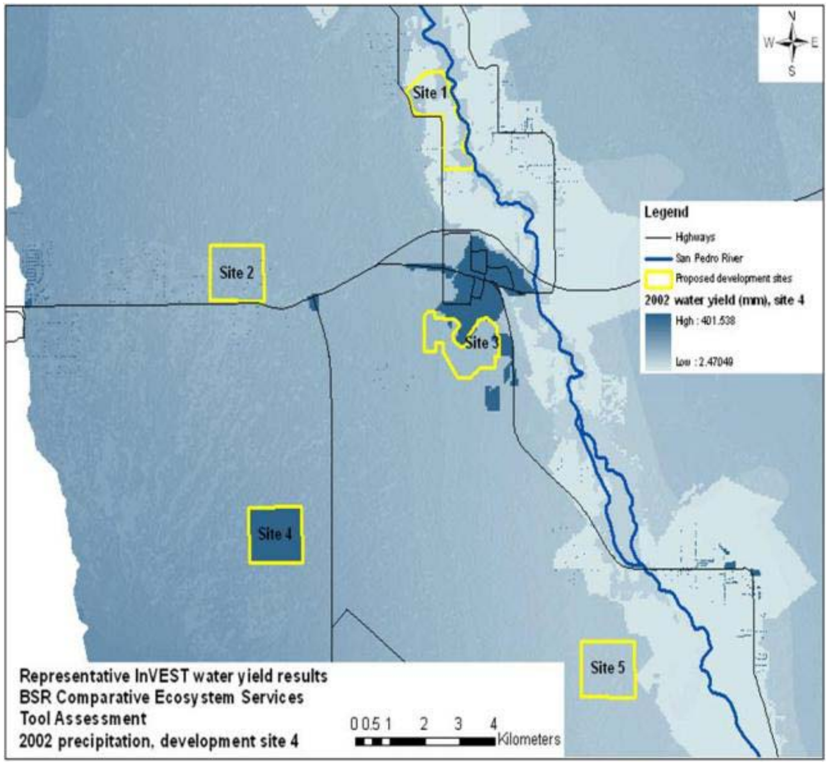


Figure 3: Water: InVEST Water Yield Versus ARIES Potential Surface Water Sink (Summed Potential Infiltration and Evapotranspiration)

InVEST

Water Yield (millimeters per year, dry year or wet year)



ARIES

Surface Water Sink (millimeters per year, dry year or wet year)

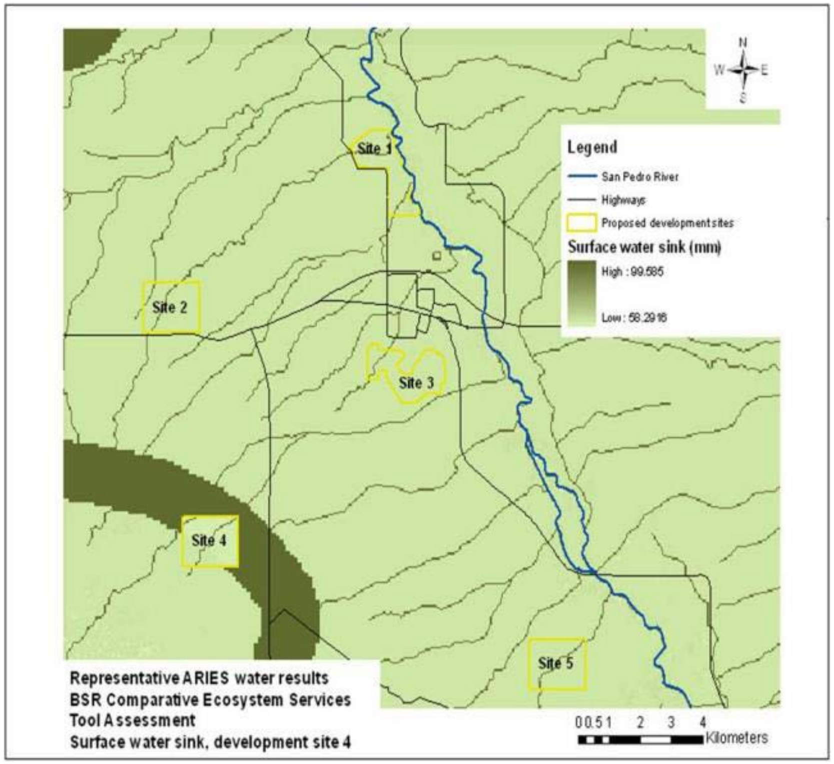
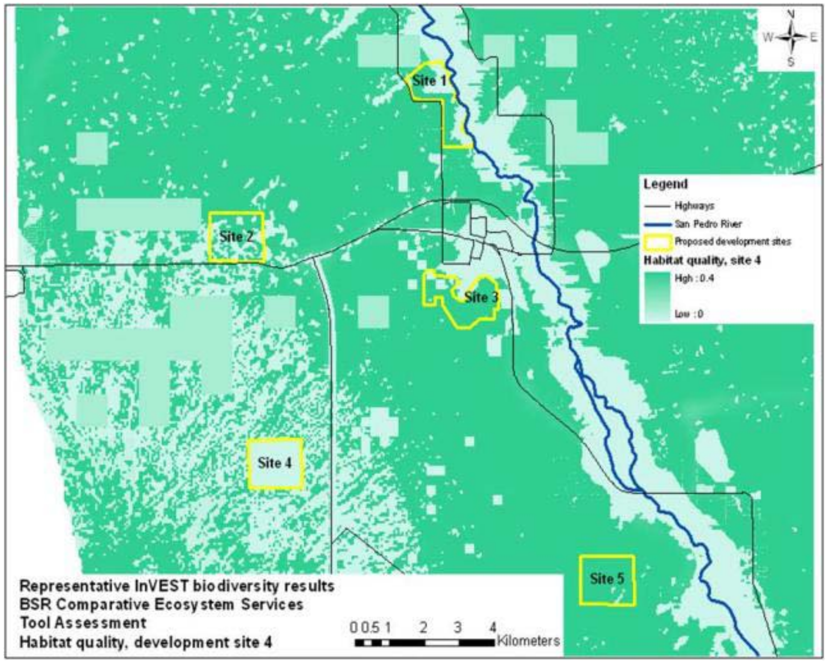


Figure 4: Biodiversity: InVEST Habitat Quality

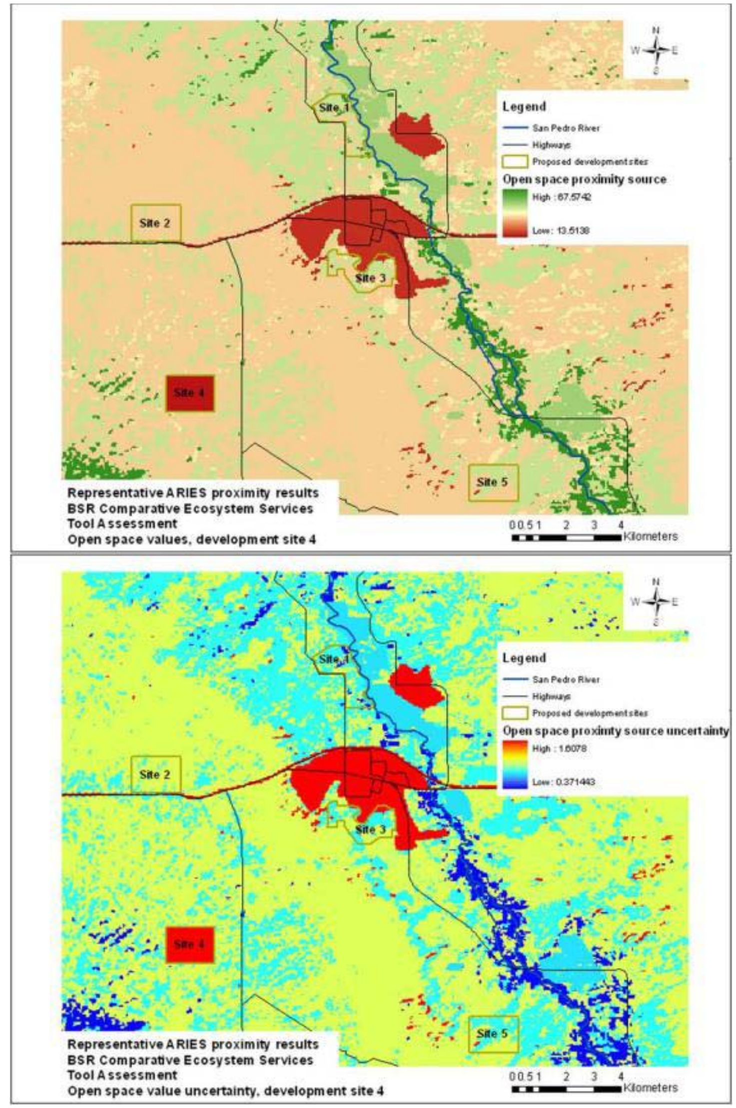
InVEST
Habitat Quality



Note: No comparable ARIES model

Figure 5: Aesthetics: ARIES Open Space Proximity Values

ARIES
Open Space Proximity Values



Note: No comparable InVEST model

Overall, both models concluded (within a decision-making context that weighted all assessed ecosystem services equally) that development on hypothetical site 2 would minimize impacts on ecosystem services. In specific real-world applications, one ecosystem service, such as water, may carry more weight than others. In addition, in some cases there will be tradeoffs among services where increasing provision of one is coupled with decreasing provision of another. In other words, each choice involves compromise.

The InVEST model found that development of hypothetical sites 1, 4, or 5 would result in greater loss of carbon storage. Site 1 caused the greatest increase in water yield—seen as a negative in arid lands and areas undergoing rapid urbanization, where slowing the movement of water through the hydrologic system and maintaining aquifer recharge are high priorities. Site 2 minimized the loss of carbon storage and of habitat quality, and minimized the increase in water yield.

In the case of the ARIES model, site 2 had minimal impacts on carbon sequestration and infiltration of surface water. It also led to improvements in viewshed quality and minimized future releases of stored carbon at risk of release because of wildfire. Sites 1 and 4 were the worst choices in terms of ecosystem services impacts. Site 4 would have significant negative impacts on groundwater recharge as a result of its location in a zone where mountain front recharge occurs. Site 1's proximity to the river means that its development would result in the greatest loss of carbon sequestration and viewshed values. ARIES uncertainty maps are included in this report's supplementary materials. However, uncertainty results are not presented in Table 7 because total uncertainty for the carbon and aesthetics models did not change across scenarios. Additionally, ARIES ecosystem service flow maps are not included since the flow models are still undergoing testing.

Despite the finding that the InVEST and ARIES models supported the same conclusion—that development at site 2 would minimize impacts on ecosystem services—none of the outputs were directly comparable. The two tools simply measure and model ecosystem services differently. Since the ARIES and InVEST models produce results that are not directly comparable, it would be valuable to conduct further work to determine whether tools would come to the same conclusions in other geographic settings or decision contexts.

In addition, these conclusions were made in a hypothetical case *without* considering real or hypothetical public values for ecosystem services, in dollar terms or otherwise. A tool like ESValue could be used to draw comparisons of how people value quantified ecosystem services tradeoffs modeled using InVEST and ARIES. The ESValue tool, which more directly incorporated stakeholder preferences, supported development at site 5. This finding suggests the value of improving links among biophysically-based models, such as ARIES and InVEST, and understanding how stakeholders value specific ecosystem services and potential tradeoffs among services.

The decision support provided by all results would benefit from further model review and refinement. The San Pedro Watershed application suggests that models' production functions need to be made more defensible, the models need to better reflect local conditions, and they need to be better capable of integrating cross-boundary (e.g. United States-Mexico) data.

For InVEST, further expert review of results for water yield in the context of arid environments would be beneficial; the models were not designed in the context of ecological processes in arid regions. Specifically, the InVEST team and the technical analyst saw potentially misleading results, such as increasing water yield following residential development. Future model development may help improve the accuracy of InVEST water models and their applicability to all types of ecosystems, including arid areas.

ARIES would also benefit from additional expert review in terms of both the magnitude of its outputs and the probability tables underlying the Bayesian models. In addition, ARIES results may suggest different outcomes once flow models are complete, which will change maps from those of potential ecosystem service provision to actual ecosystem service provision and use (e.g., for water supply).

Overall, both ARIES and InVEST would benefit from improved interfacing with local ecological, hydrologic, and process models, as is planned for both tool's future releases. ARIES and InVEST tool developers are testing the accuracy of the models with observed data in a wide variety of contexts around the world. Improvements in reliability and functionality are expected, with opportunities to reduce resource requirements to run the models. Opportunities also exist for carefully targeted funding and incentives for collaboration among project teams and other interested organizations. However, without such additional funding support and incentives, some improvements needed to make the tools most useful for both the public and private sectors will take time.

Key Insights from Tool Assessment

A number of valuable insights emerged from the comparative assessment of ecosystem services tools.

INSIGHT #1: Side-by-side tool comparisons are difficult, given the tools' very different definitions of ecosystem services.

The San Pedro Watershed comparative tool assessment used a diverse set of analytical measures and generated an equally diverse set of results. The methods and metrics rarely overlapped across the tools. Interestingly, however, the overall conclusions of some tools, such as ARIES and InVEST, generally agreed. Other tools, such as ESValue, reached distinctly different conclusions.

This finding highlights the ongoing debate over how to translate ecosystem services concepts into clear, commonly accepted measures that can inform decision making. Without agreed-upon metrics and assessment methodologies for ecosystem services, corporate decision-makers will have to carefully justify their selection of any one tool over another. Independent examination and a common set of measures, or metrics, as well as a methodology, will hasten uptake by providing key credibility for, and validation of, a particular approach.

INSIGHT #2: The ecosystem services tools offer insights that can be relevant to corporate decision-making processes. However, none readily mesh with key existing corporate processes. Thus they do not appear to be ready for immediate, widespread, off-the-shelf business application.

Analysis of tools during and following the 2010 BSR roundtable led to the conclusion that none are ready for broad-scale implementation in the corporate context. All the tools would either require assistance with interpreting findings within a corporate setting or would need to be tailored to fit particular corporate decision-making contexts.

One key issue is the gap between what tool developers offer and what corporate decision-makers need. Specifically, many of these tools have been developed for use with expert support to provide detailed assessments using powerful modeling and scenario development for forecasting. Several of the tools require complex validation and are research-driven. Some tools incorporate stakeholder input, but others do not allow for this input.

Many corporate decision-makers are looking for a flexible, modular toolbox. They commonly want help making more immediate, practical decisions, including exploring options for fast-track action, especially at the project and site level. Business decision-makers also need tools to help understand how stakeholders depend on, value, and approach tradeoffs among ecosystem services in specific contexts. Consideration of stakeholder needs and priorities is integral to many key corporate decision processes.

Given this gap, both ecosystem services tools, as well as business decision-makers, could benefit from pilot test applications and refinement in business settings. Overlapping areas among tools and collaborative application opportunities are other areas of opportunity. (For further discussion about the strengths and weaknesses of specific tools, individually and comparatively, based on roundtable discussions among corporate decision-makers, please see the supplementary materials.)

Box 9: The Business Case to Adopt Ecosystem Services Metrics

» Widespread stakeholder support for the tool
» Documented cases of similar findings, indicating results can be duplicated at another location or time
» Effective communication of complex data sets
» More informed decisions
» Risk identification and management, resulting in decreased vulnerability to risk
» Cost savings
» Competitive advantage
» Improved relationships with stakeholders, including regulators, investors, and shareholders
» Streamlined permitting processes
» Customer retention

INSIGHT #3: Because tool applications are limited within corporate decision-making processes, it is not yet clear what additional value ecosystem services tools will add when compared to the existing approaches companies use to assess performance.

Private-sector test applications of tools will be essential to understanding the value these tools add and for building the business case within companies. In particular, the way that tools may mesh with existing corporate decision-making processes, particularly as related to environmental and social impacts of projects, remains to be seen. Ultimately, ecosystem services tools will need to demonstrate key benefits not otherwise obtainable if their use is to be justified (see Box 9).

Overall, business managers need clarity on how, when, and why to apply tools to particular business activities and issues. At present, the diversity of both tools and business settings present a significant challenge. Pilot applications will have to consider both issues around which tools are most appropriate for a certain decision-making context, as well as how tools could link to, or augment, existing processes and protocols, most notably including environmental/social impact assessments (E/SIAs) and life cycle analyses (LCAs).

Looking forward, business managers will need to learn from a robust set of new private-sector applications of tools. These pilot applications will likely require some industry-specific, as well as industry-initiated, work, because of unique issues and assessment processes. Testing tools in multiple private sector contexts will help clarify whether and how ecosystem services metrics and tools can interface with existing corporate processes for undertaking environmental and social assessments. Ideally, pilot tests will also bring greater clarity on when, where, and how to integrate new metrics around ecosystem services, or even help identify the need for new tool development.

Potential Corporate Applications

Discussions among BSR's ESTM Working Group members indicate some promising applications of ecosystem services tools within companies:

» New project planning and development, particularly in terms of impact assessment and permitting processes, to show companies, governments, and other stakeholders where and how impacts or co-benefits may result
» Real estate strategy and management
» Property portfolio priority-setting exercises to assess relative risk and opportunity for property retention, disposition, remediation, restoration, and other options
» Ongoing management and decommissioning of operations
» Valuations of ecosystem services impacts or benefits
» Corporate performance and communication dashboard or scorecard, in terms of measuring performance and progress toward a corporate-level ecosystem services goal (including key performance indicators, baseline, impacts, progress, and monitoring)
» Providing a more complete picture of corporate environmental performance, using ecosystem services concepts to integrate currently discrete natural resource parameters
» Scenario planning and modeling, such as linking to corporate climate change adaptation strategy development

» Project planning within a landscape-level context, in terms of natural resources uses, beneficiaries, and minimum ecological parameters for continued flow of ecosystem services

» Operational assessment of E/SIAs, such as by providing additional baseline data, integrating existing baseline data, assessing significant potential for future ecosystem service changes, and identifying necessary mitigation or enhancement measures

» Operational assessment of life cycle impacts of products, such as in terms of additional parameters and bounding analyses

» Selection of potential building sites in terms of optimization of benefits and minimization of impacts

» Understanding ecosystem service functions at facility-scale

» Identifying corporate dependencies on ecosystem services at various geographical and supply chain levels

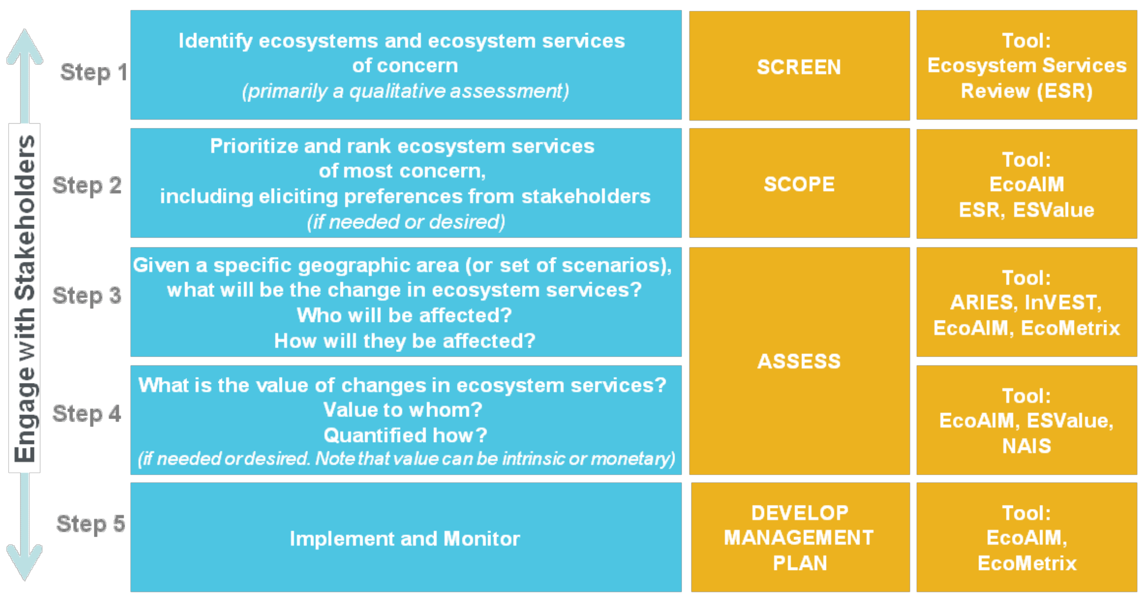
» Exploring new strategies and scenarios

» Optimizing the sourcing of natural resources

» Engaging stakeholders in at least some of the above-mentioned contexts

Figure 6 suggests a potential mapping of tools included in the assessment to steps in an illustrative corporate decision-making process.

Figure 6: Steps and Tools for Applying Ecosystem Services in Corporate Settings



Overall, ecosystem services metrics and tool uptake by companies will be based on a strong business case that demonstrates the value that an ecosystem services lens adds relative to current approaches to considering performance (e.g., E/SIAs, LCAs, etc.). Specifically, a side-by-side assessment of “business as usual” (in terms of EIAs and other environmental management approaches) versus an ecosystem services tool–based approach would be extremely useful, particularly in clarifying the need for additional data or new processes, as well as new insights that companies could gain.

INSIGHT #4: Independent, third-party comparative review of analytical and modeling frameworks underlying ecosystem services tools will build and ensure credibility.[30]

The ecosystem services tool domain is relatively crowded and complex. Multiple definitions, frameworks, and approaches are used. Tools often lack transparency, and they are difficult to compare.

Looking forward, it will be essential to have clear evidence of tool credibility and widespread support to justify applying ecosystem services concepts and tools to their activities. Key areas of need are to explore harmonization of ecosystem services definition and metrics used by tools, to conduct rigorous comparative assessments of multiple tools, and to assess data needs, as well as provide quality control. Box 9 identifies some organizations that might be well positioned to undertake such reviews.

Box 10: Possible Independent Third-Party Reviewers

Potential entities positioned to address the credibility of analytical frameworks within ecosystem services tools could include:

» IPBES
» European Environment Agency (EEA)
» U.S. NSF
» U.S. National Ecosystem Services Partnership (NESP)
» USDA's Office of Environmental Markets (OEM)
» USGS

The key will be close coordination among the multiple, prospective public and private users, as well as the many developers crafting the most promising tools.

[30] Some individual tools have been vetted through peer-reviewed publications. For example, see:

P. M. Kareiva, T. H. Ricketts, G. C. Daily, H. Tallis, and S. Polasky, eds. *Natural Capital: Theory and Practice of Mapping Ecosystem Services.* Oxford University Press, 2011.

Stephen Polasky, Erik Nelson, Derric Pennington, and Kris Johnson. *The Impact of Land-Use Change on Ecosystem Services, Biodiversity and Returns to Landowners: A Case Study in the State of Minnesota. Environmental and Resource Economics.* In press. Published online November 17, 2010, http://dx.doi.org/10.1007/s10640-010-9407-0.

E. Nelson, H. Sander, P. Hawthorne, M. Conte, D. Ennaanay, S. Wolny, S. Manson, and S. Polasky. *Projecting Global Land-Use Change and Its Effect on Ecosystem Service Provision and Biodiversity with Simple Models. PLoS ONE* 5 (12): e14327, 2010. doi:10.1371/journal.pone.0014327.

Erik Nelson, Guillermo Mendoza, James Regetz, Stephen Polasky, Heather Tallis, D. Richard Cameron, Kai MA Chan, Gretchen C. Daily, Joshua Goldstein, Peter Kareiva, Eric Lonsdorf, Robin Naidoo, Taylor H. Ricketts, and M. Rebecca Shaw. *Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production, and Tradeoffs at Landscape Scales. Frontiers in Ecology and the Environment* 7, 1: 4–11, 2009.

Heather Tallis and Steve Polasky*. Mapping and Valuing Ecosystem Services as an Approach for Conservation and Natural-Resource Management. Annals of the New York Academy of Sciences* 1162: 265–283, 2009.

INSIGHT #5: A “taxonomy” for the emerging ecosystem services tool domain would assist with selecting tools that are best suited for specific applications.

This San Pedro Watershed comparative tool assessment highlighted areas of potential complementarities between tools. For example, ESR could offer a structure for priority setting prior to doing a landscape-level assessment using either ARIES or InVEST. The EcoMetrix tool could then assist with site-level analysis.

However, many questions remain, such as:

» How would connections among tools work in practice? Would there be linked software or online web portals?

» Would it be time- or cost-effective to use multiple tools?

» Would new insights, relative to current corporate environmental assessments, be gleaned?

In addition, it would be useful to be able to more systematically compare to tools to one another and understand them in this context and in terms of their ideal applications. Figure 7 outlines a possible approach to a tool taxonomy.

Figure 7: Potential Ecosystem Services Tool Taxonomy

Target User	Policymaker	Corporate	Academic and NGO
User Motivation	» New policy designs or elimination of subsidies » Regulatory enforcement » Mapping of new protected areas » Education » Seeding of new environmental markets	» Risk mapping for ecosystem decline » Strategy and policy design » Location screening » Footprint measurement » Liability transfer » New revenue-generating transactions » Social license-to-operate	» Advancement of conservation science techniques » Recommendations for delineation of protected areas » Integration of data sets with other organizations
Desired Outputs	» Spatially-explicit maps » Valuation analysis » ROI prediction » Sensitivity-analysis results for scenario planning	» Spatially-explicit maps » Valuation analysis » ROI prediction » Sensitivity-analysis results for scenario planning	» Spatially-explicit maps » Valuation analysis » ROI prediction » Sensitivity-analysis results for scenario planning
Primary Ecosystem Services of Interest	» Supporting services (from MEA) » Provisioning services » Regulating services » Cultural services	» Regulating services » Cultural services	» Supporting services (from MEA) » Provisioning services » Regulating services » Cultural services
Quality of Input Data	» High quality » Medium quality » Low quality	» High quality » Medium quality » Low quality	» High quality » Medium quality » Low quality

- Recommended suite of tools: X, Y, Z
- Recommended point of application
- Recommended roles and responsibilities

Conclusions and a Look Forward

The findings of this comparative assessment leave many open questions. However, discussions during the process indicated that ecosystem services approaches and tools could offer value to companies if the tools can help companies more effectively and efficiently:

» Compare the tradeoffs various projects or initiatives would involve
» Broaden the benefits for the local populations where they operate
» Retire or decommission a project in a way that maximizes benefits and is cost-effective and timely
» Take a landscape-level perspective, but also see facility-level effects along the supply chain
» Understand potential effects and dependencies on ecological functions
» Understand how local populations may affect and depend on ecological functions
» Make informed decisions based on sound science and stakeholder input
» Collaborate and communicate with regulators and communities in a transparent process

This list is ambitious, but not impossible to achieve. As ecosystem services tools continue to develop, they may complement one another or be able to be integrated into internal processes many companies have already undertaken, and so ultimately deliver on many desired benefits.

Looking forward, a set of robust ecosystem services tools that have been approved or well-vetted by regulators, stakeholders, and companies for use at different geographic scales in a wide variety of business activities will eventually emerge. Ideally, the tools will allow companies to carefully examine various decisions' tradeoffs in ways that mesh with current decision-making protocols in a cost- and time-effective manner.

To be most useful to companies, tools will need to have certain key attributes that may be challenging to deliver, such as:

» Scalability and adaptability for different locations, conditions, and types of company activity
» Ability to generate and compare scenarios
» Ease of use (related to time and resources)
» Generation of spatially-explicit displays of information (e.g., maps)
» Transparency (no "black boxes")—easy to understand and communicate tool inputs, operation, and outputs
» Avoidance of new corporate-level metrics (unless there is a corporate-wide policy that names ecosystem services)
» Levels of (un)certainty
» 'Roll up' and 'roll down' findings
» Highlight trends
» Benchmarks
» Maps, charts, and tables—all of which should be able to be exported into PowerPoint presentations or document
» Development of internal corporate plug-and-play applications or augment existing tools

In addition, the universe of tools will proliferate, not consolidate in the coming years. It will encompass a range of tools specialized for different scales, climates, and applications. Within this context, private-sector players must develop an understanding of, not only of using ecosystem services concepts and tools, but also of costs and resources needed to integrate these issues within corporate governance, strategy, and operations.

The trends are clear, even if specific outcomes are currently uncertain. Ecosystem services concepts and tools appear increasingly in public policy and business operational arenas globally. All stakeholders have an opportunity to engage in robust, constructive discussion around how ecosystem services concepts and tools can best support efforts to improve the structure and functioning of ecosystems, and their ability to deliver the services on which society and business relies.