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# Tools for measuring, modelling, and valuing ecosystem services

## Guidance for Key Biodiversity Areas, natural World Heritage sites, and protected areas

Rachel A. Neugarten, Penny F. Langhammer, Elena Osipova, Kenneth J. Bagstad, Nirmal Bhagabati, Stuart H. M. Butchart, Nigel Dudley, Vittoria Elliott, Leah R. Gerber, Claudia Gutierrez Arrellano, Kasandra-Zoica Ivanić, Marianne Kettunen, Lisa Mandle, Jennifer C. Merriman, Mark Mulligan, Kelvin S.-H. Peh, Ciara Raudsepp-Hearne, Darius J. Semmens, Sue Stolton and Simon Willcock

Craig Groves, Series Editor

Best Practice Protected Area Guidelines Series No. 28

WCPA World Commission on Protected Areas
Convention on Biological Diversity
SNAPP
BfN Federal Agency for Nature Conservation
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
ASU Center for Biodiversity Outcomes, Arizona State University

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**IUCN PROTECTED AREA DEFINITION, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES**

IUCN defines a protected area as:
**A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.**

The definition is expanded by six management categories (one with a subdivision), summarised below.
**Ia. Strict nature reserve:** Strictly protected for biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
**Ib. Wilderness area:** Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
**II. National park:** Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
**III. Natural monument or feature:** Areas set aside to protect a specific natural monument, which can be a landform, seamount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
**IV. Habitat/species management area:** Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
**V. Protected landscape or seascape:** Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
**VI. Protected areas with sustainable use of natural resources:** Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management (where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims).

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75% rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types.
**Type A. Governance by government:** Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).
**Type B. Shared governance:** Trans-boundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).
**Type C. Private governance:** Conserved areas established and run by individual landowners; non-profit organisations (e.g. NGOs, universities) and for-profit organisations (e.g. corporate landowners).
**Type D. Governance by Indigenous peoples and local communities:** Indigenous peoples' conserved areas and territories - established and run by Indigenous peoples; community conserved areas – established and run by local communities.

For more information on the IUCN definition, categories and governance types *see* Dudley (2008). *Guidelines for applying protected area management categories,* which can be downloaded at: www.iucn.org/pa_categories

For more on governance types, *see* Borrini-Feyerabend, et al., (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/sites/library/files/documents/PAG-020.pdf

# Tools for measuring, modelling, and valuing ecosystem services

Guidance for Key Biodiversity Areas, natural World Heritage sites, and protected areas

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The Convention on Biological Diversity (CBD), which entered into force in December 1993, is an international treaty for the conservation of biodiversity, the sustainable use of the components of biodiversity and the equitable sharing of the benefits derived from the use of genetic resources. With 193 Parties, the Convention has near universal participation among countries. The Convention seeks to address all threats to biodiversity and ecosystem services through scientific assessments, the development of tools, incentives and processes, the transfer of technologies and good practices, and the full and active involvement of relevant stakeholders, including indigenous and local communities, youth, NGOs, women and the business community. The tenth meeting of the Conference of the Parties to the CBD, held in 2010, adopted a revised and updated Strategic Plan for Biodiversity for 2011–2020, comprising five strategic goals and 20 Aichi Biodiversity Targets. The Plan is the overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system.

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**www.bfn.de**

### Science for Nature and People Partnership (SNAPP)

SNAPP is a collaboration between three partners: The Nature Conservancy (TNC), the Wildlife Conservation Society (WCS), and the National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California, Santa Barbara. SNAPP envisions a world where protecting and promoting nature works in concert with sustainable development and improvements to human well-being. SNAPP's multi-disciplinary research teams gain access to funding, neutral meeting spaces, and travel, computational and logistical support. These enabling conditions help SNAPP teams rapidly synthesize knowledge about a specific challenge, in order to deliver evidence-based, scalable solutions like policy recommendations and decision tools. Relevant decision makers from governments, international business, and global NGOs are embedded on SNAPP teams from the start, and thus support the responsiveness and effectiveness of SNAPP's "science to solutions" approach.

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**sustainability.asu.edu/biodiversityoutcomes**

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Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0002
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# Acronyms

| | |
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| **ABWRET** | Alberta Wetland Rapid Evaluation Tool |
| **ARIES** | Artificial Intelligence for Ecosystem Services |
| **BANCA** | Biodiversity and Nature Conservation Association |
| **BfN** | Federal Agency for Nature Conservation of Germany |
| **BMU** | Federal Ministry of the Environment, Nature Conservation and Nuclear Safety of Germany |
| **BVMtool** | Marine Biological Valuation Mapping |
| **C$N** | Co$ting Nature |
| **CCEA** | Canadian Council on Ecological Areas |
| **ES** | ecosystem services |
| **ESII Tool** | Ecosystem Services Identification & Inventory Tool |
| **ESP-VT** | Ecosystem Services Partnership Visualization Tool |
| **EST** | Ecosystem Services Toolkit |
| **EVT** | Ecosystem Services Valuation Toolkit |
| **GIS** | Geographic Information System |
| **IAFE** | Institute for Agriculture, Forestry and the Environment |
| **InVEST** | Integrated Valuation of Ecosystem Services and Tradeoffs |
| **IUCN** | International Union for Conservation of Nature |
| **KBA** | Key Biodiversity Area |
| **MIDAS** | Multi-scale Integrated Decision Analysis System |
| **MIMES** | Multiscale Integrated Model of Ecosystem Services |
| **NCEAS** | National Center for Ecological Analysis and Synthesis |
| **NGO** | non-governmental organisation |
| **OECMs** | other effective area-based conservation measures |
| **OUV** | Outstanding Universal Value |
| **PA** | protected area |
| **PA-BAT** | Protected Areas Benefits Assessment Tool |
| **PES** | Payments for Ecosystem Services |
| **REDD+** | Reduced Emissions from Deforestation and Forest Degradation |
| **SDGs** | Sustainable Development Goals |
| **SNAPP** | Science for Nature and People Partnership |
| **SolVES** | Social Values for Ecosystem Services |
| **TELSA** | Tool for Exploratory Landscape Scenario Analyses |
| **TESSA** | Toolkit for Ecosystem Service Site-based Assessment |
| **UNCBD** | United Nations Convention on Biological Diversity |
| **UNEP-WCMC** | United Nations Environment Programme World Conservation Monitoring Centre |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |
| **USDA** | United States Department of Agriculture |
| **WaSSI** | Water Supply Stress Index Model |
| **WCPA** | World Commission on Protected Areas |
| **WESPUS** | Wetlands Ecosystem Services Protocol for the United States |
| **WHS** | World Heritage sites |
| **WW** | WaterWorld |
| **WWF** | World Wildlife Fund |

Rwenzori Mountains National Park World Heritage site (Uganda) © Andrew Plumptre

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# Contributors

Rachel A. Neugarten, Conservation International

Penny F. Langhammer, Global Wildlife Conservation, Amphibian Survival Alliance and Center for Biodiversity Outcomes, Arizona State University

Elena Osipova, IUCN World Heritage Programme

Kenneth J. Bagstad, U.S. Geological Survey

Nirmal Bhagabati, World Wildlife Fund US

Stuart H. M. Butchart, BirdLife International

Nigel Dudley, Equilibrium Research

Vittoria Elliott, Conservation International

Leah R. Gerber, Center for Biodiversity Outcomes, Arizona State University

Claudia Gutierrez Arrellano, King’s College London

Kasandra-Zoica Ivanić, World Wildlife Fund Adria

Marianne Kettunen, Institute for European Environmental Policy

Lisa Mandle, Natural Capital Project and Stanford University

Jennifer C. Merriman, WSP and BirdLife International

Mark Mulligan, Department of Geography, King’s College London

Kelvin S.-H. Peh, Biological Sciences, University of Southampton

Ciara Raudsepp-Hearne, McGill University

Darius J. Semmens, U.S. Geological Survey

Sue Stolton, Equilibrium Research

Simon Willcock, School of Environment, Natural Resources and Geography, Bangor University

# Executive summary

Increasing interest in measuring, modelling and valuing ecosystem services (ES), the benefits that ecosystems provide to people, has resulted in the development of an array of ES assessment tools in recent years. Selecting an appropriate tool for measuring and modelling ES can be challenging. This document provides guidance for practitioners on existing tools that can be applied to measure or model ES provided by important sites for biodiversity and nature conservation, including Key Biodiversity Areas, natural World Heritage sites, and protected areas. This guidance builds on existing reviews of ES assessment tools, but has an explicit focus on assessing ES for sites of importance for biodiversity and nature conservation.

Key Biodiversity Areas (KBAs) are sites contributing significantly to the global persistence of biodiversity. Natural World Heritage sites (WHS) are natural features, formations and areas which, because of their exceptional qualities, are considered to be of 'Outstanding Universal Value' and therefore merit special protection. Protected areas (PAs) are clearly defined geographical spaces, recognised, dedicated and managed through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

Information about ES provided by KBAs, WHS and PAs can be useful for many reasons, including increasing support for safeguarding the multiple benefits provided by sites, informing management decisions, ensuring equity in resource use and benefits sharing, and enabling evaluation of the consequences of management or policy changes on ES provided by the sites. In this guide, we summarise a range of possible reasons for ES assessment and identify tools that can be used for each purpose. We review the importance of scoping the purpose and objectives of the ES assessment in guiding tool selection and in engaging stakeholders. We also differentiate between qualitative and quantitative ES assessment and when each type of assessment (or both) might be useful.

We compare a set of nine ES assessment tools that are (a) most commonly applied, (b) available to practitioners at no cost, and (c) can be applied in new contexts (i.e. they are not restricted to specific countries or case studies). These nine were selected from a broader review of 30 tools, and we provide links to resources where information on a larger number of ES assessment tools and approaches can be found. We divide the nine tools into two types: written step-by-step tools and computer-based modelling tools.

Selecting an appropriate tool for ES assessment is informed by three factors: (1) purpose of the assessment, (2) required outputs (qualitative or quantitative, spatial or non-spatial, monetary or non-monetary), and (3) practical considerations such as time, budget and data availability. We provide a series of comparisons of ES tools according to each of these considerations along with decision trees that can help guide a practitioner to a tool based on assessment objectives, practical considerations, and the type of output desired. We also summarise which ecosystem services can be assessed using each of the tools and the key differences between them. In the Annexes, we provide a short description of each of the nine reviewed tools and case studies demonstrating how they have been applied to assess ES within a KBA, WHS or PA.

Three of the tools reviewed—EST, TESSA, and PA-BAT—are PDF documents that walk users step-by-step through an ES assessment. The EST is a guidance document consisting of steps with practical worksheets for conducting qualitative and/or quantitative ES assessment, indicators, advice on relevant issues, and a compendium of tools, methods, and models that might be applied. The PA-BAT is a rapid, workshop-driven and standardised assessment of different stakeholders' perceptions about ES benefits from protected and other areas. TESSA is a PDF manual that provides accessible guidance and low-cost methods to evaluate the benefits people receive from nature at particular sites.

The other six tools reviewed are computer-based modelling tools. ARIES and MIMES are modelling platforms, which can incorporate scenarios, spatial assessment and economic valuation of ES and integrate different ecological and economic models to understand and visualise ES values. InVEST is a suite of software models with defined model parameters for mapping and quantifying ES in biophysical or economic terms under different scenarios for which the user must simply provide the input data. CostingNature and WaterWorld are web-based tools for spatially analysing ES which provide model parameters and all the required input datasets and the user needs only to specify an area of interest and choose from pre-selected scenarios (e.g. land use and climate change) or design their own. SolVES is an ArcGIS-dependent application that allows the user to identify, assess and map the perceived social values that people attribute to cultural ES, which requires conducting stakeholder surveys and running models to produce spatial outputs.

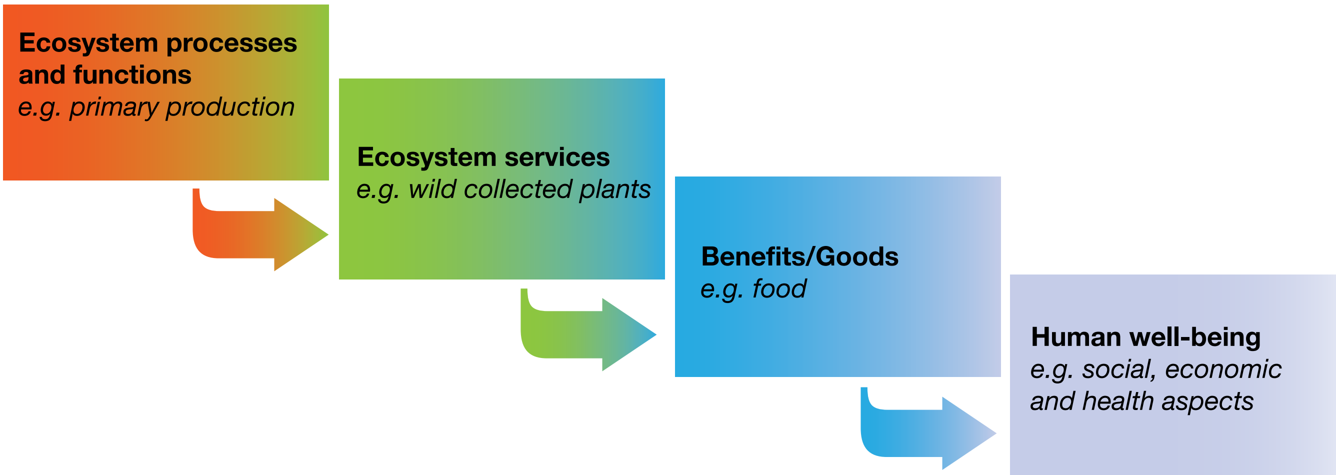
Selecting an appropriate tool requires identifying the specific question being addressed, what sorts of results or outputs are required, and consideration of practical factors such as the level of expertise, time and data required for applying any given tool. While each tool is different, they all provide an opportunity to shed light on ecosystem services issues and support management and policy decisions.

# Introduction

1

Greater Blue Mountains Area World Heritage site (Australia) © Alison Woodley

**Figure 1.** Conceptual framework of ecosystem services




Adapted from Haines-Young and Potschin (2010)

There is an increasing interest in measuring, modelling, and valuing *ecosystem services,* the benefits that nature provides to people. Ecosystem services (ES) include *provisioning* services such as firewood, fisheries, and raw materials; *regulating* services such as climate regulation, regulation of water flows, and water purification; and *cultural* services such as recreation, scenic values, spiritual values, or values that are important for cultural heritage or identity. ES are produced as a result of ecosystem processes and functions such as soil formation, nutrient cycling and primary production. ES then flow to people in the form of benefits or goods, supporting human well-being. The link between ecosystem functions, ecosystem services, benefits and human well-being is illustrated in Figure 1.

Information about ES can guide decision making and support protection and management of natural ecosystems to ensure an ongoing sustainable flow of benefits for current and future generations. Key Biodiversity Areas, protected areas, and natural World Heritage sites provide value to humanity not only for the biodiversity they contain, but also because they sequester and store carbon, purify water, provide recreation and tourism opportunities, contain cultural or spiritual values, and deliver a range of other benefits. Quantifying and mapping these benefits can help managers and decision makers justify the importance of these sites for conservation, attract new sources of funding, manage the sites more effectively, and allocate scarce financial or human resources to the places they are most needed.

Following the increased awareness and acknowledgement of nature's role in supporting human well-being, a plethora of tools for measuring, modelling and valuing ES have been developed in recent years. These include written step-by-step guidance tools such as the *Toolkit for Ecosystem Service Site-based Assessment* (TESSA; Peh et al., 2017), the *Protected Areas Benefits Assessment Tool* (PA-BAT; Dudley & Stolton, 2008), and the *Ecosystem Services Toolkit* (EST; Value of Nature to Canadians Study Taskforce, 2017). They also include computer-based modelling tools such as *Artificial Intelligence for Ecosystem Services* (ARIES; Villa et al., 2014), *Co$ting Nature* (Mulligan, 2015), *Integrated Valuation of Ecosystem Services and Tradeoffs* (InVEST; Sharp et al., 2018), the *Multiscale Integrated Model of Ecosystem Services* (MIMES; Boumans et al., 2015), *WaterWorld* (Mulligan, 2013), and many others. For a more comprehensive compilation of ES assessment tools and methods, see the ValuES Database (www.aboutvalues.net/) or the EST (Value of Nature to Canadians Study Taskforce, 2017).

For practitioners, selecting an appropriate tool or suite of tools for measuring and modelling ES can be confusing. Tools are created for different purposes, produce different outputs and have different requirements in terms of time, data and specialised expertise. There are several existing comparisons that evaluate ES assessment tools against standard criteria. Several recent efforts include Bagstad et al. (2013), Christin et al. (2016), Healy & Secchi (2016), and Grêt-Regamey et al. (2017). One recent review (Harrison et al., 2018) provides useful decision trees for selecting biophysical, socio-cultural or monetary ES assessment methods, but it does not compare specific models or tools. Another recent report provides guidance on selecting an ES model for decision making, but includes only a few tools (Bullock & Ding, 2018).

This document builds upon these efforts. The focus of our guidance is tools that can support ES assessment of important sites for biodiversity and nature conservation, including Key Biodiversity Areas (KBAs), natural World Heritage sites (WHS), and protected areas (PAs) as recognised by IUCN and the UN Convention on Biological Diversity. This document provides guidance for practitioners on existing tools for measuring, modelling or valuing the ecosystem services delivered by these sites.

We review a set of commonly applied ES assessment tools and provide a set of practical recommendations for selecting an appropriate tool. We distinguish between initial *identification* of ES, such as developing a checklist of benefits based on expert knowledge or stakeholder consultation, and ES *measurement, modelling, or valuation,* which involves more in-depth analysis that includes qualitative or quantitative measurement based on primary data collection, spatial modelling or valuation. It is important to note that 'valuation' refers to the process of identifying and assessing diverse kinds of values through (but not limited to) qualitative, quantitative, monetary and non-monetary approaches.

This guidance document does not aim to include all tools that have been developed for assessing ES. We focus on those tools that are freely available, can be applied anywhere in the world, and which have demonstrated applications in sites such as Key Biodiversity Areas, protected areas, or natural World Heritage sites. A number of specific methods and techniques for qualitative assessment of ES such as expert interviews, focus groups and review of available data are also available. These methods have been incorporated into some of the tools (e.g. TESSA and PA-BAT), but they are not reviewed specifically in this guidance document.

# Overview of Key Biodiversity Areas, natural World Heritage sites, and protected areas

# 2

Gran Bois, Massif de la Hotte KBA (Haiti) © Robin Moore

In this document, we refer to Key Biodiversity Areas, protected areas, and natural World Heritage sites collectively as 'sites'. Although they have unique aspects described below, these sites are fundamentally similar when considering how ES can be measured, modelled or valued, and hence it makes sense to treat them under the same guidance. These sites have explicit objectives related to, or have particular importance for, biodiversity and nature conservation. This guidance is thus provided within a framework of respecting and taking into consideration their underlying biodiversity importance and/or conservation objectives, and indeed, is relevant for site conservation efforts in general.

Key Biodiversity Areas, protected areas, and natural World Heritage sites may contribute to ES in different ways. ES may be produced locally within the site (e.g. pollination services that originate within the site), or the ES may be produced elsewhere but flow through the site to beneficiaries (e.g. a river that flows through a site). These ES may be received as benefits by people residing within, near, or distant from the sites. ES assessments should consider these different ways in which sites contribute to the delivery of ES as site management may enhance or degrade ES, or alter access to ES by beneficiaries.

KBAs, PAs, and WHS are all characterized by having important conservation values. In many cases, conservation of the biodiversity values of these sites will contribute to or enhance the provision of ES. It is important to recognise that certain ES (e.g. unsustainable fishing) might conflict with the conservation objectives of the site, however. Trade-offs between the ongoing provision of ES and biodiversity conservation goals may be necessary in these cases. Well-conserved sites can also contribute ES to surrounding areas, for example by serving as fish nursery habitat or sources of genetic diversity. Therefore KBAs, PAs and WHS play a crucial role in securing the long-term delivery of ES. Their importance will only grow as natural ecosystems in surrounding areas are increasingly lost or degraded (e.g. through land conversion for agriculture). Being able to understand and measure ES provided by these important sites can support their designation and management and contribute to ensuring a better balance in ES provision.

## 2.1 Key Biodiversity Areas

Key Biodiversity Areas (KBAs) are sites contributing significantly to the global persistence of biodiversity (IUCN, 2016). They are identified by national constituencies using globally standardised criteria and quantitative thresholds. More than 15,000 KBAs have been identified to date and appear in the World Database of Key Biodiversity Areas™ (www.keybiodiversityareas.org; BirdLife International 2018). Identifying and effectively safeguarding these sites is critical to the conservation of biodiversity at the global level (Edgar et al. 2008). However, KBAs are a scientific designation and are not necessarily protected areas. Many will need to be safeguarded through other management approaches (see section 2.3).

The criteria for KBAs are restricted to elements of biodiversity including species, ecosystems, biological processes, and ecological integrity. However, *A Global Standard for the Identification of Key Biodiversity Areas* (IUCN, 2016) recommends that the documentation for each site include information on ES. This documentation is basic and qualitative; it comprises the list of ES delivered by the site, reason(s) why the site is particularly important for those services, and beneficiaries. The guidance provided in this document is for users who wish to go a step beyond documentation to undertake a more in-depth assessment of ES delivered by one or more KBAs. Measuring, modelling and valuing the ES provided by KBAs can improve our understanding of the co-benefits these sites provide to human well-being and strengthen the case for conservation and sustainable management.

## 2.2 Natural World Heritage sites

World Heritage sites (WHS) are cultural monuments and sites or natural features, formations and areas which, because of their exceptional qualities, are considered to be of 'Outstanding Universal Value' (OUV) and therefore merit special protection (UNESCO World Heritage Centre, 2017). Natural WHS are those that have been identified for their outstanding natural values and include places such as East Africa's Serengeti, Yellowstone National Park and the Great Barrier Reef.

To be included on the World Heritage List, a site must meet at least one out of ten criteria (six criteria are applied to cultural heritage and four[1] to natural heritage), as well as conditions of integrity, and protection and management standards. The vast majority of natural WHS, and many cultural sites, are protected areas with governance types and categories varying among sites. As of April 2018, there were 35 mixed (both cultural and natural) and 206 natural WHS globally. Although they represent only about 0.1% of the total number of protected areas globally, natural WHS cover 294 million hectares and account for approximately 8% of the area of terrestrial PAs and 6% of marine PAs (Osipova et al., 2017).

WHS by definition contain globally significant cultural and/or natural values. In addition to being of OUV, these sites also provide important ES (Osipova et al., 2014). Like KBAs and protected areas, natural WHS contribute to food and water provision, carbon sequestration, and natural hazard regulation, and they provide many other benefits such as tourism opportunities and preservation of places of cultural and spiritual value. Because the main objective of WHS is the protection of their OUV, some activities, such as hunting and fishing, might be prohibited, and so the delivery of some ES, particularly harvesting of some resources, might not be allowed within WHS. When properly implemented, increased protection of WHS aimed at preserving their OUV also results in better conservation of intact and well-functioning ecosystems, which increases the

1 (vii) – contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
(viii) – be outstanding examples representing major stages of Earth's history, including record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;
(ix) – be outstanding examples representing significant on-going geological processes in the evolution and development of terrestrial, freshwater, coastal and marine ecosystems and communities of plants and animals;
(x) – contain the most important and significant natural habitats for in situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation.

potential of WHS to provide regulating services, such as water flow and climate regulation.

## 2.3 Protected areas

Protected areas (PAs) are clearly defined geographical spaces, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley 2008). Whilst many PAs are designated for their conservation value, PAs also have a role in safeguarding other important benefits, through the provision of a wide range of ES. As of 2016, just under 15% of the world's terrestrial areas and inland waters, 12.7% of the coastal and marine areas within national jurisdiction, and approximately 4% of the global ocean are covered by PAs (UNEP-WCMC & IUCN, 2016). In addition to conserving biodiversity and providing important recreational, tourism, and other cultural ecosystem services, well-managed protected areas can ensure water quality and in some situations also increase quantity of water available; increase the resilience of vulnerable human communities to cope with natural disasters; and promote human health and well-being (Stolton & Dudley, 2010). PAs increase food security by serving as nurseries and seed sources, enhancing wild fish stocks, and providing pollination and other ES which support agriculture, aquaculture and forestry. Understanding the ES associated with PAs, in terms of both social and economic values, may increase support for their designation and inform efforts to conserve and manage these sites for their multiple benefits.

Not all sites of importance for nature are managed as nationally or internationally designated protected areas. Some indigenous people's territories, sacred sites, watershed protection areas, and military training grounds may provide effective biodiversity conservation without necessarily having conservation as a primary objective. Such management regimes are referred to as 'other effective area-based conservation measures' (OECMs) in the language of Aichi Target 11 of the Strategic Plan for Biodiversity. A draft definition (IUCN WCPA, 2018) for OECMs has been proposed for adoption at the Conference of the Parties of the Convention on Biological Diversity in November 2018. The ES assessment tools described here are equally appropriate for application in OECMs.

## 2.4 Similarities & differences between KBAs, WHS, and PAs

KBAs, WHS and PAs are similar in that they are all important for conserving or safeguarding places of important natural or cultural value. The species, ecosystems and genetic diversity found within these sites also provide benefits to people in the form of food, water, energy, basic materials and cultural benefits (Larsen et al., 2012; Osipova et al., 2014; Neugarten et al., 2016; Ivanić et al., 2017; Mandle et al., 2017). However, the site type has implications for its management; in the case of KBAs, their identification does not imply any particular management system and is unrelated to a site's legal status. Fewer than 20% of KBAs are completely protected, and the mean protected area coverage of each KBA is 46% (Key Biodiversity Areas Partnership, 2017). PAs are formally designated sites that are managed by governments, local communities, private individuals or trusts, or other formal resource managers for a combination of nature conservation, recreation, cultural heritage or other uses. For natural WHS, adequate protection and management are part of the requirements for inscription on the World Heritage List and therefore most of them are officially designated protected areas, but their categories and governance types vary.

Thus, while we are including all three types of sites in our guidance due to their broad similarity and role in delivering ES, the specific needs for ES assessment and the implications of ES information for site management may vary between different categories of sites, as well as between sites within each category. For example, PAs and WHS typically have an established management and decision-making context in place that an ES assessment should consider, and this may not necessarily be the case for KBAs that are not yet protected or managed to maintain their biodiversity values. In addition, there are timing considerations as to when to conduct an ES assessment that may differ between KBAs, PAs and WHS (Annex I).

# Why measure, model, or assess values of ecosystem services delivered by sites?

# 3

Hawaiian fisherman (USA) © Troy K Shinn/ www.troyshinn.com

Detailed information about ES provided by KBAs, WHS and PAs can be useful for many reasons, including by increasing awareness of the benefits provided by these sites, which can help solicit support for safeguarding them. ES information can also support site management decisions and help ensure equity in resource use and benefits sharing among stakeholder groups. An ES assessment can be used to establish a baseline to monitor changes over time, or to enable evaluation of the consequences of management decisions or policy changes on ES delivery. It can be used as additional evidence in applications to accreditation or certification systems, such as the IUCN Green List of Protected and Conserved Areas (IUCN and WCPA, 2018), which seeks to encourage management effectiveness in protected areas and highlights ES. ES information can also support the development of mechanisms to compensate landowners or rights holders for implementing management practices supporting conservation outcomes, or unlock new sources of funding for site conservation.

Information about ES provided by these sites can also demonstrate their importance in achieving international conservation targets, such as the UN Convention on Biological Diversity Aichi Target 11 on land/water protection, which references "areas of particular importance for biodiversity and ecosystem services"[2]. Lastly, this information can inform how these sites contribute to achieving the goals of the 2030 Agenda for Sustainable Development[3], as highlighted, for example, in the "Policy for the integration of a sustainable perspective into the processes of the World Heritage Convention" (UNESCO, 2015).

Table 1 below summarises a wide range of potential applications of ES assessment for individual sites or networks of sites and potential users of that information. *Table 3* in section 4.2 provides a summary of the ES tools included in our review that might be applied for each of the purposes described. All of these purposes can be fulfilled with a combination of assessing biophysical, social and economic values or with biophysical and sociocultural values alone, without using monetary valuation.

## 3.1. The importance of scoping

Defining the purpose and objectives should be the starting point for carrying out an ES assessment, as this informs whether it makes sense to undertake an assessment in the first place, the scope and depth of the assessment, and the selection of the most appropriate tool(s). In general, an ES assessment of one or more sites is worthwhile when there is a need for additional ES understanding, there are clear objectives for the assessment (such as those listed in Table 1), and there is a clear plan as to how the results will be used to support site conservation or management. It may not make sense to undertake an in-depth ES assessment if, for example, it would divert scarce resources from other more pressing needs such as conservation activities, site management, and biodiversity assessments, or it would not provide clear added value to site management.

2 www.cbd.int/sp/targets/
3 www.un.org/sustainabledevelopment/

Monetary valuation of ES can sometimes be in conflict with conservation objectives if the economic values associated with conservation are not as high as alternative land uses in the short term (Schröter et al., 2014). This does not mean that the site should be converted, but that the conservation value needs to be assessed from a non-monetary perspective, such as globally significant biodiversity values, irreplaceable cultural values or relational values (Chan et al., 2016). Also, certain ES (such as cultural heritage) are difficult to assess in monetary terms and may be better evaluated using non-monetary measures. It is important to keep these risks and limitations in mind and to be strategic about when and how to undertake an ES assessment. In particular, it is important to identify situations when conservation strategies and arguments based on biodiversity or other cultural or social values may be more effective than assessing economic values.

A scoping phase can provide an overall picture of the full range of ES provided by a site or sites and the associated beneficiaries at local, regional, national and global levels. While only some of these ES might be selected for further assessment, scoping helps to ensure that all benefits are identified and accounted for. It can also help to draw attention to benefits that might become more important in the future, for example due to climate change or resource scarcity. Scoping also allows the assessment of site ES to be placed in a broader socio-economic context, helping to ensure correct use and targeting of results, and can help identify different rights holders and stakeholders that should be considered or engaged in the assessment process. All ES tools recommend scoping as an initial step in any ES assessment. Several ES tools have specific guidance on how to undertake ES scoping including the EST, TESSA and PA-BAT.

## 3.2 Stakeholder engagement

All ES assessment processes should involve some level of stakeholder engagement. Stakeholders can help identify the relevant ES to assess at a site; provide sources of data, information and knowledge that can result in a more robust assessment; help to validate ES assessment results; and ensure that assessment results are actually used for management or policy decisions. Including stakeholders from the beginning also helps build trust and ensure that the information produced during the assessment process will be accepted by the people or groups who will ultimately be responsible for the management of the site. Some tools reviewed here explicitly require a stakeholder workshop (PA-BAT) or a survey (SolVES) in order to be applied—other tools strongly recommend stakeholder engagement but can be applied without it.

## 3.3 Qualitative and quantitative ES assessment

Depending on the question and context for the ES assessment, qualitative or quantitative methods may be preferred. Qualitative assessment is important for scoping, identification of relevant services, identifying which groups of stakeholders benefit from particular services, and prioritising sites for more in-depth research. Qualitative assessments also have benefits

**Table 1.** Reasons for measuring ES provided by sites

| Reasons for measuring ES provided by sites | Main audience |
|---|---|
| **Public/policy support** | |
| Provide additional evidence and justification for the importance of conserving a particular site | Government agencies, policy and decision makers, local stakeholders, businesses, donors |
| Foster local awareness of the ES provided by a particular site | Local communities, Indigenous and traditional people, local decision makers |
| Build support for the conservation of multiple sites through increased understanding of their wide range of benefits | Government agencies and ministries, civil society |
| Link ES contributed by all sites in a country to international or national sustainability goals and national policies (e.g. Sustainable Development Goals) | Government, international community |
| **Site management** | |
| Establish the baseline of ES provided by a site to enable monitoring of changes and support management planning | Site managers and others responsible for monitoring sites |
| Reveal synergies and possible trade-offs between ES and/or ES and conservation objectives to identify management options for the site and better define conservation objectives | Site managers, local stakeholders |
| Develop, implement and update management strategies for the site, building on the understanding of ES (e.g. integration of ES into site's management plan or developing a business plan for the site) | Site managers, local communities, Indigenous and traditional people, conservation organisations, businesses |
| **Human well-being** | |
| Ensure a good understanding of the ES values that are important to resident, local and more distant stakeholders | Managers, communities, companies using ecosystem services, municipalities |
| Assess compensation options to resident and local stakeholders for ES forgone as a result of biodiversity conservation, to contribute to discussions about Free Prior and Informed Consent, conflict resolution, etc. | Land and water managers, communities living in or near the site |
| **Planning** | |
| Support spatial and strategic conservation planning and investment by identifying areas of particular importance for ES | Government agencies, conservation organisations, donors |
| Assess potential consequences of different sectoral (e.g. agriculture, hydropower, infrastructure) decisions and policies on ES delivered by sites (scenario comparison) | Government agencies and ministries, businesses, landowners, resource rights holders, local communities, multilateral financial institutions |
| Assess potential consequences of climate change scenarios on ES provided by a site | Government agencies and ministries, conservation organisations, landowners, Indigenous and traditional people, businesses, communities living in or near a site, managers |
| Integrate ES delivered by sites into land-/water-/resource-use planning at regional, national or sub-national scales (e.g. Strategic Environmental Assessment), understand implications for management of surrounding areas to improve flows from or resilience of site ES | Government agencies and ministries, conservation organisations |
| **Private sector engagement** | |
| Help businesses manage risks and meet their social and environmental responsibility targets, by identifying possible impacts on ES and beneficiaries (e.g. Environmental Impact Assessments, corporate sustainability assessments) | Businesses, consultants or conservation organisations working with businesses, government agencies, eco-certification assessors |
| Provide incentives for businesses to engage in the conservation of sites by demonstrating the dependence of the businesses on ES provided by sites (e.g. public-private funding schemes, in-kind support, branding) | Businesses, site managers, local communities, Indigenous and traditional people, consultants or conservation organisations working with businesses, government agencies, eco-certification assessors |

| Reasons for measuring ES provided by sites | Main audience |
|---|---|
| **Funding and investment** | |
| Attract government and donor investment from other sectors concerned with conservation of ES (e.g. water management, public health, national security) and/or donors interested in sustainable development | Government ministries, development agencies and organisations |
| Support the development of new sustainable finance mechanisms for conservation of the sites, such as Payments for Ecosystem Services (PES) or carbon financing such as Reduced Emissions from Deforestation and Forest Degradation (REDD+) | Businesses, public and private investors, government agencies, conservation organisations, local communities |
| **Knowledge generation** | |
| Inform research on ES provided by sites locally, nationally, regionally or globally | Academics, students, conservation organisations, research organisations |
| Inform research on the synergies and trade-offs between conserving biodiversity and ES, between different ES, and between different stakeholders | Academics, students, conservation organisations, research organisations |

in bringing together stakeholders to think about ES values and implications of management decisions. Furthermore, qualitative methods can be used to identify sociocultural values. In one survey in sub-Saharan Africa, the majority (88%) of stakeholders and decision makers were satisfied with qualitative information (Willcock et al., 2016).

While some of the applications described in Table 1 can therefore be achieved with qualitative information, some applications will be better served with quantitative data measured in either biophysical (e.g. cubic metres of water) or monetary units (e.g. dollars per cubic metre of water), or with spatially explicit data (e.g. maps in a Geographic Information System (GIS)). The need for quantitative or spatial information depends on the context. For example, a government agency seeking to understand the benefits of the sites to the people of its country might simply need qualitative information documenting the various benefits that people receive from the sites, such as a list (e.g. "carbon storage and sequestration, water purification, pollination services, tourism"). However, if there is interest in establishing a Payments for Ecosystem Services[4] (PES) scheme, those benefits might need to be quantified to determine more accurately how much of a given service is being produced by a given site and how the delivery of that service is affected by management, in order to set up an equitable system of payments between the beneficiaries of the service and the service providers.

Quantitative measurement or spatial modelling of ES, such as monitoring data on a particular ES, can be particularly helpful if a site is under significant pressure of conversion to an alternative land or water use scenario. It can also help elucidate trade-offs and synergies between alternative resource use strategies and therefore inform management decisions. For example, stakeholders may disagree about whether to continue to allow timber harvesting within a KBA. In this case, quantifying the ecosystem services provided by the site (such as carbon storage and sequestration, flood regulation, and recreation) under different management scenarios might help elucidate the implications of continued timber harvesting for other ES. However, when planning and undertaking an ES assessment in KBAs, PAs or WHS, the primary conservation objectives of the sites, including their globally significant biodiversity values and Outstanding Universal Values should be considered and respected. For more guidance on when an ES assessment might be necessary (or not), and what level of effort is appropriate, see the *Ecosystem Services Toolkit* (Value of Nature to Canadians Study Taskforce, 2017) or *Social and Economic Benefits of Protected Areas: An Assessment Guide* (Kettunen & Brink, 2013)

For a more holistic understanding of ES, the combination of both quantitative and qualitative methods can also be powerful. Qualitative assessment can be used during scoping to identify relevant services and beneficiaries. Quantitative assessment can then be conducted to measure or spatially model the identified set of services in biophysical or monetary terms. However, combining qualitative and quantitative analysis can be beneficial at all stages of an ES assessment.

Although the purpose of the assessment should drive the choice of qualitative and/or quantitative methods, the capacity and resources available to the assessment team is always a factor. In general, quantitative ES assessments require more technical expertise, such as the ability to collect and analyse biophysical data on ecosystem services or conduct spatial analyses using GIS-based modelling software. The time and skills required for conducting a rigorous qualitative assessment should not be underestimated, however. For example, conducting a series of workshops with the full suite of stakeholders associated with a PA; or conducting a large, well-designed survey to assess ES provided by a natural WHS both require time, resources and specific skills such as stakeholder analysis, workshop facilitation, survey design and data compilation and analysis. The methods chosen should be informed by the scoping phase and primary objectives of the ES assessment.

4 Payments for ecosystem services (PES) occur when a beneficiary or user of an ecosystem service makes a direct or indirect payment to the provider of that service. PES involve a series of payments to land or other natural resource owners in return for a guaranteed flow of ecosystem services or certain actions likely to enhance their provision. Reference: www.undp.org/content/sdfinance/en/home/solutions/payments-for-ecosystem-services.html

# Comparison of ecosystem services tools

4

Algonquin Provincial Park (Canada) © Alison Woodley

The ES tools included in our review are summarised in Table 2. Descriptions of each tool and case studies are included in Annex II. We conducted a high-level review of 30 tools (see Annex III) and then selected a smaller set of nine tools that are (a) most commonly applied, (b) available to practitioners at no cost, and (c) can be applied in new contexts (i.e. they are not restricted to specific countries or case studies). We added two tools not reviewed in past comparisons: PA-BAT and EST. PA-BAT was considered especially relevant because it was designed to assess ES benefits of protected areas. The EST was developed recently (2017) and therefore was not included in earlier reviews. We excluded several of the tools included in earlier reviews (e.g. Bagstad et al., 2013) because they are proprietary or still under development.

We divided tools into two types:

1. Written step-by-step tools—written guidance documents with specific measurement protocols enabling ES assessment of a site, such as the Toolkit for Ecosystem Service Site-based Assessment (TESSA) or the Protected Area Benefits Assessment Tool (PA-BAT);
2. Computer-based modelling tools—software or web-based tools that enable ES assessment of one or more sites.

For more comprehensive compendiums of ES assessment tools and methods, see the ValuES Methods Database (www.aboutvalues.net/) or the Ecosystem Services Toolkit (Value of Nature to Canadians Study Taskforce, 2017). The ValuES Database is an online resource that consists of guidance, case studies, a comprehensive searchable online library of ES assessment tools and methods, training courses and other resources (Berghöfer et al., 2014). The EST is a downloadable, interactive (hyperlinked) PDF and consists of guidance and practical worksheets, case studies, factsheets about tools and methods, and other resources.

## 4.1 Tool selection

Selecting an appropriate tool for ES assessment is informed by three factors (Figure 2):

1) **Purpose of the assessment.** Why is the assessment being conducted? Is it to inform site management, establish a finance mechanism, elucidate trade-offs between resource use scenarios, or some other purpose? Who is the audience for the assessment?

2) **Required outputs.** Which ES are being assessed? What type of results are needed and in what format (qualitative/quantitative, spatial/non-spatial, monetary/non-monetary)?

3) **Practical considerations.** How much time and budget are available for the assessment? Are data in the required format and spatial scale already available? Is it feasible to collect primary data or survey stakeholders? Do the assessors have specialised expertise in GIS or modelling and are there resources for training?

In this document, we have attempted to provide guidance on selecting an appropriate tool by considering all three factors. A note of caution about applying any modelling tool: the accuracy of model results always depends on the accuracy of the input data, the model assumptions, and the level of calibration and model validation. We have not attempted to rate tools according to the accuracy of their outputs here, because the accuracy will vary depending on the factors listed above. Model results should always be validated using empirical data. If that is not feasible, expert or local knowledge can in some cases be used to review and validate model results.

**Figure 2.** Tool selection should be informed by the purpose of the assessment, the required outputs, and practical considerations

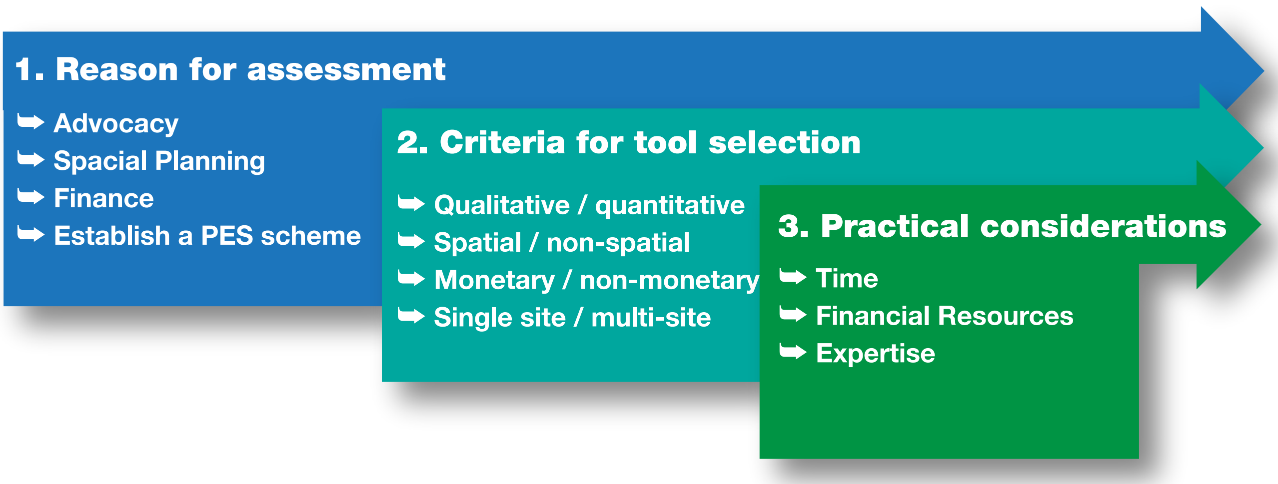


**Table 2. Ecosystem services assessment tools included in this review**

| Tool name and website | Acronym | Tool description | Citation |
|---|---|---|---|
| **Written step-by-step tools** | | | |
| Ecosystem Services Toolkit<br><br>publications.gc.ca/site/eng/9.829253/publication.html | EST | The EST is a guidance document consisting of steps with practical worksheets for conducting qualitative and/or quantitative ES assessment, indicators, advice on relevant issues, and a compendium of tools, methods, and models that might be applied. It is a freely available dynamic PDF. The EST itself does not require computer modelling but guides a practitioner to select appropriate measurement, modelling or other assessment methods. | (Value of Nature to Canadians Study Taskforce, 2017) |
| Protected Areas Benefits Assessment Tool<br><br>wwf.panda.org/our_work/biodiversity/protected_areas/arguments_for_protection/ | PA-BAT | The PA-BAT is a rapid, workshop-driven and standardised assessment of different stakeholders' perceptions about ES benefits from protected and other areas. It is freely available in PDF format, does not require modelling or other computer skills, and can be adapted. It requires stakeholder engagement such as a workshop. | (Dudley & Stolton 2008; Ivanić et al. in press) |
| Toolkit for Ecosystem Service Site-based Assessment v.2.0<br><br>tessa.tools/ | TESSA | TESSA is a PDF manual that provides accessible guidance and low-cost methods to evaluate the benefits people receive from nature at particular sites. TESSA generates information that can be used to influence decision making. It does not require computer modelling but it does require stakeholder participation and encourages primary data collection using the methods provided. | (Peh et al., 2017) |
| **Computer-based modelling tools** | | | |
| Artificial Intelligence for Ecosystem Services<br><br>aries.integratedmodelling.org | ARIES | ARIES is an ecosystem services modelling platform. ARIES' underlying software, k.LAB, is designed for integrated socioeconomic-environmental modelling, which includes ES. ARIES can accommodate a range of different users and user needs, including scenarios, spatial assessment and economic valuation of ES, optimisation of payments for ecosystem services programs, and spatial policy planning. Using ARIES currently requires modelling skills and GIS. | (Villa et al., 2014) |
| Co$ting Nature v.3<br><br>www.policysupport.org/costingnature | C$N | C$N is web-based tool for spatially analysing ES and assessing the impacts of human interventions such as land use change scenarios. It provides a globally or locally relative index of service provision that can be used for ES assessment, conservation prioritisation, analysis of co-benefits, pressures and threats. Version 3 includes economic/monetary valuation. Using C$N does not require modelling skills or GIS. | (Mulligan, 2015) |
| Integrated Valuation of Ecosystem Services and Tradeoffs 3.4.2<br><br>www.naturalcapitalproject.org/invest/ | InVEST | InVEST is a suite of software models for mapping and quantifying ES in biophysical or economic terms under different scenarios (e.g., policy or management options). InVEST models are based on simple, generalised production functions and require commonly available input data. Using InVEST requires GIS but not modelling skills. | (Sharp et al., 2018) |

| Tool name and website | Acronym | Tool description | Citation |
|---|---|---|---|
| Multiscale Integrated Models of Ecosystem Services<br><br>www.afordablefutures.com | MIMES | MIMES is an analytical framework designed to integrate different ecological and economic models to understand and visualise ES values. MIMES relies on SIMILE software and each MIMES application is customised to a specific socio-ecological system. Using MIMES requires modelling skills and GIS. | (Boumans et al., 2015) |
| Social Values for Ecosystem Services<br><br>solves.cr.usgs.gov | SolVES | SolVES is an ArcGIS-dependent application that allows the user to identify, assess and map the perceived social values that people attribute to cultural ES, such as aesthetic or recreational values. Combining spatial and points-allocation responses from surveys (which can be undertaken in person, online or through mailing), it produces points-based social-values metric and raster maps of social value intensities. Using SolVES requires GIS. | (Sherrouse et al., 2011) |
| WaterWorld v.2<br><br>www.policysupport.org/waterworld | WW | WW is a web-based tool for modelling hydrological services associated with specific activities under current conditions and under scenarios for land use, land management and climate change. It provides quantitative biophysical results or relative indices that can be used to understand hydrological ecosystem services, water resources and water risk factors. Using WW does not require GIS or modelling skills. | (Mulligan, 2013) |

## 4.2 Purpose of assessment

Possible purposes for ES assessment are outlined in Table 1, above. We assessed which tools can be used for various purposes and summarised this information in Table 3, below. While it is important to understand the purpose of the assessment, many of the reviewed tools can serve many objectives; therefore we found that the purpose of the assessment does not, in and of itself, help identify the most appropriate tool. To select a tool, the purpose of the assessment needs to be considered in combination with other information such as the required outputs and practical considerations outlined below.

## 4.3 Required outputs & practical considerations

Depending on the context, an assessment might require results that are spatial, such as maps or GIS data. Some assessments might require information that is quantitative, measured in biophysical units (e.g. tons of carbon, cubic metres of water) or monetary units. For other assessments, qualitative information on the presence or absence of a given ES, or the relative importance of ES provided by a site (e.g. low to high), might suffice. Some assessments might require results that are explicitly comparative (e.g. between two alternative land use or policy scenarios). Practical considerations such as the time and budget available for the assessment, the level of expertise or training of assessors, and the feasibility of primary data collection will also vary between assessments. Lastly, some tools can be applied in terrestrial, freshwater and/or marine realms, and others are restricted to terrestrial or freshwater services. We outline a set of considerations related to both the required outputs and practical considerations. Table 4 summarises these considerations and which tools can be used in each case. Again, many of the tools can be applied in many contexts. Therefore, each consideration may not be useful alone, but in combination they can help a practitioner select a tool. We have also developed a set of decision trees that can help users select a tool based on aims of the assessment and required outputs (Figure 3) or practical considerations (Figure 4). For decision trees covering a wider array of ES assessment methods, see Harrison et al. 2018.

**Table 3.** **Purpose of measuring, modelling or valuing ES of KBAs, natural World Heritage sites, and protected areas, and tools that might be applied. ✓ = can potentially be used; ✓✓ = can potentially be used and there are case studies available. For case studies, see Annexes II and IV.**

| Reasons for measuring ES provided by sites | ARIES | C$N | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|---|---|
| **Public/policy support** | | | | | | | | | |
| Provide additional evidence and justification for the importance of conserving a particular site | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ |
| Foster local awareness of the ES provided by a particular site | ✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ |
| Build support for the conservation of multiple sites through increased understanding of their wide range of benefits | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ |
| Link ES contributed by all sites in a country to international or national sustainability goals and national policies (e.g. SDGs) | ✓ | ✓✓ | | ✓✓ | ✓ | ✓✓ | | | ✓✓ |
| **Site management** | | | | | | | | | |
| Establish the baseline of ES provided by a site to enable monitoring of changes and support management planning | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ |
| Reveal synergies and possible trade-offs between ES and/or ES and conservation objectives to identify management options for the site | ✓ | ✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ |
| Develop, implement and update management strategies for the site (e.g. integration of ES into site's management plan or developing a business plan for the site) | ✓ | ✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓ |
| **Human well-being** | | | | | | | | | |
| Ensure a good understanding of the ES values that are important to resident, local and more distant stakeholders | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ |
| Assess compensation options to resident and local stakeholders for ES forgone as a result of biodiversity conservation, to contribute to discussions about Free Prior and Informed Consent, conflict resolution, etc. | | | | ✓ | | ✓ | ✓ | ✓ | ✓✓ |
| **Planning** | | | | | | | | | |
| Support spatial conservation planning and investment by identifying areas of particular importance for ES | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓ | | ✓✓ | | ✓ |
| Assess potential consequences of different sectoral (e.g. agriculture, hydropower, infrastructure) decisions and policies on ES delivered by sites (scenario comparison) | ✓✓ | ✓ | ✓ | ✓✓ | ✓✓ | | ✓ | ✓✓ | ✓✓ |
| Assess potential consequences of climate change scenarios on ES provided by a site | ✓ | ✓ | | ✓✓ | ✓✓ | | | ✓ | ✓✓ |
| Integrate ES delivered by sites into land-/water-/resource-use planning at regional, national or sub-national scales (e.g. Strategic Environmental Assessment) | ✓✓ | ✓ | ✓ | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ |

| Reasons for measuring ES provided by sites | ARIES | C$N | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|---|---|
| **Private sector engagement** | | | | | | | | | |
| Help businesses manage risks and meet their social and environmental responsibility targets by identifying possible impacts on ES and beneficiaries (e.g. Environmental Impact Assessments, corporate sustainability assessments) | ✓ | ✓✓ | | ✓✓ | ✓ | ✓ | ✓ | ✓ | ✓✓ |
| Provide incentives for businesses to engage in the conservation of sites by demonstrating the dependence of the businesses on ES provided by sites (e.g. public-private funding schemes, in-kind support, branding) | ✓ | | ✓ | ✓✓ | ✓ | ✓✓ | | | |
| **Funding and investment** | | | | | | | | | |
| Attract government and donor investment from other sectors concerned with conservation of ES (e.g. water management, public health, national security) and/or donors interested in sustainable development | ✓✓ | ✓ | ✓ | ✓✓ | ✓ | ✓✓ | ✓ | | ✓✓ |
| Support the development of new sustainable finance mechanisms for conservation of the sites, such as Payments for Ecosystem Services (PES) or carbon financing such as Reduced Emissions from Deforestation and Forest Degradation (REDD+) | ✓ | ✓✓ | | ✓✓ | ✓ | | | ✓✓ | ✓✓ |
| **Knowledge generation** | | | | | | | | | |
| Inform research on ES provided by sites locally, nationally, regionally or globally | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ |
| Inform research on the synergies and trade-offs between conserving biodiversity and ES, and between different ES | ✓✓ | ✓✓ | ✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓✓ | ✓ |

**Table 4. Types of outputs and requirements for each tool. Table represents what is possible in the free version of each tool as of March 2018. *New ARIES functionality (e.g. a web-based interface) is under development and planned for a December 2018 release.**

| Tool | ARIES* | C$N | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|---|---|
| **Type of outputs that can be produced** | | | | | | | | | |
| Maps of services (GIS based) | ✓ | ✓ | | ✓ | ✓ | | ✓ | | ✓ |
| Maps of services (participatory mapping) | | | | | | ✓ | ✓ | ✓ | |
| Relative or qualitative values | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Quantitative (biophysical units) | ✓ | | | ✓ | ✓ | | | ✓ | ✓ |
| Monetary value | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| Designed for scenario comparison (e.g. between land use or policy scenarios) | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ |
| **Time, resources and skills required** | | | | | | | | | |
| Requires additional paid software licenses | | | | | ✓ | | ✓ | | |
| Requires use of GIS software | ✓ | | | ✓ | ✓ | | ✓ | | |
| Requires modelling skills | ✓ | | | | ✓ | | | | |
| Requires social science knowledge | | | ✓ | | | | ✓ | | |
| Online training available for modelling tools | | ✓ | | ✓ | ✓ | N/A | ✓ | N/A | ✓ |
| User support available | ✓ | ✓ | | ✓ | ✓ | ✓ | | | ✓ |

| Tool | ARIES* | C$N | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|---|---|
| **Stakeholder engagement** | | | | | | | | | |
| Requires stakeholder consultation, participatory workshop or surveys | | | | | | ✓ | ✓ | ✓ | |
| Designed to address benefits to different beneficiary groups | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| **Data/input requirements** | | | | | | | | | |
| Requires primary data collection (e.g. vegetation surveys, soil or water sampling, stakeholder consultation or social surveys) | | | | | ✓ | ✓ | ✓ | ✓ | |
| Ability to get results without any user-provided data (e.g. desk-based research using built-in land use maps, population data or other inputs) | ✓ | ✓ | | | ✓ | | | | ✓ |
| Ability for user to adapt the tool, provide their own data, or customise inputs | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Allows development and parameterisation of a user's own models | ✓ | | | | ✓ | N/A | | N/A | |
| **Environment where tool can be applied** | | | | | | | | | |
| Freshwater | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Terrestrial | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Marine (coastal) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Marine (pelagic) | ✓ | | | ✓ | ✓ | | ✓ | | |
| **Scale of application** | | | | | | | | | |
| Single site per application | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Multiple sites simultaneously per application | ✓ | ✓ | | ✓ | ✓ | | | | ✓ |

*Includes new ARIES models planned for release in December 2018.

## 4.4 Relevant ecosystem services

Depending on the context, there might be interest in assessing provisioning ES, such as the provision of food, water and basic materials to local communities; regulating services, such as carbon storage and sequestration, water purification, flood regulation, and coastal protection; and cultural services, such as recreation, tourism, education or research opportunities, and cultural or spiritual values. Not all tools are equipped to assess all services; therefore it is useful to consider which ES are relevant before selecting a tool or suite of tools. Table 5 summarises the set of ES that can be assessed by each tool.

To synthesise as much information about the tools as possible in a single table, we evaluated each tool against a standard set of criteria and summarised this information in Table 6. Our review builds on existing comparisons of ES tools provided by Healy and Secchi (2016) and Bagstad et al. (2013). The criteria used in existing reviews included:

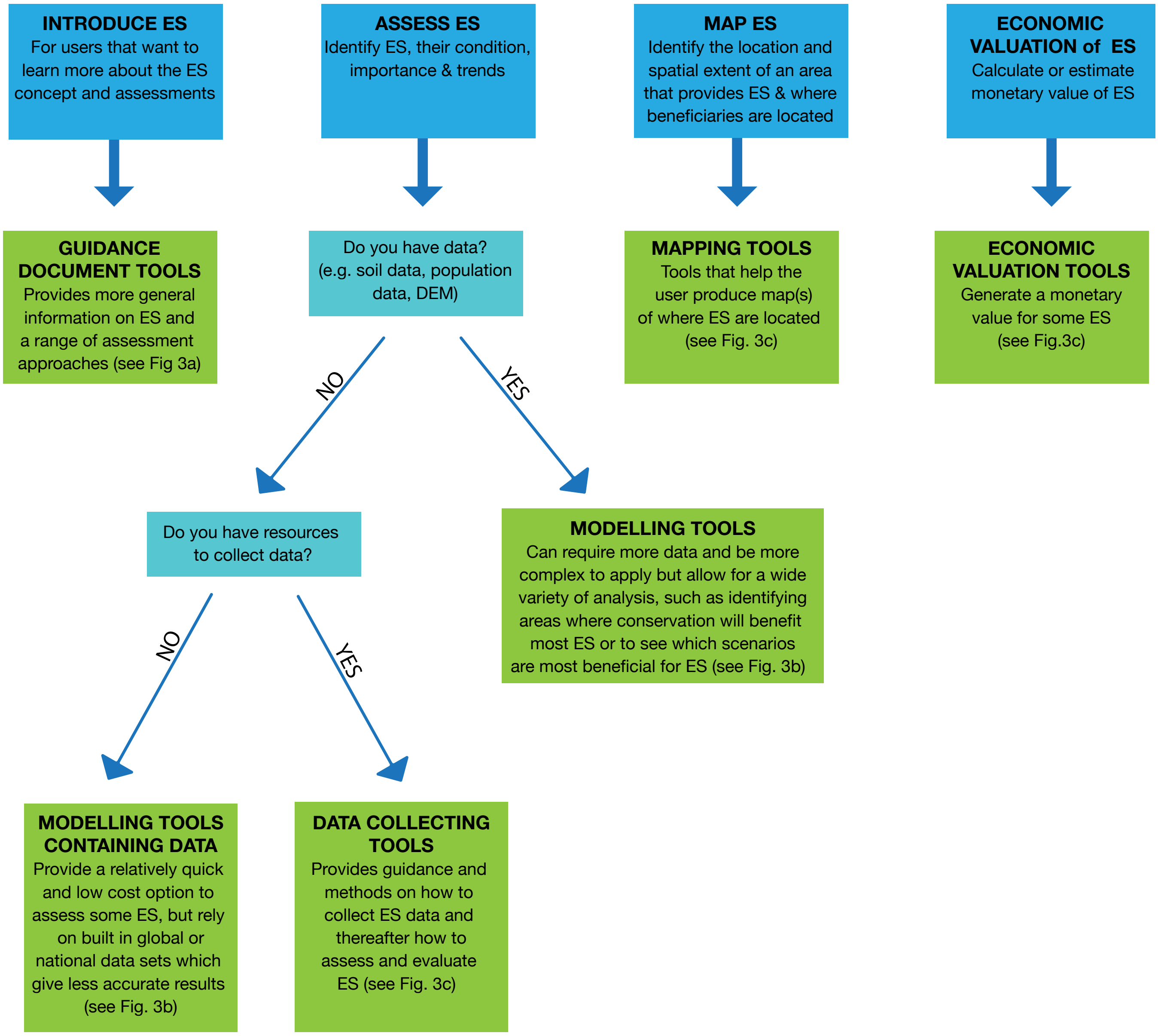
- cost/availability (free/open source)
- time requirements (low to high)
- data input demand (low to high)
- skill requirements (low to high)
- scale of analysis (site to global)
- quantitative / qualitative
- monetary / nonmonetary
- spatially explicit / not spatially explicit
- technical requirements (e.g. internet connection, GIS or other specialised software)
- user support provided (low to high)
- level of development and documentation
- approach to uncertainty
- capacity for independent application
- generalisability (i.e. can the model/tool be applied in new places or contexts).

We added several criteria that we believe are needed when evaluating the suitability of existing tools for measuring and modelling ES for important sites, specifically:

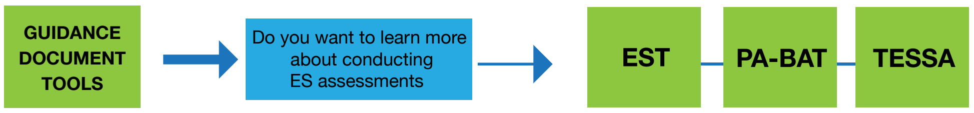
- applicability to terrestrial, freshwater, marine ecosystems
- level of stakeholder engagement required
- outputs expressed as absolute vs. relative values
- model or method is explicitly comparative, i.e. users are encouraged to compare the site's current ES values with those it would deliver in an alternative state or with those delivered by an alternative site.

**Figure 3. Decision trees for ES tool selection based on aims of the assessment and required outputs**

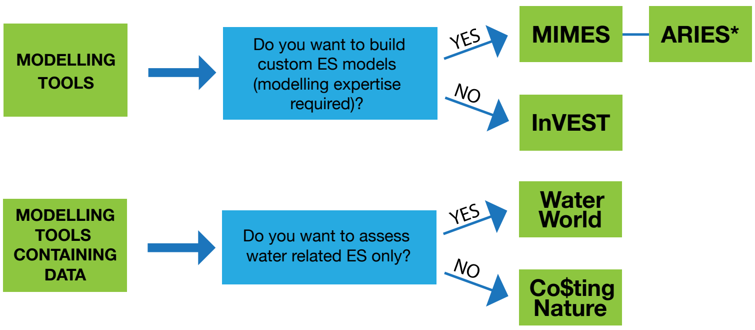
Initial guidance to help choose between modelling tools and tools for collecting data, mapping and economic valuation



**(a) Guidance document tools**




**(b) Modelling tools and modelling tools containing data**




*New version of ARIES (including a web interface) planned for release in December 2018 which will not require modelling expertise

**(c) Data collecting, mapping and economic valuation types of ES tools**

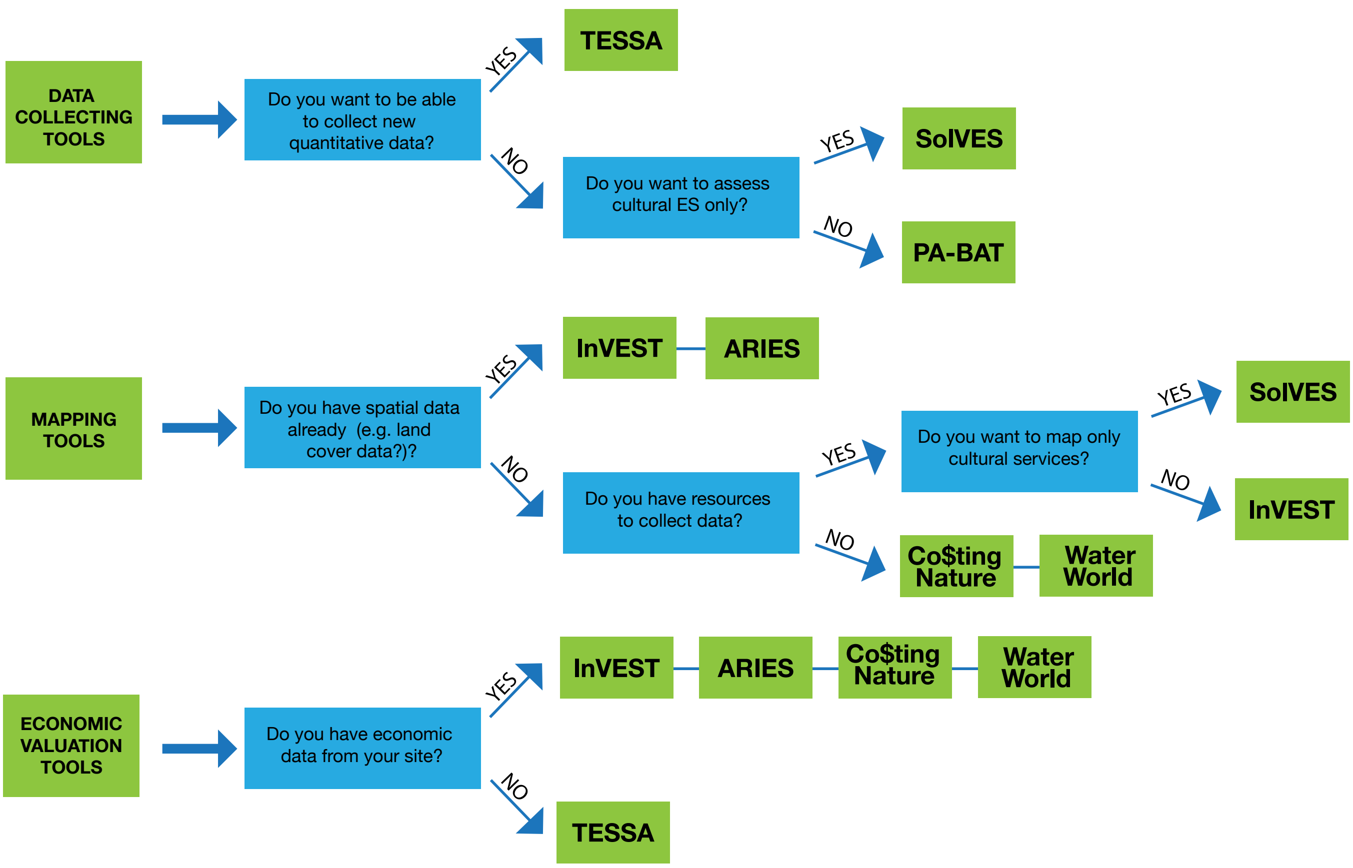


**Figure 4.** Decision tree for ES tool selection based on practical considerations. This decision tree is based on a complete application of the tools; some tools can also be used just for qualitative scoping (e.g. TESSA). EST was excluded because it is high-level guidance that can lead to the selection of any other tool or method. For additional decision trees comparing other biophysical, socio-cultural and monetary ES assessment methods, see Harrison et al., 2018.

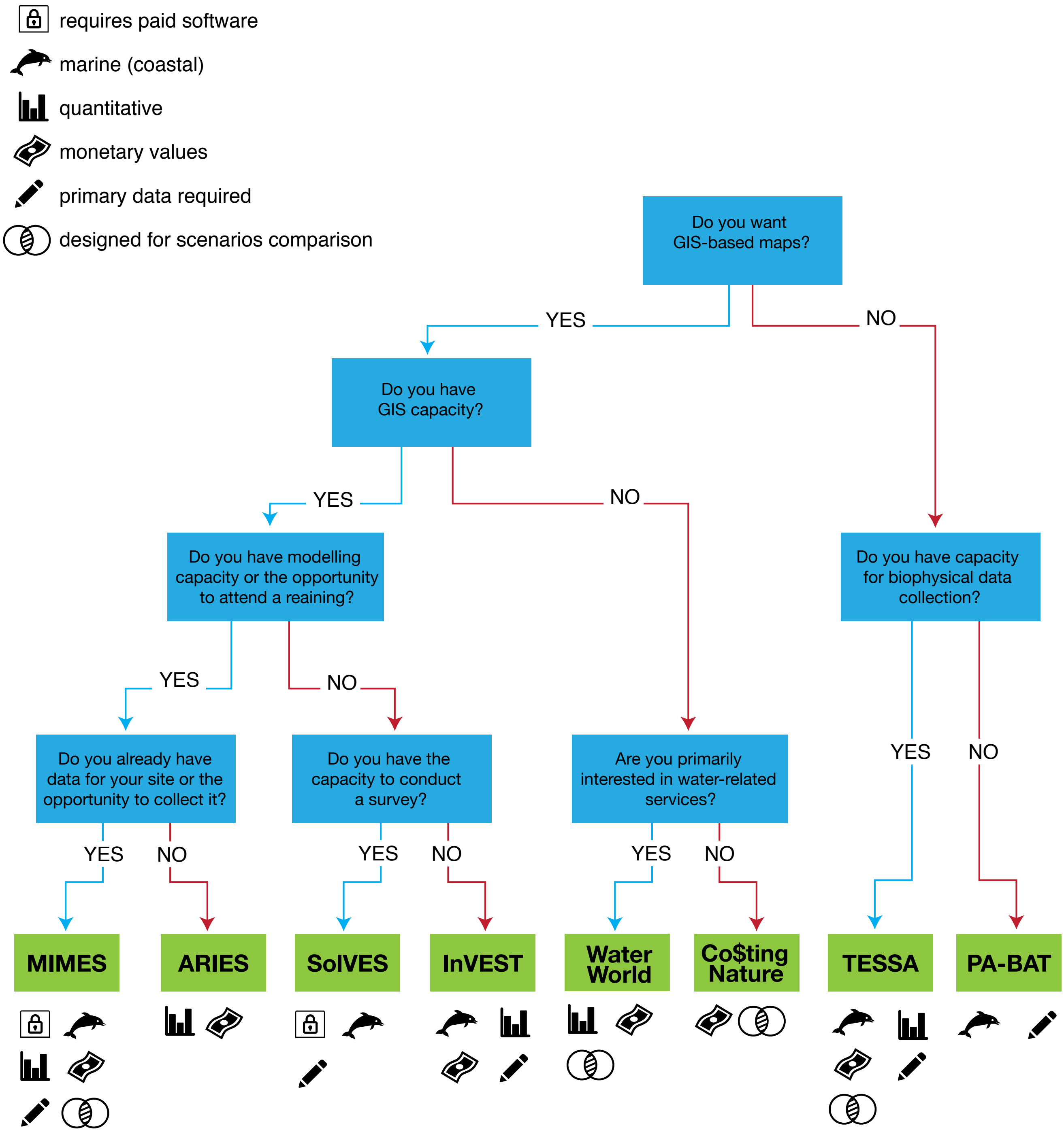


**Table 5.** Set of ecosystem services that can be assessed by each tool. EST and MIMES were excluded as they can be used to assess any ES. ES names were derived from the tools; this is not a comprehensive list of all ES. Table represents ES that can be assessed in the free version of each tool as of March 2018.

| Ecosystem Service | ARIES* | C$N | InVEST | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|
| **Provisioning** | | | | | | | |
| Fisheries / Subsistence fisheries (wild) | | ✓ | ✓ | ✓ | | ✓ | |
| Freshwater aquaculture | | ✓ | | | | ✓ | |
| Fuelwood | | ✓ | | ✓ | | ✓ | |
| Genetic material | | | | ✓ | | | |
| Harvested wild goods / Hunting / Non-wood forest products (e.g. honey, mushrooms, berries) | | ✓ | | ✓ | | ✓ | |
| Livestock grazing | | ✓ | | ✓ | | ✓ | |
| Marine fish aquaculture | ✓ | | ✓ | ✓ | | | |
| Material extraction (e.g. coral, shells, resin, rubber, grass, rattan) | | | | ✓ | | ✓ | |
| Medicinal resources | | | | ✓ | | ✓ | |
| Production / Cultivated goods / Traditional agriculture | | | | ✓ | | ✓ | |
| Timber | | ✓ | | ✓ | | ✓ | |
| Water - Water provision / Water supply / Water quantity / Water yield | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| **Regulating** | | | | | | | |
| Carbon (sequestration) | | ✓ | ✓ | | | ✓ | |
| Carbon (storage) (terrestrial) | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Coastal blue carbon | ✓ | | ✓ | | | | |
| Coastal protection / Coastal flood regulation / Coastal vulnerability | | ✓ | ✓ | ✓ | | ✓ | |
| Erosion | | ✓ | | ✓ | | ✓ | ✓ |
| Flood protection / Flood regulation / Flood prevention | ✓ | ✓ | | ✓ | | ✓ | ✓ |
| Greenhouse gas flux | | | | | | ✓ | |
| Landslide risk / Soil stabilisation / Avalanche protection | ✓ | ✓ | | ✓ | | | |
| Pest & disease regulation | | ✓ | | ✓ | | | |
| Pollination / Crop pollination | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Sediment retention / Sediment regulation / Sediment delivery / Sediment provision | ✓ | | ✓ | ✓ | | | ✓ |
| Seasonal water yield - regulation of timing | | ✓ | ✓ | | | ✓ | ✓ |
| Water purification / Water quality | | ✓ | ✓ | ✓ | | ✓ | ✓ |

*Includes new ARIES models planned for release in December 2018.

| Ecosystem Service | ARIES* | C$N | InVEST | PA-BAT | SolVES | TESSA | WW |
|---|---|---|---|---|---|---|---|
| **Cultural** | | | | | | | |
| Cultural and historical values / Cultural heritage / Inspiration, creative or artistic / Social relations/community benefits | | ✓ | | ✓ | ✓ | ✓ | |
| Health, mental & physical | | | | ✓ | | ✓ | |
| Peace & stability | | | | ✓ | | | |
| Research / Knowledge | | | | ✓ | ✓ | ✓ | |
| Education | | | | ✓ | | ✓ | |
| Recreation / Nature tourism / Leisure | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Spiritual values / Sacred natural sites | | | | ✓ | | ✓ | |
| Sense of place / Identity | | | | | | ✓ | |
| Scenic quality / Aesthetic viewsheds | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| Wilderness and iconic values [as a cultural value] | | | | ✓ | ✓ | ✓ | |
| **Other benefits that can be modelled/assessed** | | | | | | | |
| Employment | | | | ✓ | | | |
| Existence / Bequest value | | | | | | ✓ | |
| Habitat quality / Nature conservation / Biodiversity | | ✓ | ✓ | ✓ | | | |
| Habitat risk assessment | | ✓ | ✓ | | | | |

*Includes new ARIES models planned for release in December 2018.

**Table 6.** Comparison of ES assessment tools against standard criteria. Table adapted from Bagstad et al. (2013) and Healy & Secchi (2016).

| Criterion | ARIES | Co$ting Nature | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WaterWorld |
|---|---|---|---|---|---|---|---|---|---|
| Cost & open/closed source | Free, open-source | Free (policy analyst or scientist version) or paid license (advanced user or commercial versions), closed-source | Free, open-source | Free, open-source | Free, open-source; requires purchase of SIMILE software (closed-source) | Free, open-source | Free, requires purchase of ArcGIS software (closed-source) | Free, open-source | Free (policy analyst or scientist version) or paid license (advanced user or commercial versions), closed-source |
| Availability | Available | Available | Available | Available | Available | Available | Available | Available | Available |
| Time requirements | Low for global models; High for new case studies | Low | Low to high | Moderate to high | High for new case studies | Low to moderate | Low to high | Low to high | Low |
| Data input demand | Low to high | Low | Low to high | Moderate to high | Moderate to high | Low | Low to moderate | Moderate to high | Low |
| Skill requirements | Low to high | Low | Low to high | Moderate to High | High | Low | Moderate | Low | Low |
| Scale of analysis | Local to global | Local to global | Local to global | Local to global | Local to regional | Local | Local to regional | Local | Local to global |
| Quantitative / Qualitative | Quantitative or Qualitative | Quantitative (relative values) | Quantitative or Qualitative | Quantitative or Qualitative | Quantitative | Qualitative | Quantitative | Quantitative or Qualitative | Quantitative (absolute physical magnitudes) |
| Monetary / Nonmonetary | Monetary or nonmonetary | Monetary or nonmonetary | Monetary or nonmonetary | Monetary or nonmonetary | Monetary or nonmonetary | Nonmonetary | Nonmonetary | Monetary or nonmonetary | Nonmonetary |
| Spatially explicit | Yes | Yes | Either | Yes | Yes | No | Yes | No | Yes |
| Technical requirements | Computer and internet access | Computer and internet access | None | Computer, GIS software | Computer access, Simile software, GIS software | None | Computer, ArcGIS | Field equipment (optional) | Computer and internet access |
| User support | Moderate | Moderate | Low | High | Moderate | Moderate | Moderate | Low | Moderate |
| Level of development & documentation | Case studies & global models developed and documented | Partially documented | Fully developed and documented | Fully developed and documented | Case studies developed and documented | Fully developed and documented | Fully developed and documented | Fully developed and documented | Partially documented |

| Criterion | ARIES | Co$ting Nature | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WaterWorld |
|---|---|---|---|---|---|---|---|---|---|
| Interface | Specialised software (k.LAB/Eclipse) and web application | Web application | Guidance document (interactive PDF) | Desktop application; Python API (optional) | MIDAS/SIMILIE (not open source) | Survey form (PDF), Slides for workshops (PPT), database for results | ArcGIS (add-in toolbar) | User manual (interactive PDF) | Web application |
| Generalisability / Applicability in new contexts | High for global models, low for case studies | High | High | High, though limited by availability of underlying data | High, though limited by availability of underlying data | High | Moderate | High | High |
| Approach to uncertainty | Uncertainty through Bayesian networks, Monte Carlo simulation, and machine learning | Uncertainty through sensitivity analysis | Guidance for addressing uncertainty is provided, including how to specify confidence levels | Uncertainty through varying inputs | Uncertainty through varying inputs (automated) | None (paper form) | Reports statistics that indicate how well the model is able to reproduce reserved value observations | Guidance provided on level of confidence | Through sensitivity analysis |
| Nonmonetary & cultural perspectives | Biophysical values, can be monetised | Outputs indexed, bundled ecosystem service values | Describes nonmonetary and socio-cultural perspectives, values, and analysis methods | Biophysical values, can be monetised | Monetary valuation via input–output analysis | Describes nonmonetary and monetary values and economic potential | Nonmonetary preferences (rankings) of relative values for stakeholders | Biophysical values and nonmonetary valuation of cultural services | Biophysical values only |
| Applicable to terrestrial, freshwater, marine | All | Terrestrial, Freshwater | All | All | All | All | All | All | Freshwater, terrestrial |
| Level of stakeholder engagement required | Low | Low | Low to high | Low | Low to high | Moderate | High | High | Low |
| Absolute vs. relative value | Absolute or relative | Relative | Absolute or relative | Absolute or relative | Absolute or relative | Relative | Relative | Absolute or relative | Absolute |
| Scenario comparison | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Single/multiple site | Single or multiple | Single or multiple | Single or multiple | Single or multiple | Single or multiple | Single | Single or multiple | Single | Single or multiple |
| Static (single time period) / dynamic (temporal variation) | Static or dynamic | Static | Static or dynamic | Static | Static or Dynamic | Static | Static | Static | Static |

| Criterion | ARIES | Co$ting Nature | EST | InVEST | MIMES | PA-BAT | SolVES | TESSA | WaterWorld |
|---|---|---|---|---|---|---|---|---|---|
| **Range of time for full application in a new site (scoping, data collection, analysis follow-up)** | Days to weeks for pre-existing models; months to a year for a new case study | Minutes to hours for application of the model with all provided data | Hours to days for scoping process; highly variable for a complete assessment depending on the methods/tools selected, resources / capacity of assessment team, and extent/quality of results expected | 1-3 months for smaller projects, less if data exist and scenarios identified up-front; 6 months to 2 years for larger projects with multiple ES, depending on level of stakeholder involvement | 3 months to learn model functioning, 1-3 months for smaller projects, 6 months to 2 years for larger projects | 1 day workshop, days to weeks for preparation, subsequent analysis of workshop results, follow-up | Months to a year for survey design and gathering survey data; minutes to run the model once survey data are available | 20-60 person days for prepa-ration, primary data collection (biophysical and socioeconomic), and analysis | Minutes to hours for application of the model with all provided data |
| **General summary / insights** | Spatially explicit ecosystem service trade-off, flow and uncertainty maps; currently time consuming for new applications, unless using global models | Rapid analysis of indexed, bundled services based on global data, along with conservation priority maps | Detailed step-by-step guide with built-in tools to complete ES assessment including analysis of biophysical, sociocultural, and economic values; compendium of additional tools, methods, and data sources; and guide to using results in multiple policy/decision contexts | Spatially explicit ecosystem service trade-off maps; currently relatively time consuming to parameterise | Dynamic modelling and valuation using input–output analysis; ecosystem trade-off and decision making, highly time consuming to develop | Qualitative paper-based forms for protected area managers and stakeholders to assess benefits provided by protected areas | Provides maps of social values for ecosystem services; time consuming for new studies but lower-cost for value transfer | A collection of site-based comparative assessment methods targeted at practitioners without specialised skills | Rapid analysis of detailed biophysical assessment based on global data, along with conservation priority maps |

# Summary: Key differences between tools

5

Cendrawasih Bay (Indonesia) © Conservation International/photo by Mark Erdmann

Many of the available tools can be applied to answer a diversity of questions about the provision of ES from important sites. As summarised in Table 3, many of the tools can be used to support advocacy for conservation of a site, elucidate trade-offs, identify management options, conduct research, or achieve a variety of other goals. Each tool was developed for a different purpose, and therefore each one has different strengths and limitations and provides different kinds of information. Three of the tools—EST, TESSA, and PA-BAT—are PDF documents that walk users step-by-step through an ES assessment, including scoping exercises, worksheets for capturing ES information, and guidance for conducting more in-depth ES measurement using primary data collection (TESSA, EST), a stakeholder workshop (PA-BAT, TESSA), or a variety of primary research and analysis methods along with additional tools that could be used (EST). Four of the tools—EST, PA-BAT, SolVES and TESSA—were designed to capture information about social and cultural ES through stakeholder surveys or workshops. Six of the reviewed tools provide results that are spatial (ARIES, Co$ting Nature, InVEST, MIMES, SolVES, WaterWorld). Several of the tools can be used to estimate economic values (ARIES, Co$ting Nature, EST, InVEST, MIMES, TESSA), though it is not their sole aim.

The tools have different requirements for data, time and specialised expertise. These practical considerations are important when selecting a tool. MIMES and ARIES are modelling platforms within which other models can be developed or integrated. These tools can be used for multiple purposes, ranging from assessing impacts of different policy scenarios to estimating the economic value of a site for ES. The user specifies the model parameters, provides the input datasets, develops scenarios, and customises the model to provide the desired output in the desired format (qualitative or quantitative, spatial, monetary, or otherwise). SolVES requires conducting stakeholder surveys and running models (GIS and Maxent) to produce spatial outputs. Currently, these three tools require GIS capacity as well as relatively high levels of data, time and technical skills when compared to some of the other tools.

This contrasts with ‘off the shelf’ tools like InVEST where the model parameters have all been defined for the user, who simply must provide the input data and parameter values in the correct format. InVEST was designed to compare alternative scenarios (e.g. land use) to evaluate their implications for ES provision. InVEST nonetheless requires the user to provide some input data and have GIS skills, and it requires some time to learn each model, refine the model with iterative runs, and interpret the model results correctly.

At the other end of the spectrum are the completely ‘self-parameterising’ models Co$ting Nature and WaterWorld, which provide model parameters and all the required input datasets; the user only specifies an area of interest and chooses from a pre-selected set of land use or climate change scenarios or designs their own. When ARIES global models are available (late 2018), the user will also have an option to run self-parameterising models within the framework by specifying the location, time period, and services they wish to model.

EST and TESSA provide options, ranging from expert-opinion-based qualitative assessment methods to field sampling, to modelling or use of published data if field data collection isn’t feasible. So, the time and data required to use these tools varies depending on the method used.

EST provides step-by-step guidance from defining the issue driving the need for an assessment, through all of the scientific, analytical and management actions in completing an assessment, communicating results, and incorporating results in management or policy decisions in various contexts. EST was developed to provide an integrated, fully interdisciplinary, adaptable, comprehensive tool for ES assessment that allows for the incorporation of many different types of analyses if needed to address a breadth of possible questions.

TESSA was designed specifically for comparing the impact of different decisions on the value of ES provided by a site, for example to quantify the difference in ES provided by a site with different levels of human modification or conservation management. All of the spatial models reviewed here (ARIES, Co$ting Nature, InVEST, MIMES, SolVES and WaterWorld) allow scenario analysis, for example allowing assessment of the implications of different land use or climate change scenarios on ES. The other tools (EST, PA-BAT) can also be used for comparison or impact analysis if they are applied in a consistent way to multiple sites or to the same site over time.

One distinguishing characteristic of TESSA and PA-BAT is that they were designed as site-level assessment tools. This contrasts with the other tools reviewed, which can be applied at multiple scales ranging from site-level to global, if input data at the appropriate scale are available.

InVEST is the only tool reviewed that includes fully developed models for multiple marine and coastal ES; some of the other tools (such as ARIES or MIMES) could be applied in the marine realm if appropriate data and methods were available, while TESSA and Co$ting Nature contain methods for assessing coastal defence services. WaterWorld, as implied by its name, can only be used to assess freshwater ES. The EST, PA-BAT and SolVES can be applied in any context.

Where time and resources allow, combining tools can be used to harness their individual strengths. For example, a team could first use the EST, PA-BAT, or the TESSA scoping module to conduct a qualitative scoping exercise. This could help identify important ES and sources of data that could feed into a spatially explicit model such as InVEST, ARIES, or MIMES. Or, the scoping exercise could guide the team to methods for more in-depth measurement of biophysical or cultural ES using data collection protocols from TESSA or social survey methods from SolVES.  Alternatively, a tool that is designed for assessing social and cultural ES (such as the PA-BAT or SolVES) could be combined with one that is designed for assessing biophysical ES (such as InVEST or ARIES.) For a case study in which SolVES and ARIES were combined, see Annex IV.

## 5. Summary: Key differences between tools

In summary, selecting an appropriate tool requires identifying the specific question being addressed, the type of results or outputs required, and consideration of practical factors such as the level of expertise, time, and data required for applying any given tool. While each tool is different, all of the tools provide an opportunity to shed light on ES issues and support management and policy decisions. Tools should be selected based on the goal of the assessment as well as the data, capacity and resources available. While users may initially find the diversity of available tools overwhelming, it is hoped that the guidance provided here will help them navigate this complexity and identify which tool is most appropriate for their specific context and needs.

# Annex I. Timing considerations for ES assessment

## Key Biodiversity Areas

In the case of KBAs, measuring and modelling ES delivered by sites is typically preceded by the steps of KBA identification, delineation, and documentation. These different steps require different kinds of data and expertise.

KBA identification involves compiling information on the occurrence, population size, and distribution of biodiversity elements (e.g. threatened species or ecosystem types, biological processes) potentially triggering the KBA criteria in a country or region and evaluating whether those elements meet the criteria and thresholds in the global KBA Standard (IUCN, 2016) at specific sites.

Delineation is the process through which the boundaries of a KBA are drawn on a map in consultation with local stakeholders and is a required step of the KBA identification process. The aim is to derive boundaries that are ecologically relevant and delimit an area that is actually or potentially manageable as a single unit.

A minimum set of information is required to propose a site as a KBA, which enables independent review of the data and a basic presentation of each site on the World Database of Key Biodiversity Areas™ (www.keybiodiversityareas.org; BirdLife International, 2018). This required documentation includes information such as the KBA name, KBA criteria met, and details about the biodiversity elements that trigger the site as a KBA. There is a set of additional information that is recommended for each KBA to support management of the biodiversity elements triggering the criteria; site-scale monitoring; conservation planning and priority-setting; and analyses of KBA data. This includes basic information about the ES provided by a site, their importance and primary beneficiaries.

This guidance is for conservation practitioners, site managers or researchers who may wish to go beyond documentation to the measurement, modelling or valuation of ES delivered by KBAs to support conservation action and investment, site management, private sector engagement, knowledge generation, or other activities within the KBA outlined in Table 1.

## Protected areas and natural World Heritage sites

ES assessment can be useful at any stage of protected area designation or management, but it has particular roles at different periods. In the case of World Heritage sites, an ES assessment can be undertaken for sites already inscribed on the World Heritage List but also for sites on countries' 'Tentative Lists', which can help identify relevant stakeholders and beneficiaries and inform the process of developing a nomination.

When a protected area or a new World Heritage nomination is planned, it is important to have a basic understanding of existing ES provided by the site. Some of these will remain unchanged by designation, and indeed protection might provide additional security. For example, protection of a watershed may secure water quality benefits to a city downstream, or maintenance of mangroves and coral reefs may secure coastal populations against storms. Other ES may be enhanced in the medium or long term, but may be reduced in the short term. For example, designation of marine protected areas can increase fish stocks in the future by providing a safe place for fish to breed, but fishing communities may be negatively impacted if they must set aside part of their fishing grounds in the short term. A third group of ES may be permanently lost to their traditional users; for example, setting up a wildlife reserve that bans hunting of threatened or endangered species may eliminate access to traditional hunting grounds or sources of food.

ES assessment at the planning stage can help in setting up compensation systems for foregone benefits, ideally looking at options for livelihood benefits for communities. Conversely, ES assessment may be a vehicle for identifying and agreeing to options related to Payment for Ecosystem Services (PES) schemes. ES data can also be important for setting a baseline that can be used to measure trends in effects from protection and under different management approaches. For example, the establishment and effective management of new protected areas may result in the restoration of ES that have previously been degraded or lost.

ES assessment may also be useful for existing PAs and WHS for many reasons. ES assessments may be required for implementing certain management options or accessing different funding streams. Knowledge of carbon storage and sequestration is needed for Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes, for example. Freshwater services, presence of crop wild relatives, and ecosystems that can supply natural infrastructure outcomes and disaster risk reduction benefits can all attract support or funding from donors or commercial operations that may have little interest in biodiversity conservation. Understanding locally relevant ES and planning/managing so as to secure, replace, or compensate local communities for the loss of ES can help bolster support for a PA in local communities. Finally, as understanding of ES benefits increases, their inclusion in PA management plans is becoming increasingly common.

# Annex II. Description of tools and case studies

A short description of each tool including user requirements, strengths and limitations, potential applications for important sites, and case studies in which the tools have been applied at the site level are summarised below. We have focused here on tools that are available at no cost and can be applied in new contexts (i.e. they are not restricted to specific countries or case studies). For a more comprehensive set of tool descriptions, please see the ValuES Database (www.aboutvalues.net/) and the Ecosystem Services Toolkit (Value of Nature to Canadians Study Taskforce, 2017).

## Artificial Intelligence for Ecosystem Services (ARIES)

### Description

Artificial Intelligence for Ecosystem Services (ARIES; aries.integratedmodelling.org/) is an ES modelling platform (Villa et al., 2014). Theoretically, any ES can be modelled using ARIES, but currently (early 2018) the following ES models have been developed and tested: carbon storage, flood regulation, pollination, and cultural / recreational values. Models for several additional ES are under development: mangrove carbon storage, mariculture suitability, water provision, landslide risk, and sediment provision. Case studies have also been developed for carbon sequestration, coastal protection, cultural values, erosion, fisheries, biodiversity, crop production, scenic value, and sediment retention/delivery.

### User requirements

Currently ARIES consists of specialised software (a graphical user interface (GUI) for collaborative modelling) and a series of linked web-based databases for uploading, storing and accessing data. Thus, ARIES currently requires specialised expertise or training, unless the user is running global models (available at the time of this review) on a web interface (planned for completion before fall 2018), in which case models are much more accessible to non-technical users. The data flow and parameterisation of global models is fully automated. However, applying non-global models in new contexts requires the user provide all the necessary input data (unless using global data that are already integrated into the modelling system) as well as specify all the model parameters and algorithms. By late 2018, a web-based application will be developed.

### Strengths

ARIES can accommodate sophisticated modelling techniques including agent-based modelling in which the behaviour of individual actors, such as individuals or groups, is simulated, to assess effects on the system. ARIES can also accommodate dynamic modelling, in which model processes change over time, and machine learning, where model relationships are learned from data. ARIES also can account for uncertainty (Villa et al., 2014). Two unique contributions made by ARIES to the universe of ES assessment tools is a standardised lexicon or semantics, in which a given term such as "aboveground biomass carbon storage," is always defined and measured consistently, no matter which model or analysis it appears in. This enables ARIES to match data and models to the appropriate spatial and temporal context and scale, overcoming common challenges of unit and/or scale matching and contextualisation in ES modelling. A second contribution is the creation of a global database and model repository where users submit relevant datasets and models; over time, this will become an invaluable resource as data limitations are often the key factor hindering ES assessments. The collaborative, cloud-based, context-specific elements of ARIES distinguish it from other approaches. Specifically, collaborative modelling via web platforms such as BitBucket allows a community of modellers to contribute and re-use models. Finally, the automated production of reports describing the modelling methodology and results enables global models to be run and the outputs readily understood (Willcock et al., In press).

### Limitations

ARIES currently requires specialised training. User documentation is available via an online collaborative forum (integratedmodelling.org/confluence/). Currently for all new case studies, ARIES requires a user to have specialised expertise, provide all the necessary data, and specify all the model parameters and algorithms (unless utilising global data and models). Training is available (springuniversity.bc3research.org/). As a result, model customisation is time and data-intensive, making it impractical for rapid ES assessments, and so use of global data and models within ARIES is recommended for these occurrences.

### Potential applications for KBAs, WHS and PAs

For nontechnical users, ARIES' global models provide a uniform package of models that can be run anywhere using global datasets, but for which local data can be easily substituted (particularly when the accessibility of these models is improved by the release of the web browser interface). ARIES also provides a sophisticated modelling approach for users who wish to gain specialised training, provide their own data, and specify the model parameters themselves. Because it can accommodate agent-based modelling, dynamic modelling, machine learning, and uncertainty, ARIES is an advanced solution for addressing the complexity of socio-ecological processes. Models developed within ARIES could provide detailed information about the interacting effects of multiple user groups, for example, or variation in ES flows over time.

### Summary

ARIES is one of the more sophisticated tools included in this review, and as such has the potential to provide information about ES that reflects the complex, dynamic, interactive flows of benefits from nature to people. Due to the requirements for specialised expertise, data and time to apply ARIES in new contexts, however, it also represents one of the most time consuming and challenging tools to apply, except when the user wants to use global models that have already been developed, tested, and served through a web-based interface. In the future (by late 2018) the online user interface will make it easier for non-experts to use.

## ARIES Case Study:

### Evaluating biophysical and cultural ecosystem service hotspots using ARIES and SolVES to inform national forest planning in the United States

**Context:** The USDA Forest Service has been a leader among U.S. land management agencies in advancing the use of ES concepts and tools for forest planning, in part as an outgrowth of their 2012 Planning Rule. Given the inherently spatial nature of forest planning, two ES tools were jointly applied to map different aspects of forest ecosystem services, and then their results were combined to build more informative maps for managers. First, the ARIES modelling platform was used to model four biophysically-based ES across six national forests in the Rocky Mountains of Colorado and Wyoming. Second, survey data on public values (largely corresponding to cultural ES) for the same national forests with the SolVES tool were used to model these values spatially. By estimating biophysical and cultural ES 'hotspots' (high ES value areas) and 'coldspots' (low ES value areas) and overlaying the two, a matrix of biophysical/cultural hot-warm-coldspots across a large extent of public lands in the Rocky Mountains region of the western U.S. was produced, with distinct management implications. For example, a biophysical-cultural ES hotspot analysis can identify regions where traditional uses are strongly supported by managers or may require further evaluation for conflicts, areas suitable for development or resource extraction, and areas where public outreach might be needed to build support for management (Figures A1 and A2).

**Motivation/question being addressed:** This analysis builds on an earlier analysis from Colorado's Pike-San Isabel National Forest to evaluate the use of alternative hotspot methods across a wider region of national forests in the U.S. Rocky Mountains. Six different hotspot methods (quantile, area-based, and statistical) were tested to determine their sensitivity for identifying ES hot/coldspots. The presence of ES hot/coldspots in wilderness vs. non-wilderness areas of the National Forests across a gradient from urban proximate (forests near the Colorado Front Range urban corridor) to remote (northwest Wyoming) were also evaluated.

**Location/scale:** The analysis was conducted for six U.S. National Forests in the states of Colorado and Wyoming (an area totalling almost 57,000 km$^2$) at a 450 m resolution.

**Time and resources:** The project entailed synthesis of existing ARIES and SolVES models for the Rocky Mountains. ARIES models were developed, tested and refined over a total period of about 9 months. SolVES data were derived from three separate surveys of national forests, conducted over an 8-year period. The time to develop, pilot test, and administer surveys by mail was roughly 9-12 months for each survey. Digitising survey data, preparing environmental data, and running SolVES took an additional 2-4 weeks.

**Linked to other tools:** The ARIES and SolVES tools were used jointly to show the complementarity of biophysical models and public participatory GIS approaches for more comprehensively assessing ES and potential public awareness/support for relevant management actions.

**Stakeholders/collaborators/partners:** This project was led by the U.S. Geological Survey. The USDA Forest Service was consulted during the development of the project and dissemination of results. SolVES surveys were developed and administered in collaboration with social science researchers at Colorado State University.

**Services assessed:** Four biophysical ES were modelled using ARIES: carbon sequestration and storage, scenic viewsheds, sediment retention, and water yield. Eleven social value types/cultural ES were mapped using SolVES: aesthetic, cultural, economic, future, historic, intrinsic, learning, recreational, spiritual, subsistence, and therapeutic value.

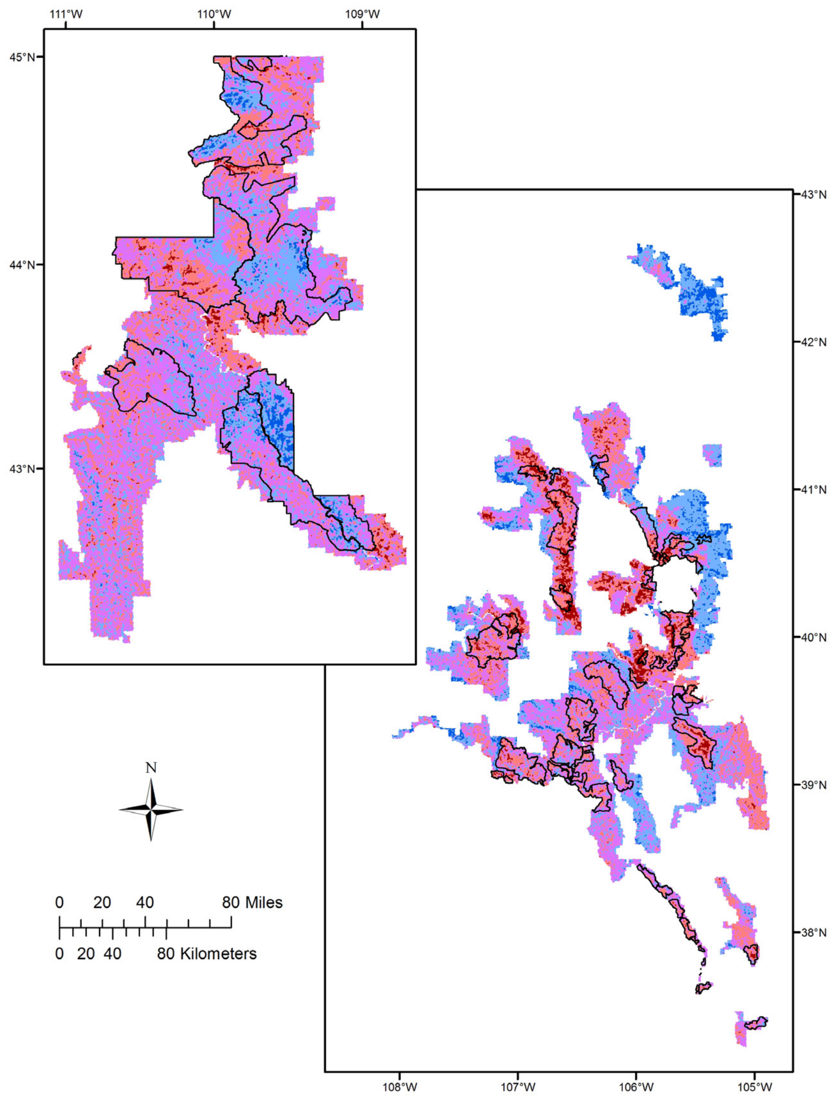
**Beneficiaries:** Scenic viewsheds were calculated for residents living within view of the six national forests and from recreation sites located within the national forests. Given the forests' location at the headwaters of a number of major rivers (Arkansas, Colorado, Green, Missouri, Platte, and Snake Rivers) with significant downstream beneficiaries, it was assumed that hydrologic ES (sediment regulation and water yield) were used uniformly by downstream water users. Beneficiaries of carbon sequestration and storage were assumed to be global. Cultural ES data were collected from surveys of residents in counties surrounding the national forests.

**Key results:** The six hot/coldspot delineation methods identify distinctly different numbers and edge-to-area ratios for hot/coldspots, with important implications for management when hot/coldspot methods are used in decision making. For large national forests, methods of intermediate conservatism that produced clustered hot/coldspots (i.e. statistical methods) may be most informative for planning. Hotspots were more common and coldspots less so in wilderness areas of four national forests closest to the Colorado Front Range urban corridor, while the opposite pattern was observed for two more remote national forests in northwest Wyoming. These trends are likely due to differing demographics and values for wilderness areas of residents living near these forests. They align well with past findings about public attitudes toward wilderness, to which these results add a spatial dimension. This work shows how information from cultural ES assessments using public participatory GIS techniques (mapped using the SolVES

**Figure A1.** Potential management implications of cultural/biophysical hot/coldspot analysis

| | | Biophysical modeled ecosystem services (mapped using ARIES) | | |
|---|---|---|---|---|
| | | **Hot** | **Warm** | **Cold** |
| Cultural ecosystem services (mapped using SolVES) | **Hot** | High management support (if cultural & biophysical services are synergistic) OR potential conflict between management and traditional uses (if tradeoffs exist between cultural & biophysical services) | | High support for traditional uses; cases where biophysical modeling alone is inadequate to map value |
| | **Warm** | | | |
| | **Cold** | Public outreach need to build support for management (e.g. for watershed protection programs) | | Areas suitable for development or resource extraction, assuming other important natural or cultural resources are absent (e.g. high biodiversity, threatened & endangered species, indigenous cultural significance) |

**Figure A2.** Hot/coldspot maps for six national forests in Colorado and Wyoming calculated using the Getis-Ord Gi* statistic at α = 0.10 significance level. Wilderness areas are outlined.




(Source: Bagstad, K.J. et al., 2017)

modelling tool) and biophysical ES assessments (mapped using the ARIES modelling tool) can be combined to provide novel information that may assist managers. Biophysical and cultural ES maps developed using alternative methods or tools could be similarly combined using the methods developed for this study.

### ARIES references:

Bagstad, K.J., Semmens, D.J., Ancona, Z. and Sherrouse, B. (2017). 'Evaluating alternative methods for biophysical and cultural ecosystem services hotspot mapping in natural resource planning. *Landscape Ecology* 32:77–97. doi.org/10.1007/s10980-016-0430-6

Bagstad, K.J., Reed, J., Semmens, D., Sherrouse, B. and Troy, A.R. (2016). 'Linking social values and ecosystem services: Social-ecological hotspots for public lands management'. *Regional Environmental Change* 16:2005–2018. doi.org/10.1007/s10113-015-0756-7

Czaja, M. and Cottrell, S.P. (2014). 'Integrating social science research into wildland fire management'. *Disaster Prevention and Management* 23:381–394. doi.org/10.1108/DPM-10-2013-0193

Sherrouse B.C., Semmens, D.J. and Clement, J.M. (2014). 'An application of social values for ecosystem services (SolVES) to three national forests in Colorado and Wyoming'. *Ecological Indicators* 36:68–79. doi.org/10.1016/j.ecolind.2013.07.008

## Co$ting Nature

### Description

Co$ting Nature (www.policysupport.org/costingnature) is an easy to use rapid, web-based tool for mapping terrestrial ES, conservation priority areas, current pressures, and future threats using global data (Mulligan, 2015). Ecosystem services included in the model include water, carbon, nature-based tourism and hazard mitigation (version 2) and timber, fuelwood, grazing/fodder, non-wood forest products, water provisioning (quantity, quality), fish catch, carbon, natural hazard mitigation (flood, drought, landslide, coastal inundation), culture-based tourism, nature-based tourism services, environmental and aesthetic quality services, wildlife services (pollination, pest control), wildlife dis-services (crop raiding, pests) (version 3). Results are calculated in biophysical units but for comparison are provided on a scale of 0-1 (lowest to highest) locally or globally depending on user choice. The model can be run at scales from local (1 ha resolution) through national or basin (1 square km resolution) anywhere in the world. It incorporates spatial models for both biophysical and socio-economic processes along with scenarios and models for land use (either pre-defined or user-defined). Different features are available to users depending on whether they use the free policy analyst or scientist versions or purchase a license for advanced or commercial uses, which enables the latest functionality.

### User requirements

Co$ting Nature was designed to provide rapid spatial data on terrestrial ES and conservation priority areas, and assess implications of policy scenarios, for users who have no GIS capacity, no data, and limited time/budget. Thus Co$ting Nature has the fewest barriers to use of any of the computer-based modelling tools included in this review.

### Strengths

Co$ting Nature is rapid (model runs take a few minutes); it can be run anywhere in the global terrestrial realm with no input data requirements; and it pulls from existing global datasets, many of which are not otherwise available or easily accessible to decision makers and practitioners. With a paid license (offered for free to organisations with few resources), users can run the model with their own datasets and receive further support. Co$ting Nature can be run at small scales (1 ha resolution for small areas) and large spatial scales: nationally, for large watersheds (1 km resolution).

### Limitations

Because Co$ting Nature pulls from global datasets and because all the modelling parameters are pre-set by the model developer, it may not provide the most accurate outputs at the scale of an individual site; as with any model, validation of the results is required to assess accuracy. For simplicity, outputs of Co$ting Nature (free version) are relative, which do not allow for quantitative analysis in biophysical units. Differentiation between services is only possible for points (e.g. within individual pixels), not as maps. For small sites (smaller than a few square km) the resolution of global data may be too coarse to provide useful results. The model is published but closed source; the basic functionality required by most users is free, but more advanced functions, including running the model with a user's own data, require paid licenses and GIS capacity. The use of Co$ting Nature does require an internet connection, which can be a barrier to its use in certain contexts. In addition, Co$ting Nature bundles several ES together; the model doesn't allow disaggregation of individual ES (e.g. water, carbon, recreation, hazard mitigation, etc.) but it does provide a map of the most important service in each pixel.

### Potential applications for KBAs, WHS and PAs

Co$ting Nature can be used for exploratory analysis and scoping, by quickly providing spatially explicit information on a wide number of ES and biodiversity values in one or more sites. Co$ting Nature can be applied across relatively large spatial extents (such as an entire country) with no additional effort, which allows analysis of the ES provided by many sites simultaneously (e.g. an entire PA network or all KBAs in a given country or region). Co$ting Nature has advanced functionality for testing user assumptions concerning perceived or economic values for specific services and its implications on overall conservation priority. It also has functionality to understand the impacts of user-defined scenarios for land use change.

### Summary

Because it is free (for the basic functionality), fast, and requires no user input data or GIS capacity, and can be run anywhere in the terrestrial world, Co$ting Nature is a useful tool for running exploratory baseline or scenario analyses (e.g. for land use change scenarios). It is also a useful solution when there is limited time or resources for more detailed analysis, when local data are not available, or when field data collection is not feasible. However, because it pulls from global data, the results should be used with caution at the site scale, as they may not be very accurate for an individual site or for very small sites. As with any model, validation of the model results is necessary to assess their accuracy, and users are encouraged to do this. (The model developers have a project www.freestation.org to provide equipment support for model validation.) Because the model is closed source and does not allow disaggregated mapping of ES, it is not easy to customise for different contexts or to tease out maps for individual ES in a way that some practitioners or researchers might prefer.

## Co$ting Nature Case Study:

### The future of Yasuni (Ecuador)

**Context:** Yasuni National Park is a UNESCO biosphere reserve in the Amazon lowlands of Ecuador and, arguably, falls within the most biodiverse place on Earth.

**Motivation/question being addressed:** Co$ting Nature (v. 2.46) was used to ask: How important is Yasuni and what might be the future of Ecuador's Amazon forest if deforestation rates continue as they are now? What if new roads are built to support oil developments such as the ITT (Ishpingo-Tambococha-Tiputini) project?

**Location/scale:** The analysis was conducted at a national scale for the country of Ecuador.

**Time and resources:** Ecosystem service modelling was completed by King's College London. The total time spent was approximately 2 hours, including writing the application note. This included scenario development, model runs, analysis of results, and production of the application note.

**Stakeholders/collaborators/partners:** This project was led by King's College London alongside related research by students of the Universidad San Francisco de Quito pursuing PhDs at King's during the period of the analysis.

**Services assessed:** Four groups of services were assessed: water, carbon, hazard mitigation and nature-based tourism alongside species richness and endemism.

**Beneficiaries:** The focus was all beneficiaries of these services (globally for carbon, downstream in Ecuador and Brazil for water and hazard mitigation, and locally for nature-based tourism).

**Key results:** Yasuni is the most important area in Ecuador for biodiversity and for the provision of ES (water, carbon, hazard mitigation and nature-based tourism) into the future. Continued deforestation at current rates in the Ecuadorian Amazon would lead to loss of most of the country's remaining forest if PAs are ineffective. This would lead to significant losses of carbon stock and sequestration, contributing to climate change but also immediate losses in species richness and range that would likely lead to population crashes for many species. The most immediate local impacts would be on water resources and water quality affecting local populations.

Effective PAs would improve the situation dramatically for biodiversity (in particular population viability) and a little for carbon and water, arresting deforestation over some 7% of the area. Yasuni is important for Ecuador but also for the world. A global analysis conducted using Co$ting Nature indicates that Yasuni is in the top few PAs globally for species richness, carbon stock and sequestration density.

URL: www.policysupport.org/costingnature/example-applications/the-future-of-yasuni

### Co$ting Nature Reference

Mulligan, M. (2015). 'Trading off agriculture with nature's other benefits, spatially. In: C. A. Zolin and R. de A. R. Rodrigues (eds.) *Impact of Climate Change on Water Resources in Agriculture*. Boca Raton, FL: CRC Press.

## Ecosystem Services Toolkit (EST)

### Description

The Ecosystem Services Toolkit is a PDF format guidance document that consists of a set of steps for conducting ES assessment, as well as an extensive compendium of available analytic tools and methods and data sources that might be applied (Value of Nature to Canadians Study Taskforce, 2017). The EST can be downloaded from publications.gc.ca/site/eng/9.829253/publication.html. Each step includes guidance as well as templates such as worksheets that can assist with the completion of the step. In addition to the step-by-step guidance, the EST includes a typology of ES with descriptions of each one; discussion of cross-cutting issues (such as scale and uncertainty); guidance on conducting ES assessment with Indigenous communities (it is the only such toolkit reviewed with specific guidance on this issue); discussion of approaches to both economic valuation and sociocultural valuation, and resources such as tables of possible ES indicators to support analysis, guidance on approaches to valuation, and a compendium of factsheets describing data sources, and analytic methods and tools relevant to ES assessment. The EST advises users to start by defining the question that is driving their need for an assessment and to choose indicators, data and analysis methods to answer that question in a relevant and credible way (a problem-oriented approach). In addition, the EST contains advice about how to integrate ES assessment results and other ES considerations into the established practices associated with a wide range of policy and decision contexts.

### User requirements

Because EST is not a software tool but rather a guidance document and compendium of other ES assessment tools and approaches, the user requirements vary from relatively low (for rapid assessments that provide more general descriptive information) to quite high (if more complex analyses or higher precision results are required).

### Strengths

There are several key strengths to the EST: first, it walks a team step-by-step through an ES assessment and includes a significant amount of background material and worksheets to support each step. Second, it is extremely comprehensive, covering everything from diverse valuation methods to software-based modelling tools (ARIES, InVEST, etc.). It also includes many ES, going beyond some of the tools reviewed here which only include a limited set of services. Chapter 3 of the EST provides advice about how to incorporate results of ES assessment and other ES-focused information into eleven common policy activities such as land use planning, impact assessment, and conservation incentives. This chapter is specific to Canada but the policy areas are relevant in much of the world. It emphasises the importance of doing an ES assessment only after clearly defining how the resulting information will be used. Otherwise, an ES assessment will not be worthwhile, as an assessor likely won't be able to choose the right approach, relevant metrics, or a relevant or credible format of results.

### Limitations

The sheer length of the EST document (284 pages) could seem daunting to a project team with limited time. (But we note that it is designed so that users can select the sections they need to focus on, without having to read it cover-to-cover. Those sections will direct users to the relevant supporting resources elsewhere in the Toolkit.) While it is comprehensive, this might also pose a challenge, as a user must navigate a multitude of options when it comes to assessment methods and tools, select the most appropriate one, and then spend time learning and applying the selected methodology. (But we note that the EST contains practical worksheets so users can identify what information they need and the most practical way to obtain it). Thus, the comprehensiveness is both a strength and a challenge to users who might be working with limited time and resources.

### Potential applications for KBAs, WHS and PAs

EST can support ES assessments generally, including those that involve Indigenous peoples, which can often be relevant for site-level assessments. The EST's Priority ES Screening Tool can be used to determine whether an ES assessment is necessary or useful, and it can be the basis for a "rapid assessment" when time and resources are severely constrained. EST can also be used for moderate and more comprehensive assessments if needed. It also provides guidance on how to make sure results will feed into a specific decision-making process or audience.

### Summary

The EST is a comprehensive guide for completing assessment for all types of ES, with built-in tools, advice and supporting resources. It also provides summaries of additional ES assessment tools that may be incorporated into an assessment or used independently. It can be used for both preliminary and comprehensive assessments for a wide range of policy-relevant purposes.

## Case Study that informed development of EST:

### Ecosystem Services Pilot project in Alberta, Canada to inform provincial wetland policy and develop capacity for ES assessment

**Context:** The Alberta provincial government (Canada) was interested in the potential of the ecosystem service (ES) concept to support natural resource management and inform planning at different scales. One of the first steps in exploring this objective was an on-the-ground pilot project initiated in 2010 to demonstrate whether ES assessment could be useful as a decision-support tool within various government agencies. The process that was used in the pilot is similar to the process described in the Ecosystem Services Toolkit (EST; Value of Nature to Canadians Study Taskforce 2017). Many of the lessons learned from this pilot refined knowledge gained from primary research and involvement in the Millennium Ecosystem Assessment, contributing directly to the guidance in the EST. The ES Pilot process was developed using the best guidance and expertise available at the time: Ecosystem Services and Human Well-Being: a manual for assessment practitioners (Ash *et al.*, 2010) and Ecosystem Services: a guide for decision makers (WRI, 2008). Consultations were held with various stakeholders and government agencies to develop overall objectives, gather resources and internal support for this work, and to focus the work on a specific topic and geographic area.

**Motivation/question being addressed:** The result of the consultations was to focus the ES pilot project on improving and informing the wetland approval process in Alberta. The wetland approvals process is followed any time a project is proposed that could impact a wetland in some way. The approvals process determines whether the proposal is accepted (with or without compensation), or denied. The Alberta ES pilot had the following specific objectives: (1) Test and demonstrate how ES assessment can be used to support decision-making by explicitly demonstrating the trade-offs between current approaches to development and ES benefits provided by wetlands; (2) Support wetland management in the province by providing additional information for integration into the wetland approvals process to support potential compensation decisions related to land-use development; and (3) Identify information and capacity gaps for ES assessment to support future ES work in Alberta.

**Location/scale:** The assessment focused on an area covering 274 $km^2$ in southern Alberta encompassing portions of the City of Calgary, Rocky View County and the Town of Chestermere (Figure A3), called the 'Greater Shepard Slough'. The area was chosen because of the large number of wetlands there and their rapid rate of conversion, intense land use pressures (agricultural residential and industrial), localised flooding, available data and willing municipal partners.

**Time and resources:** The ES Pilot took 16 months from inception to completion at a cost of approximately $450,000 and 10 full-time equivalent staff positions. About 40 people in total contributed to the work. A Steering Committee and Review Panel were assembled to ensure the quality and relevance of the work. Most of the contributors were government employees, but a number of consultants and academic partners were contracted to provide specific expertise. Data sets held within the government were used in most analyses, although some new fieldwork was required in the form of surveys. A number of meetings and workshops were convened to learn about and apply different ES assessment tools. For example, the Wetland Ecosystem Services Protocol for the United States (WESPUS), designed by Dr. Paul Adamus, was introduced to stakeholders in a workshop format. The WESPUS tool was restructured, tested and calibrated for use in the ES Pilot. Further work was completed to develop the Alberta Wetland Rapid Evaluation Tool (ABWRET) which has since been adopted by the Government of Alberta, City of Calgary, Rocky View County and Ducks Unlimited Canada for use in their work, and was included as a tool in Alberta's new wetland policy (Adamus 2013). Other tools explored or used during the pilot include remote sensing, hydrological modelling, social science surveys of citizens to elicit ES values, economic valuation (multiple approaches), literature reviews, expert elicitation, statistical analysis (including trade-off and ES bundle analyses), InVEST. All of these tools are described in the EST.

**Stakeholders/collaborators/partners:** This project was led by Alberta Environment and Water, a ministry of the provincial government of Alberta (now Environment and Parks). Stakeholder groups and experts included wetland policy experts, regional government staff and biological/ecological/economic experts from the Alberta Environment, other ministries and other institutions, academics and the citizens of the municipalities included in the study. Additional experts participated in assessment activities, including academic partners and consulting companies, as well as non-governmental organizations.

**Services assessed:** Water storage/supply, flood control and water purification/quality were selected by stakeholders as the three ES of primary relevance to the overall provincial wetlands approval process. These ES were chosen for in-depth biophysical and socio-economic assessment along with carbon storage, which was included because carbon storage opportunities feature importantly in the provincial Climate Change Strategy and related regulations. Additional ES were included in order to meet the broader goals of the Alberta ES pilot related to developing an ES approach for use within the provincial government, however most of these were assessed qualitatively using desktop research. The additional ES were crops/food, pollination, soil formation/erosion control, and cultural ES (heritage values, science/education, aesthetic benefits, tourism/recreation).

**Beneficiaries:** Beneficiaries of wetland ES in the study area include residents living there, municipal governments responsible for development, and security of residents, and citizens visiting the area for recreation or education. The ES Pilot, and the concept of ES, supports important work in Alberta, including the Land Use Framework and regional plans, the provincial wetland policy, Rocky View County and the City of Calgary polices on wetlands and riparian areas, and the Institute for Agriculture, Forestry and the Environment's (IAFE) work on ES and innovation in the forestry and agriculture sectors (Kennedy, 2010).

**Key results:** Results for each ES addressed biophysical condition, recent trends in condition, economic values reported in a manner that was relevant to decision-makers and the general public, and in some cases, social and cultural values. See GoA (2012) for all results. For illustrative purposes, a sampling of specific results for two ES, water storage and flood control, are provided:

- The total water storage capacity of all wetlands in the study area was estimated to be 36.3 million cubic metres. This represents a volume of water greater than the combined total storage capacity of the Glenmore Reservoir and Lake Chestermere, the two most important water reservoirs on the landscape.
- An analysis of water storage capacity by Stewart & Kantrud (S&K) wetland class showed that because there is a large number of wetlands that are Class I or II, their contribution to water storage on the landscape is substantial, even if individually they hold less water than Class III-V wetlands.
- The estimated total storage capacity lost due to wetland drainage between 1965 and the present is 9.2 million cubic metres. This represents a 20 per cent decrease in available water storage capacity in the study area.
- All wetlands in the case study area contribute to flood control. There were no clear trends found for flood control values across either S&K or size classes, suggesting that high or low flood control depends more on landscape context than on class or size of wetlands.
- The cost of replacing natural wetlands with built infrastructure was estimated from the total area of engineered wetlands that would be required to provide the same flood control services that are currently supplied by natural wetlands. A replacement cost of all wetlands was estimated at about $338 million. This corresponds to an estimated $2 million per year in economic losses when the historic rate of wetland area loss is applied.
- The estimated cost of restoring all wetlands on the landscape would be $43 million. This corresponds to an estimated $257,250 per year in restoration costs if the historic rate of wetland loss is applied (0.6 per cent between 1960's and 2005).

## References:

Adamus, P., (2013). *Manual for Wetland Ecosystem Services Protocol for Southern Alberta (WESPAB) Alberta Environment and Sustainable Resource Development*. Edmonton, Alberta: Government of Alberta

Ash, N., Blanco, H., Brown, C., Garcia, K., Henrichs, T., Lucas, N., Raudsepp-Hearne, C., Simpson, R.D., Scholes, R., Tomich, T.P., Vira, B., and Zurek, M. (2010). *Ecosystems and Human Well-being: A Manual for Assessment Practitioners*. Washington, DC: Island Press.

GoA (Government of Alberta) (2012). *Ecosystem Services Approach Pilot on Wetlands: Integrated Report* [online report]. Available at: www.canadianfga.ca/wp-content/uploads/2013/12/ES-approach-pilot-on-wetlands-in-AB.pdf

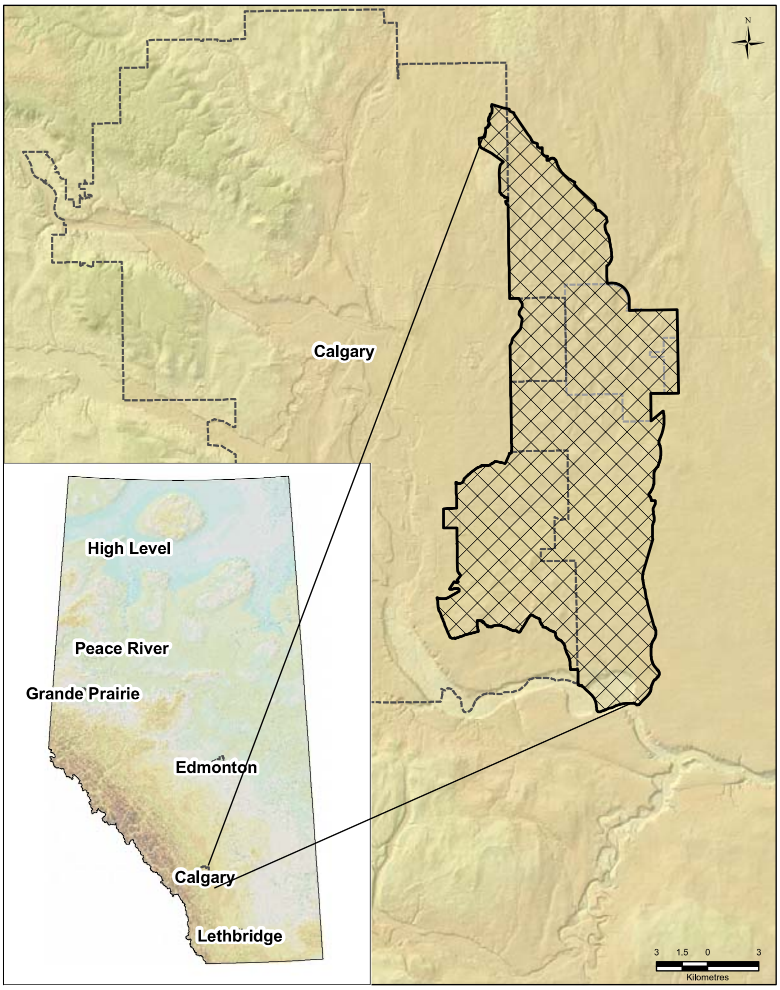
Kennedy, M. (2010). 'New Policy Tools for Conservation in Alberta's Boreal Natural Region' [online article]. Available at: albertawilderness.ca/2010-08-new-policy-tools-for-conservation-in-albertas-boreal-natural-region/ (Accessed: 29 May 2018).

WRI (World Resources Institute (2008) *Ecosystem Services: A Guide for Decision makers* [online book]. Washington, DC: World Resources Institute. Available at: www.wri.org/publication/ecosystem-services-a-guide-for-decision makers

## EST Reference:

Value of Nature to Canadians Study Taskforce (2017). *Completing and Using Ecosystem Service Assessment for Decision-making: An Interdisciplinary Toolkit for Managers and Analysts*. Ottawa, ON: Federal, Provincial, and Territorial Governments of Canada. Available at: publications.gc.ca/site/eng/9.829253/publication.html (Accessed 30 April 2018).

**Figure A3 - Map of study area in southern Alberta, Canada**




(Source: Government of Alberta, 2012)

# Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

## Description

InVEST is a software package for assessing the implications of different policy, climate, land use, coastal marine use, or other scenarios on the spatial provision of ES (Tallis & Polasky, 2009). InVEST can be downloaded from www.naturalcapitalproject.org/invest/. Currently InVEST includes a suite of computer-based models for mapping and quantifying 18 individual ES, as well as supporting tools and models. Ecosystem services that can be modelled in InVEST include: carbon, coastal blue carbon, coastal vulnerability, crop pollination, fisheries, habitat quality, habitat risk assessment, marine fish aquaculture, marine water quality, nearshore waves and erosion, offshore wind energy, recreation, reservoir hydropower production (water yield), scenic quality, sediment retention, water purification, and wave energy. The aim of all InVEST models is to compare scenarios, such as different land use scenarios, to evaluate the implications for the provision of ES. The Natural Capital Project produces several other free, open-source tools for ES assessments in specific decision contexts (see www.naturalcapitalproject.org/software/#tailored-tools.) RIOS (Resource Investment Optimization System), created for identifying priority areas for restoration or other activities to benefit ES and biodiversity, and for designing Payments for Ecosystem Services schemes, may be particularly relevant for application to KBAs, WHS, and PAs.

## User requirements

InVEST is a stand-alone software program and can be downloaded and run without any specialised software. GIS software is required to both create input datasets and to visualise model outputs. Different InVEST models have different requirements for input data; many models come pre-packaged with some of the data required to run them, if local data are unavailable.

## Strengths

Because it is free, open source, and requires little specialised expertise (except for GIS), InVEST is relatively easy to learn and apply. Relative to other tools reviewed here, InVEST has a much larger user community and many applied case studies and scientific publications that can be replicated or used for training or communication. Detailed online model documentation, annual in-person trainings, and an online forum for posting questions and getting support from the model developers ensures that it is possible for beginners to learn and apply InVEST. InVEST is the only model included in the review that includes fully-developed models for coastal marine ES; while some other tools such as ARIES or MIMES could be applied to marine contexts, they do not include marine ES in their existing models.

## Limitations

Most of the InVEST models require the users to provide at least some of their own data in the appropriate format (spatial or tabular). Applying InVEST at large (national or global) scales depends on the availability of appropriate data and requires sufficient computer processing times. This may change in the future as the models are expanded and improved, data become more available, and computer processing technology improves.

## Potential applications for KBAs, WHS and PAs

In terms of applications for KBAs, WHS and PAs, InVEST could provide useful information about ES flows from individual sites or networks of sites within a geographic region. InVEST can be used to answer questions such as what ES benefits are currently provided by sites, who receives those benefits, and how might those benefits change under alternative management options or climate scenarios. InVEST and RIOS can be used to design Payments for Ecosystem Services schemes that might support site-level conservation. The strength of InVEST is in scenario comparison; therefore, it could provide information about the implications of different land and coastal/marine management scenarios on ES provided by sites. The case study provides more information.

## Summary

InVEST provides an intermediate option, in that it does require moderate levels of time, data, and GIS expertise to learn and run. It is not as rapid or simple as tools such as Co$ting Nature, but it does allow for more customisation of input data and parameters. However, the models are relatively simple, and the data, expertise and time requirements are significantly less than those for other tools, such as ARIES and MIMES.

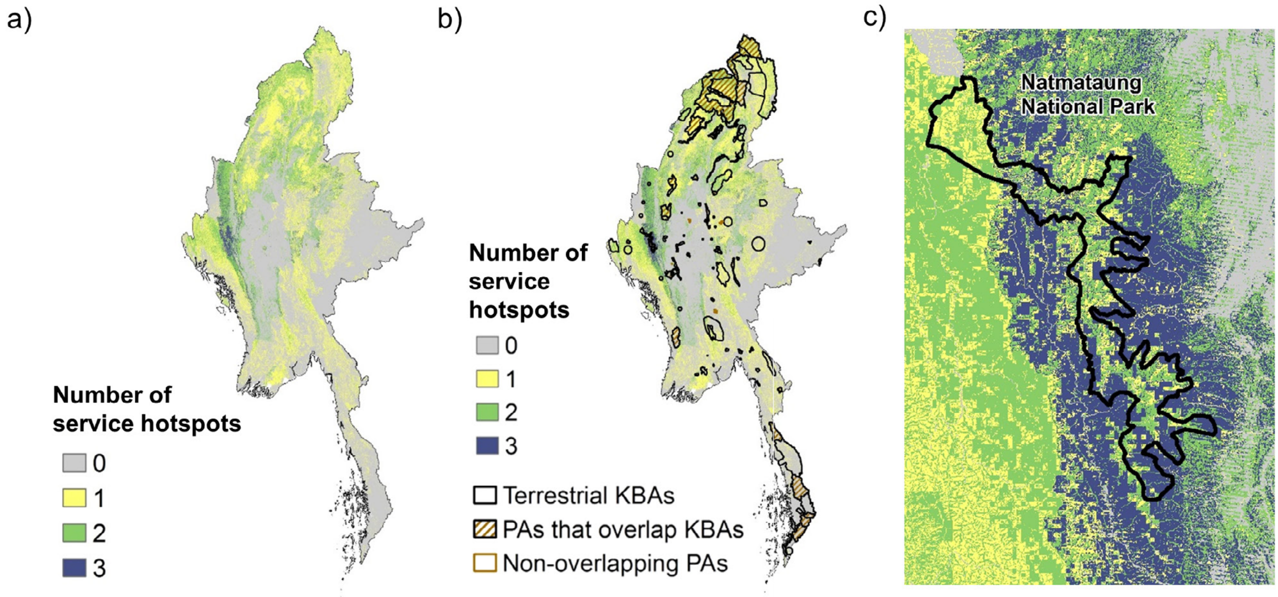
## InVEST Case Study:

### Assessing ES provision and overlap with KBAs and PAs in Myanmar to inform conservation and development planning

**Context:** Myanmar is seeking a path that allows for economic development while preserving ecosystems and the critical services they provide to the country's citizens and its economy, after decades of restrictive military rule that both limited economic development and influenced the rate and nature of natural resource exploitation. Recognising the value of nature for the country's prosperity and the security of its people, the Myanmar government is developing a number of strategies, procedures, rules and policies to improve environmental conservation in the country, including an updated overarching environmental policy aimed at mainstreaming environment and climate resilience into development planning and implementation. In addition, Myanmar's National Land Use Policy includes as one of its key objectives to "promote sustainable land use management and protection of cultural areas, environment, and natural resources for the interest of all people in the country."

**Motivation/question being addressed:** This analysis was intended to build an understanding within Myanmar's government and civil society of the value of natural capital (biodiversity and ecosystems providing benefits to people in the form of ES), and to support conservation and development planning and policy implementation by identifying areas of particular importance for ES provision. Specifically, this assessment evaluated: 1) where natural ecosystems provide benefits to people and infrastructure for four focal ES; 2) how provision of these benefits may change under future climate scenarios; and 3) the degree to which the most important ecosystem service provision areas overlap with PAs and KBAs.

**Figure A4.** Overlap of ES provision hotspots (top 20% of service provision area for sediment retention for drinking water quality, regulation of dry-season baseflows for drinking water provision, inland flood risk reduction for flood-prone villages) and their intersection with PAs and KBAs




(Source: Mandle, L. et al., 2017)

**Location/scale:** The analysis was conducted at a national scale for the country of Myanmar.

**Time and resources:** Ecosystem service modelling was completed by Natural Capital Project staff, including a senior GIS analyst and ecologist, with some support from a hydrology expert. The total time spent was approximately 9 full-time person-months over 1.5 years. This included multiple stakeholder engagement workshops with regional and national government officials, scenario development and integration of climate change scenarios, data acquisition and pre-processing, model runs, analysis of results, and production of reports and a peer-reviewed publication. It also includes multiple InVEST trainings provided to researchers, students and government staff. This estimate does not include the time spent on related activities carried out by project partners (e.g. climate modelling, additional project management, report preparation, etc.).

**Stakeholders/collaborators/partners:** This project was led by WWF-Myanmar in partnership with WWF-US, the Center for Climate Systems Research at Columbia University, and the Natural Capital Project (www.naturalcapitalproject.org/). Other collaborators include: the Myanmar Forest Department and Environmental Conservation Department, the Ministry of Natural Resources and Environmental Conservation, the Department of Meteorology and Hydrology, and the Ministry of Transportation and Communications.

**Services assessed:** Four focal services were assessed: sediment retention for drinking water quality and reservoir function, regulation of dry-season baseflows for drinking water provision, inland flood risk reduction for flood-prone villages, and coastal protection for coastal populations.

**Beneficiaries:** In the case of sediment retention for drinking water purification and regulation of dry-season baseflows for drinking water provision, the beneficiaries included households reliant on surface water for drinking. Reservoirs were beneficiaries in the case of sediment retention for reservoir function. Villages that were affected by flooding in 2015 were the focal beneficiaries of inland flood risk reduction, under the assumption that further loss of this ES benefit would increase flood risk to these already-susceptible populations. For coastal vulnerability, we considered the total population living within 3 km of a focal shoreline segment as beneficiaries.

**Key results:** PAs cover over 5% of Myanmar's land area, and KBAs over 15%, with nearly all PAs also falling within designated KBAs. Overall, KBAs and PAs included more areas important for ES ('hotspots') than expected simply from chance: 50% of the area of KBAs and 62.3% of the area within PAs were also areas in the top 20% for at least one of three services (Figure A4). However, while KBAs and PAs included a large amount of the hotspots for sediment retention and inland flood risk reduction, hotspots for dry-season baseflows for drinking water were not well represented KBAs or PAs.

Reflecting enhanced understanding of the importance of ES, the Myanmar government has adopted a natural capital framing in several policy and strategy documents, including the national environmental policy, national climate change strategy, the strategic framework for implementation environmental policy, and the green economy policy framework.

## InVEST Case Study References:

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Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., Dixon, A., Horton, R., Lesk, C., Manley, D. and De Mel, M. (2017). 'Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar'. *PloS ONE*, 12:e0184951 doi.org/10.1371/journal.pone.0184951

# Multiscale Integrated Model of Ecosystem Services (MIMES)

## Description

MIMES is a suite of linked economic and ecological models. It is extremely versatile and can incorporate temporal (time series) and spatial (GIS) data to simulate ecosystem and economic dynamics through space and time. Stakeholder input is used to define demand for ES. MIMES can be used to model any ES; the accuracy of model output is determined by the availability of appropriate input data. MIMES uses scenarios to forecast how different actions affect the distribution of ES benefits in the future. MIMES can be used to compare scenarios, such as different land use, hydrology, or climate scenarios, to evaluate the implications for the provision of ES and determine trade-offs between services, as well as impacts. To date, MIMES has been applied at the global scale, at the watershed scale and in a marine setting (Boumans et al., 2015).

## User requirements

MIMES itself is a free, open source, downloadable ZIP file. However, using MIMES requires purchasing and learning SIMILE visual modelling software. Application of MIMES for any new context requires customisation and parameterisation as well as user-provided data that are tailored to the specific ecological and socioeconomic context. Depending on which tier of MIMES is used, different input data are required. For tier 1, GIS data and a benefits transfer method is used to develop spatially explicit economic values. Tier 2 is similar to tier 1 but also incorporates land use change simulations and time series data to model temporal dynamics. Tier 3 incorporates GIS data, biophysical models to calculate ecosystem dynamics, and an economic production function (marginal price approach) instead of benefit transfer to model temporally dynamic biophysical and economic values. In the future, tier 4 (under development) will incorporate GIS data, biophysical models, and input-output economic models for 'complete green accounting'. Additional tiers as required can be included to model additional services such as incorporating evaluation of nature's values.

Expertise is needed in: (i) programming with SIMILE, (ii) identifying indicators and data for the model input, (iii) knowledge of ecological, biophysical and socio-economic attributes and interdependences to parameterise model and determine algorithms for connections, and (iv) expertise with stakeholder engagement to adjust the qualitative settings of the MIMES models.

Up to three months are needed to parameterise and run the model. Costs of applying the model depend on data availability and on number of experts needed for programming and using the model, as well as biophysical and socio-economic experts for consultation and model refinement.

## Strengths

Due to its sophistication, MIMES is better able to capture the complexity of dynamic socio-ecological systems than some of the other tools reviewed. It is designed to be customised for each context and therefore is better suited to tailored analyses. It can integrate multiple types of biophysical and socioeconomic data and models. It can also model spatially explicit and temporally dynamic systems. The tiered approach enables it to be applied in both data poor or data rich environments. It enables spatially explicit trade-off analyses. Finally, MIMES can be developed for any ES, in terrestrial/freshwater/marine environments, and at any scale, if relevant data are available.

## Limitations

MIMES is a sophisticated model that is customised for every new application and cannot be generalised or applied 'out of the box' the way tools like Co$ting Nature or InVEST can be. Developing and adjusting MIMES models requires a relatively high level of technical expertise or time investment to learn SIMILE software and the MIMES model. MIMES is completely dependent on user-provided data. Developing a new application of MIMES requires more time than many of the other tools reviewed here. Therefore, the requirements in terms of time, expertise and data are relatively high when compared to other tools. Being a complex systems model, it can be subject to compounded error if scenarios are not developed carefully.

## Potential applications for KBAs, WHS and PAs

Potential applications of MIMES for sites include research on the production and use of ES by natural ecosystems and human user groups; evidence of the importance of sites for conservation; evaluating trade-offs between different management options; targeting management activities spatially; understanding dependence of different groups or sectors on ES, impacts on ES by human activities, and risks (e.g. to businesses); site prioritisation (spatially explicit information on the relative importance of different sites for ES); large scale spatial planning (e.g. watershed scale); and understanding the contributions of sites to ES globally.

## Summary

MIMES is a sophisticated solution for integrated, spatially explicit modelling of linked biophysical and socioeconomic data and processes. As such, it enables users to model more complex socio-ecological systems and bring together spatial, economic, ecological and social data. It enables dynamic systems modelling, allows a user to test scenarios (based on data availability) and to run theoretical and empirically-based experimental models of the scenario outputs. Because each application of MIMES is customised for a particular socio-ecological context, MIMES is not easily adapted or generalised from one context to the next. It requires relatively high levels of technical skills, GIS, data inputs, and time to develop each new application of MIMES, relative to other tools reviewed here.

## MIMES Case Study:

### Assessing ES trade-offs with MIMES to inform basin development planning and sustainable policy decisions in the Cambodian Mekong Basin

**Context:** Facing rapid development and an unpredictable climate future, Cambodia's productive freshwater system is under pressure from multiple conflicting needs. So much of the economy and welfare of Cambodia's people is reliant on nature, and understanding the value of that nature is critical for defining sustainable policies and management planning. The government and decision-makers (basin planners, businesses, etc.) need information and an understanding of trade-offs between conflicting needs for ES by beneficiaries in order to define solutions that can balance economic development and ES provisioning. The Cambodian government has an acute understanding of the value of nature for supporting Cambodia's economy and the food security of the nation's people. The Cambodian government is developing strategies and policies to improve natural resource use and particularly freshwater provisioning and environmental conservation. This includes fisheries management, a new fish law, community-based management, land-use planning, and an over-arching environmental code.

**Motivation/question being addressed:** The MIMES case study for the Tonle Sap and Cambodia's freshwater system was initiated in response to a need expressed by the Cambodian government and civil society to better understand the impact of rapid development in the region and trade-offs between the various ES being exploited. The model aims to determine equitable solutions for economy and society and to demonstrate sustainable solutions for development and the exploitation of natural resources. Specifically, the assessment examines: 1) hydropower and climate impacts on fisheries and biodiversity, 2) trade-offs between land-uses, including land concessions, agriculture and conservation areas, 3) the impact of urbanisation on natural resources, and 4) the food-energy-water nexus. The analysis also provides the opportunity for users to determine their priorities and to identify impacts of decision-making—demonstrating the trade-offs between services and how to determine balanced options.

**Location/scale:** The analysis was conducted at a national scale for the country of Cambodia.

**Time and resources:** ES modelling was completed by Boston University staff with support from Conservation International and the Cambodian Ministry of Fisheries, including a senior GIS analyst, ecologist, a hydrology expert, a modeller, and fisheries experts. The total time spent was approximately 20 full-time person-months over 4 years. This included multiple stakeholder engagement workshops with regional and national government officials, scenario development and integration of climate change scenarios, data acquisition and pre-processing, model runs, analysis of results, and production of reports and a peer-reviewed publication. It also included development of webinars, a course in MIMES modelling, and a series of workshops to train students, government staff, decision makers and other relevant stakeholders. This estimate does not include the time spent on related activities carried out by project partners (e.g. climate modelling, additional project management, report preparation, etc.).

**Stakeholders/collaborators/partners:** This project was led by Boston University in partnership with Conservation International and the Inland Fisheries Research and Development Institute, Cambodian Fisheries Administration. Other collaborators include: Ministry of Agriculture Forestry and Fisheries, Ministry of Environment, Apsara Authority, and the Center for Khmer Studies.

**Services assessed:** Various focal services were assessed: freshwater provisioning, food-energy-water provisioning, and seasonal flows for fish and rice.

**Beneficiaries:** The principle beneficiaries included decision-makers, land-use and development planners, ecotourism businesses, and communities that are reliant on fisheries and agriculture production. The fishery was treated as a beneficiary as it will be affected by development and climate. Scenarios were developed to work with dam operators to mitigate these impacts. Dam operators were beneficiaries as they gained understanding of opportunities for conflict resolution. The flooded forest was a beneficiary of vital ES for system function. Basin development planners benefitted from greater insight to sustainable pathways for water management.

**Key results:** Opportunities to minimise impacts of hydropower development on fisheries and for dam operations to rescue fisheries from climate change were determined. Cambodian government fish law and management policies reflect the increased understanding of ES trade-offs.

# Protected Area Benefits Assessment Tool (PA-BAT)

## Description

The Protected Area Benefits Assessment Tool (PA-BAT) is a PDF/PowerPoint format tool for identifying the range of ES and other benefits (such as employment) supplied by a protected area. The current version of the PA-BAT can be downloaded from wwf.panda.org/our_work/biodiversity/protected_areas/arguments_for_protection/. An updated version, with improved guidance, is coming online in 2018. The PA-BAT uses a questionnaire approach in a workshop with a range of local stakeholders, representing different interest groups, to identify PA benefits. Park staff attend the workshop to contribute to and learn from the dialogue. The tool is designed for use anywhere in the world, and can be adapted for specific regions, sites, biomes, or PA networks. The tool includes a list of 24 benefits; which of these are assessed depends on the particular PA. Usually, questions are only asked if use is legal (e.g. if bushmeat hunting is banned then the bushmeat question would be omitted). Nine stakeholder types are assessed, ranging from Indigenous peoples to the global community; specific stakeholder groups can be adapted depending on the area. Each benefit is classified as a minor, major and/or a potential benefit, and either as an economic or non-economic/subsistence benefit. If time allows, information is collected on the area (location and extent) of the PA providing the benefit and the time period (e.g. season) in which the benefit is present. The PA-BAT includes a range of potential add-ons, including the use of artists to illustrate results in a workshop setting, participatory mapping, and others.

## User requirements

The PA-BAT is a downloadable PDF/PowerPoint file available in several languages. Once downloaded, it does not require an internet connection or specialised software. PA-BAT is typically applied in a 1-day participatory workshop, but time for workshop preparation (including identification of all relevant stakeholder groups) and analysis of workshop results can take additional days to weeks. The process of dialogue and group work requires an experienced facilitator. Ideally, two people work together: one facilitating and one capturing the results and any additional information, stories or opinions that emerge. A slide presentation helps both to explain the process through pictures of the benefits being discussed and also allows results to be captured and projected at the same time, ensuring complete transparency. The PA-BAT can be adapted according to the local context and user requirements.

## Strengths

The PA-BAT is one of the few tools reviewed that allows for rapid assessment of key benefits to different stakeholder groups. It also focuses on social and cultural values, for which some assessment tools (e.g. biophysical modelling tools) are less well designed. The process to apply the PA-BAT is quick and relatively inexpensive, requiring only resources for a stakeholder workshop (e.g. travel, expenses for facilitators and workshop participants and usually lunch/refreshments) and time for analysis. (Assessment of 58 national parks in the Dinaric Arc of Europe, each with its own workshop, cost €30,000 in addition to staff salaries for two people). Workshops usually take less than a full day (morning, lunch and short afternoon session); based on past experience this is the most time that many stakeholders are able to commit to the process. The process provides a direct opportunity for local people to give their perspective; in most cases workshops unearth information on benefits previously unknown to park staff. It also allows different stakeholders to meet and exchange ideas, and it is often the first time that stakeholders have interacted with park staff. Feedback is generally positive and results have been used all the way from political lobbying to development of associated on-site projects.

## Limitations

Results are generally based on local knowledge rather than biophysical data and therefore are subject to the limitations and/or biases of local stakeholders (there may be exceptions, where biophysical data have already been collected). Results are not generally quantified and may under-represent or under-estimate the importance of certain ES if particular stakeholders are absent (e.g. water values might be under-estimated if water company officials do not attend). Selection of stakeholders often relies on advice from PA staff, which may lead to bias or lack of representation of certain stakeholder groups. Guidance on the application of the PA-BAT does however include a verification process that can be used to ensure no major errors occur. The PA-BAT can only be applied to one site at a time; it is not feasible to apply it to multiple sites simultaneously.

## Potential applications for KBAs, WHS and PAs

The PA-BAT was developed for PAs and has already been used widely in a range of sites, including some natural WHS and KBAs that are also protected areas. It could theoretically be applied in an unprotected KBA; one practical challenge might be in finding a person or organisation with convening power and ability to identify a representative range of stakeholders. KBA boundaries might not be demarcated on the ground or known by local stakeholders; therefore detailed maps might be required in order to conduct the workshop, so that stakeholders can identify where various benefits derive from within the KBA.

## Summary

The PA-BAT is a rapid, questionnaire-based approach to identifying the full range of benefits from PAs, working with a representative range of stakeholders. It has some unique strengths in its focus on the different benefits accruing to different stakeholder groups and its focus on social and cultural values. One challenge is that it must be applied one site at a time. It could be applied more broadly to other area-based designations such as KBAs.

**Figure A5.** Dinaric Arc region


**Figure A6.** PA-BAT workshop in Kopaonik National Park, Serbia

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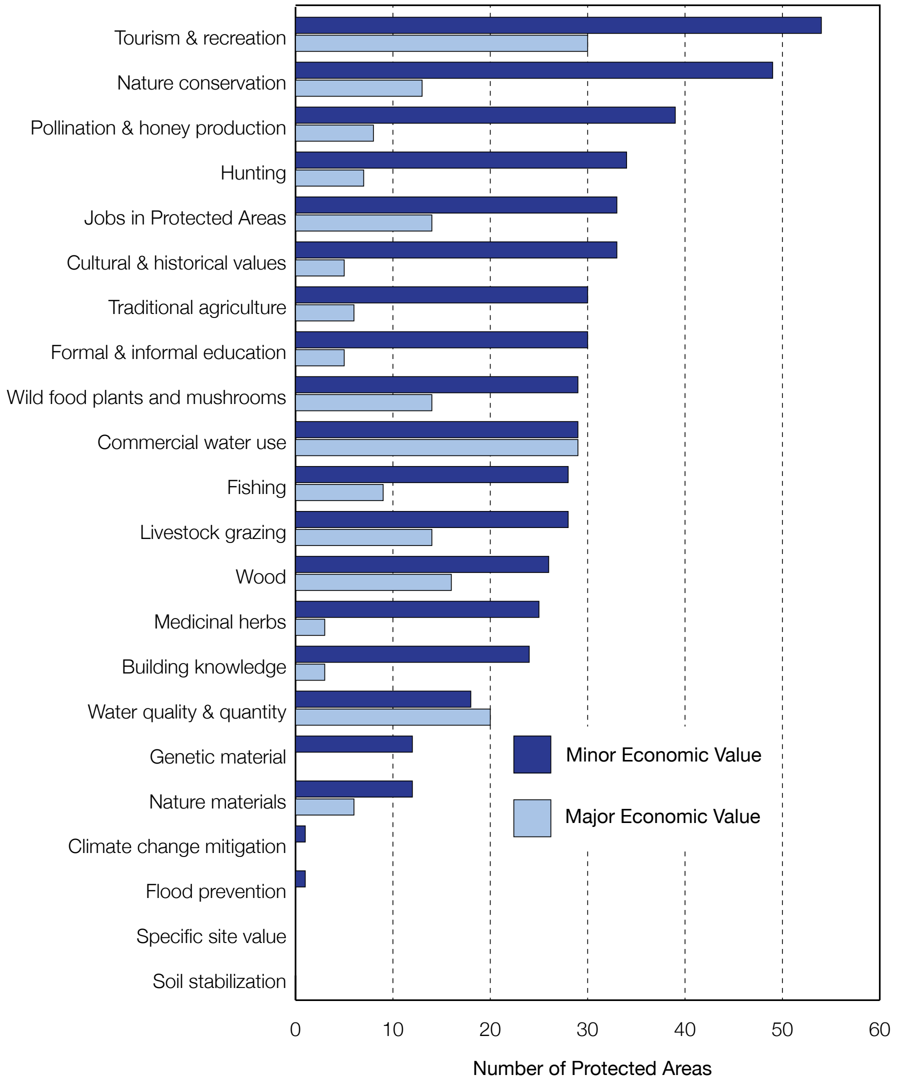
## PA-BAT Case study:

### A participatory assessment of ecosystem services in 58 protected areas from eight southern European countries using the Protected Areas Benefit Assessment Tool (PA-BAT)

**Context:** It has been two decades since the war in the former Yugoslavia that affected people throughout the Western Balkans, and the consequences are still visible in some parts of the region. The rate of unsustainable exploitation of natural resources has grown. Increasing numbers of people are moving into cities and abandoning traditional small-scale farming and cattle breeding, which also negatively affects ecosystems and biodiversity. Most PAs in the region are both rich in biodiversity and are sites of intense human activity. Therefore, they are 'natural laboratories' for finding model solutions to reconcile development challenges while safeguarding natural capital. As PA are the backbone of the European Union's Natura 2000 network (ec.europa.eu/environment/nature/natura2000/index_en.htm), they are also good sites for developing cooperative models required for successful implementation of EU environmental directives.

**Figure A7. Minor and major economic benefits from 58 PAs in the Dinaric Arc region recognised by local stakeholders**




This region of the world has been a cultural ‘melting pot’, and unfortunately also often a boiling pot, of Europe. A complex mountainous terrain produced strong local cultural identities. At times this has been uniting, at times divisive and a source of social tension, which is why it is important for all ethnic groups to be heard in discussions about resource management. This is why the PA-BAT was used, because local stakeholders had a chance to talk through one-day participatory workshops. More than 1,250 local stakeholders from 58 protected areas in eight countries in the territory of the Dinaric Arc region shared their perceptions on PA benefits and current PA management. This was the biggest ever participatory assessment of PA benefits in the region and took two years to complete.

**Motivation/question being addressed:** This analysis identifies the main drivers relevant for the PAs and countries’ development policies; identifies flows of economic benefits and a need to develop strategies to return revenues to compensate local people and PAs; and it also highlights the importance of jobs in PAs—vital for rural economies and relevant for politicians.

The World Wildlife Fund (WWF) wanted to have a central database of information about benefits from over 50% of the PA territory in the Dinaric Arc with over 22,000 pieces of information on PA benefits and economic flows received by local stakeholders. This database is now available online: natureforpeople.org/protected_areas/

One goal of this assessment was to raise awareness and to gather arguments on the wider benefits of PAs so that national governments in the region recognise the role of natural capital in the prosperity of the country and the security of their people. A second goal was for governments to include the values of PAs and their ecosystems while developing PA management plans, national strategies, procedures, rules and policies. This will help local and national PA managers and local stakeholders to consider a wide variety of benefits, and develop suitable management processes.

**Location/scale:** The analysis was conducted at a regional scale in 58 protected areas from the eight countries in southeastern Europe (Albania, Bosnia and Herzegovina, Croatia, Kosovo[5], the Former Yugoslav Republic, Macedonia, Montenegro, Serbia and Slovenia) (Figure A5).

5 This designation is without prejudice to positions on status and is in line with UNSCR 1244/99 and the IJC opinion on the Kosovo declaration of independence.

**Time and resources:** One-day PA-BAT workshops were conducted by two WWF staff (Figure A6). One acted as a neutral facilitator to complete the PA-BAT during a day-long multi-stakeholder workshop, while the other person took notes. Running PA-BAT workshops is energy consuming and requires facilitation skills to moderate and deal with possible conflicts between participants, especially in regions with a history of violent conflict. Group discussions and participation of all stakeholders is crucial. The methodology is relatively quick (one week preparation, one day workshop, one to two days write up). Costs include staff time (two to three people per workshop), travel costs and workshop expenses.

The total time spent gathering the data was approximately two full-time person-months over 1.5 years. Workshops included national and local government officials, PA managers, scientists and experts, local community members, civil society organisations and user groups (e.g. hunting organisations, fishing associations, plant/mushroom collection groups, sports organisations), and the business sector. Analysis of results and production of reports and a peer-reviewed publication took one full-time person-months over one year. It also included a PA-BAT training for researchers, PA manager and government staff, led by the developers of the PA-BAT methodology, Sue Stolton and Nigel Dudley.

**Stakeholders/collaborators/partners:** This project was led by WWF Adria with the expert support of Equilibrium Research. A focal point was nominated in each Ministry and institute in charge of national PA management for the eight countries. Focal points from all 58 assessed PAs provided support and helped organise the workshops. In some countries, other ministries such as tourism ministries also provided support.

**Services assessed:** The PA-BAT methodology is used to assess 22 legal values produced from protected areas. Values are organised in nine major groups: nature protection, protected area management, food, water, culture and history, health and recreation, knowledge, ecosystem regulatory services and natural materials. Note that this assessment included ‘nature conservation’ and ‘jobs in protected areas’ as these are important benefits, but they are not ecosystem services *per se*.

**Beneficiaries:** The assessment and the related discussions may inform PA managers, the business sector and local stakeholders of possible new activities they can undertake on a range of issues. These include new or more effective sustainable economic activities leading to rural development, educational activities, or more effective mitigation of threats such as floods or avalanches. PA managers can use the results for updating management plans, to achieve more effective management or to improve relationships with local stakeholders. Governmental staff and civil society organisations can use the results for improving system-level policies, sector dialogues and to enable more funding for nature conservation.

**Key results:** The process was as important as the results because in most PAs, this was the first time that members of the local community could share their opinion on PA management and PA benefits with PA managers. The PA-BAT identified some important trends (Figure A7). In 96% of PAs some stakeholders receive economic gain from tourism, and most see this as an important potential growth area. Over half the PAs supply water for commercial use, although here the beneficiaries are mainly companies and governments. Most stakeholders also saw parks as places for education and knowledge-sharing. Importantly, jobs linked to conservation are the only source of employment in a quarter of the PAs and are important throughout the sector; as traditional rural livelihoods decline, PAs are helping to reduce rural depopulation and migration to urban areas. The results of the PA-BAT exercises are being used both to influence national policies towards natural resource management in the area and to help develop sustainable projects in individual PAs.

For more information and additional case studies, see natureforpeople.org/protected_areas/ which includes national reports and results of the PA-BAT from individual sites, including two World Heritage sites.

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## Social Values for Ecosystem Services (SolVES)

### Description

SolVES (Social Values for Ecosystem Services) is a GIS application for assessing, mapping, and quantifying the social values of ES. SolVES derives a quantitative, 10-point, social-values metric, called the Value Index, from a combination of spatial and non-spatial responses to public value and preference surveys. It uses these data, together with user-provided environmental data, to model the spatial distribution of cultural ES provision across a region or landscape. The ES that can be assessed using SolVES depend on the social-values typology used in the public value and preference survey but have commonly included aesthetic appreciation, recreation, spiritual experience and identity, learning, and future/bequest value.

### User requirements

Using SolVES requires having capacity to design and conduct a survey to elicit social value information from a target population. In addition to requiring a social survey, running SolVES requires specifically formatted data (e.g. survey data coding). SolVES version 3.0 requires input files to be in the file geodatabase format. Therefore, SolVES requires expertise in GIS data and software, specifically ArcGIS. SolVES version 3.0 requires the SolVES application (ZIP-file), ArcGIS 10.x (with Spatial Analyst extension), and the freely available Maxent maximum entropy modelling software. Additionally, the user's computer must also run the .NET Framework and Java. In terms of data requirements, the main requirement is primary data from a social survey, including value allocations and associated point locations. The Value Transfer Tool allows a previously developed model to be applied to a physically and socially similar area, but this is only an option if a suitable model happens to be available for transfer. Other input data include the environmental (GIS) data layers used to represent key features of the landscape that the model uses to explain the presence of point values; these can vary from widely available land cover or elevation data to user-derived data layers such as slope, distance to water, roads, trails, or historic sites.

### Strengths

SolVES is the only tool reviewed here that is specifically designed to examine and articulate the values that people attribute to publicly available benefits from nature, such as the beauty of a landscape, or the cultural or recreational value of a protected forest. Shared social values (as opposed to private values) can be evaluated for various stakeholder groups, which may differ in their attitudes and preferences. SolVES provides a quantitative, spatially explicit analysis of social values. It can be used to assess relationships among values, attitudes, and preferences, which can be assessed independently for different stakeholder groups. Outputs of intermediate calculation steps and data layers provide transparency and enable discussion of uncertainty. SolVES is a flexible tool that can be adapted to new regions and has some options for setting up model configurations. SolVES has detailed documentation that is designed to help new users learn and apply the tool.

### Limitations

Because of its dependency on social survey data and ArcGIS, using SolVES is relatively time-consuming, requires purchasing an ArcGIS license, and requires expertise in social science and/or survey design, GIS expertise, and familiarity with Maxent. This combination of requirements may exceed the capacity of some ES assessment teams. Cultural ES models developed with SolVES may not be transferrable to other locations. As with all value transfer models, the policy (receiving) site must be physically and socially similar to the study (originating) site in order for model results to be valid.

### Potential applications for KBAs, WHS and PAs

Because SolVES is designed to elicit stakeholder values and then map them spatially, it has unique potential for understanding and mapping social and cultural values provided by KBAs, WHS, and PAs. For example, SolVES could be used to understand and map culturally valuable features to ensure their protection or proper management, to design recreation use plans based on stated preferences of different user groups, identify sites or areas where multiple social and cultural values overlap, and help elucidate potential trade-offs or conflicts between different user groups. When used in combination with other spatially explicit modelling tools that focus on biophysical ES values (e.g. ARIES or InVEST), SolVES can provide a complementary assessment to ensure that social and cultural values are not ignored, or elucidate trade-offs between different types of ES.

### Summary

SolVES is the only tool reviewed that allows a user to spatially map social and cultural values. Using SolVES requires ArcGIS software (which requires purchasing a license), conducting a survey of stakeholders to elicit their values, and conducting modelling using Maxent and GIS. Using SolVES therefore requires skills in survey design as well as spatial analysis, a relatively high level of technical skill relative to some of the other tools reviewed. SolVES also requires relatively high levels of user-provided data (from surveys) and time for survey design, implementation, analysis, and spatial modelling, when compared to some of the other models.

### SolVES Case Study:

#### An application of Social Values for Ecosystem Services (SolVES) to three national forests in Colorado and Wyoming

**Context/background:** The study area for this assessment included Arapaho-Roosevelt, Medicine Bow-Routt, and White River National Forests, located in the southern Rocky Mountains of Colorado and Wyoming, USA. These national forests rank as some of the most visited in the U.S. and are used by the public for many activities such as: skiing, snowmobiling, hiking, camping, boating, horseback riding, fuelwood collection, hunting, fishing, ATV riding, and many others. Ecosystems within these forests range from grassland at the lowest elevations, up through montane forests to alpine tundra, with elevations ranging from c. 6,000 to in excess of 14,000 feet (4,267 m).

**Motivation/question being addressed:** The primary motivation for conducting the public attitude and preference survey for these three forests as a group was to inform the management of tree mortality from mountain pine beetle with respect to mitigating the risk of fire. The survey also permitted the application of SolVES to demonstrate its potential to guide the management of sites, including prioritising areas for fire mitigation work.

**Location/scale:** The Arapaho-Roosevelt, Medicine Bow-Routt, and White River National Forests cover an area of 8,175 square miles (21,173 km$^2$) in northern Colorado and southern Wyoming. The large scale of analysis, coupled with the necessity of sending 11x17 inch paper maps with the mail-based survey, limited the resolution of our analysis to a 450 meter grid size.

**Cost/time/resources:** The survey was conducted by a team of social scientists from Colorado State University over a period of approximately 9 months and at a cost of $120,000, including design, distribution, and post processing. A GIS specialist spent an additional 3-4 weeks digitising points from the paper maps, building the geodatabase, and developing the models.

**Linked to other tools:** This particular study did not apply SolVES in combination with other tools.

**Stakeholders/collaborators/partners:** This study involved a collaboration of scientists from Colorado State University, the U.S. Geological Survey, and the U.S. Forest Service.

**Services assessed:** Models and maps were developed for each of the 13 social-value types identified in the forest-values typology applied in the survey. These included aesthetic, biodiversity, cultural, economic, future, historic, intrinsic, learning, life sustaining, recreation, spiritual, subsistence, and therapeutic values. These were well suited to U.S. Forest Service management goals, but they do not all translate directly to cultural ES. The social-values typology employed in the survey, and thus available for use by SolVES, can be customised to meet the specific objectives of each new project.

**Beneficiaries:** Beneficiaries of the cultural ES mapped in this study were limited to the residents of counties surrounding each forest. While a much larger population of beneficiaries exists for these services, the surveys targeted local residents and their values.

**Key results:** The study demonstrated that cultural ES information could be analysed by specific value type or in combination, by specific stakeholder group or in aggregate, and between different management units. The study found that aesthetic, biodiversity, life sustaining, and recreation value types were the most valued by survey respondents and resulted in the best performing models across all three forests.

**Decision-making, policy, management relevance:** Utilisation of ES information by government agencies has been limited both by the availability of this information and the ability to incorporate it into long established management and planning protocols given the available staff expertise. This study focused on demonstrating how spatial information on cultural ES could be generated as a component of established survey procedures used to inform management. It further demonstrated that information on cultural ES can contribute to integrated resource assessment, planning, and management of forests and other ecosystems.

Also see ARIES-SolVES case study, above.

## Toolkit for Ecosystem Services Site-based Assessment (TESSA)

### Description

TESSA is an interactive PDF that provides practical guidance on how to identify which ES to assess at a site, what data are needed to measure them, what methods or sources can be used to obtain the data, the steps required for each method, and how to communicate the results to inform decision making. TESSA can be downloaded from tessa.tools/. There are two key steps: the Preliminary Scoping Appraisal (conducted through a stakeholder workshop) which produces qualitative information about all the ES provided by a site, followed by a full assessment whereby methods for quantifying a set of ES are provided. Multiple methods have been included for individual services so that they are applicable across all terrestrial habitat types and under different resource constraints. TESSA is not a software-based tool. It focuses on collecting local data wherever possible and on engaging with stakeholders at the site throughout the assessment and interpretation process.

### User requirements

TESSA, like PA-BAT and the EST, is a downloadable PDF and once downloaded, does not require an internet connection or specialised software to use. Although TESSA is designed to be accessible to non-experts, understanding ES can be technical. Therefore, some relevant experience and/or training may be needed. The user may need: (1) some scientific training to understand basic sampling methods, statistics, production of graphs and presentation of data; (2) some training in, or understanding of, socio-economic methods; and (3) competent computer skills and numeracy.

### Strengths

TESSA is both a framework and a methods manual for practitioners wanting to understand the ES provided by a site compared to an alternative state. The two stages mean that it can be used for qualitative assessment only (through the Preliminary Scoping Appraisal) or for quantifying the value of selected ES in biophysical and monetary units. The toolkit can provide approximate service estimates that are robust enough for informing decision-making, without necessitating investment of considerable resources (i.e. time and funding) or requiring specialist technical knowledge.

### Limitations

The tools in TESSA do not aim to help with assessment of all services, as many are extremely hard to quantify or to assess in a robust and rapid way. So far, TESSA V2.0 provides full assessment methods for coastal protection, cultivated goods, cultural services, global climate regulation, hydrological services, harvested wild goods, nature-based recreation and pollination. Results derived from TESSA represent snapshots of each of the two states (i.e. current and alternative) of the focal site. The toolkit does not yet address complexities such as long-term sustainability, non-linearities, tipping points, discount rates and resilience. TESSA does not produce spatial outputs.

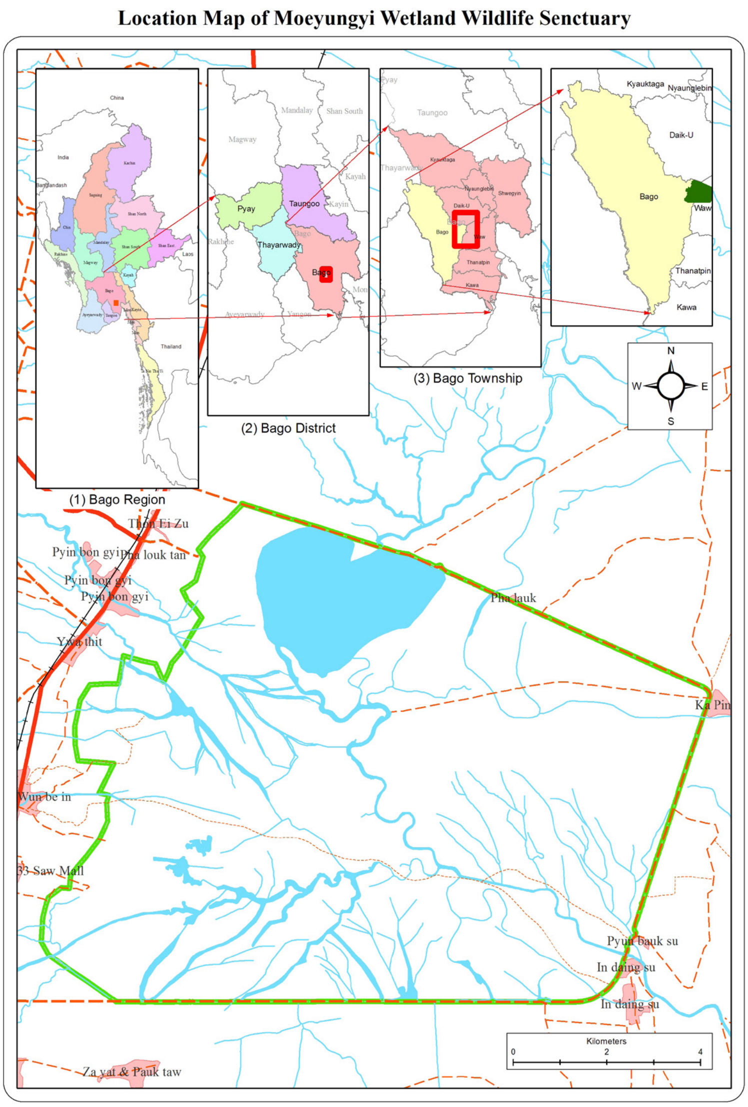
### Potential applications for KBAs, WHS and PAs

Potential applications of TESSA for sites include determining the significant ES provided by a site and measuring them rapidly and cheaply; identifying the important stakeholders and beneficiaries; revealing the most likely alternative state of a site and the net consequences for ES values, to inform local decision making and site-level planning; evaluating synergies and trade-offs among different ES within a site; and providing locally relevant information for more detailed assessments and mapping.

### Summary

TESSA is a compilation of rapid ES assessment methods for helping non-experts to understand the impacts on ES of plausible land-use changes. It is the only site-based tool that provides comprehensive guidance on how to collect and analyse data for informing decision-making based on policy or land use changes at the site.

**Figure A8.** Map of Moeyungui Wetlands Wildlife Sanctuary in Myanmar




(Source: Peh, K.S-H. et al., 2016)

## TESSA Case Study:

### Assessing ecosystem services of the Moeyungyi Wetland Wildlife Sanctuary, Myanmar

**Context/background:** An assessment of the ES provided by Moeyungyi Wetland Wildlife Sanctuary was carried out using TESSA.

**Location/scale:** Moeyungyi Wetland—located in the administrative region of Bago in Myanmar (Figure A8)—covers 10,360 ha, 82% of which is freshwater marshes, 10% permanently covered by the lake and 8% rice paddies in the dry season. At the end of the wet season, water covers the whole site. This wetland is a man-made reservoir to store water for irrigation and to use as an embankment for flood protection.

**Motivation/question being addressed:** During a period of rapid developmental change in Myanmar, it is likely that rice cultivation will expand in the coming years. Thus, it is important that the non-market values provided by wetlands are recognised and incorporated into decisions that result in sustainable outcomes at the local and national scale. This assessment was to raise awareness about these important economic and social values that wetlands provide to people across all sectors and spatial scales.

**Cost/time/resources:** This assessment was carried out by a total of six personnel from BANCA (Biodiversity and Nature Conservation Association), a BirdLife International partner in Myanmar, who had no prior experience in assessing ES. Preparatory meetings were held from 18–22 December 2014 (10 person-days). During the meetings, existing information and data were collated and the feasibility of an ES assessment was discussed. Subsequently, a preliminary scoping workshop of key stakeholders involved at Moeyungyi Wetland Wildlife Sanctuary was then convened on 6–7 February 2015 (8 person-days). Data collection was carried out over the period from 5–8 February (12 person-days). The assessment took an estimated 30 person-days to complete.

**Stakeholders/collaborators/partners:** A preliminary scoping workshop involving government staff from the conservation, irrigation, agriculture and fishery departments, park wardens, and representatives from surrounding villages and towns was convened to identify the main ES provided by the wetland.

**Services assessed:** These benefits were (1) global climate regulation in terms of carbon storage; (2) nature-based recreation; (3) flood protection; (4) water provision (for domestic use and irrigation); (5) harvested wild goods (fish, aquatic plants for buffalo grazing, molluscs and lotus stalk); and (6) rice production during the dry season.

**Beneficiaries:** Local farming communities, national and international visitors, and the global community.

**Key results:** The core concept of TESSA is a comparative state assessment—an evaluation of the conservation state versus the same site in an alternative state (converted or pre-restoration degraded state). In consultation with all stakeholders, it was agreed that the most plausible alternative state would likely be a doubling of paddy cultivation (i.e. to 33,040 ha) in the near future, resulting in a decrease of water level (i.e. more marshes) in the dry season due to increased water use for irrigation.

Using the methods provided in TESSA for the key services identified in the scoping appraisal, the study identified that Moeyungyi Wetland Wildlife Sanctuary provides annual benefits of at least $22 million ($2,130 per hectare per year) and that these benefits are received by local communities (approximately 12,000 households), downstream rice farms, and the international communities through global climate regulation and opportunities for tourism. The evaluation of the alternative state included all ES measured in the current state, as well as significant increase in some services that the alternative would provide (e.g. use of water for irrigation and rice production). In this preliminary study, an increase in water use for expanding agriculture in Bago town was not considered to have a dramatic effect on the benefits that the wetland currently provides, because there is plentiful water supply into Moeyungyi lake from upstream dams. However, widespread rice cultivation could have more significant and detrimental impacts on human health and wild species populations due to pollution from agro-chemicals; availability of water due to siltation and soil erosion; subsistence and livelihood incomes due to loss of habitat for species used traditionally by local people; and the potential to market wetlands as eco-tourism destinations. A full impact assessment at Moeyungyi Wetland Wildlife Sanctuary would require further exploration of the above factors and an analysis of the changing landscape across the catchment area.

This assessment provides information for local and national stakeholders on the broader importance of the conservation of wetlands for the benefit of people, due to the economic and social benefits they provide. By incorporating these ES values alongside biodiversity values, sustainable management pathways for wetland sites across Myanmar could be achieved.

### TESSA Case study reference:

Peh, K.S-H., Merriman, J.C., Dae We Aung, T., Theint, S.M., Murata, N., Suzue, K. (2016). Case study - Moeyungyi Wetland, Myanmar. In J.C. Merriman and N. Murata (eds.) *Guide for Rapid Economic Valuation of Wetland Ecosystem Services*. Tokyo, Japan: BirdLife International.

# WaterWorld

## Description

WaterWorld (www.policysupport.org/waterworld), like its sister tool Co$ting Nature, is a web-based, spatially explicit modelling tool that comes with all the data required to run the model. Unlike Co$ting Nature, WaterWorld specifically focuses on a range of water-related ES. WaterWorld can be used to understand the hydrological and water resources baseline and water risk factors associated with specific activities under current conditions and under scenarios for land use, land management and climate change. It incorporates detailed spatial datasets at 1 square km and 1 hectare resolution for the entire terrestrial world, spatial models for biophysical and socio-economic processes along with scenarios for climate, land use and socio-economic change. A series of land and water management interventions (policy options) can also be modelled. The model outputs can be viewed online or downloaded in a range of geospatial formats for visualisation in GIS.

## User requirements

Using WaterWorld only requires a computer and web connection. It does not require the use of GIS unless the user wishes to download model results and conduct additional analyses. The basic features are free; more advanced features (such as the ability to replace the model-provided data with a user's own data) requires purchasing a paid license. Application with the provided datasets takes around half an hour. Bringing in local datasets will take longer depending on the availability, level of processing, format and consistency of those datasets, and also requires GIS capacity.

## Strengths

Like Co$ting Nature, WaterWorld is fast, easy to use, and free for the basic functionality. It requires no user-provided data and no GIS expertise, can be applied anywhere in the terrestrial world, and only takes a few minutes for each model run. It pulls from global data which may not otherwise be accessible to local actors and decision makers. It can be run for both relatively small sites or across large spatial areas (e.g. large watersheds or entire countries). With a paid license (offered free to organisations with few resources), users can run WaterWorld with their own data, use the latest developed advanced functionality, and receive greater support. Though it uses global data, WaterWorld is a sophisticated hydrological model and includes many processes usually ignored in other models including wind-driven rain, fog and snow and ice models.

## Limitations

Also like Co$ting Nature, the free version of WaterWorld uses global datasets and all modelling parameters are pre-set by the model developer; these data and parameters might not be the best for a given site or location. As with any model, modelling results should be validated by the user. (The model developers can help provide equipment for this: www.freestation.org.) For small sites (smaller than a few square kilometres) the resolution of global data may be too coarse to provide useful results. The model is closed source; the basic functionality required by most users is free, but more advanced functions, including running the model with user-defined data or for commercial use, require paid licenses and GIS capacity. Using WaterWorld requires an internet connection, which can be a barrier in certain contexts.

## Potential applications for KBAs, WHS and PAs

Since it is rapid, free, and easy to learn, WaterWorld can be used for rapid assessments of water-related services at one or multiple sites. It can be used for exploratory analyses or scoping before conducting more detailed assessment on the ground. It can be run across relatively large spatial areas enabling modelling of multiple sites simultaneously.

## Summary

WaterWorld is a rapid, easy to use modelling tool. Because it does not require any data or specialised expertise, it can provide useful information that can either be used to inform decisions or provide the basis of more in-depth ES assessment.

## WaterWorld Case study:

### Using WaterWorld as a Fundamental Tool in the Prioritisation of Actions and Areas to Environmental Compensation in Mining and Infrastructure Projects of Colombia (author: César Augusto Ruiz-Agudelo)

Regardless of its natural riches and renowned diversity, present-day Colombia faces the challenge of attaining economic growth supported by a sustainable management of its natural resources and ES. The current National Development Plan 2014-2018: Todos Por Un Nuevo País, proposes to build a peaceful, just and educated Colombia with an economic growth based on five pillars of development, namely agriculture, mining and energy, infrastructure, housing, and innovation. These pillars will affect the integrity of Colombia's natural capital in greater or smaller measure and will in all likelihood cause conflicts between the environment and economic growth.

In this socio-economic and environmental context, mining and extractive activities are one of the central drivers of the country's economic development. This has inspired varied debates: political, philosophical, ethical, cultural, nationalist, conservationist, developmental, and even normative. Unfortunately, a good part of these debates, and their contributions to public opinion, have been based more on perception rather than on the knowledge and scientific or technical evidence available. When the debate is shaped by perception and 'passion', one loses objectivity on the question debated, unleashing social movements that struggle, without an adequate comprehension of the facts, based on mainly emotional causes.

From a policy perspective, the Colombian government has made progress in formulating laws seeking to ensure that mining and infrastructure projects in Colombia comply with the mitigation hierarchy and plan their proposals for environmental compensation for any unmitigated impacts. In this aspect, in the definition of decision criteria to define actions and areas of environmental compensation for mining and infrastructure projects, the use of WaterWorld has been fundamental to add robust technical information to evaluate the feasibility of implementation of these types of projects.

The potential impact of large-scale mining and infrastructure development on water resources in Colombia (in terms of water availability, quality and flow regulation) has been the main source of the country's largest socio-environmental conflicts and debates. The concern about the availability of water resources is of the greatest interest to local actors and other interested parties in this type of project.

WaterWorld has been a fundamental tool for understanding these socio-environmental conflict, and for the contribution of solid technical evidence to the decision makers in governmental, private, local, NGO, academia, and other roles. With the application of this tool it has been possible to understand:

1. The hydrological dynamics in regions with potential development of large mining and infrastructure projects in Colombia;
2. Water regulation in regions with potential mining and infrastructure projects in Colombia;
3. What would be the impact (evaluated a priori - ex ante) of the large mining and infrastructure projects in Colombia on water balance, water quality and water regulation.

Based on the understanding of these impacts, WaterWorld has made it possible to prioritize areas (sectors of the country) where it is most necessary to develop environmental compensation projects for water balance, water quality and water regulation. As well as, it has allowed the development of technical criteria that support the viability or non-feasibility of these projects, according to their impact on this valuable natural resource and its central ecological functions.

WaterWorld results in the Colombian case have been shown to be strong in terms of their technical robustness and their graphic power to convey concrete messages (about the viability or lack of viability of development projects in Colombia) to decision-makers in government, private sector, and NGOs, among others. To date Conservation International Colombia, and mining and infrastructure development companies, have implemented WaterWorld in the Cundinamarca, Antioquia, Santander, Caquetá and Putumayo, Chocó, Guajira and Magdalena Colombian departments.

In all these cases, WaterWorld has allowed the incorporation of new and robust technical criteria into the decision-making process regarding the implementation and viability of these project types in different regions of Colombia. The focus was in water resource management, facilitating decision making and actions (both governmental and corporate) that are more informed, and in favour of safeguarding of Colombia's natural capital.

### Reference:

Ruiz, C.A. (2017). 'Using Waterworld as a Fundamental Tool in the Prioritization of Actions and Areas to Environmental Compensation in Mining and Infrastructure Projects of Colombia' [online article]. *Policy Support.* Available at: blog.policysupport.org/2017/11/using-waterworld-as-fundamental-tool-in.html?q=mining (Accessed: 23 April 2018).

# Annex III. Evaluation of all tools reviewed against different criteria

| | Cost and availability for application to new sites | | | | | Scale and environmental context | | | Time, data and resources requirements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Cost** | **Availability** | **Open source (for software)** | **Generalizability / Applicability in new contexts** | **Capacity for independent application** | **Single/ multiple site** | **Scale of analysis** | **Applicable to terrestrial, freshwater, marine** | **Time requirements** | **Data input demand** | **Technical requirements** | **Skill requirements** | **Interface** | **Level of stakeholder engagement required** |
| **ARIES** | Free | Available | Open source | High for global models, low for case studies | Yes, through web explorer or stand-alone software tool | Single or multiple | Local to global | All | Low for global models; High for new case studies | Low to high | Computer and internet access | Low to high | Specialized software (k.LAB/Eclipse) and web application | Low |
| **Co$ting Nature** | Free (basic version) or paid license (advanced versions) | Available | Closed-source | High | Yes | Single or multiple | Local to global | Terrestrial, Freshwater | Low | Low | Computer and internet access | Low | Web application | Low |
| **CSR** | Free | Available | N/A | High | Yes | Single or multiple | Local | All | Low | Low | None | Low | Guidance document (.pdf) | Moderate |
| **EST** | Free | Available | N/A | High | Yes | Single or multiple | Local to global | All | Low to high | Low to high | None | Low to high | Guidance document (.pdf) | Low to high |
| **InVEST** | Free | Available | Open source | High, though limited by availability of underlying data | Yes | Single or multiple | Local to regional | All | Moderate to high | Moderate to high | Computer, GIS software | Moderate to High | Desktop application; Python API (optional) | Low |

| | Cost and availability for application to new sites | | | | | Scale and environmental context | | | Time, data and resources requirements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Cost** | **Availability** | **Open source (for software)** | **Generalizability / Applicability in new contexts** | **Capacity for independent application** | **Single/ multiple site** | **Scale of analysis** | **Applicable to terrestrial, freshwater, marine** | **Time requirements** | **Data input demand** | **Technical requirements** | **Skill requirements** | **Interface** | **Level of stakeholder engagement required** |
| **LUCI** | Free, requires purchase of ArcGIS software | Requires collaboration with model developers | Open source | Low; currently developed for UK and New Zealand only | No. Supported for UK, NZ. Exploring applications in Australia, Philippines, Vietnam, Samoa, other Pacific Islands | Single | Local to regional | Terrestrial, freshwater | Moderate | Moderate to high | Computer, ArcGIS | Moderate | ArcGIS | Low to high |
| **MIMES** | Free, requires purchase of SIMILE software | Available | Open source (SIMILE software is closed-source) | Low until global or national models are completed | Yes, assuming user has access to SIMILE modeling software | Single or multiple | Local to regional | All | High for new case studies | High | Computer and internet access, Similie software, GIS software | High | MIDAS/SIMILIE (not open source) | High |
| **PA-BAT** | Free | Available | N/A | Low | Yes | Single | Local | All | Low to moderate | Low | None | Low | Survey form (.pdf) | Moderate |
| **SolVES** | Free, requires purchase of ArcGIS software | Available | Closed-source | Low until value transfer can be shown to successfully estimate values at new sites | Yes, assuming user has access to ArcGIS | Single or multiple | Local to regional | All | Low to high | Low to moderate | Computer, ArcGIS | Moderate | ArcGIS (add-in toolbar) | High |
| **TESSA** | Free | Available | N/A | High | Yes | Single | Local | All | Low to high | Moderate to high | Field equipment (optional) | Low | User manual (interactive .pdf) | High |
| **WaterWorld** | Free (basic version) or paid license (advanced versions) | Available | Closed-source | High | Yes | Single or multiple | Local to global | Freshwater | Low | Low | Computer and internet access | Low | Web application | Low |

## Annex III. Evaluation of all tools reviewed against different criteria

| | Cost and availability for application to new sites | | | | | Scale and environmental context | | | Time, data and resources requirements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Cost** | **Availability** | **Open source (for software)** | **Generalizability / Applicability in new contexts** | **Capacity for independent application** | **Single/ multiple site** | **Scale of analysis** | **Applicable to terrestrial, freshwater, marine** | **Time requirements** | **Data input demand** | **Technical requirements** | **Skill requirements** | **Interface** | **Level of stakeholder engagement required** |
| **WHBET** | Free; requires MS Excel software | Available | Requires use of MS Excel | Low; currently developed for the US only | Yes, within the U.S. | Single or multiple | Local to regional | Terrestrial, freshwater | Low | Low | Computer and internet access, MS Excel | Low | Excel spreadsheets (.xls) | Low |
| **An introductory guide to valuing ES** | Free | Available | N/A | High | Yes | Single or multiple | Local to global | All | Low | Low | None | Low | Pdf guidance document | N/A |
| **EcoSERVE** | Free | Available | Requires use of ArcGIS | UK specific | Yes | Single | Local | Terrestrial and freshwater | High | Medium | ArcGIS with the Spatial Analyst Extension | High | Requires use of ArcGIS | Low |
| **Ecosystem Services Assessment: how to do one in practice** | Free | Available | N/A | High | Yes | Single or multiple | Local to global | All | Low | Low | None | Low | Pdf guidance document | N/A |
| **Ecosystem Services Assessment Support Tool** | Free | Available | N/A | High | Yes | Single or multiple | All | All | Low | None | Computer, internet access | Low | Online guidance | None |
| **Ecosystem services identification and inventory tool** | Free for version one | Available | Closed source | High | Yes | Single | Local | All (but not tested in marine environments) | Medium | High (field data collection) | Computer or iPad for the app | Low | Web-based or an app | Low |
| **Ecosystem Services Partnership Visualization Tool (ESP-VT)** | Free | Yes | N/A | N/A | Yes | N/A | Local to national | All | Low | Low | Computer, internet access | Low | Website | None |
| **Ecosystem services Valuation Toolkit (EVT)** | Not available currently | At present, EVT is an internal tool for access by Earth Economics team members only | N/A | Low | No | N/A | All | All | Low | None | Computer, internet access | Low | Database | None |
| **EnviroAtlas** | Free | Available | N/A | USA only | Yes, within the USA | Sinlge or multiple | Local to national | All | Low | None (included in the tool) | Computer and internet access | Medium | Web application | Low |

| | Cost and availability for application to new sites | | | | | Scale and environmental context | | | Time, data and resources requirements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Cost** | **Availability** | **Open source (for software)** | **Generalizability / Applicability in new contexts** | **Capacity for independent application** | **Single/ multiple site** | **Scale of analysis** | **Applicable to terrestrial, freshwater, marine** | **Time requirements** | **Data input demand** | **Technical requirements** | **Skill requirements** | **Interface** | **Level of stakeholder engagement required** |
| **Envision (Evoland modelling platform 3.5)** | Free | Available | Open source | Time consuming and costly to apply in new areas | Yes | Single | Landscape | All | High | High | Computer, internet access | High | Desktop application | Varies |
| **GecoServe** | Free | Available | N/A | A searchable database of ecosystem services value information for the Gulf of Mexico | Yes | N/A | All | Marine | Low | None (included in the tool) | Computer, internet access | Low | Website | None |
| **Marine Biological Valuation Mapping (BVMtool)** | Free | Available | Open source | Unknown | Yes | Single | Marine habitats | Marine | High | High | Computer; R | High | R scripts | Low |
| **Measuring ES - Guide for developing ES indicators** | Free | Available | N/A | High | Yes | Single or multiple | Local to regional | All | Low | Low | None | Low | Pdf guidance document | N/A |
| **MIDAS** | Free | Available for sites that have been developed | Open source | High | Yes | Single or multiple | All | All | Medium | Dependent on depth of question and analysis required | Computer and internet access | Low | Web interface | None-Moderate (as desired) |
| **Ocean Data Viewer** | Free | Yes | N/A | Global datasets | Yes | N/A | All | Marine | Low | None (included in the tool) | Computer, internet access | Low | Web-based | None |
| **Planning management for ES Manual** | Free | Available | N/A | High | Yes | Single | Local to regional | Terrestrial, freshwater | Low | Low | None | Low | Pdf guidance document | High |
| **Quickscan** | Free, but additional software is required for some functionality (e.g. ArcGIS) | Available | Unknown | High | Yes | Single | Regional to national to continental | All | Low to high | High | Computer, GIS software | Medium | Specialized software | High |

## Annex III. Evaluation of all tools reviewed against different criteria

| | Cost and availability for application to new sites | | | | | Scale and environmental context | | | Time, data and resources requirements | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criterion | Cost | Availability | Open source (for software) | Generalizability / Applicability in new contexts | Capacity for independent application | Single/ multiple site | Scale of analysis | Applicable to terrestrial, freshwater, marine | Time requirements | Data input demand | Technical requirements | Skill requirements | Interface | Level of stakeholder engagement required |
| **TELSA** | Requires commercial software products (MS Access and ArcView/ Spatial Analyist GIS) | Available | Closed source | High | Yes | Single | Landscape | Terrestrial | High | High | Requires commercial software products (MS Access and ArcView/ Spatial Analyist GIS) | Medium | Specialized software | Medium |
| **WaSSI** | Free | Available | Unknown | US, Mexico, Rwanda and Burundi | Yes | Single or multiple | Local to regional | Terrestrial | Low | None (included in the tool) | Computer, internet access | Moderate | Web-based | None |

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| Criterion | Quantitative / Qualitative | Monetary / Nonmonetary | Spatially explicit? | Absolute vs. relative value | Scenario comparison | User support | Level of development & documentation | Approach to uncertainty | Static (single time period) / dynamic model (temporal variation) | General summary / insights |
| **ARIES** | Quantitative or Qualitative | Monetary or non-monetary | Yes | Either | Yes | Moderate | Case studies & global models developed and documented | Uncertainty through Bayesian netwrosk, Monte Carlo simulation and machine learning | Static or dynamic | Spatially explicit ecosystem service tradeoff, flow, and uncertainty maps; currently time consuming for new applications, unless using global models |
| **Co$ting Nature** | Quantitative (relative values) | Monetary or non-monetary | Yes | Relative | Yes | Moderate | Partially documented | Uncertainty through sensitivity analysis | Static | Rapid analysis of indexed, bundled services based on global data, along with conservation priority maps |
| **CSR** | Qualitative | N/A | Yes | N/A | No | Low | Fully developed and documented | T/P | N/A | A guidance document with step by step guidance on qualitative ES assessment based on using expert input, with a focus on risks and opportunities for business |

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Quantitative / Qualitative** | **Monetary / Nonmonetary** | **Spatially explicit?** | **Absolute vs. relative value** | **Scenario comparison** | **User support** | **Level of development & documentation** | **Approach to uncertainty** | **Static (single time period) / dynamic model (temporal variation)** | **General summary / insights** |
| **EST** | Quantitative or Qualitative | Monetary or non-monetary | Either | Either | Yes | Low | Fully developed and documented | N/A (there is a section that explains how to approach uncertainty issues) | N/A | A detailed step by step guidance document on conducting ES assessment in various contexts, a comprehensive review of all existing methods and tools |
| **InVEST** | Quantitative or Qualitative | Monetary or non-monetary | Yes | Either | Yes | High | Fully developed and documented | Uncertainty through varying inputs | Static | Spatially explicit ecosystem service tradeoff maps; currently relatively time consuming to parameterize |
| **LUCI** | Quantitative | Nonmonetary | Yes | Relative | No | Low | Case studies developed and documented | Currently does not report uncertainty | Static | Spatially explicit ecosystem service tradeoff maps; designed to be relatively intuitive to use and interpret |
| **MIMES** | Quantitative | Nonmonetary | Yes | Either | Yes | Moderate | Case studies developed and documented | Uncertainty through varying inputs (automated) | Static or Dynamic | Dynamic modeling and valuation using input–output analysis; highly time consuming to develop and run |
| **PA-BAT** | Qualit ative | Nonmonetary | No | Relative | No | Moderate | Fully developed and documented | None (paper form) | Static | Qualitative paper-based forms for protected area managers and stakeholders to assess benefits provided by protected areas |
| **SolVES** | Quantitative | Nonmonetary | Yes | Relative | No | Moderate | Fully developed and documented | No explicit handling of uncertainty | Static | Provides maps of social values for ecosystem services; time consuming for new studies but lower cost for value transfer |
| **TESSA** | Quantitative or qualitative | Monetary or non-monetary | No | Absolute or relative | Yes | Moderate | Fully developed and documented | Guidance provided on level of confidence | Static | A collection of site-based comparative assessment methods targeted at practitioners without specialized skills |
| **WaterWorld** | Quantitative (relative values) | Nonmonetary | Yes | Relative | No | Moderate | Partially documented | None | Static | Rapid analysis of indexed, bundled services based on global data, along with conservation priority maps |
| **WHBET** | Quantitative | Monetary | No | Absolute | Yes | Moderate | Fully developed and documented | None | Static | An excel-based set of tools for analyzing the economic value of conservation or natural areas using the benefits transfer method; tool developed for application in the U.S. |

# Annex III. Evaluation of all tools reviewed against different criteria

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Quantitative / Qualitative** | **Monetary / Nonmonetary** | **Spatially explicit?** | **Absolute vs. relative value** | **Scenario comparison** | **User support** | **Level of development & documentation** | **Approach to uncertainty** | **Static (single time period) / dynamic model (temporal variation)** | **General summary / insights** |
| **An introductory guide to valuing ES** | N/A | N/A | No | N/A | N/A | N/A | Fully developed and documented | N/A | N/A | The aim of this Guide is to provide an introduction to the valuation of ecosystem services. It provides a practical introduction to the key steps to be undertaken in valuing ecosystem services in a policy appraisal context. The Guide takes an impact pathway approach to valuing ecosystem services. |
| **EcoSERVE** | Quantitative and qualitative | Nonmonetary | Yes | Absolute and relative | Yes | Unknown | Fully developed and documented | Unknown | Static | EcoSERVE-GIS is a Geographical Information Systems (GIS) toolkit for mapping ecosystem services at the county scale, which has been developed for the Wild life Trusts. The toolkit generates fine scale (Default 10m grid cell resolution) maps illustrating the requirement (human need or demand) for each service as well as the capacity of the natural environment to provide the service, using scientifically-based, standardised methods and widely available datasets. |
| **Ecosystem Services Assessment: how to do one in practice** | N/A | N/A | No | N/A | N/A | N/A | Fully developed and documented | N/A | N/A | Good Introductory Guidance on the topic. The guide provides generic information about the value of and the steps entailed in undertaking an ecosystem services assessment, drawing upon learning from a series of published ecosystem services case studies and providing references to further guidance and sources of information. |
| **Ecosystem Services Assessment Support Tool** | N/A | N/A | No | N/A | N/A | Unknown | Fully developed and documented | N/A | N/A | Online guidance to ecosystem services assessment. Breaks down the ecosystem services assessment process into logical sequence of steps |
| **Ecosystem services identification and inventory tool** | Quantitative or qualitative | Nonmonetary | Yes | Absolute and relative | Yes | Online forum | Fully developed and documented | Unknown | Unknown | The Ecosystem Services Identification & Inventory Tool, or the ESII Tool, is an iPad app and web interface that lets people understand the benefits that nature provides and incorporate the value of nature into decision making. |
| **Ecosystem Services Partnership Visualization Tool (ESP-VT)** | N/A | N/A | N/A | N/A | N/A | Low | N/A | N/A | N/A | The ESP-VT is an interactive knowledge platform that allows users to share information on ecosystem services maps, data and mapping methods. |
| **Ecosystem services Valuation Toolkit (EVT)** | Qualitative | Monetary | No | Absolute and relative | Unknown | Unknown | Partially documented | N/A | N/a | Ecosystem services Valuation Toolkit (EVT) is a comprehensive, searchable database of ecosystem service values. It compiles values from ES values databases and academic journals. |

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Quantitative / Qualitative** | **Monetary / Nonmonetary** | **Spatially explicit?** | **Absolute vs. relative value** | **Scenario comparison** | **User support** | **Level of development & documentation** | **Approach to uncertainty** | **Static (single time period) / dynamic model (temporal variation)** | **General summary / insights** |
| **EnviroAtlas** | Quantitative/qualitative | Monetary and non-monetary | Yes | Absolute and relative | Yes | Moderate | Fully developed and documented | N/A | N/A | Tool seeks to meet a range of needs by bringing together environmental, economic and demographic data in an ecosystem services framework. Within EnviroAtlas, there are three primary types of geospatial data: research-derived ecosystem services indicator data in their native resolution, indicator data that have been summarized to standard reporting units, and reference data. Reporting units include watershed basins across the contiguous U.S. and Census block groups throughout featured urban areas. EnviroAtlas includes both current and future drivers of change, such as land use and climate, for addressing issues of adaptation, conservation, equity, and resiliency. In addition to geospatial data, EnviroAtlas includes geospatial and statistical tools, and resources that support research, education, and decision-making. |
| **Envision (Evoland modelling platform 3.5)** | Quantitative or Qualitative | Monetary and non-monetary | Yes | Absolute and relative | Yes | Moderate | Fully developed and documented | Unknown | Unknown | GIS based tool for scenario -based community and regional integrated planning and environmental assessments. Provides a robust platform for integrating a variety of spatially explicit models of landscape change process and production for conducting alternative future ananlyses. Envision was created to conduct research about the nature and properties of coupled human and natural environmental systems in the context of climate change. The approach employed scenarios, data and evaluative models. |
| **GecoServe** | N/A | Monetary and non-monetary (refers to valuation case studies) | N/A | N/A | N/A | Unknown | Partially documented | N/A | N/A | The two main goals of the GecoServ database are to allow for the distribution and sharing of information about ES valuation studies relevant to the Gulf of Mexico region and to identify current gaps in the ES literature. |
| **Marine Biological Valuation Mapping (BVMtool)** | Quantitative | Monetary and non-monetary | Yes | Relative | Unknown | Unknown | Fully developed and documented | Unknown | N/a | BVMtool is a set of R scripts automating marine biological valuation calculations based on the biological valuation concept as developed by Derous et al. (2007) and described by Deneudt et al. (2013).The results of the valuation questions are summarized in final scores for each ecosystem component and can be combined with the final results obtained for other ecosystem components. Subzones can be defined as raster grid cells of a desired size or can be based on polygons of a habitat classification provided by the user. |
| **Measuring ES - Guide for developing ES indicators** | N/A | N/A | No | N/A | N/A | N/A | Fully developed and documented | N/A | N/A | The guidelines have been produced to support the development of ecosystem service indicators at the national and regional level for uses in reporting, policy-making, biodiversity conservation, ecosystem management, environmental management, development planning and education. The guidance is designed to assist in the development of ecosystem service indicators on both a 'one-off' basis to meet the needs for a particular study or report (e.g. ecosystem assessments), or for long-term reporting and decision making (e.g. to Conventions such as the CBD). |

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Quantitative / Qualitative** | **Monetary / Nonmonetary** | **Spatially explicit?** | **Absolute vs. relative value** | **Scenario comparison** | **User support** | **Level of development & documentation** | **Approach to uncertainty** | **Static (single time period) / dynamic model (temporal variation)** | **General summary / insights** |
| **MIDAS** | Quantiative and qualitative | Monetary modules | Yes | Either | Yes | Moderate | Documentation available for developed scenarios | Uncertainty through sensitivity analysis | Static or dynamic | The Multi-scale Integrated Decision Analysis System (MIDAS) is a software tool that was developed to assist users and managers in understanding the critical factors that influence governance nad managment effects so that they can plan accordingly, to estimate likely impacts of cision-making based on the ecological, socioeconomic and governance conditions, to evaluate tradeoffs for ESS needs and finally, to advise management plan revisions that will result in optimization of outcomes and outputs. The model can be described as a spatial decision support system to help managers and users quickly analyze and visualize outcomes from the interaction of socio-economic, governance, and ecological factors of ESS management and planning. |
| **Ocean Data Viewer** | Quantitative/qualitative | N/A | Yes | Absolute and relative | No | User guide | Fully developed and documented | N/A | N/A | The Ocean Data Viewer offers users the opportunity to view and download a range of spatial datasets that are useful for informing decisions regarding the conservation of marine and coastal biodiversity. |
| **Planning management for ES Manual** | N/A | N/A | N/A | N/A | Yes | Moderate | Fully developed and documented | N/A | N/A | A training manual on planning management that presents key knowledge and six steps for setting objectives and choosing actions to manage environments for multiple ecosystem services. |
| **Quickscan** | Qualitative | Monetary and non-monetary | Yes | Absolute and relative | Yes | Moderate | Fully developed and documented | N/A | N/A | QUICKScan is both an approach and a software tool that is applied in group process with policy makers and experts to develop and explore potential policy options and assess likely impacts of those options. |
| **TELSA** | Quantitative/qualitative | Nonmonetary | Yes | Absolute and relative | Yes | Unknown | Fully developed and documented | Unknown | Dynamic | The Tool for Exploratory Landscape Scenario Analyses (TELSA) is a spatially explicit, GIS-based landscape-level model for simulating terrestrial ecosystem dynamics and assessing the consequences of alternative management scenarios at the landscape scale. |

| | Type of outputs and results | | | | | User support and available guidance/training | | Characteristics of models | | General summary/description |
|---|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **Quantitative / Qualitative** | **Monetary / Nonmonetary** | **Spatially explicit?** | **Absolute vs. relative value** | **Scenario comparison** | **User support** | **Level of development & documentation** | **Approach to uncertainty** | **Static (single time period) / dynamic model (temporal variation)** | **General summary / insights** |
| **WaSSI** | Qualitative and quantitative | Nonmonetary | Yes | Absolute and relative | Yes | Unknown | Fully developed and documented | WaSSI water and carbon predictions are subject to similar uncertainties associated with all ecosystem models, including uncertainty in input data, uncertainty in the representation of the physical processes that govern the watershed water balance and ecosystem productivity. | Dynamic | The Water Supply Stress Index Model (WaSSI) is a web-based tool that can be used to project the effects of land use change, climate change, and water withdrawals on river flows, water supply stress, and ecosystem productivity (i.e., carbon sequestration dynamics) across the conterminous United States, Mexico, Rwanda, and Burundi. As water yield and carbon sequestration are tightly coupled, WaSSI is useful for evaluating trade-offs among management strategies for these ecosystem services. |

# Annex IV. References to case studies showcasing use of tools for different purposes

| | **Public/policy support** | | | |
|---|---|---|---|---|
| **Reasons for measuring ES provided by sites** | Provide additional evidence and justification for the importance of conserving a particular site | Foster local awareness of the ES provided by a particular site | Build support for the conservation of multiple sites through increased understanding of their wide range of benefits | Link ES contributed by all sites in a country to international or national sustainability goals and national policies (e.g. SDGs) |
| **ARIES** | Multiple examples - see aries.integratedmodelling.org/?page_id=546 | | link.springer.com/article/10.1007/s10980-016-0430-6, link.springer.com/article/10.1007/s10113-015-0756-7 | |
| **Co$ting Nature** | blog.policysupport.org/search?q=guest+co$ting%20Nature www.policysupport.org/costingnature/example-applications | blog.policysupport.org/search?q=co$ting+nature+local+awareness | blog.policysupport.org/2017/04/using-coting-nature-to-assess-guinean.html | blog.policysupport.org/2016/08/world-conservation-congress-2016-we.html?q=WDPA |
| **InVEST** | Bhagabati, Nirmal K., Taylor Ricketts, Thomas Barano Siswa Sulistyawan, Marc Conte, Driss Ennaanay, Oki Hadian, Emily McKenzie et al. 'Ecosystem services reinforce Sumatran tiger conservation in land use plans.' *Biological Conservation 169* (2014): 147-156. doi.org/10.1016/j.biocon.2013.11.010 | Natural Capital Project in the Heart of Borneo: Investing in Nature for a Green Economy www.naturalcapitalproject.org/wp-content/uploads/2017/05/Natural-Capital-Project-in-the-Heart-of-Borneo.pdf | Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., Dixon, A., Horton, R., Lesk, C., Manley, D. and De Mel, M., (2017). 'Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar'. *PloS ONE*, 12(9), p.e0184951. doi.org/10.1371/journal.pone.0184951 See also: www.naturalcapitalproject.org/wp-content/uploads/2016/07/natural-connections-how-natural-capital-supports-myanmars-people-and-economy.pdf | Clarke, C., Canto, M., & Rosado, S. (2013). *Belize integrated Coastal Zone management plan. Coastal Zone Management Authority and Institute* (CZMAI), Belize City. www.coastalzonebelize.org/wp-content/uploads/2015/08/BELIZE-Integrated-Coastal-Zone-Management-Plan.pdf |
| **PA-BAT** | Final thesis "Applicability of Results from the Protected Area Benefit Assessment Tool (PA-BAT) to Protected Area Management in Croatia – The Example of Paklenica National Park" www.researchgate.net/publication/319208174_Applicability_of_Results_from_the_Protected_Area_Benefit_Assessment_Tool_PA-BAT_to_Protected_Area_Management_in_Croatia_-_The_Example_of_Paklenica_National_Park | www.researchgate.net/publication/319208174_Applicability_of_Results_from_the_Protected_Area_Benefit_Assessment_Tool_PA-BAT_to_Protected_Area_Management_in_Croatia_-_The_Example_of_Paklenica_National_Park | Multiple examples - see 4 national reports natureforpeople.org/protected_areas/ | Multiple examples - see 4 national reports natureforpeople.org/protected_areas/ |

| | Public/policy support | | | |
|---|---|---|---|---|
| **SolVES** | | | Bagstad, K.J., Reed, J.M., Semmens, D.J., Sherrouse, B.C., and Troy, A. (2016). 'Linking biophysical models and public preferences for ecosystem service assessments: a case study for the Southern Rocky Mountains'. *Regional Environmental Change* 16 (7): 2005-2018. | |
| **TESSA** | Peh, K. S-H., Thapa, I., Basnyat, M., Balmford, A., Bhattarai, G. P., Bradbury, R. B., ... Merriman, J. C. (2016). 'Synergies between biodiversity conservation and ecosystem service provision: lessons on integrated ecosystem service valuation from a Himalayan protected area, Nepal'. *Ecosystem Services*, 22(Part B), 359-369. 10.1016/j.ecoser.2016.05.003 | Birch, J. C., Thapa, I., Balmford, A., Bradbury, R. B., Brown, C., Butchart, S. H. M., ... Thomas, D. H. L. (2014). 'What benefits do community forests provide, and to whom? A rapid assessment of ecosystem services from a Himalayan forest, Nepal'. *Ecosystem Services*, 8, 118-127. 10.1016/j.ecoser.2014.03.005 | BCN and DNPWC (2012) *Conserving biodiversity and delivering ecosystem services at Important Bird Areas in Nepal*. Kathmandu and Cambridge, UK: Bird Conservation Nepal, Department of National Parks and Wildlife Conservation, and BirdLife International | |
| **WaterWorld** | www.policysupport.org/waterworld/example-applications/water-based-ecosystem-services-for-the-shivapuri-national-park | blog.policysupport.org/search?q=local+awareness | blog.policysupport.org/search?q=%-22global+analysis%22+AND+waterworld<br>blog.policysupport.org/2017/04/using-waterworld-to-provide-water.html<br>blog.policysupport.org/search?q=multiple+sites | blog.policysupport.org/2016/06/waterworld-being-applied-for-world-bank.html<br>blog.policysupport.org/2014/09/a-spatially-explicit-state-of-worlds.html |

| | Site management | | |
|---|---|---|---|
| **Reasons for measuring ES provided by sites** | Establish the baseline of ES provided by a site, to enable monitoring of changes and support management planning | Reveal synergies and possible trade-offs between ES and/or ES and conservation objectives to identify management options for the site | Develop, implement and update management strategies for the site, building on the understanding of ES (e.g. integration of ES into site's management plan or developing a business plan for the site) |
| **ARIES** | Multiple examples - see aries.integratedmodelling.org/?page_id=546 | | |
| **Co$ting Nature** | blog.policysupport.org/2017/06/towards-eba-using-waterworld-and-coting.html | | |
| **InVEST** | Evaluating the Impacts of Water Funds on Ecosystems and People www.naturalcapitalproject.org/wp-content/uploads/2017/05/Evaluating-the-Impacts-of-Water-Funds-on-Ecosystems-and-People.pdf | Ma, S., Duggan, J.M., Eichelberger, B.A., McNally, B.W., Foster, J.R., Pepi, E., Conte, M.N., Daily, G.C. and Ziv, G., (2016). 'Valuation of ecosystem services to inform management of multiple-use landscapes'. *Ecosystem Services*, 19, pp.6-18. doi.org/10.1016/j.ecoser.2016.03.005<br>Also see: www.naturalcapitalproject.org/wp-content/uploads/2017/04/Enlisting-Ecosystem-Services-with-the-DoD.pdf | Ma, S., Duggan, J.M., Eichelberger, B.A., McNally, B.W., Foster, J.R., Pepi, E., Conte, M.N., Daily, G.C. and Ziv, G., (2016). 'Valuation of ecosystem services to inform management of multiple-use landscapes'. *Ecosystem Services*, 19, pp.6-18. doi.org/10.1016/j.ecoser.2016.03.005<br>Also see: www.naturalcapitalproject.org/wp-content/uploads/2017/04/Enlisting-Ecosystem-Services-with-the-DoD.pdf |

| | Site management | | |
|---|---|---|---|
| **PA-BAT** | www.researchgate.net/publication/319208174_Applicability_of_Results_from_the_Protected_Area_Benefit_Assessment_Tool_PA-BAT_to_Protected_Area_Management_in_Croatia_-_The_Example_of_Paklenica_National_Park | www.researchgate.net/publication/319208174_Applicability_of_Results_from_the_Protected_Area_Benefit_Assessment_Tool_PA-BAT_to_Protected_Area_Management_in_Croatia_-_The_Example_of_Paklenica_National_Park | www.researchgate.net/publication/319208174_Applicability_of_Results_from_the_Protected_Area_Benefit_Assessment_Tool_PA-BAT_to_Protected_Area_Management_in_Croatia_-_The_Example_of_Paklenica_National_Park |
| **SolVES** | Sherrouse, B.C., Semmens, D.J., Anchona, Z., and Brunner, B., (2017). 'Analyzing land-use change scenarios for trade-offs among cultural ecosystem services in the Southern Rocky Mountains'. *Ecosystem Services*, 26:431-444. doi.org/10.1016/j.ecoser.2017.02.003 | Sherrouse, B.C., Semmens, D.J., Anchona, Z., and Brunner, B., (2017). 'Analyzing land-use change scenarios for trade-offs among cultural ecosystem services in the Southern Rocky Mountains'. *Ecosystem Services*, 26:431-444. doi.org/10.1016/j.ecoser.2017.02.003<br>Lin, Y., Lin W., Li H., Wang, Y., Hsu, C., Lien, W., Anthony, J., Petway, J.R. (2017). 'Integrating social values and ecosystem services in systematic conservation planning: A case study in Datuan Watershed'. *Sustainability* 9(5): 718. doi.org/10.3390/su9050718 | |
| **TESSA** | Peh, K. S-H., Balmford, A., Birch, J. C., Brown, C., Butchart, S. H. M., Daley, J., ... Bradbury, R. B. (2015). 'Potential impact of invasive alien species on ecosystem services provided by a tropical forested eco-system: a case study from Montserrat'. *Biological Invasions*, 17(1), 461-475. 10.1007/s10530-014-0743-9 | Muoria, P., Field, R., Matiku, P., Munguti, S., Mateche, E., Shati, S., Odeny, D. (2015) Yala Swamp Ecosystem Service assessment. Nature Kenya, Nairobi | Peh, K. S-H., Balmford, A., Field, R. H., Lamb, A., Birch, J. C., Bradbury, R. B., ... Hughes, F. M. R. (2014). 'Benefits and costs of ecological restoration: rapid assessment of changing ecosystem service values at a U.K. wetland'. *Ecology and Evolution*, 4(20), 3875-3886. 10.1002/ece3.1248 |
| **WaterWorld** | blog.policysupport.org/2017/06/towards-eba-using-waterworld-and-coting.html | blog.policysupport.org/2016/05/predicting-water-availability-trends.html | |

| | Human well-being | |
|---|---|---|
| **Reasons for measuring ES provided by sites** | Ensure a good understanding of the ES values that are important to resident, local and more distant stakeholders | Assess compensation options to resident and local stakeholders for ES forgone as a result of biodiversity conservation, to contribute to discussions about Free Prior and Informed Consent, conflict resolution, etc. |
| **ARIES** | www.ecologyandsociety.org/vol19/iss2/art64/ | |
| **Co$ting Nature** | blog.policysupport.org/search?q=wellbeing | |
| **InVEST** | Mandle, L., Tallis, H., Sotomayor, L. and Vogl, A. L. (2015), 'Who loses? Tracking ecosystem service redistribution from road development and mitigation in the Peruvian Amazon'. *Frontiers in Ecology and the Environment*, 13: 309–315. doi:10.1890/140337 | |
| **PA-BAT** | Multiple examples - see 4 national reports natureforpeople.org/protected_areas/ | |
| **SolVES** | | |
| **TESSA** | Birch, J. C., Thapa, I., Balmford, A., Bradbury, R. B., Brown, C., Butchart, S. H. M., Thomas, D. H. L. (2014). 'What benefits do community forests provide, and to whom? A rapid assessment of ecosystem services from a Himalayan forest, Nepal'. *Ecosystem Services*, 8, 118-127. 10.1016/j.ecoser.2014.03.005 | |
| **WaterWorld** | blog.policysupport.org/search?q=wellbeing | blog.policysupport.org/2014/02/compandes-project-closes-having.html?q=benefit+sharing |

| | Planning | | | |
|---|---|---|---|---|
| **Reasons for measuring ES provided by sites** | Support spatial conservation planning and investment by identifying areas of particular importance for ES | Assess potential consequences of different sectoral (e.g. agriculture, hydropower, infrastructure) decisions and policies on ES delivered by sites (scenario comparison) | Assess potential consequences of climate change scenarios on ES provided by a site | Integrate ES delivered by sites into land-/water-/resource-use planning at regional, national or sub-national scales (e.g. Strategic Environmental Assessment) |
| **ARIES** | link.springer.com/article/10.1007/s10980-016-0430-6, link.springer.com/article/10.1007/s10113-015-0756-7 | www.sciencedirect.com/science/article/pii/S1364815214003740 | | Multiple examples - see aries.integratedmodelling.org/?page_id=546 |
| **Co$ting Nature** | blog.policysupport.org/search?q=%22conservation+prioritization%22 | blog.policysupport.org/2014/02/analysing-multiple-threats-to-water.html | | |
| **InVEST** | Vogl, Adrian L., Stacie Wolny, Alejandro Calvache, Heather Tallis and Silvia Benitez. *Science-based investment targeting for the Water for Life and Sustainability Fund, Colombia* www.naturalcapitalproject.org/wp-content/uploads/2015/11/WaterFund_Case_Study_Cauca_22Sep2015_eng.pdf | Mandle, L., Tallis, H., Sotomayor, L. and Vogl, A. L. (2015), 'Who loses? Tracking ecosystem service redistribution from road development and mitigation in the Peruvian Amazon'. *Frontiers in Ecology and the Environment*, 13: 309–315. doi:10.1890/140337 | Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., Dixon, A., Horton, R., Lesk, C., Manley, D. and De Mel, M., (2017). 'Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar'. *PloS ONE*, 12(9), p.e0184951. doi.org/10.1371/journal.pone.0184951 See also: www.naturalcapitalproject.org/wp-content/uploads/2016/07/natural-connections-how-natural-capital-supports-myanmars-people-and-economy.pdf | Sustainable Development Master Plan for Andros Island, Available online at www.naturalcapitalproject.org/wp-content/uploads/2017/06/AMP-EXECUTIVE-SUMMARY-FINAL-VERSION-FEB-2017.pdf |
| **PA-BAT** | | | | |
| **SolVES** | Lin, Y., Lin W., Li H., Wang, Y., Hsu, C., Lien, W., Anthony, J., Petway, J.R. (2017). 'Integrating social values and ecosystem services in systematic conservation planning: A case study in Datuan Watershed'. *Sustainability* 9(5): 718. doi.org/10.3390/su9050718 | | | Ancona, Z.H., D.J. Semmens, and B.C. Sherrouse. (2016). *Social-value maps for Arapaho, Roosevelt, Medicine Bow, Routt, and White River National Forests, Colorado and Wyoming. U.S. Geological Survey Scientific Investigations Report 2016-5019.* |
| **TESSA** | | Blaen, P. J., Li, J., Peh, K. S-H., Field, R. H., Balmford, A., MacDonald, M. A., & Bradbury, R. B. (2015). 'Rapid assessment of ecosystem services provided by two mineral extraction sites restored for nature conservation in an agricultural landscape in Eastern England'. *PLoS ONE*, 10(4), 1-20. DOI: 10.1371/journal.pone.0121010 | | Refer to TESSA case study in this document |
| **WaterWorld** | | blog.policysupport.org/2016/02/using-waterworld-to-inform-climate.html | blog.policysupport.org/search?q=%22climate+change%22 blog.policysupport.org/?q=GCM | blog.policysupport.org/search?q=%22water+resources+planning%22 |

| | Private sector engagement | | Funding and investment | |
|---|---|---|---|---|
| Reasons for measuring ES provided by sites | Help businesses manage risks and meet their social and environmental responsibility targets, by identifying possible impacts on ES and beneficiaries (e.g. Environmental Impact Assessments, corporate sustainability assessments) | Provide incentives for businesses to engage in the conservation of sites, by demonstrating the dependence of the businesses on ES provided by sites (e.g. public-private funding schemes, in-kind support, branding) | Attract government and donor investment from other sectors concerned with conservation of ES (e.g. water management, public health, national security) and/or donors interested in sustainable development | Support the development of new sustainable finance mechanisms for conservation of the sites, such as Payments for Ecosystem Services (PES) or carbon financing such as Reduced Emissions from Deforestation and Forest Degradation (REDD+) |
| **ARIES** | | | See Villa et al. chapter in: www.cambridge.org/us/academic/subjects/earth-and-environmental-science/hydrology-hydrogeology-and-water-resources/water-ecosystem-services-global-perspective | |
| **Co$ting Nature** | sites.google.com/site/cpwfandes3/products/basin-stories/coello/coello-in-the-national-context | | | blog.policysupport.org/search?q=REDD+ |
| **InVEST** | Kennedy, C.M., Hawthorne, P.L., Miteva, D.A., Baumgarten, L., Sochi, K., Matsumoto, M., Evans, J.S., Polasky, S., Hamel, P., Vieira, E.M. and Develey, P.F., (2016). 'Optimizing land use decision-making to sustain Brazilian agricultural profits, biodiversity and ecosystem services'. *Biological Conservation*, 204, pp.221-230. doi.org/10.1016/j.biocon.2016.10.039 (open access)<br>Also see: nature.org/TNC-Dow-Brazil | Reddy, S.M., Guannel, G., Griffin, R., Faries, J., Boucher, T., Thompson, M., Brenner, J., Bernhardt, J., Verutes, G., Wood, S.A. and Silver, J.A., (2016). 'Evaluating the role of coastal habitats and sea-level rise in hurricane risk mitigation: An ecological economic assessment method and application to a business decision'. *Integrated environmental assessment and management*, 12(2), pp.328-344. doi.org/10.1002/ieam.1678 (open access) | Vogl, A.L., Dennedy-Frank, P.J., Wolny, S., Johnson, J.A., Hamel, P., Narain, U. and Vaidya, A., (2016). 'Managing forest ecosystem services for hydropower production'. *Environmental Science & Policy*, 61, pp.221-229. doi.org/10.1016/j.envsci.2016.04.014 | Vogl, Adrian L., Stacie Wolny, Alejandro Calvache, Heather Tallis and Silvia Benitez. *Science-based investment targeting for the Water for Life and Sustainability Fund, Colombia*<br>www.naturalcapitalproject.org/wp-content/uploads/2015/11/WaterFund_Case_Study_Cauca_22Sep2015_eng.pdf |
| **PA-BAT** | | www.kdmp.gov.tr/img/files/BUSINESS_PLAN_FOR_KMNP_Final_Report.pdf | Multiple examples - see 4 national reports natureforpeople.org/protected_areas/ | |
| **SolVES** | | | | |
| **TESSA** | | | | Khe Nuoc Trong, Vietnam case study available at: www.birdlife.org/assessing-ecosystem-services-tessa/case-studies |
| **WaterWorld** | www.policysupport.org/waterworld/example-applications/alto-putumayo<br>sites.google.com/site/cpwfandes3/products/basin-stories/coello/mining | | blog.policysupport.org/search?q=%22benefit+sharing%22 | blog.policysupport.org/search?q=REDD+ |

| | **Knowledge generation** | |
|---|---|---|
| **Reasons for measuring ES provided by sites** | Inform research on ES provided by sites locally, nationally, regionally or globally | Inform research on the synergies and trade-offs between conserving biodiversity and ES, and between different ES |
| **ARIES** | Multiple examples - see aries.integratedmodelling.org/?page_id=546 | www.sciencedirect.com/science/article/pii/S1364815214003740, www.sciencedirect.com/science/article/pii/S0169204616000050 |
| **Co$ting Nature** | blog.policysupport.org/search?q=WDPA | www.policysupport.org/costingnature/example-applications/biodiversity-strategy-and-action-for-the-uk<br>www.policysupport.org/costingnature/example-applications/madagascar<br>www.policysupport.org/costingnature/example-applications/impacts-of-progressive-deforestation |
| **InVEST** | See many examples here: www.naturalcapitalproject.org/library/<br>For example: Arkema, K. K., G. M. Verutes, S. A. Wood, C. Clarke-Samuels, S. Rosado, M. Canto, A. Rosenthal, M. Ruckelshaus, G. Guannel, J. Toft, J. Faries, J. M. Silver, R. Griffin, and A. D. Guerry. (2015). 'Embedding ecosystem services in coastal planning leads to better outcomes for people and nature'. *Proceedings of the National Academy of Sciences* 112:7390–7395. 10.1073/pnas.1406483112 | See many examples here: www.naturalcapitalproject.org/library/<br>For example: Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. R. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. R. Shaw. (2009). 'Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales'. *Frontiers in Ecology and the Environment* 7:4–11. doi.org/10.1890/080023 |
| **PA-BAT** | Multiple examples - see 4 national reports natureforpeople.org/protected_areas/ parksjournal.com/wp-content/uploads/2017/04/PARKS-23.1-Ivani%C4%87-et-al-10.2305IUCN.CH_.2017.PARKS-23-1K-ZI.en_.pdf; dergipark.gov.tr/download/article-file/371599 | |
| **SolVES** | See many examples here: solves.cr.usgs.gov/publications.shtml<br>For example: van Riper, C.J. and G.T. Kyle. (2014). 'Capturing multiple values of ecosystem services shaped by environmental worldviews: A spatial analysis'. *Journal of Environmental Management* 145: 374-384. doi.org/10.1016/j.jenvman.2014.06.014 | Bagstad, K.J., Semmens, D.J., Ancona Z.H., and Sherrouse, B.C. (2017). 'Evaluating alternative methods for biophysical and cultural ecosystem services hotspot mapping in natural resource planning'. *Landscape Ecology* 32 (1): 77-97. doi.org/10.1007/s10980-016-0430-6 |
| **TESSA** | Blaen, P. J., Li, J., Peh, K. S-H., Field, R. H., Balmford, A., MacDonald, M. A., & Bradbury, R. B. (2015). 'Rapid assessment of ecosystem services provided by two mineral extraction sites restored for nature conservation in an agricultural landscape in Eastern England'. *PLoS ONE*, 10(4), 1-20. 10.1371/journal.pone.0121010 | Peh, K. S-H., Thapa, I., Basnyat, M., Balmford, A., Bhattarai, G. P., Bradbury, R. B., ... Merriman, J. C. (2016). 'Synergies between biodiversity conservation and ecosystem service provision: lessons on integrated ecosystem service valuation from a Himalayan protected area, Nepal'. *Ecosystem Services*, 22(Part B), 359-369. doi.org/10.1016/j.ecoser.2016.05.003 |
| **WaterWorld** | blog.policysupport.org/search?q=WDPA | |

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FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland, Switzerland
Tel: +41 22 999 0000
Fax: +41 22 999 0002
**www.iucn.org**