A COMPARATIVE ANALYSIS OF ECOSYSTEM SERVICE VALUATION DECISION SUPPORT TOOLS FOR WETLAND RESTORATION

Prepared for the Association of State Wetland Managers

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ABSTRACT

The Association of State Wetland Managers (ASWM) published a report in 2014 on the valuation of ecosystem services as an advantageous method for the promotion of wetland restoration. In addition to an explanation of fundamental ecosystem service valuation methodology and presentation of selected case studies, the 2014 report provided a broad list of pertinent decision support tools. As a continuation to this effort, in 2015 we conducted an extensive review of existing decision support tools suitable for the valuation of ecosystem services for wetland restoration. In turn, we chose six tools that maintain "off-the-shelf" capability and currently demonstrate the greatest potential for widespread dissemination and use. In order to aid natural resource managers' consideration of these decision support tools, we organized our findings into a three part report. The first section defines and introduces twelve criteria for comparison and differentiation between the six selected decision support tools. The subsequent section includes a collection of discrete tool profiles that outline succinctly tool features, intended application, and an outlook on future development. The third section reviews the selected tools handling of eight essential wetland ecosystem services grouped into biogeochemical, hydrological, and ecological categories. Tool functionality and resulting outputs are demonstrated and discussed through firsthand assessment and reference to publically available literature for further exploration. We conclude with insights drawn from our investigation for potential users of the selected decision support tools.

ACKNOWLEDGEMENTS

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EPA United States Environmental Protection Agency

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INTRODUCTION

The aim of this report is to provide wetland managers a resource for the selection of decision support tools (DST) appropriate for the valuation of benefits derived from wetland ecosystems in the context of wetland restoration. Many tools concerned with ecosystem management have arisen in recent years and are catalogued in NatureServe's Ecosystem-Based Management Tools Network. Nevertheless, the proliferation of tools establishes a daunting task of tool selection. In order to expedite this process, we present six DST that were filtered through initial criteria to signify tools' capacity for widespread dissemination among our target audience – wetland managers interested in the valuation of wetland ecosystem services to substantiate restoration and conservation efforts. Principally, we required that DST maintain "off-the-shelf" capability. Thus, our selected DST are readily available to the general public or are under promising development with intentions of widespread dissemination. Further, ample documentation and peer-review substantiation were necessitated, in order to signal quality and credibility.

At the outset, it is worth mentioning that we do not attempt to provide an exhaustive review of available DST and opt to concentrate on the six tools in greater depth. Observably, many noteworthy valuation tools are not included in this report as they retain attributes that limit widespread utilization. We elected to exclude DST that are proprietary (SERVES, EcoAIM, EcoMetrix, ESValue, NAIS), require contractual obligations (MIMES), retain geographic restrictions (InFOREST, Minnesota and Oregon web applications), are intended for the corporate sector (ESR, CEV), or lack explicit valuation support (WRAP, IWAT).

In order to provide a useful resource for our target audience, we begin our report with concise definitions and commentary on twelve criteria chosen to aid in tool differentiation and potential selection. After their presentation, the criteria are featured concisely in a comparative matrix along with the six selected DST (**Table 1**). The next section of the report includes the DST featured in profiles. These profiles include a succinct description of the tool's characteristics, target users indicated by developer(s), a list of the ecosystem services modeled or addressed by the tool, relevant methodology or background information, a developmental outlook, tool documentation, suggested resources (related to wetland ecosystems when possible), and extended treatment of the assessment criteria.

The second half of the report reviews DST treatment of essential wetland ecosystem services. **Table 2** forms a loose outline for the ensuing investigation and provides a quick reference for each tool's breadth of application pertaining to wetland ecosystems. We close the report with a list of insights drawn from our exploration of the DST.

To aid in understanding, it will be helpful to make a few remarks in advance. Readers will notice that we have delineated three ecosystem service categories: (1) biogeochemical services, (2) hydrological services, and (3) ecological services (defined below). These categories differ from the well-known Millennium Ecosystem Assessment (MA) classification that assigns services to four groups: (1) provisioning services, (2) regulating services, (3) cultural services, and (4) supporting services (MA 2005) (see Glossary). The MA categories can cause confusion when analyzing the flow of ecosystem functions (biophysical) to ecosystem services (human).

The three aforementioned categories that we use in this report provide a straightforward conceptual framework that aligns aptly with wetland restoration defined as "the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to former or degraded wetland" (U.S. EPA 2012). Wetland managers may conceivably opt to concentrate on one or more of the categories for restoration or conservation efforts.

Clearly, these ecosystem service categories are not discrete and each service contributes directly and indirectly to each other and an assortment of intermediate and final ecosystem services.

Intermediate services are impractical to value as they do not provide direct benefits to society. Rather, final ecosystem services are often appraised as they represent the environmental benefit used by society. For instance, **Figure 1** graphically shows a simplified flow from intermediate to final services. The biogeochemical service and wetland ecosystem function of nutrient cycling may be conceived as an intermediate service. This service, though crucial, is not directly utilized by society.

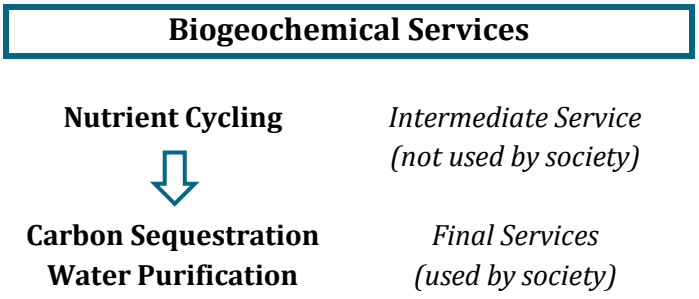


Figure 1. Flows between intermediate and final ecosystem services

In order to effectively value the functional service, one must trace the flow to the end users where the service is used. In **Figure 1**, the intermediate service, nutrient cycling, produces two final services. These final services, carbon sequestration and water purification, are of direct benefit to society and may be separately quantified.

ASSESSMENT CRITERIA

1. **Accessibility,** the degree of tool availability and potential for modification by the general public

   While DST may be advertised as being freely available, some retain various restrictions such as tiered pricing for advanced features or the inability to modify the software (if applicable). Generally, offering of program source code allows for greater user flexibility and facilitates peer collaboration.

2. **Interface,** the mode in which the tool is operated by the user

   Tools found in this report are developed with differing means of user interaction including graphical, web based, and command line interfaces. This plays an important factor in the prospective tool's ease of use as command line interfaces are relatively less accessible to general users and may require familiarization with employed programming languages.

3. **Analysis scale,** the relative spatial extent that the tool can successfully conduct examination; specified at *local, regional,* and *global* scales

   A persistent dilemma in ecosystem service valuation is that coarse global analyses are often not relevant in local contexts. Conversely, it is typically difficult or erroneous to extrapolate data from local analyses to larger scales. It is often advantageous to conduct analyses at differing spatial extents as the magnitude and the dynamic complexity of benefits derived from ecosystems varies over space (Hein et al 2006). Consequently, it is imperative that potential users recognize the spatial capacity of the prospective tools.

4. **Analysis type,** categorization of tool analysis as *quantitative*, *qualitative*, or both

   Quantitative analyses are typically concerned with measurable numerical data. Not all ecosystem services are easily (or suitably) quantifiable. A qualitative approach may be assumed entirely or as preliminary to a quantitative analysis.

5. **Data input demand,** the relative level of user provided data required to operate the tool; scaled from *low* to *high*

   A lack of preexistent data to conduct an analysis is perhaps a common motivation to seek the assistance of DST. Unfortunately, the data intensive nature of some tools render them unsuitable for local contexts as users are forced to employ coarser regional or global data. Other tools attempt to bypass the quandary through value transfer methods or even procedural guidance on the collection of data firsthand. Nevertheless, there is an unmistakable tradeoff between the amount of user supplied data and the degree of valuation utility. Potential users need to consult DST data input requisites as deficiencies may limit full functionality.

6. **Valuation units,** categorization of tool outputs as *monetary*, *nonmonetary,* or both

   Ecosystem services may be valued using economic, biophysical, and social metrics. We simplify this further to monetary or nonmonetary units. Ecosystem service valuation is often misunderstood as a monetary-only enterprise. Conversely, it has been shown that stakeholders are often interested in both monetary and nonmonetary valuation of benefits with linkages to human-welfare enhancement (Ruckelshaus et al 2013).

7. **Cartographic output,** indication of whether the tool generates data visualization in map form

   The mapping of ecosystem services may conceivably enhance communication of value. Particularly, cartographic outputs are effective synthesizers of dynamic landscapes not easily represented by precise quantitative measurements (Troy and Wilson 2006). The production of maps also allows users to easily use the generated data with other DST and/or GIS software for further analysis.

8. **Tool requirements,** the devices, equipment, and/or software required to operate the tool; computer and internet access are assumed if not listed

   At a basic level, all DST require a desktop or mobile computing device with an internet connection to access and often operate the tool. Some tools require standard field equipment to conduct optional field studies. A handful of DST require GIS software such as ArcGIS or QGIS to operate the tool, review results, and/or conduct further analysis.

9. **Time requirements,** an estimation of time demanded to conduct a complete analysis with the DST; scaled from *low* to *high* [*low* < 30 days; *high* > 90 days]

   Demanding timetables are likely another motivator for DST consultation. Unfortunately, many comprehensive assessments require substantial time and investment of manpower inhibiting wider tool utilization. This may lead potential users to opt for partial ecosystem service valuations using modular DST that are cost-effective increasing the appeal of tools through relatively rapid results.

10. **Skill requirements,** the relative level of technical competencies and/or expertise in particular subject-matter(s) necessitated to operate the tool; scaled from *low* to *high*

    The complexity of natural capital assessments is a driving factor in the development of these DST as decision-makers often do not have the scientific expertise necessitated to effectively quantify ecosystem values. Although closing the scientific gap is a priority for many developers, the tools in this report assume a wide range of technical competency obligations – some still necessitate expert consultation or are developed with more advanced users in mind.

11. **User support,** the relative degree of technical assistance offered by developers; scaled from *low* to *high*

    If potential users have limited technical capacity, then the degree of user support offered becomes more crucial. Moreover, extensive user support schemes may contribute to capacity building. We gauge the availability of technical assistance in the form of thorough user manuals, blogs and forums, instructional videos, and training programs.

12. **Cost,** a relative estimation of the cost required to fully operate the tool; scaled from *low* to *high*

    There are many factors that contribute to the full cost of using each DST. We make approximate estimations based on factors such as specified costs, assessment methodology, and person-hours needed to collect, process, or analyze data.

Table 1. Comparative matrix with Decision Support Tools and assessment criteria

	InVEST	TESSA	Co$ting Nature	WHBET	ARIES	SolVES
Availability	Free and open-source	Free	Tiered costs and closed-source	Free	Free and open-source	Free and closed-source
Interface	Desktop application; Python API (optional)	User manual (.pdf)	Web application	Excel spreadsheets (.xls)	Integrated Development Environment	ArcGIS (add-in toolbar)
Analysis scale	Local to Global	Local	Regional to Global	Local to Regional	Local to Global	Local to Regional
Analysis type	Quantitative	Qualitative; Quantitative	Qualitative	Quantitative	Quantitative	Quantitative
Data input demand	Low to High	Low to Moderate	Low	Low	Low to High	Low to Moderate
Valuation units	Monetary; Nonmonetary	Monetary; Nonmonetary	Nonmonetary	Monetary	Nonmonetary	Nonmonetary
Cartographic output	Yes	No	Yes	No	Yes	Yes
Tool requirements	GIS software to view results; 1 model requires ArcGIS	Field equipment (optional)	Computer and internet access	Computer and internet access	Computer and internet access	ArcGIS
Time requirements	Low to High	Low to Moderate	Low	Low	Moderate to High	Low to Moderate
Skill requirements	Moderate to High	Low	Low	Low	Moderate to High	Low
User support	High	Moderate	Moderate	Moderate	Low	Moderate
Cost	Low to High	Low to Moderate	Low to Moderate	Low	Low to High	Moderate to High

DECISION SUPPORT TOOLS
PROFILES

InVEST

Integrated Valuation of Ecosystem Services and Tradeoffs

Description

- Collection of models intended for the valuation and mapping of terrestrial, wetland, and aquatic ecosystem services
- Developed to cultivate incorporation of natural capital into development and conservation decision-making

Target Users

Governments, non-profits, international lending institutions, corporations

Ecosystem Service Models

Applicable to Wetland Ecosystems

- carbon
- coastal blue carbon
- coastal protection
- habitat quality
- habitat risk assessment
- recreation
- scenic quality
- sediment retention
- water purification

Background/Methodology

The suite of models are offered to accomplish Natural Capital Project's threefold resolution to: (1) provide evidence for the viability of incorporating natural capital into decision-making, (2) offer replicable methods or tools (i.e. InVEST) for widespread use, and (3) dissemination of methodology and capacity building.

The ecosystem service models may be applied individually or in an integrated manner to quantify the value of ecosystem services in economic and biophysical units. InVEST is able to conduct static and dynamic assessments and is useful for the analysis of tradeoffs in forecasted development and land-use change scenarios.

Development Outlook

InVEST 1.0.0 (beta) offered 6 ecosystem service models. Today, version 3.2.0 offers 18 functional models, some of which have been continually refined and updated. Initially, InVEST models were developed to work with ArcGIS software. Currently, nearly all models are offered in standalone configurations for Windows operating environments. Many supporting tools aimed to simplify user application have been developed and are currently offered under an experimental platform.

References and Additional Resources

Sharp R, Tallis HT, Ricketts T, et al (2015) InVEST 3.2.0 User's Guide.

Arkema KK, Guannel G, Verutes G, et al (2013) Coastal habitats shield people and property from sea-level rise and storms. Nature Climate Change 3:913–918. doi: 10.1038/nclimate1944

Arkema KK, Verutes GM, Wood SA, et al (2015) Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. Proceedings of the National Academy of Sciences 112:201406483. doi: 10.1073/pnas.1406483112

Flight MJ, Paterson R, Doiron K, Polasky S (2012) Valuing Wetland Ecosystem Services: A Case Study of Delaware. National Wetlands Newsletter 34:16–20.

Nelson E, Mendoza G, Regetz J, et al (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4–11. doi: 10.1890/080023

Web Page:
http://www.naturalcapitalproject.org/invest/

Multimedia:

- NOVA Article
  http://www.pbs.org/wgbh/nova/next/earth/putting-a-price-on-nature/
- Stanford University Online Course, 'Intro. to the Natural Capital Project Approach'
  http://ncp101.class.stanford.edu

General Information

Collaborator(s):

- Natural Capital Project
- Institute on the Environment (UofM)
- Stanford University
- The Nature Conservancy
- World Wildlife Fund

Version: 3.2.0 (2015)

Availability: Free and open-source

Interface: Desktop application

Python application program interface (API) is facilitated but optional (API standalone)

Analysis scale: Local to Global

The appropriate scale is largely contingent on the resolution of user supplied data, aim of analysis, and ecosystem service(s) addressed. Nevertheless, InVEST maintains the capacity for multi-scale analysis

Analysis type: Quantitative

Data input demand: Moderate to High

Higher if economic valuation is desired; there is variation between existing models (data matrix)

Valuation units: Monetary; Nonmonetary

Cartographic output: Yes

Tool requirements:

- *Internet connection is needed to run selected models*
- *GIS software is required to view results (as well as pre-processing if needed)*
- *The Coastal Protection toolkit requires ArcGIS*

Time requirements: Low to High

There is variation between existing models; many models may require considerable time for data preparation; yet, most models require little time to run if data is readily available

Skill requirements: Moderate to High

- *moderate to advanced scientific expertise*
- *GIS proficiency*
- *Scripting proficiency (optional)*

User support: High

NatCap offers a thorough user manual, forums, and various training programs

Cost: Low to High

Cost is related to the person-hours allocated to the assessment

TESSA

Toolkit for Ecosystem Service Site-Based Assessment

Description

- Adaptable suite of methods for identification and evaluation of terrestrial and wetland ecosystem services
- Developed to provide a framework for spatial and temporal analysis of land use change at a scale relevant to local policy

Target Users

Conservation managers and practitioners with limited capacities

Ecosystem Services

- climate regulation
- flood protection
- water provision
- recreation
- water quality improvement

Background/Methodology

The toolkit roughly adheres to a six step process with ongoing stakeholder engagement: (1) contextualize area of interest, (2) rapid appraisal (scoping), (3) identify plausible alternative state(s), (4) select assessment methods, (5) data acquisition, and (6) analysis and communication.

As TESSA is intended to be an adaptable schema, fifty assessment methods are presented with guidance on selection, preparation, and application (steps 4-6) categorized according to their applicable ecosystem service. Elective processes include stakeholder workshops, expert consultation, mapping, gathering of data from existing publications, field measurements, questionnaire surveys, web-modeling, and analysis. Instruction on economic valuation of select ecosystem services is incorporated.

Development Outlook

Developers intend to extend TESSA's breadth, adding as many as three ecosystem service modules in 2016 – coastal protection, cultural services, and pollination services. At present, TESSA's water-related services have been developed for inland wetlands. Developers have indicated plans for inclusion of coastal wetlands in future versions of the toolkit. They have also expressed interest in providing future guidance on using TESSA for monitoring systems and multi-site analyses (see Thapa et al., 2014) and general improvement of the toolkit's economic valuation component.

References and Additional Resources

Peh KS-H, Balmford AP, Bradbury RB, et al (2014) Toolkit for Ecosystem Service Site-based Assessment (TESSA). Cambridge, UK

Peh KS-H, Balmford A, Bradbury RB, et al (2013) TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. Ecosystem Services 5:51–57. doi: 10.1016/j.ecoser.2013.06.003

Peh KS-H, Balmford A, Field RH, et al (2014) Benefits and costs of ecological restoration: Rapid assessment of changing ecosystem service values at a U.K. wetland. Ecology and evolution 4:3875–86. doi: 10.1002/ece3.1248

Thapa I, Butchart SHM, Gurung H, et al (2014) Using information on ecosystem services in Nepal to inform biodiversity conservation and local to national decision-making. Oryx 1–9. doi: 10.1017/S0030605314000088

Web Page:
http://birdlife.org/worldwide/science/assessing-ecosystem-services-tessa

Multimedia:
- EBM Tools Network Webinar
  https://youtu.be/yKjCHuOyV0Q

General Information

Collaborator(s):
- University of Cambridge
- Anglia Ruskin University
- Birdlife International
- Tropical Biology Association
- Royal Society for the Protection of Birds
- UNEP-WCMC

Version: 1.2 (2014)

Availability: Free

Interface: User manual (.pdf)
Some methods direct users to web-based policy support tools Co$ting Nature and WaterWorld

Analysis scale: Local
The toolkit has demonstrated suitability for multi-site analyses (Thapa et al 2014) that could serve as a proxy for more complex regional studies

Analysis type: Qualitative; Quantitative

Data input demand: Low to Moderate
Pre-existing data is not required as the toolkit guides users in the procurement of needed data.

Valuation units: Monetary; Nonmonetary

Cartographic output: No

Tool requirements:
- *computer and internet access*
- *field equipment (optional)*

Time requirements: Low to Moderate
Developers estimate 90 person-days (at minimum) to conduct full assessment with stakeholder engagement; partial studies would require less time; studies where users opt to administer field surveys would require more time

Skill requirements: Low
- *elementary scientific proficiency*
- *computer literacy*

User support: Moderate
The toolkit is very thorough providing technical background in an accessible format

Cost: Low to Moderate
Contingent upon selected assessment methods; developers estimate a cost of $6000 to conduct a full assessment

Co$ting Nature

Description

- A globally calibrated web application to map and assess landscape potential and realized ecosystem service provision and pressures
- Developed to aid prioritization in planning by providing land use and land cover change scenarios for spatio-temporal analysis

Target Users

Non-profits, policy analysts, scientists, agricultural and extractive industries

Ecosystem Service Indices

- water provisioning
- recreation services
- conservation and biodiversity
- carbon services
- hazard mitigation

Background/Methodology

The tool is one of many policy support web applications developed by King's College London and AmbioTEK with various concentrations yet sharing a common ambition to make sophisticated science more accessible to the general public.

Co$ting Nature's general functionality may be divided into static and dynamic processes. The tool maps static benefits derived from nature and their beneficiaries through underlying stacked global resolution datasets. Benefits are differentiated by consumed services (realized) and non-utilized (potential) services. Further, users are able to analyze and map dynamic changes in landscape service provision under pre-loaded and user defined land use change scenarios.

Development Outlook

Version 1 (2011) capability was limited to static analyses. Version 2 (2014) incorporated more dynamic analyses such as land use change scenarios. New mapping metrics have been continually updated and offered. Version 3 is currently under development.

References and Additional Resources

Mulligan M (2015) User guide for the CO$TING NATURE Policy Support System v. 2.

Mulligan M, Guerry A, Arkema K, et al (2010) Capturing and Quantifying the Flow of Ecosystem Services. In: Silvestri S, Kershaw F (eds) Framing the flow: Innovative Approaches to Understand, Protect and Value Ecosystem Services across Linked Habitats. United Nations Environment Programme, pp 26–33

Web Page:
http://www.policysupport.org/costingnature

Multimedia:

- InfoAmazonia Article
  http://costingnature.infoamazonia.org/en/
- PSS Webinar
  https://youtu.be/7suKajOIGhs

General Information

Collaborator(s):

- King's College London
- Bioversity International
- UNEP-WCMC
- AmbioTEK

Version: 2 (2011)

Availability: Tiered costs and closed-source

There is tiered licensing for advanced functionality (see table below)

Interface: Web application

Analysis scale: Regional to Global

Pre-loaded remotely sensed data have coarse granularity, often not suitable for local analyses. Models are simulated on 1 hectare or 1 kilometer tiles.

Analysis type: Qualitative

Data input demand: Low

Includes option to augment analysis with user supplied data

Valuation units: Nonmonetary

Cartographic output: Yes

Tool requirements:

- *computer and internet connection*
- *GIS software (for optional post-processing)*

Time requirements: Low

A rudimentary analysis may be conducted in a few hours; however, advanced features take more time to learn and implement

Skill requirements: Low

- *computer literacy*
- *GIS proficiency (for optional post-processing)*

User support: Moderate

Cost: Low to Moderate

Standard access is free; however, tiered costs are incurred for advanced functionality; we do not account for-profit costs in our relative estimation

	Non-Profit	*For-Profit*
Tier 1	*Free*	*$1500**
Tier 2	*$750**	*$4000**
Tier 3	*$1500**	*$7500**
Tier 4	*$3000**	*$12000**

**approximation (converted from GBP)*

Wildlife Habitat Benefits Estimation Toolkit (WHBET)

Description

- A spreadsheet based toolkit for conservation and natural areas facilitating recreational benefit transfer, visitor estimation, and analysis of open space property value
- The developers of the toolkit have amassed value tables derived from thorough literature review and organized an economic valuation database primed for meta-analysis

Target Users

Natural resource managers, non-economists

Models

- visitor use estimation
- recreation
- open space property value premiums
- threatened, endangered, and rare species

Background/Methodology

The development of the toolkit was funded by NCSE's Wildlife Habitat Research Program primarily to provide natural resource managers a tool to rapidly estimate wildlife-based economic value when firsthand studies are not feasible.

The toolkit is comprised of four models with respective outputs: (1) a visitor use estimation model drawn from a 2005 USFWS refuge visitation report; (2) a benefit transfer model using meta function and value transfer methods; (3) an open space property value premium estimator model using meta-analysis; and (4) threatened, endangered or rare species and salmon models.

Development Outlook

Through an ongoing collaboration between the Bureau of Land Management, U.S. Geological Survey, Colorado State University, and Oregon State University to direct case studies concentrated on the quantification of nonmarket values, the 2008 toolkit is planned to be updated (Richardson et al 2015).

References and Additional Resources

Kroeger T (2008) Open Space Property Value Premium Analysis. Washington, DC

Kroeger T, Loomis J, Casey F (2008) Introduction to the Wildlife Habitat Benefits Estimation Toolkit. Washington, DC

Loomis J, Richardson L (2008a) USER MANUAL: Benefit Transfer and Visitor Use Estimating Models of Wildlife Recreation, Species and Habitats. Washington, DC

Loomis J, Richardson L (2008b) Technical Documentation of Benefit Transfer and Visitor Use Estimating Models of Wildlife Recreation, Species and Habitats. Washington, DC

Richardson L, Loomis J, Kroeger T, Casey F (2015) The role of benefit transfer in ecosystem service valuation. Ecological Economics 115:51–58. doi: 10.1016/j.ecolecon.2014.02.018

Web Page:
http://www.ncseonline.org/programs/science-solutions/whprp/toolkit

Multimedia:

- NCER Presentation Slides http://conference.ifas.ufl.edu/ncer2011/Presentations/Thursday/Harborside%20C-E/am/1100_Richardson.pdf

General Information

Collaborator(s):

- Colorado State University
- Defenders of Wildlife
- National Council for Science and the Environment

Version: Published 2008

Availability: Free

Interface: Excel spreadsheets (.xls)

Analysis scale: Local to Regional

The visitor use estimation model allows for assessment at a refuge or state scale

Analysis type: Quantitative

Data input demand: Low

Valuation Units: Monetary

Cartographic output: No

Tool requirements:

- *computer and internet connection*

Time requirements: Low

Skill requirements: Low

- *computer literacy*
- *elementary statistical proficiency*

User support: Moderate

Includes thorough user manuals and technical documentation

Cost: Low

ARIES

ARtificial Intelligence for Ecosystem Services

Description

- Collection of probabilistic ecosystem service models powered by an artificial intelligence engine
- Developed to reveal linkages between human and natural systems to inform resource policy and management

Target Users

Governments, non-profits, scientists, corporations, resource managers

Ecosystem Service Models

- carbon sequestration and storage
- riverine and coastal flood regulation
- sediment regulation
- water supply
- fisheries
- pollination
- open space proximity
- recreation
- aesthetic value

Background/Methodology

ARIES developers seek to facilitate global collaboration of scientists and sharing of data and models. The ARIES models are reliant on an artificially intelligent modeling software application. The software, k.LAB, is a semantically annotated cloud-based network.

ARIES uses algorithms to produce quantitative maps of the flow of ecosystem services from the environment to society. These outputs are made possible through spatial investigation into the sources, sinks, beneficiaries, and flows of services over landscapes using probabilistic, Bayesian models.

Development Outlook

New ARIES models are continuously under development given the collaborative nature of the software using k.LAB. ARIES was first provided in 2008 in a web-based format but has since been withdrawn. An updated released of k.LAB is expected in late 2016 along with k.EXPLORER, a relatively user friendly web-based application. k.EXPLORER is under development to provide end-users access to the semantic cloud network and administer rapid ecosystem service valuations. The late 2016 release is also planned to include tutorials and updated documentation.

References and Additional Resources

Bagstad KJ, Villa F, Johnson GW, Voigt B (2011) ARIES–ARtificial Intelligence for Ecosystem Services: a guide to models and data, version 1.0. ARIES Report Series 1

Bagstad KJ, Reed JM, Semmens DJ, et al (2015) Linking biophysical models and public preferences for ecosystem service assessments: a case study for the Southern Rocky Mountains. Regional Environmental Change. doi: 10.1007/s10113-015-0756-7

Bagstad KJ, Semmens DJ, Winthrop R (2012) Ecosystem Services Valuation to Support Decisionmaking on Public Lands—A Case Study of the San Pedro River Watershed, Arizona. US Geological Survey

Bagstad KJ, Villa F, Batker D, et al (2014) From theoretical to actual ecosystem services: mapping beneficiaries and spatial flows in ecosystem service assessments. Ecology and Society. doi: 10.5751/ES-06523-190264

Batker D, Kocian M, Lovell B, Harrison-Cox J (2010) Flood Protection and Ecosystem Services in the Chehalis River Basin. Earth Economics. Tacoma, WA

Villa F, Bagstad KJ, Voigt B, et al (2014) A methodology for adaptable and robust ecosystem services assessment. PloS one 9:e91001. doi:10.1371/journal.pone.0091001

Web Page:
http://aries.integratedmodelling.org/ (under development February 2016)

Multimedia:

- ARIES Webinar https://vimeo.com/148101968

General Information

Collaborator(s):

- National Science Foundation
- UNEP-WCMC
- Gund Institute (UVM)
- Conservation International
- Earth Economics
- Basque Centre for Climate Change
- Instituto de Ecología

Version: 0.9.9 (k.LAB software)

Availability: Free and open-source

Interface: Integrated Development Environment

The modeling language (k.IM) is native to the k.LAB software

Analysis scale: Local to Global

ARIES includes both local and global models that have been developed for particular contexts

Analysis type: Quantitative

Data input demand: Low to High

Demand is higher if economic valuation is desired; there is variation between existing models

Valuation units: Monetary; Nonmonetary

Cartographic output: Yes

Tool requirements:

- *computer and internet connection*
- *GIS software (for pre- and post-processing)*

Time requirements: Moderate to High

Without pre-existing data, time required for the collection of data and model parameterization for a new site can be extensive

Skill requirements: Moderate to High

- *moderate to advanced scientific expertise*
- *GIS proficiency*
- *scripting/programming proficiency*

User support: Low

Additional guides/tutorials are forthcoming.

An annual two-week intensive course for integrated modeling of ecosystem services with ARIES is provided in Bilbao, Spain. (International Spring University)

Cost: Low to High

Cost is related to the person-hours allocated to the assessment

SolVES

Social Values for Ecosystem Services

Description

- A GIS based application for the quantification and mapping of beneficiaries' perceived social values
- Developed in response to difficulty quantifying non-material social values and to facilitate these perceived values incorporation into resource management

Target Users

Natural resource managers, decision-makers, and researchers

Social Values

Investigated in Sherrouse et al 2014

- aesthetic
- biodiversity
- cultural
- economic
- future
- historic
- intrinsic
- learning
- life sustaining
- recreation
- spiritual
- subsistence
- therapeutic

Background/Methodology

The geographic information system tool synthesizes Maxent modeling software and public value and preference surveys to spatially index perceived social value. The 10-point value indices are conducive for hotspot analysis and may supplement economic and biophysical valuation.

If users are unable to conduct primary surveys, a value transfer model may be employed. However, the transferred survey data must be drawn from previous SolVES analyses and sites with comparable geographic features.

Development Outlook

Version 3.0 improved the value transfer functionality and allowed for additional user flexibility. SolVES functionality has been continuously updated and documentation has been recently expanded. It is worth noting that the advantages of the value transfer model cannot be fully realized for wetland ecosystems until a database of appropriate transfer cases is developed.

References and Additional Resources

Sherrouse BC, Semmens DJ (2015) Social Values for Ecosystem Services, version 3.0 (SolVES 3.0): documentation and user manual. US Geological Survey

Bagstad KJ, Reed JM, Semmens DJ, et al (2015) Linking biophysical models and public preferences for ecosystem service assessments: a case study for the Southern Rocky Mountains. Regional Environmental Change. doi: 10.1007/s10113-015-0756-7

Sherrouse BC, Clement JM, Semmens DJ (2011) A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. Applied Geography 31:748–760. doi: 10.1016/j.apgeog.2010.08.002

Sherrouse BC, Semmens DJ, Clement JM (2014) An application of Social Values for Ecosystem Services (SolVES) to three national forests in Colorado and Wyoming. Ecological Indicators 36:68–79. doi: 10.1016/j.ecolind.2013.07.008

van Riper CJ, Kyle GT, Sutton SG, et al (2012) Mapping outdoor recreationists' perceived social values for ecosystem services at Hinchinbrook Island National Park, Australia. Applied Geography 35:164–173. doi: 10.1016/j.apgeog.2012.06.008

Web Page:
http://solves.cr.usgs.gov/

Multimedia:

- EBM Tools Network Webinar
https://vimeo.com/65321697

General Information

Collaborator(s):

- U.S. Geological Survey

Version: 3.0 (2015)

Availability: Free and closed-source

Interface: ArcGIS (add-in toolbar)

Analysis scale: Local to Regional

Analysis type: Quantitative

Data input demand: Low to Moderate

Low if using value transfer function; moderate if conducting survey(s)

Valuation Units: Nonmonetary

Markedly, nonmonetary values are beneficiary values and preferences (social values)

Cartographic output: Yes

Tool requirements:

- *computer and internet connection*
- *ArcGIS*

Time requirements: Low to Moderate

Low if using value transfer function; moderate if conducting survey(s)

Skill requirements: Low

- *computer literacy*
- *GIS proficiency*

User support: Moderate

Includes thorough user manual

Cost: Moderate to High

Higher costs are associated with the requirements to use ArcGIS and administer surveys; the value transfer function would significantly reduce cost

DECISION SUPPORT TOOLS HANDLING OF ECOSYSTEM SERVICES

Table 2 may serve as a loose outline for the next section of this report. In order, we follow the list of ecosystem service categories outlined in the first column beginning with biogeochemical services, continuing to hydrological services, and concluding with ecological services. DST handling of various ecosystems services are discussed with example outputs given where feasible. Publicly available external studies and reports that more appropriately demonstrate tool usage and functionality are hyperlinked for further exploration by readers.

Table 2. Decision support tools with respective ecosystem services

	InVEST	TESSA	Co$ting Nature	WHBET	ARIES	SolVES
Biogeochemical Services	**X X**	**X X**	**X**		**X**	
Climate Regulation	Carbon Storage and Sequestration; Coastal Blue Carbon	Climate Regulation	Carbon Storage and Sequestration (index)		Carbon Storage and Sequestration	
Water Purification	Water Purification	Water Purification				
Hydrological Services	**X X**	**X**	**X**		**X X X**	
Sediment Retention	Sediment Retention				Sediment Regulation	
Inland Flood Regulation		Flood Protection	Hazard Mitigation (index)		Riverine Flood Regulation	
Coastal Protection	Coastal Protection Toolkit		Hazard Mitigation (index)		Coastal Flood Regulation	
Ecological Services	**X X X**	**X**	**X X**	**X X**	**X X**	**X**
Habitat	Habitat Quality; Habitat Risk Assessment		Conservation and Biodiversity (indices)			
Aesthetic Value	Scenic Quality			Open Space Property Value Premiums	Aesthetic Value; Open Space Proximity	Various Perceived Social Values (index)
Recreation Value	Recreation and Tourism Rates	Nature-Based Recreation	Recreational Services (index)	Visitation Rates; Recreational Value	Recreational Services	Various Perceived Social Values (index)

BIOGEOCHEMICAL SERVICES

Biogeochemical services are concerned with the storage and removal of surplus nutrients in a wetland – or nutrient cycling. Biogeochemical services contribute to an assortment of final services. Two examples include the regulation of climate through carbon storage and sequestration and the purification of water through nitrogen and phosphorus cycling. In succession, we investigate the treatment of these two services by the DST.

CLIMATE REGULATION

From an anthropogenic perspective, wetland climate regulation functions positively, through carbon sequestration and peat accumulation, and negatively, through methane emissions. Four of the six chosen DST deal with climate regulation in some form and largely emphasize carbon cycling. The **InVEST** Carbon model and **Co$ting Nature** estimate carbon stocks as a function of land use and land cover and estimate carbon storage and sequestration over a defined time period.

At minimum, the **InVEST** Carbon model requires users to provide a current land use and land cover map for the area of interest and a table of carbon pool data that correspond with LULC classes. The model is simplistic rendering the resolution of the land use and land cover map and the quality of the carbon pool data determinative of the relative accuracy of the assessment. The carbon pools accounted in the model include aboveground and belowground biomass, soil carbon, and dead organic matter and must be defined by the user through review of pertinent publications or field surveying. Industrial Economics documents this process in detail in a report prepared for Delaware Department of Natural Resources and Environmental Control (DNREC) valuing wetland ecosystem services across the entire state of Delaware (IEc 2011). We show a static output of the **InVEST** Carbon model estimating carbon storage alongside a similar **Co$ting Nature** output in **Figure 2a** using data provided by Industrial Economics.

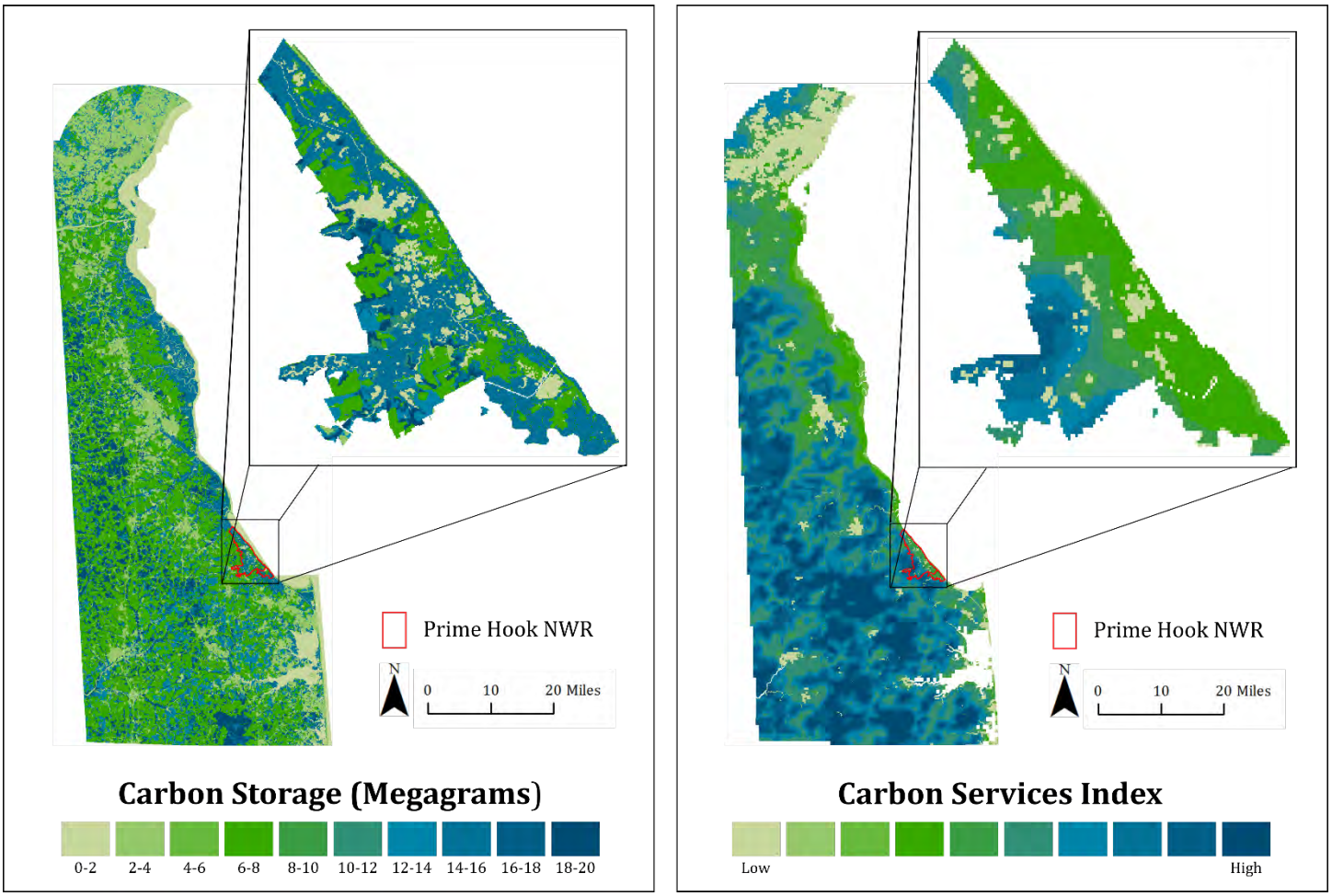
For **Co$ting Nature**, users are not obligated to supply any data (although this option is facilitated). Users must simply delineate their area of interest from a global dataset fragmented into 1 hectare or 1 kilometer tiles and prompt the tool to run a model simulation. Among other outputs, **Co$ting Nature** produces a relative carbon service map that is a combination of carbon storage and sequestration services. The output is generated through the integration of global carbon stock maps derived from pertinent studies for carbon storage and a global dry matter productivity analysis for carbon sequestration. An example output for the state of Delaware is shown in **Figure 2b** along with the **InVEST** Carbon model output.

A clear distinction may be observed in the spatial resolution of the maps. While **Co$ting Nature** allows for a relatively rapid assessment**,** the output is much more coarse limiting the tool's application. Users with smaller sites will find little utility using **Co$ting Nature**. Conversely, the **InVEST** Carbon model allows for greater detail in analysis although this advantage is conditional on the granularity of the user supplied data. This is demonstrated more clearly in the subset image accentuating Prime Hook National Wildlife Refuge. **Co$ting Nature**'s coarse analysis is capable of expressing the site's provision of ecosystem services relative to the region. However, if a finer spatial analysis is desired, such as the capacity to differentiate service provision within the site, tools allowing for multi-scale analysis will need to be employed.

The **InVEST** Carbon model and **Co$ting Nature** allow users to analyze provision of carbon services under various policy and land use scenarios. However, their methods are quite different. The **InVEST** Carbon model estimates

(a) InVEST Carbon Model (carbon storage)

(b) Co$ting Nature (carbon storage/sequestration)



Source: data provided by Industrial Economics, Inc.

Figure 2. Carbon services output comparison: (a) InVEST; (b) Co$ting Nature, Delaware, Prime Hook NWR (subset)

and maps carbon sequestration separately as a function of carbon storage over time using user generated future land use and land cover map(s) representative of anticipated management or policy scenarios. If additional economic data is supplied, the difference in carbon sequestration services between current and future land cover scenarios may be monetized. The economic inputs include the social cost of carbon, discount rate, and annual rate of change in the price of carbon.

Although **Co$ting Nature** differs from **InVEST** as it combines carbon storage and sequestration services, it does enable analysis of policy and land use scenarios as well. **Co$ting Nature** does not require users to provide a future land use and land cover map (although this option is available). Rather, the tool facilitates analysis by allowing users to assign land management priorities, weight ecosystem services, or directly define land use and land cover change rules. A second simulation may be run producing outputs for temporal comparison.

Not to be confused with the Carbon model, **InVEST** has recently developed a Blue Carbon model for coastal ecosystems. Coastal marshes and mangroves were under consideration during development. The **InVEST** Blue Carbon model's inputs and outputs are similar to the Carbon model. However, the Blue Carbon model distinctively assesses carbon accumulation and

greenhouse gas emissions – including methane. For coastal wetland ecosystems, this is a vast improvement over the Carbon model. The Carbon model, not including factors such as methane emissions, may overestimate the provisioning of climate regulation services, in the positive sense, and provide misleading valuation results for wetland ecosystems.

ARIES carbon models integrate pertinent regional spatial datasets and Bayesian networks to produce carbon sequestration and potential storage release maps along with their respective uncertainty. Carbon offsets are quantified by subtracting the estimated carbon released from the estimated carbon sequestered. **ARIES** also maps anthropogenic greenhouse gas emissions with their producers perceived as beneficiaries of the carbon offsets. Although retaining similar framework, each **ARIES** model has been developed expressly for the site of interest. Nevertheless, existing regional models could be applied to sites with similar geographic contexts. The tool's application to the San Pedro River watershed in Arizona has been documented in detail by Bagstad et al. (2012) with outputs shown comparatively alongside the **InVEST** Carbon model (Bagstad et al 2012). As with the **InVEST** Carbon model, the ARIES' outputs may be monetized.

With the exception of the **InVEST** Blue Carbon model, the **InVEST** Carbon model, **Co$ting Nature**, and **ARIES** opt to emphasize carbon regulation. This is suitable for forested and woodland land cover classes. However, for wetland ecosystems users need to assess the flux of all greenhouse gases that positively and negatively contribute to radiative forcing. **TESSA**, accommodating a broader consideration, methodically guides users in the estimation of carbon, methane, and nitrous oxide fluxes through field surveys or consultation of existing published data. Yet, there are limitations to both of these methods. The field surveys can prove to be expensive and may take additional time to administer in order to account for seasonal variation. Also, existing publications appropriate for the site of interest may not be readily available (Peh et al 2014b).

Though coarse, **TESSA** developers suggest using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Unfortunately, this report is deficient for wetland land cover. In 2013, a wetlands supplement was issued. However, it only addresses emissions from peat fires in peatlands and wood biomass making the resource insufficient for most wetland types. Regardless of selected methodology, the toolkit's full process yields a total greenhouse gas flux for a site's current and future state with further guidance on summarization and communication of results. **TESSA** does not currently offer instruction on the monetization of the biophysical valuation, although this may be accomplished without much difficulty. For instance, Peh et al. (using **TESSA**) valued foreseeable benefits resulting from a wetland restoration initiative in the United Kingdom and monetized the social value of avoided greenhouse emissions and many other ecosystem services (Peh et al 2014a).

WATER PURIFICATION

We include the **InVEST** Water Purification model in the biogeochemical section as it emphasizes the removal of nitrogen and phosphorus as a function of soil and vegetation filtration rates. The model values the improvement of water quality through estimation of land cover nutrient loading rates, modeled nutrient retention rates, and the avoided costs associated with retention beneficial to society.

Users must supply ample data for full utilization of the tool. Initially, a land use and land cover raster and a corresponding biophysical table with each land cover's nutrient loading and vegetation

filtration rates are required. To model nutrient retention rates, users will need to provide a digital elevation model, watershed vector data, and raster data for root restricting soil layer depth, plant available water content, precipitation, and evapotranspiration. The pre-processing of data require intermediate GIS competency and conceivably expert hydrological consultation to appropriately calibrate the model. At either a pixel or watershed spatial resolution, model outputs include quantitative maps showing the degree of nutrient export and retention per unit. Industrial Economics has documented the utilization of the model in a statewide wetland ecosystem service valuation report prepared for Delaware DNREC (IEc 2011).

The **InVEST** Water Purification also facilitates service monetization through user supplied economic information. These inputs include the estimated annual avoided cost of nutrient treatment removal and the respective discount rate(s). Although monetization may be useful, the tool does not model the beneficiaries of the service. These values should not be misinterpreted to imply value where there is no existing or foreseeable realization of the services. Additional guidance on model application and limitations are outlined in the InVEST User Guide.

TESSA currently addresses three water-related services that were developed for inland wetlands. Guidance for coastal wetlands are planned for future versions of the toolkit. Current services include: water provisioning, regulation, and quality. We cover the toolkit's handling of water quality here as the service is contingent largely on biogeochemical processes. In the following section on hydrological services, we present **TESSA**'s valuation of water regulation services emphasizing flood protection.

With its characteristic methodical approach, **TESSA** guides users in the estimation of a wetland's impact on water quality. Unique site characteristics demand the collection of firsthand data. If data is not readily available, **TESSA** outlines approaches to measure water quality at system inflows and outflows over time. Clearly, the development of a monitoring program would greatly increase the length of the assessment necessitating pre-emptive planning for users under time constraints. The toolkit offers limited direction in economic valuation of water quality services and suggests an external resource: Turner et al 2008. Improvement of procedural guidance in the economic valuation of services is planned in future versions of the toolkit.

HYDROLOGICAL SERVICES

The many wetland hydrological services include the regulation of sediment that directly or indirectly contribute to inland flood regulation, coastal protection, and the purification of water. Above, while addressing biogeochemical services we covered DST valuation of water purification provided through nutrient retention. Here, we investigate tools that value the final service through the assessment of sediment retention. Subsequently, we investigate DST handling of flood and coastal water protection.

SEDIMENT RETENTION

For wetlands, the retention of sediment is often of interest for the consideration of ecosystem services. The amount of suspended sediment retained by a wetland has the potential to significantly impact water quality – a final service that may be quantified. In turn, we separately address the valuation of water quality services by **InVEST** and **ARIES**.

The **InVEST** Sediment Retention model has been recently updated with the Sediment Delivery Ratio (SDR) model. The **InVEST** SDR model spatially quantifies overland sediment yield on natural landscapes. The SDR model is comparable to the **InVEST** Water Purification model and requires significant data to utilize. Inputs include standard geographic data: a land use and land cover raster, a digital elevation model, and miscellaneous hydrological vector data. In addition, the SDR model requires a rainfall erosivity index raster to indicate erosion potential influenced by rainfall intensity and a soil erodibility raster representing the integrity of soil particles on the landscape. The model has two parts and first employs the revised universal soil loss equation (RUSLE) to model soil loss using user supplied inputs (note: the RUSLE is a function of rainfall erosivity, soil erodibility, slope gradient, land management, and conservation practices). Second, the SDR model estimates sediment transport capacity as a function of the upslope land area and downslope flow path. At either a pixel or watershed spatial resolution, outputs include maps of potential soil loss, sediment retained and exported, and an index of sediment retention useful for analysis of a site's relative service contribution. Economic valuation is not integrated into the **InVEST** SDR model. However, suggestions are offered in the tool's user guide.

Similar to the **InVEST** Water Purification model, the SDR model requires intermediate GIS competency for data pre-processing and may require expert hydrological consultation to calibrate the model for unique contexts. Industrial Economics has documented the use of the prior **InVEST** Sediment Retention model in a statewide wetland ecosystem service valuation report prepared for Delaware DNREC (IEc 2011).

Calibrated for natural flow paths, the **InVEST** SDR model developers transparently disclose that their model may be unsuitable for urban sites with substantial built up land cover. However, this limitation may be remediated with user supplied drainage layers (Hamel et al 2015). For other limitations, **ARIES** developers suggest their probabilistic methodology on sites where the deterministic RUSLE is geographically inappropriate (e.g., areas with steep slopes: >20%). Using a handful of stacked spatial data sources and its characteristic probabilistic approach, the **ARIES** sediment regulation model analyzes sediment erosion (sources), sediment deposits (sinks), beneficiaries, and hydrological flow across a landscape. At present, Bayesian networks have been developed in the United States for Western Washington and the Rocky Mountains that may be transferred regionally.

INLAND FLOOD REGULATION

Wetlands are capable of providing short or long term retention and storage of water. However, this service is not easily quantifiable unless there are perceptible hydrological inflows and outflows in wetlands with recurrent flood events. Three DST attempt to value flood regulation in some form. We present their methods successively below.

TESSA addresses flood protection services provided by inland wetlands. Coastal wetlands are not covered although future inclusion is planned for future versions of the toolkit. Through decision trees and methodical guidance, the toolkit walks users through three rapid steps for an elementary valuation of flood services.

The first step involves the determination of whether the site provides flood protection to some degree. Here, users are directed to the consultation of existing firsthand hydrological data, regional flood maps, publicly available satellite imagery, or even rudimentary field inspection. The second step involves the quantification of flood abatement from a user defined single flood event. This step includes guidance on direct and indirect measurement of the impact wetland water retention has on downstream flooding (note: hydrological inflows and outflows must be perceptible). The third step outlines methodology to estimate flood frequency and analyze the magnitude of wetland flood protection. Quantitative results include the number of days of flood prevention, number of households not flooded, and number of months with reduced flood risk. These outputs may be monetized and analyzed against an alternative state. These addendums are facilitated by the toolkit. However, guidance on monetization is limited and the authors suggest an external resource: Turner et al., 2008. Peh et al. demonstrated **TESSA**'s functionality and assessed foreseeable benefits from a wetland restoration initiative in the United Kingdom. This study monetized flood protection services among other wetland ecosystem services (Peh et al 2014a).

Co$ting Nature assesses hydrological ecosystem services including indices for water provisioning and natural hazard mitigation. The natural hazard mitigation index, however, is an aggregate of flood regulation, coastal protection (discussed below), and landslide prevention. It does not explicitly address each service. Furthermore, the application of coarse global data to unique wetland hydrological regimes is problematic and should be undertaken as a last resort. Among its wide-ranging collection of methodical suggestions, **TESSA** mentions **Co$ting Nature** and **WaterWorld**, another web-based policy support system provided by **Co$ting Nature**'s developers, that emphasizes hydrological processes.

ARIES includes two flood regulation modules – riverine and coastal. We present the coastal flood regulation model in the subsequent section below. Here we look at the tool's handling of riverine flood regulation. The current model spatially investigates site flood vulnerability, service beneficiaries, and the impact alternative land use may have on flood regulation service provisioning. Contingent on data availability, **ARIES** employs stacked spatial datasets integrated into Bayesian networks to model precipitation (sources), soils and vegetation that may arrest or store floodwaters (sinks), beneficiaries, and hydrological flow across a landscape. At an early stage in the development of **ARIES**, Earth Economics extensively explored the use of the tool to inform flood protection investments in the Chehalis River Basin in Western Washington (Batker et al 2010). More recently, Bagstad et al. applied **ARIES** to the Puget Sound estuary, also in Washington, and explored the region's capacity for ecosystem service provisioning. Methodology and outputs from the analysis of flood regulation in the floodplain is exhibited among other ecosystem services (Bagstad et al 2014).

COASTAL PROTECTION

Modeling the benefits of coastal protection, or coastal flood regulation, is similar to that of inland flood regulation with the added dynamics of waves and storm surges increasing complexity. **ARIES** and **InVEST** are the only tools in our selection that address coastal protection services. We first describe how **ARIES** treatment of more general flood regulation services differs from coastal flood regulation services. Then we direct our attention to the **InVEST** Coastal Protection toolkit.

As with the riverine flood regulation module, the **ARIES** coastal flood regulation module employs stacked spatial datasets integrated into Bayesian networks. However, much of the underlying spatial data that has been employed is at a global scale. Currently, the tool models the beneficiaries of flood regulation services along with many biophysical parameters that include tropical storm waves, overland hydrological flow, and habitat that potentially alleviates wave damage. It does not presently model storm surge or wave dynamics. The **ARIES** model facilitates spatial analysis of the modeled components and quantifies realized benefits. Although the model was developed for Madagascar, the global spatial resolution of the data allows for workable transferability depending on user application.

InVEST assesses coastal protection services using a toolbox that includes two models – a coastal vulnerability model and a wave attenuation and erosion reduction model. The coastal vulnerability model analyzes a region's vulnerability to hazards and generates descriptive statistics and raster maps representing the landscape exposure index and population vulnerability. Extensive data is required to run the model as the exposure index is a function of geomorphology, relief, habitat, sea level rise, wind and wave exposure, and surge. The coastal vulnerability model can be useful for preliminary evaluation of various policy or management scenarios.

Working in tandem with the coastal vulnerability model, the **InVEST** wave attenuation and erosion model may be used for a more concentrated and complex analysis of the landscape at a finer granularity. As its designations suggest, the model assesses habitats' weakening of waves and erosion and quantifies anthropogenic services.

The wave attenuation and erosion model is data intensive as well and currently requires ArcGIS to run. Model inputs include pertinent management scenarios, land usage/cover, and storm, biotic, and social data. For economic valuation, property values and discount rates must be defined. Ultimately, the model quantifies avoided erosion and inundation, avoided damage to infrastructure, and impact on the affected population.

The **InVEST** coastal protection toolkit is demonstrably applicable to varying spatial scales. Arkema et al. (2013) applied the toolkit to the entire United States coastline (Arkema et al 2013). Subsequent reports have demonstrated the **InVEST** Coastal Protection Toolbox's utility. Arkema et al. demonstrated its contribution to the development of Belize's first Integrated Coastal Zone Management (ICZM) Plan that assessed coastal protection services with other services (Arkema et al 2015). Guannel et al. analyzed changes in ecosystem services provisioning under climate change scenarios in Galveston Bay, Texas (Guannel et al 2015).

ECOLOGICAL SERVICES

Above, we have addressed hydrological and biogeochemical services. Here, we provide a snapshot of DST valuation of ecological services. Wetland ecosystem services are primarily associated with provisioning of wetland habitat that support plant and animal biodiversity. In turn, we review DST that address wetland provision of habitat and biodiversity and then direct our attention to the treatment of cultural services, particularly aesthetic and recreational services, closely linked to habitat and biodiversity.

HABITAT AND BIODIVERSITY

Habitat, in general, is not typically treated as an ecosystem service. Service valuation is concerned with habitats' delivery of final ecosystem services such as aesthetic value and nature-based recreation as discussed below. Yet, it is important to assess habitat as it is inherently connected to many services and may provide insight to the flows of services in a system. Furthermore, many stakeholders may be concerned with the intrinsic biophysical value.

InVEST is capable of investigating wetland habitat quality and rarity. Its Habitat Quality model estimates potential levels of biodiversity producing habitat quality, degradation, and abundance maps derived from land cover and potential threat data supplied by the user.

InVEST's Habitat Risk Assessment (HRA) model is more appropriate than the habitat quality model to assess potential habitat pressures as it allows users to define additional resilience factors such as recovery time and recruitment, mortality, or connectivity rates. The model has been developed for coastal and marine habitats and can be applied to wetland ecosystems. The HRA model produces three outputs: (1) habitat risk maps, (2) risk plots that graphically show habitat/stressor interaction, and (3) recovery potential maps for the habitat or species of concern. Arkema et al. has exhibited the model's contribution to the development of Belize's first Integrated Coastal Zone Management (ICZM) Plan. Three development scenarios were evaluated with their respective impacts on mangrove forests, coral reefs, and seagrass beds (Arkema et al 2015). The **InVEST** models do not attempt to monetize habitat provisioning and provide only biophysical units.

Co$ting Nature evaluates habitat from a conservation standpoint. The tool provides conservation prioritization index maps by equally weighting and aggregating the priority areas of multiple non-governmental organizations (NGOs) that emphasize conservation. Overlap of NGO conservation priority areas result in higher values according to a relative index defined either globally or locally. The index may be combined with biodiversity and relative pressure/threat indices derived from global land use and land cover datasets to produce numerous maps for spatio-temporal analysis. However, the coarseness of the data inhibits user ability to perform large scale spatial analysis.

CULTURAL SERVICES: AESTHETIC AND RECREATION

Many non-material benefits to society may be teased out of an ecosystem's provision of habitat and biodiversity. Following the Millennium Ecosystem Assessment, these are often categorized as cultural services and include spiritual, recreational, aesthetic, and educational societal values (MA 2005). These benefits are often relatively difficult to quantify and existing methodology to do so is not without controversy. This is especially true of stated preference valuation methodology such as contingent valuation (using surveys or interviews) that can be problematic and costly to administer. Consequently, societal preference is not as readily incorporated into environmental resource management decisions.

SolVES quantifies and maps many of these nonmaterial social values that may be categorized under cultural services as well as many other perceived regulating or provisioning services that may be categorized as biogeochemical or hydrological services discussed above (see **SolVES profile** for list). The tool functions as an add-in for ArcGIS and integrates public value and preference surveys and MaxEnt modeling software to produce social value hotspot maps. Sherrouse et al. applied the tool to three national forests in Wyoming and demonstrated the capacity of the tool to inform societal value trade-offs in resource management (Sherrouse et al 2014). Although **SolVES** has not been openly used on an explicit wetland ecosystem, the tool has been applied to the Greater Sarasota Bay region in Florida demonstrating its ecological flexibility (Coffin et al 2012).

It is worth noting that some of the drawbacks of surveying methodology may be alleviated through employing benefit transfer methodology which has been recently incorporated into **SolVES**. This is a much needed extension to the tool and is of greater concern for prospective users with limited capacity. Nevertheless, the improvement cannot be fully realized for wetland ecosystems until a collection of models are generated and made available from a variety of geographic contexts. Currently, the **SolVES** benefit transfer model requires users to draw from models produced from previous **SolVES** analyses and at present these models are non-existent.

In a more concentrated approach, three of the DST address aesthetic values. The **InVEST** Scenic Quality model (currently released in beta form) produces viewshed maps modeled from minimal user supplied geographic data. The model rapidly identifies blight that adversely contributes to scenic views and facilitates the analysis of present and foreseeable land features' impact on the provision of aesthetic services. The current standalone beta version of the Scenic Quality model supports monetary valuation of the adverse blight modeled through varied mathematical functions. Users are able to apply weighting coefficients to the given model.

The **ARIES** viewshed and open space proximity models produce maps of land feature sources that contribute to aesthetic value or desirable open space, adverse blight, and the local population. In contrast to the **InVEST** Scenic Quality model, the **ARIES** models generate relative aesthetic values. Bagstad et al. 2012 applied the models to the San Pedro River watershed in Arizona producing potential and realized use maps under various scenarios. The models' outputs could conceivably be transferred into monetary values. However, the authors were unable to do so for a lack of appropriate value transfer case studies (Bagstad et al 2012).

The **Wildlife Habitat Benefits Estimation Toolkit (WHBET)** economically assesses aesthetic value using an open space property value premium estimator model. The toolkit is provided in a spreadsheet format and allows users to quickly apply a meta-analysis after providing site dimensions, local population data, and ecological variables. The model queries whether the land cover of interest is a wetland, forest, park, protected, or privately owned.

Shifting emphasis to the valuation of nature-based recreation, **WHBET** further retains the capacity to quantify wetland recreational use value. Using benefit transfer, the toolkit provides value tables and meta-functions in its spreadsheet format facilitating rapid valuation of wetland recreational services and other habitats. Similar to the open space property value premium estimator model, the toolkit facilitates estimation of visitor usage requiring minimal inputs. However, users are able to specify model predictors such as wetland acreage, proximal population and per capita

income, physiographic features, pertinent wildlife species, and geographic regions. The benefit transfer models yield daily monetized values according to the specified mode of visitor recreation. These values may be combined with the toolkits' annual use estimates or other data (if available). For demonstrative purposes, we applied **WHBET** to the Upper Mississippi River National Wildlife and Fish Refuge (NWFR), an approximately 240,000 acre floodplain refuge bordering four Midwestern states – Illinois, Iowa, Minnesota, and Wisconsin. Toolkit outputs are shown in **Table 3**.

Using the U.S. Fish and Wildlife Service "Banking on Nature 2004" report as a proxy, **WHBET** estimated that the Upper Mississippi River NWFR maintains 7,239 visitor freshwater fishing days, 6,055 visitor migratory bird hunting days, and 422,163 visitor non-consumptive (hiking, birding, boating, etc.) days (Caudill and Henderson 2005).

Table 3. WHBET outputs: visitor use estimation with annualized values via meta function and value tables, Upper Mississippi River NFWR

VISITOR USE ESTIMATION		
Freshwater Angler Days per Year	**Migratory Bird Hunter Days per Year**	**Non-consumptive User Days per Year**
7,239	6,055	422,163

META FUNCTION	
Value of Fishing per Angler Day	**Value of Waterfowl Hunting per Hunter Day**
$36.62	$26.69
Annualized Value	**Annualized Value**
$265,092.18 (2006 base year)	$161,607.95 (2006 base year)

VALUE TABLE					
Value of Fishing per Angler Day		**Value of Waterfowl Hunting per Hunter Day**		**Value of Wildlife Viewing per Viewer Day**	
NORTHEAST		NORTHEAST		NORTHEAST	
Mean	Median	Mean	Median	Mean	Median
$42.87	$27.18	$35.99	$29.21	$46.48	$37.29
NATIONAL		NATIONAL		NATIONAL	
Mean	Median	Mean	Median	Mean	Median
$55.59	$55.93	$134.23	$134.23	$31.25	$24.29
Annualized Value		**Annualized Value**		**Annualized Value**	
NORTHEAST		NORTHEAST		NORTHEAST	
Mean	Median	Mean	Median	Mean	Median
$310,335.93	$196,756.02	$217,919.45	$176,866.55	$19,622,136.24	$15,742,458.27
(2006 base year)		(2006 base year)		(2006 base year)	
NATIONAL		NATIONAL		NATIONAL	
Mean	Median	Mean	Median	Mean	Median
$402,416.01	$404,877.27	$812,762.65	$812,762.65	$13,192,593.75	$10,254,339.27
(2006 base year)		(2006 base year)		(2006 base year)	

The Upper Mississippi River NWFR did not participate in the "Banking on Nature 2004" report but was included in the more recent 2013 "Banking on Nature" report. This enabled the rough comparison of visitation estimates from the toolkit's use estimating model and first-hand estimates from Upper Mississippi River NWFR officials exhibited in **Table 4**.

The refuge figures are considerably higher than the estimates yielded from the use estimating model. Omitting additional estimates for small and big game hunting, Upper Mississippi River NWFR officials estimated total visitation to be at 4,437,390 days (Carver and Caudill 2013) compared to 434,457 days via the toolkit. Although the refuges in the "Banking on Nature" reports employ varied methods to estimate and/or record visitation rates, this comparison suggests that **WHBET** yielded a substantial underestimate holding the assumption that the Upper Mississippi River NWFR officials' assessment is relatively accurate.

Table 4. WHBET output compared with refuge estimates, Upper Miss. River NFWR

VISITOR USE ESTIMATION					
Freshwater Angler Days per Year		**Migratory Bird Hunter Days per Year**		**Non-consumptive User Days per Year**	
Toolkit	7,239	**Toolkit**	6,055	**Toolkit**	422,163
NWFR Officials	1,561,444	**NWFR Officials**	167,490	**NWFR Officials**	2,649,890
ANNUALIZED VALUES*					
Fishing		**Waterfowl Hunting**		**Wildlife Viewing**	
Toolkit	$ 310,335.93	**Toolkit**	$ 217,919.45	**Toolkit**	$ 19,622,136.24
NWFR Officials	$ 66,939,104.28	**NWFR Officials**	$ 6,027,965.10	**NWFR Officials**	$ 123,166,887.20
	(2006 base year)		(2006 base year)		(2006 base year)
*using Northeast (value table) mean daily values					

This cursory comparison does not detract from the utility of the toolkit but does expose its limitation. The Upper Mississippi River NWFR recorded the highest visitation figures among all refuges in the 2013 "Banking on Nature" report regionally and nationally making it an atypical case. There are many factors that contribute to visitation rates and users of **WHBET** should take care to examine model predictors and assess their bearing on outputs. This may reveal unique site qualities that may cause considerable underestimation or overestimation.

Additional utility may be found using the visitor use estimating models under potential restoration scenarios. Users may specify an increase in wetland acreage or refuge use access. In turn, **WHBET** projects an estimated increase in user days according to the modes of recreation.

The benefit transfer component of **WHBET** is similar to the visitor use estimation models. Two types of benefit transfer are offered, function transfer (via meta-analysis) and value transfer, offering users more flexibility (**Table 3**). The value transfer method given as tables allows for choice or comparison between regional and national statistics (we show mean and median averages) and further facilitate direct value transfer from a comparable case study if

appropriate. These values do retain considerable variation, making ranges and/or conservative estimates ideal when reporting results. In **Table 4** we show annualized values using the Northeast region (Midwestern states are included in the Northeast region) user day values: $42.87, $35.99, $46.48 for fishing, waterfowl hunting, and wildlife viewing respectively. Using toolkit visitation estimates, annualized values sum to $20,150,391.62 compared to $196,133,956.60 with refuge officials' visitation estimates. Unmistakably, user visitation estimates have a greater bearing on annualized values in the demonstrated case.

It should be noted that the units of valuation for **WHBET** do not represent historic costs incurred by visitors such as travel costs or lodging. Rather, the toolkit elicits public preference or the willingness to pay for potential benefits accrued from ecological improvement and is appropriate to substantiate wetland restoration costs.
Other DST address visitation frequency using different methods. Both **Co$ting Nature** and **InVEST** use photographic social media services to inform visitor behavior. **Co$ting Nature** employs Google's Panoramio service and the **InVEST** recreation model uses Yahoo's Flickr service. Both tools produce maps conducive for additional spatial analysis.

Co$ting Nature's recreation module extracts georeferenced Panoramio photographs and distinguishes a photographer count to indicate tourist prevalence over an area. Urban areas are masked and the extracted data is then interpolated over a 1 kilometer or 1 hectare grid generating a qualitative relative nature based tourism index. Similarly, the **InVEST** recreation model extracts georeferenced Flickr photographs and distinguishes a photographer count. In contrast, the model accounts for the number of days individual tourists took photos to calculate average photograph user days from 2005-2012 interpolated over an area of interest and delimited into a user defined cell size.

Again, for demonstrative purposes, we applied **Co$ting Nature** and **InVEST** to the Upper Mississippi River NWFR. Toolkit outputs are shown comparatively in **Figure 3**. As expected, using separate georeferenced photograph databases and differing processes, the tools produced contrasting results. However, in both outputs users may observe that visitation concentration along the Upper Mississippi River NWFR appears to retain a perceptible relationship with urban centers with greatest concentration in a Southeastern Minnesota-Western Wisconsin metro area (La Crosse-Onalaska) – accentuated as a subset in **Figure 3**. From visual analysis, users of the tools would find it difficult to quantify the degree of impact the area of interest has on nature based recreation at a regional scale.

Notably, the **InVEST** recreation model has the added advantage of being able to conduct multi-scale analysis by allowing the user to define the area of the cells, mentioned above and visible in **Figure 3a**. The model also enables estimation of the degree of land features effect on visitation trends. For example, using external GIS software, we were able to sum the photograph user days in each cell within our area of interest to 1365.

The **InVEST** recreation model facilitates analysis through simple linear regression with predictor variables defined and/or supplied by the user. We supplied Upper Mississippi River NWFR vector data and opted to use default land use and land cover model predictors in the linear regression model producing an estimate of 392 photo user days (29%) that may be attributed to landscape features. These estimates may appear inconsequential when compared to more empirical estimates. Nevertheless, Wood et al. compared empirical data from 836 global sites against georeferenced photographs from Flickr

(a) InVEST Recreation Model (using Flickr)

(b) Co$ting Nature (using Panaramio)

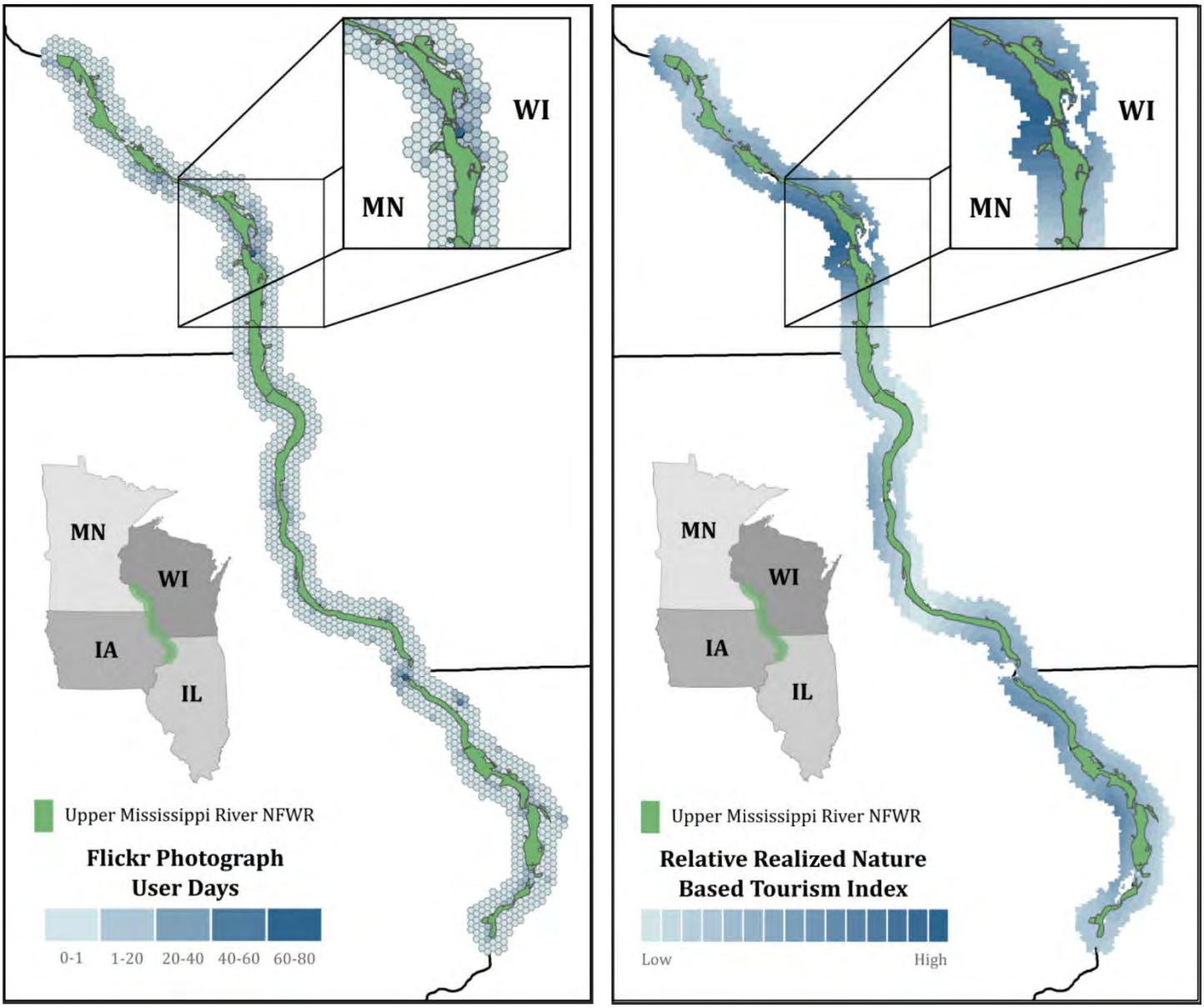


Figure 3. Visitor use estimation output comparison: (a) InVEST; (b) Co$ting Nature, Upper Mississippi River NFWR

and found that they provide an appropriate proxy for empirical assessments. They suggest application of the exhibited relationship to investigate the effect of land use and land cover change on visitation trends over foreseeable scenarios (Wood et al 2013). This may be conducted using an additional **InVEST** recreation scenario model. Not without limitations, the model is well suited to inform various policy scenarios that may result in the loss or gain of natural habitat and the resulting effect on recreation and tourism.

Akin to **Co$ting Nature**, **ARIES** recreation models generate maps with a relative valuation unit. Using stacked spatial data sources and Bayesian networks, the models account for land cover that contribute and detract from recreational use, beneficiaries, and infrastructure promoting access to recreational sites. The models are able to

differentiate between modes of recreation. Bagstad et al. applied the models to the San Pedro River Watershed in Arizona and generated recreation value maps for birding and deer hunting and quantified relative values over multiple development scenarios. Their results provided insight on the magnitude of the effect habitat improvement could have on recreational services (Bagstad et al 2012).

Finally, **TESSA** is characterized by a more hands on approach and acts as a procedural guide to conduct a rapid assessment of visitation rates and recreational value. Through written guidance and decision trees, users are directed through multiple procedures to empirically estimate visitation rates and corresponding economic value. The toolkit also offers a questionnaire template if contingent valuation methodology is preferred. Conceivably, because of its adaptable framework, **TESSA** invites users to employ multiple DST in an integrated manner. As assessing nature-based recreation is a multi-step process, users could utilize **WHBET** to estimate visitor use, for instance, and in turn derive economic data such as spending habits using a questionnaire template and elementary valuation methods facilitated by **TESSA**. Consequently, **TESSA** likely appeals to users with limited capacities and who require methodical guidance.

INSIGHTS

1	The ecotonal nature of wetlands potentially limits DST application. This is clearly manifest in many of the tools handling of carbon services where natural methane emissions are not factored in models seemingly developed with terrestrial ecosystems in mind. Conversely, marine and coastal models are not pertinent for inland wetlands. There is a need for development of DST expressly for wetlands.
2	Many DST have been developed for particular spatial contexts and their models are then extrapolated to other sites. The appropriateness of a model's application is contingent on many factors. Potential users should consult DST documentation in advance to discern limitations and/or confirm suitability.
3	The spatial granularity of inputs is often indicative of the appropriate scale of analysis for DST. Tools utilizing regional and global datasets are seldom appropriate for local analyses. Potential users should be wary of probabilistically interpolated outputs with ostensibly fine granularity prone to misinterpretation.
4	Care should be taken not to overstate estimated values directly from DST outputs. Sites may retain conditions or contexts that detract from modeled value. Tradeoffs and potential disservices resulting from prospective development should be considered as well as the consumption of services. DST may not model beneficiaries of services, without which there can be no ecosystem service value.
5	There is not a preeminent unit of valuation. Priorities of stakeholders, institutions, and managers will determine effective (or ineffective) units of valuation. The three primary units of valuation (biophysical, monetary, and social) are easily integrated in order to satisfy wide-ranging interests. Potential DST users may opt to employ multiple DST to meet this demand.
6	Units of valuation need to be properly understood in order to effectively communicate results. For instance, monetary values may express society's willingness to pay for ecological improvement or avoided costs associated with an ecological function depending on valuation methodology. Social values likely express perceived benefits and may or may not be actually realized.
7	For DST utilization, time is weighted heavily toward data collection and pre-processing that may be easily overlooked. Local and regional valuation efforts would greatly profit from advance preparation. Many DST can be augmented by first hand field surveys that may require long term monitoring programs of which some can be implemented with little cost and upkeep if emphasis is placed on select ecosystem services.
8	While most DST have been developed to inform future policy and management decisions, they may be effectively applied post-hoc with adequate data from monitoring programs. Most DST are capable of demonstrating change in ecosystem service flows that can positively validate efforts or reveal deficiencies. These assessments could also be used to inform decisions for sites with similar contexts.
9	Data deficient contexts often entice value and benefit transfer methodology. For some DST, the potential of this methodology may not be fully realized until an assemblage of wetland case studies are implemented, documented, and collected for widespread use. For wetlands, regional assessments may also be constrained without an appropriate network of case studies or monitoring programs.
10	If ecosystem service provisioning is a priority, then the DST included in this report are worth consulting, at minimum, for preliminary site scoping. Requisite regional and national data are readily available in the United States allowing the DST to conduct preliminary assessments rapidly with little to no costs.
11	Though many DST attempt to "bridge the scientific gap" for the valuation of ecosystem services, the challenge still remains. Admittedly, many DST models and functions will require expert consultation for the typical wetland manager.

GLOSSARY

Annual rate of change: the rate at which the value of benefits changes over time. Society may value benefits more or less in the future [distinct from the **discount rate**] due to contextual or biophysical dynamics.

Avoided costs: the value of ecosystem services based on the dollar value of avoided damages.

Bayesian networks: probabilistic graphical models used to represent dependencies between random variables and computationally simulate unknown knowledge

Benefit transfer valuation: benefit transfer valuation involves finding research and studies already performed for similar projects in different locations (aka "study sites") and applying the economic values estimated from those previous studies for your particular situation (aka "policy site").

Biogeochemical services: having to do with the storage and removal of surplus nutrients in a wetland – or nutrient cycling. This intermediate service lead to an assortment of final services such as the regulation of climate through carbon storage and sequestration and the purification of water through nitrogen and phosphorus cycling.

Contingent valuation: the Contingent Valuation Method can be used to estimate use and non-use values for ecosystem benefits. Use value is the benefit people derive from using a service or good. Non-use value is the value people assign to goods and services that they never have or possibly never will use. Contingent valuation is the most commonly used method for estimating non-use values (such as preserving a scenic vista, saving whales, or preserving wilderness for the next generation).

Cultural services: the nonmaterial benefits provided by ecosystems often experienced through recreation, aesthetic appreciation, spirituality, etc.

Digital elevation model: the representation of a terrain surface

Discount rate: the rate used to reduce future benefits and costs to their present time equivalent.

Ecological services: having to do primarily with provisioning of wetland habitat that support plant and animal biodiversity.

Ecosystem services: the actual life-support functions (such as cleansing, recycling, and renewal) provided by ecosystem functions - they may also confer many nonmaterial benefits [see **cultural services**].

Ecosystem service valuation: the quantification of goods and services ecosystems provide to society in monetary and non-monetary terms

Final ecosystem services: ecosystem goods and services that are directly consumed by end users

Hydrological services: having to do with the regulation of sediment that directly or indirectly contribute to inland flood regulation, coastal protection, and the purification of water.

Intermediate ecosystem services: ecosystem goods and services that provide indirect benefits to society through the production of **final ecosystem services**

Natural capital: the stock of natural ecosystems that yields a flow of valuable ecosystem goods or services into the future.

Provisioning services: the material outputs (or products) produced by ecosystems such as food, fuel, fiber, freshwater, etc.

Raster: an array of pixels (or cells) containing attribute values representative of spatial information

Regulating services: the ecosystem services provided through moderation of ecological functions such as climate, water, and natural hazard regulation.

Relative value: in contrast to absolute value which measures the dollar value of X or Y, relative value measures the value of X in relation to the value of Y – in other words, is X greater or less than Y?

Social cost of carbon: an annualized estimate of the economic damages linked to rising carbon emissions contributing to climate change

Stated preference valuation: stated preference techniques ask individuals to respond to hypothetical situations and individual responses are used to infer monetary value based on demand. Stated preference techniques include: contingent valuation and conjoint analysis.

Supporting services: ecosystem services that contribute to the production of other ecosystem services (see **intermediate ecosystem services**) such as nutrient cycling and primary production.

Vector: coordinate spatial data represented as points, lines, and polygons

Wetland restoration: the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to former or degraded wetland.

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