A GUIDE TO SELECTING ECOSYSTEM SERVICE MODELS FOR DECISION-MAKING

Lessons from Sub-Saharan Africa

WORLD RESOURCES INSTITUTE

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NATURAL ENVIRONMENT RESEARCH COUNCIL

espa ecosystem services for poverty alleviation

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EXECUTIVE **SUMMARY**

Ecosystems provide many services essential to human livelihoods. To maintain long-term sustainability of ecosystem benefits, many national policies and some international agreements include objectives to protect ecosystems. For instance, a number of the nationally determined contributions to climate action, submitted by countries under the 2015 Paris Agreement, include ecosystem-based climate mitigation and adaptation objectives. Additionally, as of December 2017, 127 United Nations member states had signed to join the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES), an independent intergovernmental body established to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being, and sustainable development.[1]

HIGHLIGHTS

- Ecosystem service modeling tools can provide decision-makers with useful information on local ecosystem services, especially when measured data are inadequate. This information is often needed to address questions about changing land use, valuing natural capital, and analyzing cobenefits and tradeoffs among different policies or activities.
- Because more than 80 fast-evolving ecosystem service models or assessment tools are available, technical advisors can benefit from guidance on the types of models available and issues that should be considered when choosing the models best suited to specific policy questions.
- This guide can help advisors to select the ecosystem service model best suited to their needs. It is based on results from the 2013–16 WISER project, which assessed several ecosystem service modeling tools in sub-Saharan Africa and provided a general assessment of their utility.

Managing for the sustainability of ecosystem services requires an understanding of their condition and extent as well as the ability to predict the impacts of alternative policy or management decisions on them. If measured data on ecosystem services are lacking, models can provide useful information based on assumptions from similar geographies. Modeling is especially useful in developing countries, where measured data may be sparse. Indeed, a recent survey conducted by Willcock et al. (2016) showed that a majority of decision-makers (73 percent of 60 respondents from 38 countries) in sub-Saharan Africa required additional information on ecosystem services to support their activities.

A number of modeling tools for mapping ecosystem services have been developed to help decision-makers better understand their local systems. These often consist of a set of models, each representing a particular ecosystem service. However, the usefulness of these modeling tools to support decision-making in practice is limited, partly because governments or other institutions lack the technical capacity and resources to maintain or run the models. A number of publications provide guidance on methods for assessing ecosystem services, including using modeling. However, these publications are generally written by technical experts for other trained professionals, rather than for decision-makers.

This guide was developed for technical advisors to government officials, business people, investors, and others who need to draw on ecosystem assessments to inform decision-making. It assesses several types of ecosystem service modeling tool, discusses issues involved in modeling ecosystem services, and provides guidance on how to choose the right model to address a specific policy question. It especially targets advisors and decision-makers in developing countries who are not experts in ecosystem service modeling and who have limited information and technical resources but must make decisions about natural resource management in relation to ecosystem services.

Five steps are proposed to help decide which model to use in a particular decision-making context:

Step 1. Determine the policy questions and scope of the research.

Step 2. Consider the decision-making context.

Step 3. Evaluate ecosystem service models in the decision-making context.

Step 4. Reassess your data resources and modeling capacity.

Step 5. Choose the most appropriate model.

The guide draws on experience of a 2013–16 project in sub-Saharan Africa, which evaluated ecosystem service models for specific decision-making contexts. The WISER (Which Ecosystem Service Models Best Capture the Needs of the Rural Poor?) project, conducted under a grant from the not-for-profit Ecosystem Services for Poverty Alleviation program, evaluated the effectiveness of a range of modeling approaches for mapping several ecosystem services—stored carbon, water availability, charcoal and firewood forest products, and grazing resources—at multiple spatial scales across sub-Saharan Africa.

Several main points emerged from the WISER study:

- Ecosystem service modeling tools and models are a resource to help decision-makers address a variety of resource management questions, particularly in assessing how different actions will affect ecosystem services and the economic value of these services.
- Models have different levels of accuracy. Generally, more complex models are more accurate. However, in any application, the accuracy of a model cannot be known without validation against measured ecosystem service data.
- Decision-makers should be aware of the uncertainty in model predictions and its impact on their decisions. Uncertainty can be mitigated if model results are compared with available data and assessed for accuracy. If possible, information should be gathered during policy implementation to ground-truth, assess, and improve the models and, where possible, run multiple models for the targeted ecosystem services to generate a range of possible outcomes.

CHAPTER 1: USING ENVIRONMENTAL SERVICE MODELS TO HELP MAKE DECISIONS

The demand for an enhanced understanding of ecosystem services has grown rapidly in sub-Saharan Africa. Policymakers and their advisors have an appetite for information about ecosystem service models and how they can support decisions.

Ecosystem services are the benefits people obtain from nature, such as clean water, nutritious food, and protection against extreme weather. To maintain the long-term sustainability of these benefits, many countries and some international environmental agreements have included the protection of ecosystems and biodiversity among their objectives. For instance, 23 of the 162 intended nationally determined contributions (covering 189 countries) submitted to the United Nations Framework Convention on Climate Change refer explicitly to ecosystem-based adaptation, and 109 countries presented ecosystem-oriented visions for adaptation (IIED, 2016). Furthermore, as of December 2017, 127 United Nations member states had signed up to participate in the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES).[2]

Managing ecosystem services requires an understanding of their status and distribution over geographical regions, as well as of the potential impacts of alternative policy or management decisions on them. Models can provide useful information even if measured data on ecosystem services are sparse, which is especially the case in many developing countries. Indeed, a recent survey showed that a majority of technical advisors to decision-makers, who are actively engaging with ecosystem services research to support policy development in sub-Saharan Africa, required additional information on ecosystem services to support their activities. Of 60 respondents from 38 countries, 73 percent stated this requirement (Willcock et al. 2016).

To meet the demand for managing ecosystem services, many modeling tools for mapping ecosystem services have been developed. They range from tools that provide simple mapping of services based on land cover to sophisticated process models that include representation of the biological and physical mechanisms that produce ecosystem services. A key aspect of these tools is that they can model multiple

ecosystem services and help people make difficult decisions when actions have conflicting effects on different ecosystem services. For example, converting forest to agriculture may enhance food production but at the expense of carbon storage and soil quality. Alternatively, agroforestry activities may benefit all three services (food production, carbon storage, and soil quality) to some extent. Modeling can help quantify tradeoffs and synergies and help develop scenarios of how specific interventions might impact different ecosystem services and beneficiaries.

But are these modeling tools really of use to decision-makers in practice? In a review of over 100 coastal ecosystem valuation studies in the Caribbean, Waite et al. (2015) found that only 17 percent had directly influenced decision-making. More recently, in the survey of decision-makers in sub-Saharan Africa (Willcock et al. 2016), fewer than 35 percent of the respondents reported using ecosystem service models to inform their activities. Respondents stated that this was partly due to the lack of technical capacity and resources to develop or run ecosystem service models. This guide will help decision-makers understand what types of data and expertise they might need for different types of models.

A number of publications provide guidance on the methods for assessing ecosystem services, including through modeling.[3] In particular, the Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES 2016) gives an in-depth analysis of the large body of knowledge about scenarios and models within IPBES's conceptual framework. However, these publications are written for advanced technical experts rather than for decision-makers and their advisors and focus on model specificities and inputs and outputs. In addition, there are many ecosystem service models to choose from: Bagstad et al. (2013) listed more than 17 ecosystem service model tools, but more have emerged (see Christin et al. [2016] and de Groot et al. [2017] for more recent updates on over 80 ecosystem service models and assessment tools). Many of these models are continuously modified to improve their performance and utility. Therefore, we do not provide guidance on specific models but on the process by which decision-makers should choose the models to use.

This guide will help decision-makers and their advisors better understand how to work with a consultant or staff experts to select appropriate ecosystem service models. It addresses how to frame policy questions, explains what types of ecosystem service models are available, discusses the issues involved in modeling ecosystem services, and provides guidance on how to choose a model that best addresses specific policy questions in different decision-making environments.

The guide draws from the WISER (Which Ecosystem Service Models Best Capture the Needs of the Rural Poor?) project,[4] funded under Ecosystem Services for Poverty Alleviation (ESPA)[5] a global interdisciplinary research program. The program was developed by the British government in response to the 2005 Millennium Ecosystem Assessment, which found that substantial gains in human well-being in recent decades have been achieved at the expense of high and often irreversible levels of ecosystem degradation. WISER evaluated the effectiveness of several modeling approaches when mapping various ecosystem services—stored carbon, water availability, firewood, charcoal, and grazing resources—at multiple spatial scales across sub-Saharan Africa. It assessed how model complexity affects performance in order to ascertain how to improve ecosystem service modeling in a way that is useful for poverty alleviation.

Ecosystem service models can provide economic values, biophysical measures, or maps that show either economic or biophysical model outputs. Using these models requires that a general policy question be translated into one or more specific questions that can be addressed using existing modeling tools. This guide discusses how to do this.

But ecosystem service models do not provide all answers to all questions about services. When the WISER team asked decision-makers in sub-Saharan African countries where they needed more information, they listed 22 areas, but models could help with only 16 of them (Appendix A).

Readers with policy questions that they think can be addressed by ecosystem models can follow the step-by-step procedure for selecting appropriate models in this guide. The steps are illustrated with examples from WISER. Following these steps will also help determine whether the policy question can be answered with existing models.

Ecosystem service models can provide economic values, biophysical measures, or maps that show either economic or biophysical model outputs.

CHAPTER 2: HOW TO SELECT AN ECOSYSTEM SERVICE MODEL

Over 80 ecosystem service models and assessment tools are available, and many are being updated regularly. Selection of ecosystem service models appropriate to the decision-making context requires well-defined policy questions and clear understanding of in-house modeling resources.

The process for using an ecosystem service model for decision-making involves two stages: first, selecting one or more models, and second, implementing and validating them. This guidebook focuses on only the first stage: how to select appropriate ecosystem service models. Models exist within ecosystem service modeling tools (Box 1). Selection should focus on the model rather than the tools. Models assess different ecosystem services, and they vary in complexity and accuracy.

The second stage of choosing a model—implementing and validating—consists of actions to allocate human resources, collect data, run the model, and obtain and interpret results. Models should be validated against measured ecosystem services, if data are available, to assess the accuracy of their results. The capital and time investment necessary to implement and validate models varies greatly depending on the type of model selected and modeling objectives and purposes. Hence, despite its importance, the subject of investment is not discussed here.

Box 1 | Models and Modeling Tools

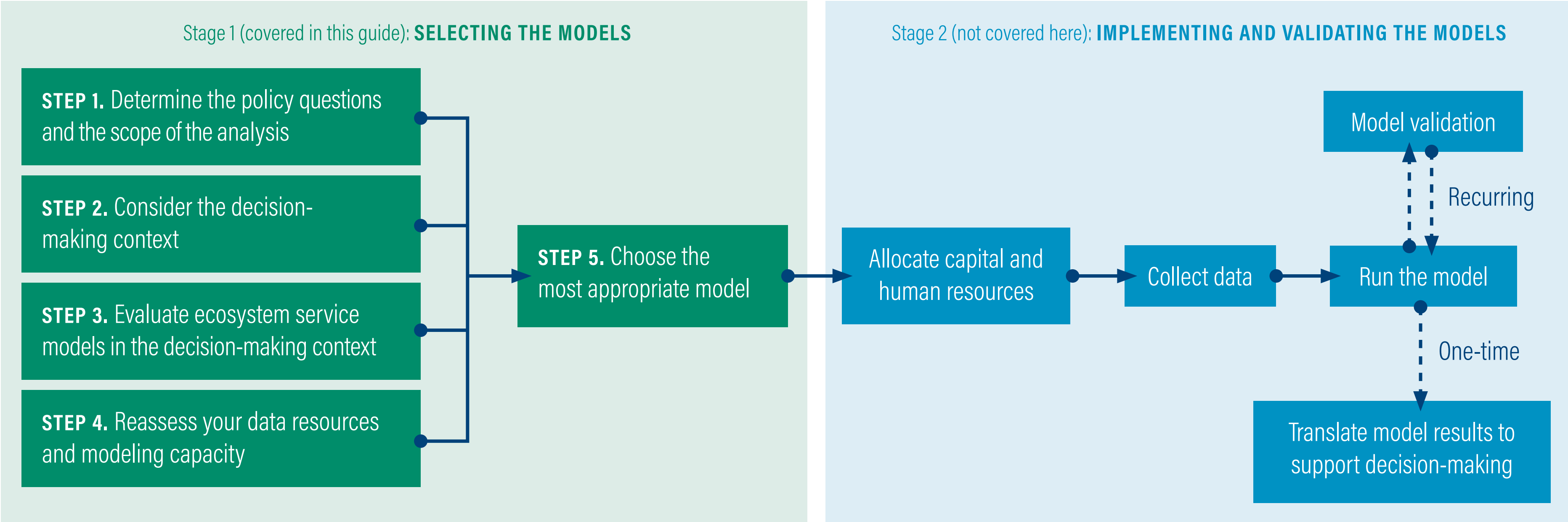
Ecosystem service modeling tools (e.g., InVEST[a] and Co$ting Nature) are platforms that provide specific models for a number of ecosystem services. For instance, the InVEST tool contains specific models that assess water supply, carbon, crop pollination, and fisheries, among others, and Co$ting Nature consists of specific carbon and water supply models.

Models vary greatly in the complexity of their structures (from the simplest benefit transfer models to deterministic models and the most complex process-based models), as well as in the number and type of data inputs they require and the number and type of outputs they produce. (See Appendix C for a detailed discussion of model complexity. Also see Box 3 for an ecosystem service modeling primer.)

Notes:

a. National Capital Project, InVEST User Guide. http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/.

Figure 1 | Decision-Making Flowchart for Selecting and Using an Ecosystem Service Model



Source: WRI.

Stage 1 comprises five steps (Figure 1):

Step 1. Determine the policy questions and scope of the research.

Step 2. Consider the decision-making context.

Step 3. Evaluate ecosystem service models in the decision-making context.

Step 4. Reassess your data resources and modeling capacity.

Step 5. Choose the most appropriate model.

These steps are described in detail herein with worksheets and examples to help users select the most appropriate model for their needs. Because there are more than 80 ecosystem service models and assessment tools and many are constantly evolving, it is not possible to give specific information on all of them. Thus this guide may be used in conjunction with a consultant or staff expert well versed in models and modeling tools. The guide gives decision-makers and their advisors enough information about what models can do and what data and expertise are needed to conduct modeling so that together they can make an informed choice among modeling tools.

The first two steps help decision-makers figure out exactly what they want to know, ask questions that can be addressed by modeling, and take stock of their in-house resources for doing modeling work. At the end of step 3, users should assemble a set of possible models that can address their questions and be used within their capacities. In step 4, they examine each model or modeling system to see how well it meets their needs. Step 5 gives an overview of how to make the final selection of the most suitable model.

STEP 1. DETERMINE THE POLICY QUESTIONS AND SCOPE OF THE RESEARCH

OBJECTIVE OF STEP 1: Determine the policy question, frame the question in a way that models can answer, identify the ecosystem services to be modeled, including the geographic scale, and identify the output type (e.g., maps, economic data) and the desired levels of accuracy.

Address the guiding questions below:

Q1 WHAT POLICY QUESTION DO WE WANT TO ADDRESS USING AN ECOSYSTEM SERVICE MODEL?	Q2 HOW CAN WE FRAME THIS QUESTION TO GET MEANINGFUL OUTPUTS FROM THE MODEL?	Q3 WHAT ECOSYSTEM SERVICES ARE IMPORTANT FOR OUR DECISION-MAKING AND WHAT IS THEIR GEOGRAPHIC SCALE?	Q4 WHAT FORMATS (BIOPHYSICAL, ECONOMIC, MAPS) ARE NEEDED FROM THE MODEL OUTPUTS?	Q5 WHAT LEVEL OF ACCURACY IS NEEDED FOR THIS DECISION?
■ Where should we allocate funds for restoration to get the most impact? ■ If we invest in landscape restoration, will it help those in poverty? ■ Would we save money in providing water services by restoring a certain wetland?	■ Which are the most effective locations for land use change/ restoration to improve specific services (e.g., sediment retention or flood alleviation)? ■ What are the economic benefits of landscape restoration for those who depend on the ecosystem services (e.g., fuelwood, forest products, grazing, water) for their livelihoods? ■ What are the economic benefits of cleaner water created by restoring this wetland?	■ Carbon storage ■ Water supply ■ Water quality ■ Crop pollination ■ Agricultural production ■ Erosion control ■ Coastal protection ■ Pest regulation ■ Recreation and tourism ■ At what scale will ecosystem services be modeled: sub-catchment, municipality level, country level, or beyond?	■ Are biophysical or economic outputs needed? ■ Are mapped outputs needed?	■ Very accurate service estimates to represent the health of current ecosystems ■ Very accurate service estimates for predicting future availability ■ Moderately accurate estimates of the economic value of ecosystems ■ Moderately accurate estimates of the most important locations for delivery of a service

WHY IS IT IMPORTANT TO DEFINE CLEAR POLICY QUESTIONS?

This process clarifies exactly what you want to know to make a policy decision regarding ecosystem services. Some typical questions for decision-makers include the following:

- Where should we allocate funds for restoration to get the most impact?
- If we invest in landscape restoration, will it help those in poverty?
- Would we save money in providing water services by restoring a certain wetland?

WHY IS IT NECESSARY TO FRAME THE QUESTION SO THAT A MODEL CAN GIVE MEANINGFUL INFORMATION?

The policy question must be framed such that a modeling tool can analyze and present data to help the user make a decision.

For example, to answer the question "Where should we allocate funds for restoration to get the most impact?" you could ask, "Which are the most effective locations for land use change/restoration to improve specific services (e.g., sediment retention or flood alleviation)?"

To answer the question "If we invest in landscape restoration, will it help those in poverty?" you could ask, "What are the economic benefits of landscape restoration to those who depend on the ecosystem services (e.g., fuelwood, forest products, grazing, water) for their livelihoods?

To answer the question, "Would we save money in providing water services by restoring a certain wetland?" you could ask, "What are the economic benefits from cleaner water created by restoring this wetland?"

Ecosystem service models are good at

- valuing ecosystem service cobenefits;
- analyzing tradeoffs of ecosystem services;
- prioritizing options, projects, or locations for resource management;
- selecting the best actions or strategies.

Asking a clear question helps clarify model objectives and select the right model to use.

Some questions framed for this purpose are shown in Table 1.

Table 1 | Policy Questions Framed for Use in Ecosystem Service Modeling

TYPE OF POLICY QUESTIONS	EXAMPLES OF QUESTIONS FRAMED FOR USE IN MODELING
Questions related to valuing ecosystem service cobenefits	■ What is the total economic contribution of specific land use classes (e.g., forests) to the regional or national gross domestic product (GDP)? ■ What is the value (monetary or to human well-being) of services from a specific land use class under alternative management options, and what are the cobenefits from sustainable management? ■ What are the potential financial returns on different resource management strategies? ■ What are the benefits of enhancing ecosystem services—for example, through landscape restoration—to multiple stakeholders, including those who invest in ecosystem service provision? ■ How is the revenue generated in a business supply chain dependent on ecosystem services?
Questions related to analyzing trade-offs of ecosystem services	■ How will a focus on, for example, forestry or agricultural production impact the supply of other ecosystem services, such as water and carbon regulation? ■ Which services will be enhanced by planting trees, and which will be negatively affected?
Questions related to prioritizing options, projects, or locations for resource management	■ Which actions will best enhance ecosystem services that are of use to those living in poverty? ■ What is the spatial overlap between areas of high priority for biodiversity conservation and areas of high priority for ecosystem services? ■ Which are the most effective locations for land use change/restoration to improve specific services (e.g., sediment retention or flood alleviation)?
Questions related to selecting the best actions or strategies	■ Which are the best actions to maintain specific services under climate change (e.g., ameliorating increased flood risk)? ■ Which potential mitigation strategies (e.g., protection vs. restoration) will best enhance ecosystem services?

Source: WRI.

WHY IS IT NECESSARY TO DEFINE THE ECOSYSTEM SERVICES OF INTEREST AND THE GEOGRAPHIC SCALE ?

To select a model, one must identify which ecosystem services need to be modeled. There are not yet models for all ecosystem services (although the number of services modeled is increasing). For example, Figure B3 presents a handful of ecosystem services that are commonly modeled by different modeling tools. In fact, the WISER survey found that out of 22 ecosystem services of interest to decision-makers in sub-Saharan Africa, only 59 percent could be modeled using existing ecosystem service models (see Appendix A).

Clearly defining the geographic scale of the analysis will help determine the data-collection efforts and anticipate the accuracy of the model outputs.

WHY IS IT NECESSARY TO CLARIFY THE EXPECTED FORMAT AND ACCURACY LEVEL OF MODEL OUTPUTS?

The type of output relates to the information needed to answer the policy question as defined above. Model outputs can be in the form of geographic information system (GIS) maps, economic data, crop yields, water-flow quantities, and many other measures. If decision-makers want mapped outputs of ecosystem service provision in the study area, they must choose a model that produces maps (or have the capability to map the outputs separately). The outputs of ecosystem service models can also be in physical terms, such as the annual water yield from a catchment, or economic terms, such as that water's net present value with the intended use of hydropower production. Ecosystem service models may generate outputs in either biophysical or economic terms, but few models provide outputs in both formats. The output format is determined by how the question is framed for the model.

Thus, to address the question in Table 1, "What is the total economic contribution of specific landuse classes (e.g., forests) to the regional or national GDP?" you need a model that gives output as economic data (or the ability to translate the given outputs to economic values).

To address the question, "How will a focus on, for example, forestry or agricultural production impact the supply of other ecosystem services, such as water and carbon regulation?" you need an output of biophysical data.

To address the question, "What is the spatial overlap between areas of high priority for biodiversity conservation and areas of high priority for ecosystem services?" you need a mapping output.

WHY DO I NEED TO SET A LEVEL OF ACCURACY?

The required accuracy is related to the decision-making context and specific policy questions. There is often a trade-off between the level of accuracy and the complexity of the model and the time available to produce results. More complex models tend to be more accurate but require more data, resources, technical expertise, and time. Box 2 gives the results of a survey of decision-makers in sub-Saharan Africa on what level of accuracy they wanted for different types of decision.

EXPECTED OUTCOMES OF STEP 1: A better understanding of the policy questions, how to frame questions that can be addressed by models, the targeted ecosystems and ecosystem services to be modeled, the scale of the analysis, and the desired format of model outputs for the intended decision-making.

Box 2 | WISER Decision-Makers Require Different Levels of Accuracy for Different Types of Decisions

A WISER survey of decision-makers (Willcock et al. 2016) in sub-Saharan African countries asked about the context for using an ecosystem model and the model accuracy required (Table B2.1).

Table B2.1 | WISER Project Identifies the Possible Decision-Making Context That Requires the Use of Ecosystem Service Models

CONTEXT FOR USING ECOSYSTEM SERVICE MODELS	PERCENT OF RESPONDENTS	TYPE OF DECISION-MAKER	MODEL ACCURACY REQUIRED
Develop policy	66	Advisors to policymakers	General patterns of ecosystem services, but less accuracy required in terms of exact values than for other users
Manage ecosystem service supply	60	Practitioners and technical staff in the government and other agencies and sustainability managers in businesses that are resource dependent	Require highly accurate modeling results
Manage land use	53		
Compare scenarios of alternative options	28		Moderately accurate results to allow ordering of scenarios
Communication and awareness raising	53	Technical advisors to nongovernmental organizations (NGOs) or policymakers	General patterns of services, but less accuracy required in terms of exact values
Understand links to human well-being	62	Technical advisors to NGOs or policymakers	

STEP 2. CONSIDER THE DECISION-MAKING CONTEXT

OBJECTIVE OF STEP 2: Determine the general level of available data resources and technical capacity available at your institution. This will help you determine how complex a model you can use.

Address these guiding questions regarding the context for decision-making:

Q1
WHAT IS THE INTENDED USE OF ECOSYSTEM SERVICE MODEL RESULTS?

- Develop future scenarios
- Conduct policy assessment
- Assess the value of ecosystem services for a region
- Determine the best actions to maintain services
- Calculate trade-offs between different services
- Assess ecosystem service benefits from biodiversity conservation actions

Q2
WHAT DATA ARE AVAILABLE ABOUT ECOSYSTEM SERVICES TO ADDRESS THE POLICY QUESTION?

- Little or no data availability beyond digital maps of land use
- A range of relevant local data available that can be used as model inputs
- High quality local data, providing detailed information of model inputs and local values of ecosystem services

Q3
DO WE HAVE IN-HOUSE MODELING CAPACITY?

- Little technical expertise available.
- Moderate technical ability in running models via online resources
- High technical ability available, or resources to buy expertise.
- In-house expertise in constructing models

Q4
WHAT IS THE TIME FRAME FOR THE DECISION?

- Less than 3 months
- Between 3 and 6 months
- Between 6 and 12 months
- More than a year

DETERMINE THE AVAILABILITY OF DATA, MODELING CAPACITY, AND DECISION-MAKING TIME FRAME

There are trade-offs between data availability, technical capacity, and time frame. More complex models generally provide more accurate predictions and have a greater range of uses, but they can also be more difficult to use and understand and require more input data and resource availability, as well as technical skills and modeling capacity. A complex model may not be the best choice for a decision needed quickly in a resource-poor location.

Regarding data inputs, maps of the relevant land use classes are a basic requirement for many ecosystem service models. An efficient approach is to examine the data input requirements of different models (e.g., the model examples selected in the WISER project: see Appendix B) to assess which of the required data sets are available. Further data gathering might be considered to support the modeling or to improve the choice of models that can be applied.

Figure 2 shows how the levels of available data and technical skills can influence model choice. The complexity levels of different models are discussed in Appendix C. One of the least complex model types, the benefit transfer approach (see Box 3 for detailed model description), might be preferred in situations where there are few or no data beyond digital maps of land use and limited technical expertise but the answers to policy questions need to be addressed rapidly (Costanza et al. 2014). Also, if few or no data are available, models using automated inputs, such as WaterWorld or those in Co$ting Nature, may be the most appropriate choice.

At the other extreme, if high-quality local data and in-house expertise in constructing models are available, customized models, such as local process-based models, might be constructed and finely tuned to address the specific policy questions.

If there is no in-house modeling expertise but some local data are available and decision-makers have sufficient resources to buy expertise, then complex process models that require expertise in running and coding models, such as the Lund-Potsdam-Jena General Ecosystem Simulator (LPJ-GUESS), might be considered.

If the technical ability to run models is moderate, but a range of relevant local data is available, then modeling tools that require extensive user-data inputs, such as InVEST, which also offers online training resources to support model users should be considered.

Another factor is how urgently the modeling results are needed to make a decision. The time needed to obtain model results varies depending on the complexity of the model structure, and the data availability and technical capacity to run the model. If a decision is needed quickly, time can be an important constraint that influences the choice of the model.

EXPECTED OUTCOMES OF STEP 2: An inventory of data available for the selected ecosystems that address the framed policy questions; a sense of whether in-house modeling capacity is low, medium, or high; and a time frame for making the policy decisions.

Figure 2 | Examples of Model Choices Based on Data Availability and Modeling Capacity

TECHNICAL SKILLS AND MODELING CAPACITY (LOW → HIGH)

DATA AND RESOURCE AVAILABILITY (LOW → HIGH)

High technical skills and modeling capacity, low data and resource availability

- **Possible model choice:** LPJ-GUESS
- **Example of policy questions to address:**
  - ✓ Which are the most important locations for delivery of a specific service?
- **Example of policy applications:** Resource conservation and management

High technical skills and modeling capacity, high data and resource availability

- **Possible model choice:** Construction of bespoke models, such as agent-based models or local process models
- **Example of policy questions to address:**
  - ✓ Which are the best actions to maintain specific services under climate change?
  - ✓ How will alternative strategies affect production of ecosystem services and their use by people?
- **Example of policy applications:** Cost-effective climate adaptation policies; UN Sustainable Development Goals

Low technical skills and modeling capacity, low data and resource availability

- **Possible model choice:** Benefit Transfer, WaterWorld, Co$ting Nature
- **Example of policy questions to address:**
  - ✓ What is the total economic contribution of each land use class in a region?
- **Example of policy applications:** Estimating value of environmental externality to correct market failure

Low technical skills and modeling capacity, high data and resource availability

- **Possible model choice:** InVEST
- **Example of policy questions to address:**
  - ✓ How will a focus on production—e.g. forestry or agriculture—impact other ecosystem services?
- **Example of policy applications:** Evaluating the benefits of landscape restoration interventions

Note: See Appendix B for details on the models mentioned.

Source: WRI.

STEP 3. EVALUATE ECOSYSTEM SERVICE MODELS IN THE DECISION-MAKING CONTEXT

OBJECTIVE OF STEP 3: Determine which ecosystem service models and modeling tools (Box 3) can be used to model the target ecosystem services in the decision-making context as identified in Steps 1 and 2 to provide answers to the policy questions.

Select a set of modeling tools of possible use (see Box 3, Appendix C, and consultants and experts). Evaluate these models against the five guiding questions below:

Q1 WHICH MODELING TOOL CAN ADDRESS THE POLICY QUESTION AND OBJECTIVE IDENTIFIED?	Q2 DOES THE TOOL INCLUDE MOST OF THE ECOSYSTEM SERVICES WE WANT TO MODEL?	Q3 IN WHAT FORMAT CAN THE TOOL PRODUCE OUTPUTS (E.G., MAPS, ECONOMIC, OR PHYSICAL DATA)?	Q4 WHAT ACCURACY LEVEL CAN THE TOOL ACHIEVE?	Q5 CAN THE TOOL DELIVER RESULTS WITHIN OUR DECISION-MAKING TIME FRAME?
■ Screen ecosystem models includedin Bagstad et al. (2013), Christin et al. (2016), de Groot et al. (2017), and the IPBES Report on Scenarios and Models of Biodiversity and Ecosystem Services.	■ Yes ■ No	■ Map of biophysical data ■ Economic value estimates ■ Tables of values per ecosystem type ■ Maps of flows of services ■ Tables of service use by people ■ Maps of uncertainty in service values	■ Very high ■ High ■ Moderate ■ Low	■ Yes ■ No

Box 3 | Introduction to Ecosystem Service Models

An ecosystem service model predicts values for a specified ecosystem service based on how one or more environmental variables affect the value of that service. "Value" can be a measure of a relevant environmental variable (e.g., tons of carbon or liters of water), the monetary or nonmonetary value to humans, or a measure of use of the service by people. Existing ecosystem service models vary in the complexity of their use of these variables to predict the service and data inputs used for constructing and implementing the model (see Appendix B for details about specific ecosystem service modeling tools and models and Appendix C for a discussion of model complexity).

Models range from those using a simple form of "benefit transfer" to complex process-based models. In the simplest benefit transfer models, specific values for a service estimated in previous studies, often for different geographic areas, are assigned to land-cover classes (e.g., forest, urban, grassland) in the region of interest. For example, the InVEST carbon model[a] simply requires a land-cover map and estimates of carbon stocks for the land-cover classes in the region of interest. Slightly more complex are deterministic models, which use assumed or measured relationships between measured data and an ecosystem service to predict values based on a statistical process. The most complex are process-based models, which use a mechanistic representation of the processes underpinning the production of the service. For example, the InVEST water quality (nutrient delivery ratio)[b] model combines a water-flow model with representations of the processes by which different land-cover types both add to and retain pollutants in water flowing over land, in order to predict pollutant levels in watercourses. This model requires a wider range of data inputs. Additionally, the dynamic vegetation model LPJ-GUESS is a process-based model that gives outputs that predict the supply of many ecosystem services (and is partly implemented within the ARIES[c] modeling tool, which maps natural capital, natural processes, human beneficiaries, and service flows to society through a network software technology).

Many ecosystem service modeling tools (e.g., InVEST[d] and Co$ting Nature) are platforms that provide specific models for a number of ecosystem services and which can be used either by free download (InVEST) or online (Co$ting Nature). The number and type of services covered differs among the tools. For example, InVEST currently provides 18 models, including coverage of crop production and pollination, terrestrial and coastal carbon, water yield and quality, and recreation values. Co$ting Nature provides models for water quantity and quality, carbon, and tourism-related services. The models available within a tool can differ in their complexity as noted in the InVEST example above.

A wide range of ecosystem service modeling tools is available, and these are frequently being updated through the addition of new models offering more services, improving existing models, or using better data. This guide mentions a few major ecosystem service modeling tools and specific models provided by these tools, focusing on those used in the WISER project. These tools and models are widely used throughout the world. More details of modeling tools and model descriptions are in Appendix B, and detailed model characteristics are provided in Appendix C. Interested readers may also refer to Bagstad et al. (2013), Christin et al. (2016), de Groot et al. (2017), and the IPBES Report on Scenarios and Models of Biodiversity and Ecosystem Services for descriptions of other ecosystem service models. A qualified consultant or staff expert can also collect information on models suitable for consideration.

Notes:

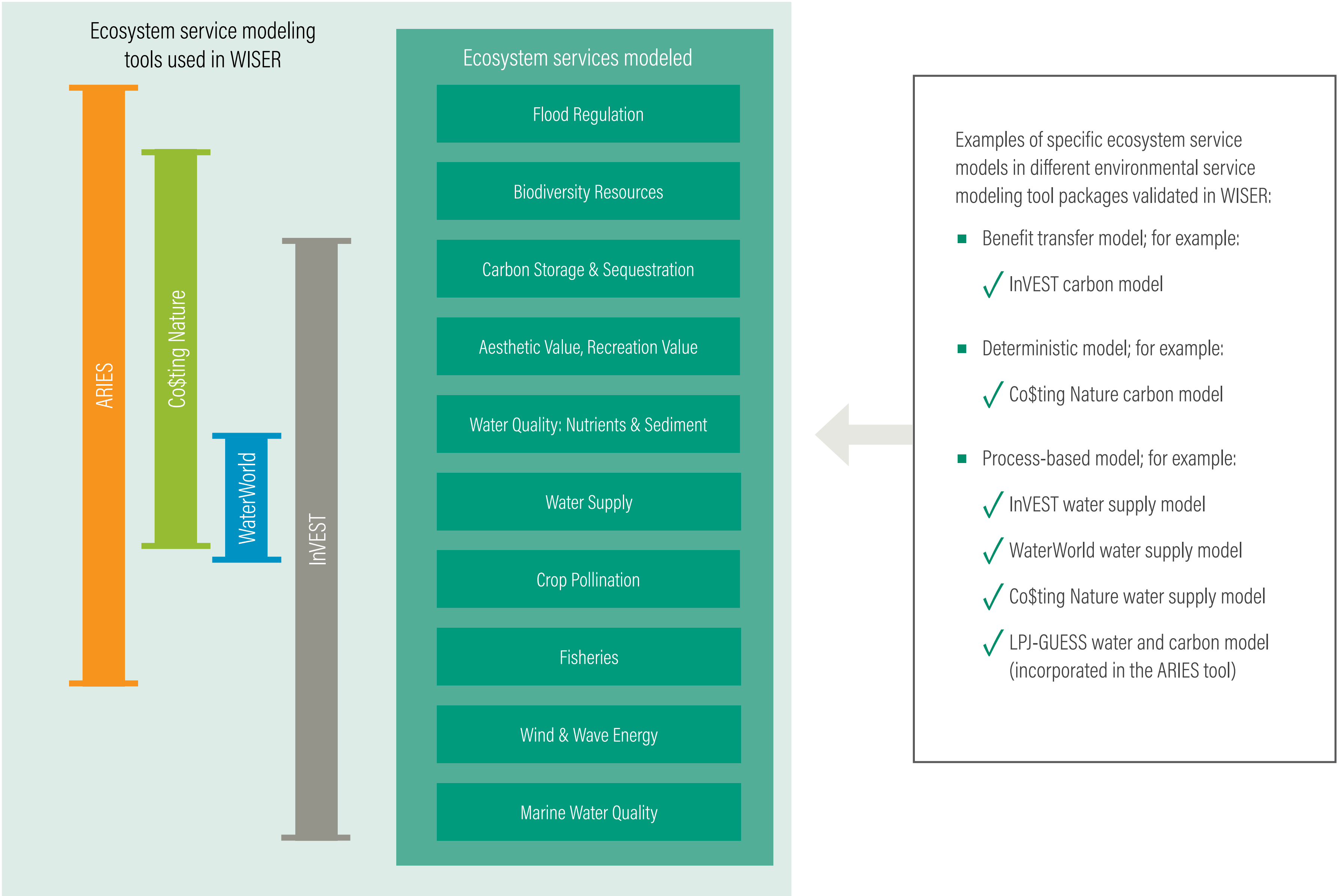
a. National Capital Project, "Carbon Storage and Sequestration: Climate Regulation," InVEST User's Guide. http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/carbonstorage.html.

b. National Capital Project, "Nutrient Delivery Ratio Model," InVEST User's Guide. http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ndr.html.

c. Artificial Intelligence for Environmental Services (ARIES), webpage. aries.integratedmodelling.org/.

d. National Capital Project, InVEST User Guide. http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/modeling.

Figure 3 | Ecosystem Service Modeling Tools Used in the WISER Project



Source: WRI.

To help decision-makers answer these questions, the specifics of the four ecosystem service modeling tools evaluated in the WISER project and the technical and input requirements of each are provided in Tables 2 and 3.

In Step 1, decision-makers clarified what they needed from an ecosystem model in terms of the policy question objectives, the type of output data they needed (biophysical, economic, or maps), and which ecosystem services were to be modeled. The selected ecosystem service models in Table 2 are rated on how they fulfilled each of these needs.

Step 2 discussed the levels of technical knowledge and data resources needed as part of the decision-making context. Table 3 shows how to evaluate the selected models in terms of the need for technical knowledge and data resources. It shows sample answers for the tools and models used in WISER. Note that models and tools are updated frequently, so these answers are subject to change.

Table 2 | How Four Ecosystem Service Modeling Tools Compare in Functions That Address the Intended Use of the Modeling Results, Format of Outputs, and Ecosystem Services Modeled

SELECTED ECOSYSTEM SERVICE MODEL/ MODELING TOOL	FUNCTIONS THAT ADDRESS THE INTENDED USE OF THE MODELING RESULTS		FORMAT OF MODEL OUTPUTS				MODELED ECOSYSTEM SERVICES	
	COMPARE FUTURE SCENARIOS	ASSESS BENEFICIARIES OF ECOSYSTEM SERVICES	BIOPHYSICAL DATA OUTPUT	ECONOMIC DATA OUTPUT	GIS MAP FORMAT	CARBON STORAGE	WATER SUPPLY	OTHER ECOSYSTEM SERVICES
ARIES: LPJ-GUESS model	✓	X	✓	X	✓	✓	✓	X
Co$ting Nature	✓	✓	✓	X	X	✓	✓	✓
WaterWorld model	✓	X	✓	X	X	X	✓	X
InVEST	✓	X	✓	✓	✓	✓	✓	✓

Note: ✓ = Yes; X = No.
Source: WRI.

Table 3 | Technical Knowledge and Input Data Required for Four Sample Ecosystem Service Models

SELECTED ECOSYSTEM SERVICE MODELING TOOL OR MODEL	USER-PROVIDED INPUT DATA REQUIRED FOR MODELING SPECIFIC ECOSYSTEM SERVICES		KNOWLEDGE REQUIREMENTS FOR IMPLEMENTING THE ECOSYSTEM SERVICE MODEL			
	CARBON STORAGE	WATER SUPPLY	SPATIAL DATA & MAPS	D TRAINING BEYOND ONLINE HELP	EXPERT HELP AVAILABLE	ECONOMIC VALUATION TECHNIQUES
ARIES: LPJ-GUESS model	Map of region to be assessed	Map of region to be assessed	✓	~	X	X
Co$ting Nature	▪ Map of region to be assessed ▪ All other data incorporated but can be supplemented with user data	▪ Map of region to be assessed ▪ All other data incorporated, but can be supplemented with user data	X	~	✓	X
WaterWorld model	Not modeled	▪ Map of region to be assessed ▪ All other data incorporated but can be supplemented with user data	X	X	✓	X
InVEST	▪ Map of land use classes ▪ Carbon store estimates for each land use	▪ Map of land use classes ▪ Catchment maps ▪ Precipitation ▪ Potential evapo-transpiration ▪ Soil texture and plant available water ▪ Maximum rooting depth, etc.	✓	~	✓	✓

Note: ✓ = required/available; X = not required/not available; ~ = would be useful for optimal running of the models.
Source: WRI.

EXPECTED OUTCOMES OF STEP 3: Decision-makers have a better understanding of the technical specificities of each model and can narrow the number of ecosystem service models or modeling tools that can be used in the decision-making context identified in Steps 1 and 2.

STEP 4. REASSESS THE DATA RESOURCES AND MODELING CAPACITY

OBJECTIVE OF STEP 4: Conduct a thorough self-assessment about your available data resources and technical capacity to determine the feasibility of implementing specific models and modeling tools. This assessment should be more in-depth than the initial assessment in Step 2.

Perform a self-assessment against the guiding questions below to better understand data resource availability and technical modeling capacity to construct or run an ecosystem service model:

Q1 DO WE HAVE THE QUALITY OF DATA NEEDED FOR THE PREFERRED MODELS?	Q2 DO WE HAVE THE TECHNICAL ABILITY TO RUN THE PREFERRED MODELS?	Q3 IF NEEDED, DO WE HAVE THE RESOURCES TO PURCHASE EXTERNAL EXPERTISE?
■ Little or no data availability beyond digital maps of land use ■ A range of relevant local data available that can be used as model inputs ■ High quality local data, providing detailed information of model inputs and local values of ecosystem services	■ Little technical expertise available ■ Moderate technical ability in running models via online resources ■ High technical ability available or resources to buy expertise. ■ In-house expertise in constructing models	■ Yes ■ No

The most important questions are question 1 about the quality of data and question 2 about technical skills needed for running the potential model. As discussed in Box 3, some models draw in existing data automatically, but others require manual inputting of local measured data. Globally available data sets such as Gourevitch et al. (2016) can be used, but local data have been shown to give more accurate ecosystem service estimates (Redhead et al. 2016).

If the technical skills to collect data and run the model are not available, the follow-up question is whether there are capital resources to hire external expertise. If the answer is yes, then it is important to clarify the amount available and engage with relevant organizations that could provide technical support.

Finally, taking a long-term perspective, it is recommended that decision-makers consider regularly validating and rerunning the models over a period of time as more and better data (and, potentially, improved models) become available.

EXPECTED OUTCOMES OF STEP 4: Decision-makers will better understand whether it is feasible to operate the ecosystem service models selected in Step 3 with the resources and technical skills at hand and, if not, whether additional funding is available to outsource experts to construct and run the model within the time frame required for decision-making.

STEP 5. CHOOSE THE MOST APPROPRIATE MODEL

OBJECTIVE OF STEP 5: Compare the outcomes of Steps 1–4 and determine the most appropriate model choice. To guide decision-makers in model selection, this section offers a worksheet and describes a few examples in which certain ecosystem service modeling approaches were chosen according to the user's goals and data and resource and technical constraints.

Fill in Table 4 with the answers to all guiding questions in Steps 1–4:

Table 4 | Worksheet for Questions and Answers in Steps 1–4

STEPS	GUIDING QUESTIONS				
STEP 1 Determine the policy questions and scope of the research	Q1. What policy questions do we want to address using an ecosystem service model?	Q2: How can we frame these questions to get meaningful outputs from the model?	Q3: What ecosystem services are important for our decision-making and what is their geographic scale?	Q4: What formats (biophysical, economic, maps) are needed from the model outputs?	Q5. What level of accuracy is needed for this decision?
STEP 2 Consider the decision-making context	Q1: What is the intended use of ecosystem service model results?	Q2: What data are available about ecosystem services to address the policy question?	Q3: Do we have in-house modeling capacity?	Q4: What is the time frame for the decision?	

STEP 3 Evaluate ecosystem service models in the decision-making context	Q1: Which modeling tool can address the policy question and objective identified?	Q2: Does the tool include most of the ecosystem services we want to model?	Q3: In what format can the tool produce outputs (e.g., maps, economic, or physical data)?	Q4: What accuracy level can the tool achieve?	Q5. Can the tool deliver results in our decision-making time frame?
STEP 4 Reassess your data resources and modeling capacity	Q1. Do we have the quality of data needed for the preferred models?	Q2. Do we have the technical ability to run the preferred models?	Q3. If needed, do we have the resources to purchase external expertise?		
STEP 5 Choose the most appropriate model					

EXPECTED OUTCOMES OF STEP 5: After answering these guiding questions, decision-makers should be able to select one or two ecosystem service models that are most appropriate for addressing their questions while also being feasible in terms of available technical skills and resources.

To help decision-makers better understand how to implement the steps to select appropriate models for a given decision, two examples from African decision-makers are shown below. The final decisions about which ecosystem service model to use are specific to each case study and should not be seen as advocating any ecosystem service model. Tables 5 and 6 illustrates the five-step process that can help determine the right ecosystem service model for a given application.

HOW TWO AFRICAN GOVERNMENTS SELECTED THE BEST ECOSYSTEM SERVICE MODEL FOR THEIR NEEDS

Together with country specialists in two African countries, Malawi and Uganda, the present research team used the five-step process to assess which modeling tools and models they could use to answer policy questions. These examples show how they answered the questions in each step. It should be noted that the model selection in these examples is limited to the modeling tools that were included in the WISER project.

CASE 1: MALAWI

In September 2016, the Government of Malawi announced its commitment to the Bonn Challenge and set the objective of restoring 4.5 million hectares of degraded land through the regional AFR100 initiative (RoM 2017). To support the country in assessing the potential ecosystem benefits of this restoration objective and identifying national action plans to support restoration activities, World Resources Institute (WRI) and the International Union for the Conservation of Nature (IUCN) provided the government with technical support to assess restoration potential, identify alternative restoration interventions, and evaluate the costs and benefits of implementing the restoration activities. We use the model selection steps in this guide to illustrate how the ecosystem service models were selected by the technical team.

Table 5 | Selecting an Ecosystem Service Model for Malawi

STEPS	GUIDING QUESTIONS				
STEP 1 Determine the policy questions and scope of the research	Q1. What policy questions do we want to address using an ecosystem service model?	Q2: How can we frame these questions to get meaningful outputs from the model?	Q3: What ecosystem services are important for our decision-making and, what is their geographic scale?	Q4: What formats (biophysical, economic, maps) are needed from the model outputs?	Q5. What level of accuracy is needed for this decision?
	A: What is the value of services from a specific land use class under alternative landscape restoration interventions?	A: Assess the changes of key ecosystem service flows from different restoration actions and the value of these changes.	A: Agriculture production, nontimber forest products, erosion and flood control, water retention. The scale is national level and subnational district level.	A: Mapped outputs of estimated average ecosystem services in biophysical terms, which can be further manipulated for performing cost-benefit analysis of restoration interventions.	A: Moderately accurate estimates of the most important locations for delivery of a service.
STEP 2 Consider the decision-making context	Q1: What is the intended use of ecosystem service model results?	Q2: What data are available about ecosystem services to address the policy question?	Q3: Do we have in-house modeling capacity?	Q4: What is the timeframe for the decision?	
	A: Develop future scenarios. Assess the value of ecosystem services for a region.	A: National level and subnational district level, land use maps and data, biophysical data.	A: Moderate technical ability in running models via online resources.	A: Between three and six months.	
STEP 3 Evaluate ecosystem service models in the decision-making context	Q1: Which modeling tool can address the policy question and objective identified?	Q2: Does the tool include most of the ecosystem services we want to model?	Q3: In what format can the tool produce outputs (e.g., maps, economic or physical data)?	Q4: What accuracy level can the tool achieve?	Q5. Can the tool deliver results in our decision-making time frame?
	A: InVEST and ARIES.	A: It includes mapping of services, but cost-benefit analysis will be done separately.	A: Map of biophysical data.	Moderate.	Yes.
STEP 4 Reassess your data resources and modeling capacity	Q1. Do we have the quality of data needed for the preferred models?	Q2. Do we have the technical ability to run the preferred models?	Q3. If needed, do we have the resources to purchase external expertise?		
	A: A range of relevant local data is available, which can be used as model inputs. Low data quality for some ecosystem services to be modeled; e.g. limited local hydrological data to model water supply.	A: The technical team that assisted the project has reliable in-house expertise in InVEST.	A: No		
STEP 5 Choose the most appropriate model	InVEST water supply and carbon models were preferred because the IUCN technical team has expertise in InVEST modeling and has model structures already created and implemented in a similar decision-making context in Africa. This advantage significantly reduced the time needed for running the ecosystem service model. Additionally, crops were modeled using spatial land productivity data.				

CASE 2: UGANDA

In Uganda, wetlands have been decreasing since the 1990s, from 15.6 percent of the country's land surface area in 1994 to only 10.9 percent in 2008. Wetland systems were found to be degraded in both rural areas and urban areas, driven by rapid population growth and urbanization. Wetlands have been converted to agricultural, industrial, commercial, and residential land uses. As a result, a variety of services provided by wetland ecosystems such as food, flood control, fresh water supply, water purification, and carbon storage are seriously affected. In response to these changes, the Ugandan government is considering plans to restore the degraded wetlands and protect existing ones. However, constrained by limited financial resources, the government needs to better understand the priority areas to restore and the economic benefits of a restoration scenario compared with the status quo. Such information will also help improve communication between decision-makers and communities with respect to restoration plans and the resulting benefits. Table 6 shows how the steps in this guide could help determine the most appropriate model or models to be used for valuing the wetland ecosystems.

ASSESSING UNCERTAINTY

Finally, no matter which ecosystem models or modeling tools are selected, decision-makers should be aware of uncertainty in model projections; that is, models produce estimates of the services based on the data and a set of assumptions, and there is usually some uncertainty about the accuracy of each. The WISER project suggested three approaches to assess uncertainty:

- **Obtain actual data on ecosystem service supply,** even if few data are available, and test model outputs against these**.** If models do not have an acceptable level of accuracy, then alternative models might be used and/or model parameters calibrated (i.e., different values used) to improve model fit to the data.
- **Run model ensembles.** That is, run multiple models for the service and use either the average values to make decisions or assess variation among models as a measure of uncertainty.
- **Treat modeling as an ongoing process.** That is, run the models and use them to make decisions. But in implementing decisions, use extra information gathered during policy implementation to assess and improve the models.

Table 6 | Determining the Best Model for Restoring Uganda's Wetlands

STEPS	GUIDING QUESTIONS				
STEP 1 Determine the policy questions and scope of the research	Q1. What policy questions do we want to address using an ecosystem service model?	Q2: How can we frame these questions to get meaningful outputs from the model?	Q3: What ecosystem services are important for our decision-making, and, what is their geographic scale?	Q4: What formats (biophysical, economic, maps) are needed from the model outputs?	Q5. What level of accuracy is needed for this decision?
	A: Which wetlands should be prioritized for restoration? What are the ecosystem benefits generated through wetland restoration compared to a no-restoration scenario?	A: Assess the value of key ecosystem service provided by ecosystem services.	A: Flood control, water purification/regulation, erosion control, fisheries, and carbon storage within the wetland; the scale is national, local, and community levels.	A: Output data should be biophysical and economic to understand the economic damages if these wetlands are not restored. The results should be in the form of GIS maps to show to stakeholders who will be engaged and compensated.	A: Moderately accurate estimates of the most important locations for delivery of a service.
STEP 2 Consider the decision-making context	Q1: What is the intended use of ecosystem service model results?	Q2: What data are available about ecosystem services to address the policy question?	Q3: Do we have in-house modeling capacity?	Q4: What is the time frame for the decision?	
	A: Determine the best actions to maintain services; calculate trade-offs between different services.	A: Digital maps on land cover are currently available, but they might not be up to date.	A: We have the capacity to master GIS software but would need to learn how to run ecosystem service models.	A: Six months.	
STEP 3 Evaluate ecosystem service models in the decision-making context	Q1: Which modeling tool can address the policy question and objective identified?	Q2: Does the tool include most of the ecosystem services we want to model?	Q3: In what format can the tool produce outputs (e.g., maps, economic or physical data)?	Q4: What accuracy level can the tool achieve?	Q5. Can the tool deliver results in our decision-making time frame?
	A: InVest and ARIES can project ecosystem value changes.	A: InVEST models, ARIES, or Co$ting Nature models could cover most of the ecosystem services of interest.	A: Map of biophysical and economic model outputs.	A: Moderate.	A: Yes.
STEP 4 Reassess your data resources and modeling capacity	Q1. Do we have the quality of data needed for the preferred models?	Q2. Do we have the technical ability to run the preferred models?	Q3. If needed, do we have the resources to purchase external expertise?		
	A: Basic GIS maps are available but more data will need to be collected.	A: Uncertain. Training or new hires are needed to run the models.	A: No.		
STEP 5 Choose the most appropriate model	ARIES and InVEST modeling tools were preferred. They can project ecosystem value changes for most of the ecosystem services that the government is interested in. However, it is unclear whether technical expertise needed for ARIES and InVEST modeling is available in Uganda. Even though local researchers can master GIS software, it is expected that extra resources will be needed to train them or hire external experts to run the models. Due to the wide range of ecosystem service coverage, it might be expected that a large amount of data and capital investments are needed. In addition, the LPJ-GUESS model should be considered when it comes to prioritizing the wetlands for restoration.				

CHAPTER 3: CONCLUSIONS

Decision-makers should not expect ecosystem service models to provide ready-made solutions. Caution must be shown when selecting models and interpreting their results.

Ecosystem service modeling and mapping tools, and the models they supply, provide a resource for decision-makers to use in addressing a variety of resource management questions relating to impacts on ecosystem services and the economic value of these services. To help decision-makers evaluate and select fit-for-purpose ecosystem service models independently, this guide outlines detailed steps to be taken in assessing models and modeling tools to use in a particular decision-making context. These include the following:

Step 1. Determine the policy questions and scope of the research.

Step 2. Consider the decision-making context.

Step 3. Evaluate ecosystem service models in the decision-making context.

Step 4. Reassess the data resources and modeling capacity.

Step 5. Choose the most appropriate model.

To illustrate model differences in terms of their specificities, complexity, input requirements, and ease of use, a few ecosystem service models and modeling tools assessed in the WISER project were used as examples throughout the guide.

This guide suggests that modeling tools are particularly useful where there is little measured or observable information on ecosystem services in the region of interest. Nevertheless, selecting an appropriate model to support decision-making is not an easy task due to different degrees of model complexity and technical capability among analysts. Therefore, decision-makers must clearly define the scope of the analysis, evaluate each model's fitness for the decision context, and conduct a self-assessment to understand whether the required modeling capability and data are available for the potentially useful ecosystem service models.

Finally, decision-makers should not expect ecosystem service models to provide ready-made solutions. Caution must be shown

when selecting models and interpreting their results. In particular, they should be aware of the following key issues:

- Although a number of modeling tools are available, including models for multiple ecosystem services, many ecosystem services are currently not modeled, which may restrict the utility of these tools in certain decision-making contexts.

- Many tools are being updated, with more ecosystem services being modeled and existing models being improved.

- The WISER project found that, in general, more complex models are more accurate. However, in any specific application, the accuracy of models cannot be known without validation against measured ecosystem service data. Models are only estimates of ecosystem services and have variable accuracy.

- Estimating uncertainty in model predictions is important. One way to reduce uncertainty is to carry out actions to improve the utility of predictions, which involves gathering extra information during policy implementation to assess and improve the models and, wherever possible, running multiple models to generate ensembles for the targeted ecosystem services.

More complex models are more accurate. However, in any specific application, the accuracy of models cannot be known without validation against measured ecosystem service data.

APPENDIX A. ECOSYSTEM SERVICES OF INTEREST TO DECISION-MAKERS IN SUB-SAHARAN AFRICA: SURVEY RESULTS OF THE WISER PROJECT

ECOSYSTEM SERVICE	ARE THERE MODELS FOR THIS SERVICE?	PERCENT OF RESPONDENTS
Food	Yes	58
Fuel	Yes	38
Fiber	No	18
Biochemicals and pharmaceuticals	No	4
Genetic resources	No	16
Freshwater supply	Yes	58
Air quality regulation	No	9
Carbon storage and climate regulation	Yes	49
Nontimber forest products	In part	40
Erosion regulation	Yes	35
Soil formation	No	20
Nutrient cycling	No	20
Primary production	Yes	31
Disease regulation	No	9
Pest regulation	Yes	9
Pollination	Yes	9
Water purification	Yes	31
Natural hazard regulation	Yes	20
Aesthetic values	Yes	24
Recreation and tourism	Yes	31
Spiritual and religious values	No	15
Cultural heritage	No	20

Source: WISER project, unpublished survey data, February–June 2014.

APPENDIX B. ECOSYSTEM SERVICE MODELING TOOLS USED IN THE WISER PROJECT

MODELING TOOL	DESCRIPTION	ECOSYSTEM SERVICES (AND ASSOCIATED VALUES) CURRENTLY MODELED USING SUBSETS OF MODELS
ARIES aries.integratedmodelling.org/	An open-source technology that can select and run models to quantify and map ecosystem services, including physical generation, flow, and extraction by beneficiaries. ARIES provides access to a library of ecosystem service models and spatial data sets at multiple scales ranging from global to local.	■ Biodiversity resources ■ Carbon storage and sequestration ■ Crop pollination ■ Aesthetic value, recreation value ■ Fisheries ■ Flood regulation ■ Water quality: Nutrients and sediment ■ Water supply
Co$ting Nature http://www.policysupport.org/costingnature	A web-based series of interactive maps that defines the contribution of ecosystems to the global reservoir of a particular ecosystem service and its realizable value (based on flows to beneficiaries of that service).	■ Biodiversity resources ■ Carbon storage and sequestration ■ Recreation value ■ Hazard mitigation ■ Water quality ■ Water supply
WaterWorld http://www.policysupport.org/waterworld	An internally parameterized model of accumulated water run-off. This web-based model incorporates all data required for application.	■ Water supply
InVEST www.naturalcapitalproject.org/invest/	A suite of free, open-source software models from the Natural Capital Project used to map and value the goods and services from nature. InVEST returns results in either biophysical or economic terms.	■ Carbon: Terrestrial and coastal storage and sequestration ■ Crops: Pollination and production ■ Scenic quality, recreation, and tourism ■ Fisheries: Marine and aquaculture habitat: Quality and risk ■ Marine water quality ■ Water quality: Nutrients and sediment ■ Water supply ■ Wind and wave energy

Source: WRI authors, adapted from Willcock et al. (2016).

APPENDIX C. ECOSYSTEM SERVICE MODEL CLASSIFICATION AND CAPACITY

This appendix explains the relationship between model complexity and accuracy of results, the range and types of model complexity, and the characteristics of different ecosystem service model inputs and outputs.

Mapping ecosystem service model complexity and accuracy

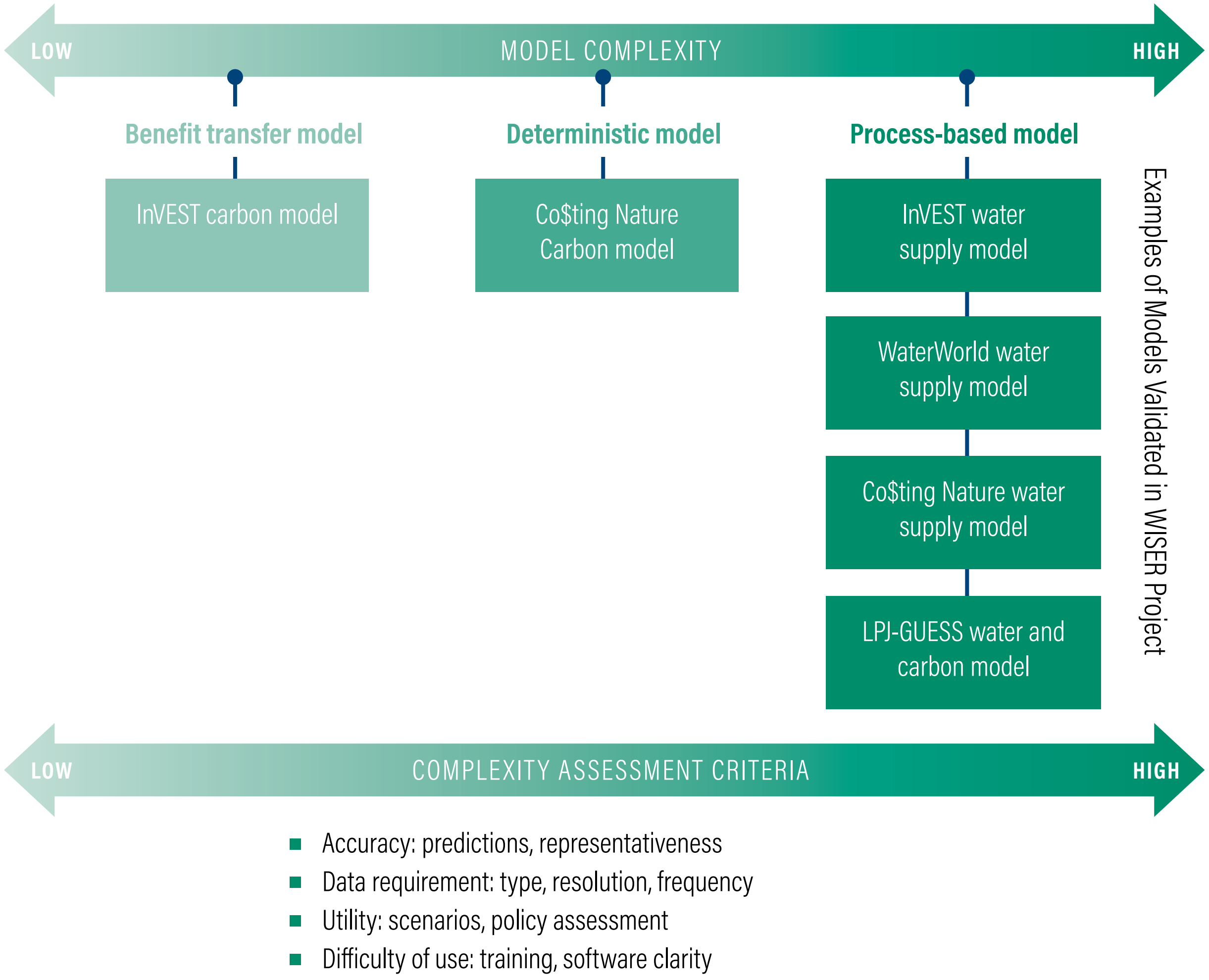
Model complexity is a key issue for users. Across the environmental sciences, it is thought that more complex models tend to give more accurate predictions and have a greater range of uses. More complex models can also be more difficult to use and understand and require more input data. These complexity relationships were confirmed by a study of the models investigated in the WISER project.

The WISER project analyzed model complexity in three areas:

Structural complexity. Ecosystem service models range from the simplest benefit transfer models to the most complex process models.

- Benefit transfer models in their simplest form assign a value for the ecosystem service to each of the land cover classes in the region of interest. Basically, this approach translates a map of land use into a map of ecosystem services. The ecosystem service value associated with each land use can be measured directly in the region of interest or can be taken from studies in other locations. It is also possible to estimate these values using expert knowledge rather than direct measurement (Jacobs et al. 2015).

Figure C1 | Schematic of the Characteristics of Less- vs. More- Complex Models



Source: WRI authors, adapted from Willcock et al. 2016.

- Deterministic models are more complex and use assumed or measured relationships between measured variables and an ecosystem service to predict values for the service based on statistical relationships. Examples might include known relationships of vegetation structure and soil type with carbon storage or rainfall and soil properties with water run-off. As such models are designed to represent general relationships, they should be transferable among geographic regions, although certain input data will need to be sourced for that specific region (e.g., land-use maps, weather, topography).

- Process-based models are the most complex and work by transforming a series of inputs into services using a mechanistic representation of the processes that lead to provision of the service. While benefit transfer and deterministic models always give the same output for a given set of inputs covering a snapshot in time, process-based models can (although not all do) represent such a complex set of interactions that outputs are variable (i.e., the models are stochastic) and dynamic (i.e., the models vary over time). While this might seem undesirable, it gives insights into the real variability of the system that is modeled. As with deterministic models, process-based models should be transferable among geographic regions, albeit with the same caveats concerning the sourcing of specific data.

Input complexity. This refers to the number of data sets required as inputs to run the model. Inputs can include maps of the region of interest, values for the ecosystem service specific to each land use, parameter estimates, and mapped values for specific data types. Different models use different types of data, and modeling tools also differ in the degree to which they require the user to provide and enter these data into the model compared with using software that automatically draws in the required data. Obviously, the latter requires less effort from the user, but may skew the results if the standard data do not match the local data.

Output complexity. Outputs are the results used for decision-making. Models produce a number of output data layers, or types of data, on ecosystem services. The types of output differ among models and tools. For example, while both Co$ting Nature and InVEST provide mapped outputs, they are different. Co$ting Nature maps water provisioning in terms of either the potential supply of water or as the relative contribution of catchments to the demand for water downstream in a river network. InVEST also provides two outputs: in physical terms as the annual water yield from a catchment, and in economic terms as that water's net present value with the intended use of hydropower production. Users may need to carry out further calculations on these outputs to obtain the exact information required for decision-making in their particular context.

The WISER project study confirmed that more complex models can produce a greater range of outputs and are generally more accurate.

More complex models require more data, but also provide a greater range of outputs, suggesting greater utility for a range of uses of the data. For the models studied, the WISER project found that all three measures of complexity are related. That is, process-based models tended to require more input data and produced more output data types.

More complex models provide more accurate assessments. In assessing models for carbon storage, water supply and use, grazing, and fuel (charcoal and firewood) use in over 36 countries in sub-Saharan Africa, WISER found evidence that more complex models provide more accurate assessments.

Accuracy was assessed by comparing outputs for several models against a large number (1,675) of measured values for these services made at locations across sub-Saharan Africa. As model complexity increases from benefit transfer models to process-based models, one might expect increased accuracy simply because the modeling better represents the mechanisms by which ecosystem services are generated. For instance, benefit transfer models assume a simple relationship between the classification of land use and the corresponding ecosystem services, which suggests minimum accuracy of the measures of the ecosystem service estimated in each land use class. Deterministic and process-based models generally use a land use map as a base but also use a range of variables, which should allow fine-tuning of the ecosystem service prediction to the local conditions.

Characteristics of different ecosystem service model inputs and outputs

Ecosystem service modeling tools and the models that compose them have distinguishing characteristics relating to how the user interacts with them. These characteristics define both the data requirements and the technical skills of the user in running the model.

Data input. While more complex models use a greater range of data types, this does not necessarily mean the user has to do more work in either obtaining input data or inputting these data. The exact requirements depend on how the modeling tool has been designed. We illustrate this point with examples of carbon modeling and water supply data in the WISER project.

- Models used to predict carbon stores included: InVEST, a benefit transfer model; Co$ting Nature, a deterministic model; and The Lund–Potsdam–Jena General Ecosystem Simulator (LPJ-GUESS), a process-based model. In running the models for WISER we found the following:
    - InVEST needed two types of input data, including a land use map and measures of carbon stores for each land use class. All input data sets had to be acquired and uploaded by the user.

- Co$ting Nature needed four types of input data, but they are drawn in by the model automatically, including the land use maps and carbon values (see Co$ting Nature Version 2 Modules, Model Documentation[7] for the data sources). Some of these data can be inputted by the user if desired.
- LPJ-GUESS used at least 36 types of input data. These included information on plant types, vegetation growth, and nutrient dynamics. Thirty-five of these data sets are preprogrammed or automatically drawn into the model (and cannot be altered by the user).

- Models used to predict water supply included a benefit transfer model adapted from classifications and values given in Contanza et al. (2014); the InVEST model, which is process-based; and the WaterWorld model, which is also process-based. In running the models for WISER we found that:
    - The benefit transfer model required two data sets composing the land use map and the values of each land-use class for water provisioning. Both data sets had to be inputted manually.
    - InVEST required 10 input datasets, including land use maps, rainfall data, evapo-transpiration data, and soil data. These all had to be sourced and inputted by the user.
    - WaterWorld, a more sophisticated model, used 125 input data sets, but all are drawn in automatically by the model.

Running the model. Most modeling tools are not straightforward to use and require some knowledge of spatial data and maps and training in their use. Some models, such as Co$ting Nature, are easier to use and require little knowledge of spatial mapping. Training is often available online. For example, InVEST provides "helper tools" and access to online forums,[8] and Co$ting Nature has a page of training resources[9] and online videos. The MESH[10] tool from the Natural Capital Project aims to make ecosystem service modeling tools (InVEST and Co$ting Nature) available in a form that is simple to run and use, although it cannot offer the range of resources of customized modeling tools. There are also regular training events for certain tools, such as InVEST and ARIES. Most modeling tools are now stand-alone and require no additional software (e.g., specialized spatial mapping software).

Interpreting outputs. There is no standard way to measure or map ecosystem services, and, in predicting any specific ecosystem service, the different tools and models have somewhat different outputs. For example, for carbon storage, InVEST outputs are maps of either tons of carbon sequestered or net economic value of that sequestered carbon, while Co$ting Nature maps show relative value (between 0 and 1). For water supply, Co$ting Nature calculates the realized water supply by mapping the relative contribution of catchments to the demand for water downstream in the river flow network; InVEST estimates the annual water yield from catchments in the region of interest; and WaterWorld calculates the monthly water runoff.

Users must determine whether their model's output data needs to be further manipulated to be of use in a particular decision-making context. Output data can be converted to match user requirements as shown in the following two examples below:

- Modeling ecosystem service use. Ecosystem services can be assessed in terms of their supply (the amount of the service produced) and their use (how much of that service is used by people) in the region of interest. Assessing potential use may be of particular interest in policy contexts where the aim is to enhance services to the poorer people in society. Currently, most ecosystem service models predict supply of services. In the WISER project, ecosystem service supply predictions were converted to potential use by multiplying service supply by the rural human population size[11] for the region of interest. These estimates were more accurate, compared with measured ecosystem service use, than the supply predictions alone.

- Converting outputs to represent other services. Many ecosystem services of potential interest to decision-makers[12] are not covered by existing modeling tools. In some cases it may be possible to convert model outputs for one service to give estimates of another. The WISER project uses models of carbon storage in vegetation in this way. First, carbon estimates are used for specific land use classes that typically provide certain ecosystem services—pasture lands for grazing services, and forests for provision of charcoal and firewood fuel—to estimate vegetation biomass. Then, it is possible to calculate livestock production, charcoal, or firewood that is converted from the proportion of biomass using known conversion fractions.

ENDNOTES

1. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). www.ipbes.net.

2. IPBES Membership. https://www.ipbes.net/members.

3. Examples: Bagstad et al. (2013) compares several decision-making support tools; Christin et al. (2016) provides guidance on models for specific use in guiding forest restoration; UNDP-GEF (2006) describes analysis of land management policy options; DEFRA (2007) provides an introductory guide to valuing ecosystem services; Van der Ploeg and de Groot (2010) list tools and databases reported by TEEB (The Economics of Ecosystem and Biodiversity).

4. Ecosystem Services for Poverty Alleviation (ESPA), WISER: Which Ecosystem Service Models Best Capture the Needs of the Rural Poor? http://www.espa.ac.uk/projects/ne-l001322-1.

5. ESPA website. http://www.espa.ac.uk/.

6. For example, the Delta Dynamic Integrated Emulator Model, developed under the ESPA DELTAS project, which is focused on coastal systems in Bangladesh. http://www.espadelta.net/ddiem/.

7. Co$Ting Nature, Version 2 Modules, Model Documentation. https://docs.google.com/document/d/19jje32EeuiBZk_ibRwT4sAObYsbdiVxp6Vh0sZDGAs/edit.

8. National Capital Project, NatCap Forums. https://forums.naturalcapitalproject.org/.

9. Co$ting Nature, Training. http://www.policysupport.org/costingnature/training.

10. National Capital Project, Mapping Ecosystem Services to Human Well-Being (MESH). https://www.naturalcapitalproject.org/mesh/.

11. Using Worldpop estimations. Worldpop. www.worldpop.org.uk.

12. The Common International Classification of Ecosystem Services (CICES) website provides a coherent list and classification. https://cices.eu/.

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We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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