INTEGRATING ECOSYSTEM VALUES INTO COST-BENEFIT ANALYSIS:

RECOMMENDATIONS FOR USAID AND PRACTITIONERS

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COVER PHOTO. NEPAL – 2017: Better availability of water for home use is one of the benefits the village of Kailas has seen as a result of conservation of the uphill forests. Photo by Jason Houston for USAID.

TOP PHOTO. 2010: Photo by USAID.

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KITTENDEN OUTPOST, KENYA: A community scout surveys the landscape.
Photo by Matthew Erdman for USAID.

INTRODUCTION

Ecosystems are fundamental to life on earth and provide goods and services that are critical to human well-being such as food, fiber, clean water, pollination and protection from extreme weather. Natural capital, the world's stock of natural resources, accounts for 47 percent of the total wealth of low-income countries and 27 percent of the total wealth of lower-middle income countries (Lange, Wodon and Carey, 2018). The value of ecosystem services lost worldwide due to land degradation is estimated at US $6.3-10.6 trillion annually, or the equivalent of 10-17 percent of global gross domestic product (ELD Initiative, 2015).

In addition to their economic importance, ecosystem services also link biodiversity conservation with other development objectives such as food security, water security and climate change mitigation and adaptation. By understanding how development objectives depend upon or impact ecosystem services, USAID staff can identify opportunities to simultaneously enhance biodiversity conservation and other development goals, and avoid activities that might undermine them. Furthermore, these opportunities for integration can be found anywhere that USAID works and are not limited to priority places receiving USAID biodiversity funding. Identifying the connections between natural ecosystems and human development can yield substantial benefits across the USAID portfolio.

Cost-benefit analysis (CBA) at USAID provides an opportunity to identify and operationalize these connections by quantifying the value of nature and including it explicitly in development decision-making. CBA is a valuable tool that allows development practitioners to assess decisions based on both their financial and economic advantages and disadvantages. It has been used at multiple points in the USAID program cycle, including comparing options during design and implementation, and informing future programming during evaluations.[1,2] CBA has also been used at USAID in a variety of programming contexts, such as food security, rural energy access and coastal protection. Because ecosystem services are often unrecognized or difficult to value, however, they have not typically been considered in USAID-funded CBAs. This puts USAID at risk of failing to identify both key programming dependencies on natural ecosystems, and possibly also significant impacts on ecosystem services and development outcomes. Integrating ecosystem service valuations in CBAs at USAID offers an opportunity to identify and mitigate these impacts, and to design innovative programming that maintains and benefits from ecosystem services.

To support this work, the USAID Offices of Forestry and Biodiversity and Economic Policy in the Bureau for Economic Growth, Education and Environment developed recommendations for including ecosystem service valuations into Agency CBAs. This was done in

1 CBA implementation is supported by the USAID Office of Economic Policy and its CBA guidelines for Agency economists and contractors (USAID, 2015).
2 Throughout this document, the term "program" or "programming" is used as a general term to encompass USAID projects and activities.

collaboration with the USAID Biodiversity Results and Integrated Development Gains Enhanced (BRIDGE) activity. During this process, BRIDGE first interviewed USAID staff from both Washington and field missions who have prepared CBAs and trained other staff in their preparation and use. They asked staff about their familiarity with ecosystem service valuation, its inclusion in CBA and key barriers and opportunities to broader inclusion. BRIDGE also conducted a literature survey to identify relevant case studies and recommended practices for ecosystem service valuation. In addition, BRIDGE prepared a catalog of key data sources that can support ecosystem service valuation. In collaboration with the Office for Economic Policy, and Forestry and Biodiversity, BRIDGE then developed recommendations to support USAID's inclusion of ecosystem service valuations in Agency CBAs.

Based on this process, BRIDGE identified four primary needs to promote the inclusion of ecosystem service valuations in Agency CBAs:

1. **Guidance** for the valuation of ecosystem services, its inclusion in CBAs and its promotion in the Agency
2. Synthesis of available **data sources and literature** that provide examples and data for ecosystem service valuations in Agency CBAs
3. **Training materials** that can be incorporated into ongoing Agency CBA training
4. **Agency champions** for the inclusion of ecosystem service valuations in Agency CBAs

This document focuses on the first two of these needs and is intended to serve as a starting point for further work on this subject, including additional Agency guidance, training materials, cultivation of champions and CBAs themselves.

PURPOSE AND STRUCTURE OF THIS DOCUMENT

The purpose of this document is to provide recommendations for the incorporation of ecosystem service valuations into Agency CBAs, both for USAID staff that produce or use CBAs, and for USAID as an institution. In addition, this document provides specific guidance for USAID sectors that are commonly integrated with biodiversity—including global climate change, food security, energy and infrastructure, and water, sanitation and hygiene—but the process and principles described here are relevant for CBAs in any sectors. The document is composed of seven sections:

- **Section I. Recommendations for Practitioners:** A four-step process for selecting and measuring ecosystem service values and incorporating them into CBAs
- **Section II. Institutional Recommendations:** Broader recommendations for USAID as an institution for the promotion of ecosystem service valuations in CBA
- **Annex I. Key Concepts:** A brief introduction for non-specialists to the justification and methods for ecosystem service valuation
- **Annex II. Literature Review:** An overview of the key services provided by natural ecosystems and examples of their valuation
- **Annex III. Data Catalog:** A catalog of data sources for ecosystem service valuations and examples of valuation methods
- **Annex IV. Examples of Interactions Between USAID Programming and Ecosystem Services:** Example lists of the impacts and dependencies that USAID programming may have on ecosystem services
- **Annex V. References:** The literature cited in this document, including sources considered in both the literature review and recommendations sections

HOW TO USE THIS DOCUMENT

This document is intended for use by USAID and its partners, including Agency economists and implementing partners who will be conducting CBAs, technical or program office staff that might be using or contributing to CBAs, and managers evaluating the merits of conducting a CBA that includes ecosystem service valuations. As such, these recommendations are intended for specialist and non-specialist audiences, and the annexes provide greater detail on select topics. Following are brief recommendations for each of these potential user groups:

- **Agency economists or contractors** conducting CBAs may prefer to proceed directly to the recommendations for practitioners, and use Annexes II, III and IV for supporting information on example valuations, available data sources and example interactions. If promoting the broader integration of ecosystem service valuations in Agency CBAs, the institutional recommendations may also be useful.
- **Technical or program office staff**, excluding economists, who do not have a background in ecosystem service valuation, may want to begin with Annex I on key concepts and then proceed to the recommendations for practitioners. If interested in supporting information on example valuations, available data sources and example interactions, Annexes II, III and IV may be useful; and if interested in broader institutional needs, the institutional recommendations section may also be useful.
- **Managers** may first want to familiarize themselves with the key concepts, and then proceed to the section on institutional recommendations. If more information is desired on the steps recommended here for conducting a CBA that integrates ecosystem service valuation, the recommendations for practitioners may also be useful. Further background on example interactions between sectors and the supporting literature may be found in Annexes II and IV.

GLOVER'S REEF, BELIZE: Nassau Grouper spawning. Photo by Enric Sala, WCS.

SECTION I
RECOMMENDATIONS FOR PRACTITIONERS

This section outlines a four-step process that CBA analysts can use to select, quantify and integrate ecosystem service interactions into their analyses:

1. Identify ecosystem interactions
2. Prioritize ecosystem interactions for inclusion in CBA
3. Assign a value to the selected interactions
4. Integrate ecosystem service valuations into CBA

The following descriptions provide guidance for each step. Although this document is intended as a companion to the USAID Guidelines for CBA (USAID, 2015), the steps and principles described here may be applied to any CBA approach.

STEP 1: IDENTIFY ECOSYSTEM INTERACTIONS

USAID projects and activities interact with ecosystem services in two ways. First, USAID programming can impact ecosystems and the services they provide both positively and negatively. For example, increasing the efficiency of irrigation techniques might have the positive impact of increasing water availability for downstream ecosystems, while the introduction of chemical fertilizers might have the negative impact of increasing nutrient loads in waterways and harming native ecosystems. Because these impacts are commonly identified through environmental compliance, they are more likely to be included in Agency CBAs than the second type of interaction described below.

Second, USAID projects and activities may depend on services provided by ecosystems. Although these dependencies are well documented in the ecosystem service literature (Annex II), these links are often not apparent or widely known to CBA practitioners without a background in this literature, and are therefore often neglected in CBAs. As a result, programming effectiveness may suffer from the degradation of ecosystems, or opportunities to use beneficial ecosystem services might be missed. For example, crop yields may be sensitive to the state of ecosystem services such as groundwater recharge, protection against flooding, pollination and pest control. Including these ecosystem dependencies in programming analysis can help USAID staff to design sustainable programs or identify "green" alternatives.

The first step for a CBA analyst is to identify all ecosystems that interact with the programming through either dependencies or impacts. In developing this initial list, it is not necessary to assess the magnitude of the effect or the quality of evidence supporting it. As long as the analyst has reasonable confidence that an interaction exists, the ecosystem or ecosystem service should be included in the preliminary list. The list can be modified in subsequent steps. Box 1 presents some questions to consider in generating this initial list. In addition, existing USAID analyses including environmental compliance

BOX 1: KEY QUESTIONS TO ASK WHEN BUILDING A PRELIMINARY LIST OF INTERACTIONS

1. What are the likely negative impacts of the programming on ecosystems and their services?
2. What are the likely positive impacts of the programming on ecosystems and their services?
3. In what ways does the programming's effectiveness and efficiency likely depend on the state of the ecosystems that surround it?

assessments may also serve as valuable sources of information regarding possible interactions and impacts.[3]

Although programming may interact with all the ecosystems surrounding it, not all of these interactions have significant values. To illustrate, analysts may anticipate a possible interaction (for example, increased water and sediment transport to waterways due to land clearing), but it might not be ecologically significant or economically important (the affected waterways do not substantively affect economic activity). Some interactions may be excluded from the final CBA model due to data, cost and time limitations. These interactions are identified and excluded from consideration during Step 2.

Multiple sources of information are available for building the preliminary list of ecosystem interactions, of which three are particularly important (Box 2): known interactions, expert advice and stakeholder consultation, and the financial cash flow statement.

BOX 2: SOURCES OF INFORMATION FOR IDENTIFYING ECOSYSTEM SERVICE INTERACTIONS

1. Documented impacts and dependencies
2. Expert advice and stakeholder consultation
3. The program's financial transactions (financial cash flow statement)

Known interactions can be identified from the scientific literature; from program documentation including project or activity designs, annual plans and performance reviews; from Agency environmental compliance documents; and from other sources including donor and civil society reports. Programming dependencies on ecosystem services, in particular, can be identified from assumptions in the program's theory of change.

Documented impacts and dependencies should also be supplemented with expert advice and consultations. Undesired impacts or unexpected dependencies may not be reported in the literature, so it may be useful to consult with experts who have been involved with the design and implementation of similar programming in the same or other countries. In addition, consultations should include a range of experts, as individual specialists may focus on issues that are common in their work. For example, environmental impact assessment specialists may focus on the negative impacts of programming. Ecosystem service specialists may be particularly interested in the opportunities afforded by "green" solutions to programming needs but may ignore the opportunity costs of these programs. Cost-benefit analysis experts may focus on cash flows and tax and subsidy-related market price distortions, but may not identify the broader interactions between the programming and ecosystems.

Lastly, a financial cash flow statement can serve as a checklist to identify important impacts or dependencies. The cash flow statement lists the equipment, materials, human resources and other

3 For more information, see the USAID publication "Environmental Compliance Factsheet: Ecosystem Services in Environmental Impact Assessment."

inputs utilized by the programming. The cost of each input represents an activity that can be associated with an impact or dependency on an ecosystem service. For example, purchase of a pesticide for a food security program can remind the analyst to consider potential impacts on downstream water quality and fish, or on native species that provide pest control. When a program is associated with some form of financial revenue, such as sales, the financial cash flows can also indicate possible impacts that relate to the marginal consumption of the program's output. Furthermore, the financial cash flow statement can also identify the financial transaction to which a dependency or impact may be attached during inclusion into a CBA. For instance, a farm's output depends on the yield rate, which can be a function of the natural pollination service provided by the surrounding ecosystems (see Step 4, below).

The tables in Annex IV provide a list of illustrative interactions between USAID programming and ecosystem services (see also Annex II for a review of the literature). The lists in Annex IV are intended to serve only as an example and should not be considered exhaustive. Each program will have unique interdependencies with the ecosystems surrounding it.

Step 1 results in two lists, one summarizing the ecosystems and ecosystem services that are possibly affected by the programming (impacts) and a second summarizing the programming's efficiency and effectiveness assumptions that are sensitive to the state of the ecosystems surrounding it (dependencies). Tables 1 and 2 provide examples of these lists.

TABLE 1: EXAMPLES OF ECOSYSTEM SERVICE-RELATED IMPACTS FROM AN AGRICULTURE EXTENSION ACTIVITY

Activity	Impacted Ecosystem	Impacted Ecosystem Service	Cause of Impact	Impact
Fertilizer application	River	Fish provision	Fertilizer application reduces water quality for fish	Reduced fishery yields (adverse)
More efficient irrigation	River	Fish provision	Water savings increase habitat availability for fish	Increased fishery yields (positive)
Land conversion to agriculture	Forest	Provisioning of non-timber forest products	Forest conversion reduces harvesting of non-timber forest products	Reduced income from non-timber forest products (adverse)

TABLE 2: EXAMPLES OF DEPENDENCIES ON ECOSYSTEM SERVICES FOR AN AGRICULTURE EXTENSION ACTIVITY

Ecosystem Service	Ecosystem Providing Service	How Ecosystem Provides Service	Dependency
Pest control	Neighboring forest	Nearby natural ecosystems support insects and bats that consume crop pests	Crop yield rate, pesticide cost
Pollination	Neighboring forest	Nearby natural ecosystems support insects that fertilize crops	Crop yield rate, rental cost of mobile bee colonies
Water provision	Upstream wetlands	Upstream ecosystems capture and store water that is used for crops	Crop yield rate, cost of building irrigation systems

STEP 2: PRIORITIZE ECOSYSTEM INTERACTIONS FOR INCLUSION IN CBA

The second step in this process is to review the interactions identified during the first step, and select ecosystem services that will be quantified and integrated into the CBA. Box 3 provides an initial set of criteria for narrowing the lists from Step 1. These criteria should not be considered the only ones for prioritizing ecosystem interactions, and the weight assigned to each criterion and need for additional criteria will evolve as USAID builds a body of experience in including ecosystem services in CBA. Box 3 outlines a description of each of the recommended criteria, followed by additional considerations for selecting or omitting interactions.

BOX 3: SUGGESTED CRITERIA FOR PRIORITIZING ECOSYSTEM SERVICES TO BE QUANTIFIED

1. Can impacts on the ecosystem service be assigned to CBA stakeholders?
2. Can the ecosystem service be legitimately valued in the programming context?
3. Is the ecosystem service impact or dependency likely to be large in magnitude?
4. Is the link between the programming and change in ecosystem service robust?

Can Impacts on the Ecosystem Services be Assigned to CBA Stakeholders?

The first criterion for prioritizing ecosystem services for inclusion in a CBA is whether impacts on these services can be assigned to CBA stakeholders. The scope of a CBA is typically limited to a specific group of stakeholders as defined by the borders of a country or region within a country.[4] Costs and benefits are then measured as they accrue to these stakeholders.

4 For more information, see the USAID CBA Guidelines (USAID, 2015).

Impacts on ecosystem services, both positive and negative, should thus be included in a CBA only if they can be assigned to CBA stakeholders. For example, although a sustainable agriculture activity might reduce water pollution and improve downstream fish catches, if the benefits from this activity do not accrue to stakeholders in the activity CBA, it is probably not appropriate to include them in the analysis. This said, if the activity is aiming to provide a more complete accounting of the benefits and costs of an activity, it may be useful to expand the CBA scope to include new stakeholders—in this case, downstream fishers.

In some cases, however, a program may yield global-scale costs and benefits that are difficult to incorporate in a local or regional CBA. Carbon emissions are a particularly important example of this challenge. A stable climate system is valuable for human well-being, but can be negatively impacted by carbon emissions. Although the global impact of emitting a marginal ton of carbon dioxide is probably significant (see Annex II), the local effects of a marginal ton of emissions may be considerably smaller. As such, if a CBA does not have a global scope, global societal losses due to climate change caused by carbon dioxide emissions from a program most likely do not belong on the list of ecosystem services quantified in the analysis. Similarly, global benefits from avoided carbon emissions or carbon sequestration by a program are also likely not appropriate for local CBAs. However, these costs and benefits may instead be valued as either potential or foregone payments from participation in compliance and voluntary carbon markets. In addition, the global costs and benefits can more properly be included in national-scale analyses, emphasizing the importance of national-scale accounting and interventions.

Can the Ecosystem Service be Reliably Valued in the Programming Context?

Ecosystem service impacts or dependencies can also be prioritized based on the reliability of their valuations, which depends on the methods used to estimate values (see Annex I). Revealed preference approaches—a type of primary study commonly used to estimate provisioning and regulating services—are estimated from choices made in real markets and are thus the preferred choice of economists. Stated preferences approaches, a second type of primary study, are less reliable than revealed preference methods as they do not evaluate actual choices, but are typically needed, however, to estimate existence and bequest values. Benefit transfer approaches are an alternative to primary study and have the advantage of requiring substantially lower effort and leveraging previous estimates of known accuracy. However, the quality of a benefit transfer can at best only match the quality of the original studies used, and establishing ecological and other similarities between sites may itself require primary data collection. (See Annex I for explanation of these terms and concepts.)

Based on the advantages and disadvantages of these approaches, ecosystem service valuations can be ranked by reliability:

1. Consumptive direct use valuations of provisioning services such as harvesting of forest products and fish are the most reliable approaches. These services can often be quantified using market prices and related data, but it is important to consider their sustainability.
2. Non-consumptive direct uses such as tourism and indirect uses or regulating services like waste filtration or coastal protection are second in reliability. These services can be valued using revealed preference approaches, but their valuation is typically more complex.
3. Non-use values for cultural services such as biodiversity existence, or sacred values and bequest values are the least reliable of approaches. These require stated preference approaches that are less defensible.

This rank order does not imply that non-use values are not as important as use values, or that the magnitude of their value is small. Instead, this order reflects the fact that using values from stated preferences approaches can reduce the perceived rigor of an analysis. Generally, if a CBA produces unambiguous results based on reliable values, it is usually not useful to include additional and potentially controversial values. This said, non-use values can certainly be included in CBA, and any perceived bias can be mitigated by presenting CBA results with and without these values as part of a sensitivity analysis. This ensures that their impact on the conclusions of the analysis is transparent and that the analyst can separately defend the robustness of the other values included in the model.

Is the Dependency or Impact Likely to be Large in Magnitude?

Although the magnitude of a program's dependence or impact upon an ecosystem service cannot be known until valuation is completed, it is often possible to generate a quick and rough estimate for when selecting services to continue to later steps. Useful sources of information include literature on relevant services (see Annex II), global datasets (see Annex III) and existing USAID analyses including environmental compliance assessments. By combining values from these sources with statistics such as the number of people whose use of a given service could be improved or disrupted, it may be possible to develop rough estimates of expected magnitudes.

Is the Link Between the Programming and Change in Ecosystem Service Robust?

Ecosystem service valuations can also be prioritized by the rigor of the process needed to generate the valuation. In general, ecosystem service valuation includes three steps:

1. Quantify the expected changes in size, configuration, composition or other attributes of an ecosystem due to a program or change in policy. For example, a new agricultural process may result in forest loss on slopes and alongside streams as observed in prior programs or environmental compliance analyses.
2. Estimate the change in ecosystem services due to the changes caused by the programming. For example, the above newly cleared lands may not retain soil as effectively as the preceding forest, resulting in increased erosion and sediment transportation, as quantified by an existing model or a mathematical relationship from the literature (see Annexes II and III).

3. Place a monetary value on the changes in the service. For example, as a result of the above flooding and sediment transportation, fishers downstream suffer a reduction in catch from the new agricultural activity. The losses from this reduction in catch can be estimated from market prices of commodities, production costs and the expected drop in quantity produced (see Annexes II and III).

Of these three steps, the intermediate step is frequently the most important in evaluating the robustness of a valuation. In some cases, this step may consist of multiple linked processes or ecological production functions that lead to a single valuation (see Annexes I and II), each of which should be evaluated for their robustness. For example, when estimating the impact of a new agricultural regime on local fisheries, one ecological production function could link forest cover lost to sediment runoff, another could estimate sediment transport dynamics and a final function would link sediment deposition to fish habitat, health and productivity. In addition, data limits may be most significant at this step, and even robust processes may lack the data needed for evaluation.

Approaches such as hedonic pricing (see Annex I) allow analysts to avoid this intermediate step and thus the challenges of ecological production functions. When the analyst can make inferences using this approach, it does not imply that the middle step of evaluating the ecological consequences of a policy action is not important, but rather, that such consequences have been estimated by buyers and sellers of property and factored into their decisions. This said, hedonic pricing is most useful in urban areas where good property sale records are available, and may be of limited utility in rural areas in developing countries.

To judge whether the link between a program and service—either a dependency or impact—can be made with confidence, the analyst can review existing evidence, available modeling platforms and meta-analyses (see Annexes II and III). In particular, when considering a specific ecosystem service dependency or impact, the analyst should determine if primary studies demonstrate the existence of a physical relationship, ideally quantifying it in monetary terms, or whether it is included in an available modeling platform or meta-analyses derived function (see Annex III). Results of similar USAID interventions should also be considered. If funds and time are available for primary data collection or physical modeling, the analyst should consider the ability to generate relevant information in the location of interest. Consultations with thematic experts for advice and technical assistance are useful for this purpose.

Documenting Evidence Gaps

The purpose of the above process is to ensure that the final CBA will be feasible, defensible and conservative. This said, due to the widespread lack of information regarding ecosystem service interactions, this process may exclude significant interactions between a program and ecosystem services. These exclusions represent important gaps in institutional knowledge. Although these gaps might be difficult to bridge given the budget and time available for an individual program, it is important to record and report them for three reasons:

1. Stakeholders who review the CBA may be concerned with these interactions, and acknowledging them may reduce uncertainty and assist the decision-making process.
2. Knowledge gaps can be added to a pipeline of priority research needs and may be addressed as funding for research becomes available.
3. Programs are commonly approved despite knowledge gaps around their interaction with surrounding ecosystems. Monitoring and evaluation is an integral part of USAID programming cycle. If monitoring and evaluation teams are made aware of these knowledge gaps, they may be able communicate them to future programming and thus bridge them over time at a modest cost.

Products of Step Two

The products of Step 2 are a list of the impacts and dependencies identified in Step 1, as prioritized by pertinence to stakeholders, perceived legitimacy of the valuation approach, expected magnitude and the evidence supporting links to the program. From this prioritized list, the team conducting the CBA may then select a subset of interactions for valuation and inclusion in the CBA during Steps 3 and 4. Through this process, the analyst will also gain an initial sense of the distribution of benefits and costs from ecosystem service interactions, and the approaches that can be used for valuations. Lastly, the analyst will have likely generated a list of interactions that may be relevant but will not be quantified, and that may represent knowledge gaps to be filled by future study.

As a last note, it is possible that interactions that score highly by one criterion (e.g., impact on an important ecosystem service) may score poorly on another (e.g., ability to value that impact reliably), and this might result in conflicting opinions between economic and environmental priorities. This emphasizes the importance of incorporating a range of opinions and participants during the CBA process (Step 1).

STEP 3: ASSIGN A VALUE TO THE SELECTED INTERACTIONS

The third step in this process is to identify valuation methods for the selected impacts and use these to conduct valuations for each scenario considered in the CBA. Two types of methods are available for valuing ecosystem services: primary studies as conducted by revealed or stated preferences approaches (Annex I) and benefit transfer as performed by modeling platforms, function transfer and unit transfer (Annex I and III). Following is a list of these approaches in approximate decreasing order of expected accuracy, and time and cost requirements. This order is only approximate, however; a literature review based on the relevant interaction and ecosystem, combined with a survey of publicly available data (Annex III), will help the analyst select the best approach.

BOX 4: APPROACHES TO VALUATION IN DECLINING ORDER OF ACCURACY AND COST

1. Primary study
2. Modeling platform
3. Function transfer
4. Unit transfer

1. **Primary study**: During primary study, revealed or stated preference approaches are used to estimate ecosystem service values (Annex I). A carefully conducted primary study is the most accurate means of quantifying ecosystem service interactions but is also the most costly and time consuming. Due to limited resources at USAID for original research, primary study may prove difficult in the USAID context.
2. **Modeling platforms**: Modeling platforms consist of causally linked ecological production functions that use the size, configuration and condition of an ecosystem to estimate the change in the services it provides and corresponding changes in value (Annex I and III). Modeling platforms can provide a convenient means to quantify changes in condition and value when available for the ecosystems and services under consideration, but still require user skill and intervention. Furthermore, although some models are able to assess changes in economic value, other models will require that the user convert modeled changes in physical units into economic value using an appropriate approach. The most commonly used modeling platform is the Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST; Natural Capital Project, 2017) (Annex III).
3. **Function transfer**: In contrast to modeling platforms, which use causally linked functions to estimate changes in ecosystem services and valuations, function transfer typically uses a single function based on one place and time to estimate values in a new place and time (see Annex I, e.g.,

Vincent et al. 2016). Alternatively, these functions may be taken from meta-analyses that incorporate large numbers of primary studies and may be a particularly useful approach for USAID when available for ecosystems of interest (see Annex I and III, and particularly Johnston and Wainger, 2015 and Boyle and Parmeter, 2017).

4. **Unit transfer**: In a unit value transfer, an analyst uses the monetary value of an ecosystem service estimated in one setting and applies it directly to another setting (Annex I). This is the approach most likely to result in errors and should be conducted only when the two settings match closely. Unit transfers can be improved by using average values from a set of studies that are related to the policy site, or by making adjustments for factors like population density, but these should still be done with caution. Due to its poor reliability, unit transfer is the least preferred of the above approaches.

In addition to selecting the most appropriate valuation approach based on needs and resources, CBA practitioners may need to set values for other key variables that are particularly important for ecosystem service valuations: the discount rate and the opportunity cost of time.

Discount Rate

The discount rate is the rate at which future benefits or costs must be reduced to estimate present value and is a key assumption in valuations of ecosystem services. Although the USAID CBA Guidelines recommend a discount rate of 12 percent for all economic costs and benefits, policymakers frequently recommend a lower discount rate for programming in specific sectors. USAID CBAs in the health sector sometimes use discount rates of 3 percent or less, supplemented by sensitivity analyses, and similarly low discount rates are sometimes used for the valuation of future ecosystem services benefits. These low rates are intended to increase the net present value of these programs and thus their apparent feasibility, and are commonly justified by the technical and other barriers to quantifying and monetizing all possible benefits.

Use of a low discount rate to compensate for limitations in the ability to quantify benefits, however, assumes that costs are realized primarily in the present and benefits in the future, which is not always the case. The systematic use of a lower discount rate for conservation or restoration programs biases analyses against present benefits and future costs, making the case for capital-intensive programming that provide benefits in the distant future. Furthermore, varying discount rates between programs encourages the use of the discount rate as a parameter that can be modified to reach a preferred conclusion.

This document thus recommends that USAID maintain its current policy of using a standard institutional discount rate in CBAs that include ecosystem service valuations, supplemented by sensitivity analysis as appropriate. This said, it is beyond the scope of these recommendations to comment on whether 12 percent is an appropriate rate, and several USAID experts interviewed for this document suggested that the recommended discount rate should be reviewed. Any rate may be subject to overestimation or underestimation of opportunity cost of capital from one context to another, but these problems are small in comparison to the errors that can be introduced by changing the discount rate from one program to another.

Opportunity Cost of Time

A second key assumption in many ecosystem service valuations relates to including the opportunity cost of time in analyses (i.e., the assignment of a monetary value to the time spent on any activity). The range of values recommended in the literature is never zero and is capped at the after-tax wage rate (see Whittington and Cook, 2017 for a recent summary for low and middle income countries). This said, it is important to distinguish between urban and rural wages, rather than applying an average, and taxes may not apply to rural and informal labor. As described above for discount rates, varying the opportunity cost of time between programs can result in strategic choices based on interest in driving the program toward approval or rejection. This document thus recommends that USAID adopt a standard procedure for incorporating the opportunity cost of time across programming within a geographical area (e.g., two-thirds of the prevailing wage rate). If appropriate, this standard could accommodate differences in foregone labor time versus the value of leisure time.

STEP 4: INTEGRATE ECOSYSTEM SERVICE VALUATIONS INTO CBA

The final step in this process is to include the valuations from Step 3 in the program CBA model. The following section provides a brief overview of the CBA process at USAID and how it accommodates ecosystem services, discusses methods for incorporating program impacts and dependencies on ecosystem services, and provides options for closing knowledge gaps during the CBA process. This section closes with five general recommendations for practitioners on integrating ecosystem service valuations into USAID CBA.

CBA at USAID

USAID guidelines call for CBAs with an integrated financial and economic analysis in which economic prices are derived primarily from financial prices but may be adjusted to account for externalities. Although financial prices are used to construct the financial cash flow statement and assess the financial sustainability of the programming, economic prices are used to build the economic resource flow statement and assess the feasibility of the programming from a broader perspective. It should be noted, however, that some economists do not use integrated models and prefer to prepare the financial cash flow and economic resource flow statements separately. Below are three relevant definitions from USAID's guidelines for CBA.

- **Financial price**: "The price of a good or service that is actually observed in a market and experienced by stakeholders. Financial prices are the prices used in financial analysis."
- **Economic price**: "The price that a good or service would sell for, if an economy contained no distortions—that is, if all taxes, subsidies and other policies that affect supply and demand were removed, all markets were perfectly competitive and complete, and there were no public goods problems."
- **Externality**: "A situation in which one or more costs or benefits of the transaction of a good or service does not accrue to the principal transactors; for example, when a gallon of gasoline is sold and

TABLE 3: EXAMPLE OF THE INTEGRATED APPROACH TO FINANCIAL AND ECONOMIC ANALYSIS INCLUDING ENVIRONMENTAL VALUES, USING HYDROPOWER ELECTRICITY DELIVERY TO AN ISOLATED POWER GRID. ALL VALUES ARE NET PRESENT VALUES

Transactions	Financial Value	External Impact	Economic Value
Sales of electricity (provision of which reduces the cost of electricity for consumers, valued at $5)	$14	$5	$19
Total benefits	$14	$5	$19
Construction of the dam (flooding land has an external cost valued at $2)	$6	$2	$8
Purchase of fuel (taxed at 20%)	$5	$-1	$4
Total costs	$11	$1	$12
Net impact	$3	$4	$7

consumed, neither the seller nor the buyer bears the whole costs of the use of that gasoline (e.g., its impact on global climate change). Because some of those costs are not borne by either market transactor, the equilibrium price of gasoline will be lower than its actual resource cost, and too much gasoline will be sold and consumed."

The term externality, as defined above, covers any impact that causes the economic net present value (NPV) of a program to be different than the financial one. It can therefore be used to refer to transfers, such as taxes and subsidies, as well as gains or losses to consumer and producer surplus. As such, impacts on ecosystem services are typically treated as externalities, and USAID CBAs include these values in the estimation of economic and not financial prices. Table 3 provides an example in which the construction of a hydroelectric dam in an isolated power grid results in the generation and sales of electricity, including price distortions and environmental externalities.

Each of the three transactions—sales of electricity, construction of the dam and the purchase of equipment—is associated with a market price that is used to estimate the financial benefits and costs for the programming. Each of these transactions is also associated with an external impact. These relationships can be expressed as follows:

Financial value + External impact = Economic value

In addition to providing a new source of electricity to customers, the programming provides a benefit that consumers value at $5 over and above what they pay for their electricity (see Annex I for a discussion of consumer surplus). This benefit is in addition to what customers pay as the financial price; it is therefore treated as an external benefit and added to the financial value when estimating the total economic benefit. In other words, the value of the electricity from the consumers' perspective is $19, of which they pay $14 and receive $5 as a net benefit.

On the other hand, the flooding of land for the dam's reservoir imposes costs on society of $2 in the form of lost agricultural production and tourism revenue. Assuming no compensation is paid to the farming or tourist sectors, these costs are in addition to the financial costs of construction. As such, this external cost is added to the financial cost when estimating the economic value. Lastly, the financial cost of purchasing fuel is distorted by a 20 percent tax, meaning that the cost of this fuel for the economy is actually lower than its financial cost to the programming.

This example highlights the manner in which USAID's existing CBA framework can readily integrate ecosystem service values if they can be credibly identified and quantified. Similarly, USAID's standard feasibility and investment criteria (i.e., Net Present Value, Internal Rate of Return and Benefit-Cost Ratio; see USAID CBA Guidelines: USAID, 2015) are also appropriate for use when conducting CBA with ecosystem service valuations.

Incorporating Programming Impacts on Ecosystem Services into Agency CBA

Integrating programming impacts on ecosystem services into CBA results in the introduction of new social values (costs and benefits) into the model. Given that these are absent from the financial prices observed in the market, these values are considered external impacts and there are three ways to introduce them into CBA.

1. ***Direct attachment to the financial value***. Direct attachment is used when the value of an externality is estimated as a percentage of the value of a financial transaction, as is the case for taxes and subsidies. In these cases, the cost or benefit of the externality is included on the same line as the financial value with which it is associated and calculated from that value accordingly. For taxes, an analyst might define an index that relates the economic price to the financial price, and then use it to convert financial cash flows into economic resource flows. These indices are referred to as "conversion factors" and are the primary focus of discussion around integration of external impacts in the current USAID CBA guidelines (USAID, 2015). An example of this approach is available in Table 3, related to "Purchase of equipment (taxed at 20 percent)." This approach, however, never applies

to impacts on ecosystem services as their value cannot be defined as a fixed fraction of a single financial price.

2. ***Indirect attachment to the financial value***. Indirect attachment is used when an externality is associated with a financial transaction, but the value of that externality is not defined as a function of the financial value. In these cases, the economic and financial prices of a transaction should not be indexed to each other. Two examples of this approach are available in Table 3, "Sales of electricity (provision of which reduces the cost of electricity for consumers, valued at $5)," and "Construction of the dam (flooding land has an external cost valued at $2)."
3. ***Attachment as a new line item***. When an external impact is not associated with any existing financial transactions, it is necessary to add a new line item to the CBA model. For example, a road program might reduce the populations of an endangered species that draws tourists, due to increased traffic in the area. Because this program includes no financial transaction that might represent the flow of traffic, the analyst should add a new line item to the resource flow statement for this external impact. The financial price of this transaction will be zero, while the economic price will represent the externality.

Any impact that can be entered in the model indirectly attached to a financial transaction could alternatively be included as a separate line item. A separate line item may be preferable when a single financial transaction can result in both positive and negative impacts. For instance, construction of a dam might have negative impacts on farming activities and migration of fish and create positive opportunities for fishing and recreation in its reservoir. Merging these impacts into one externality and attaching it into the construction cost of the dam is less informative and transparent than including each impact as a separate line item.

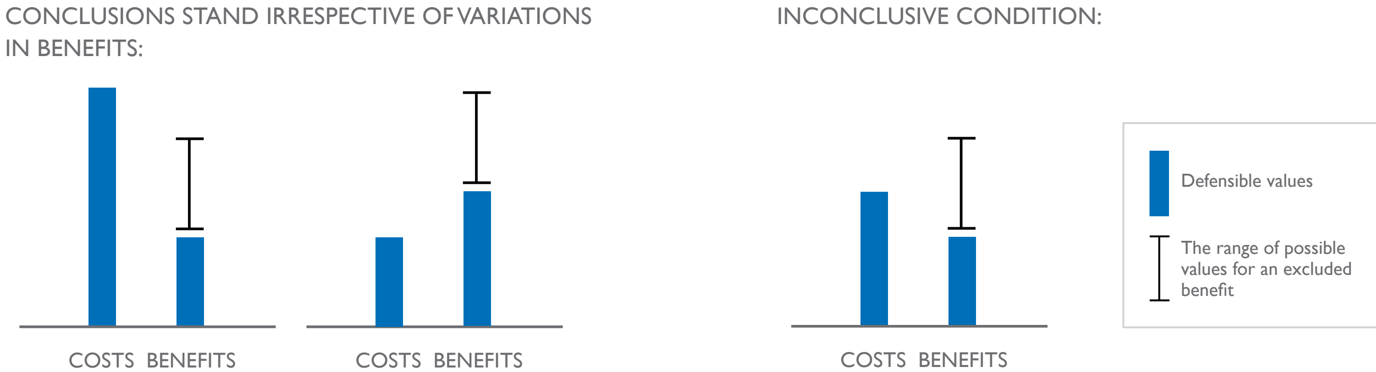
Incorporating Program Dependencies on Ecosystem Services into Agency CBA

Program dependencies on ecosystem services can be incorporated into CBA by adding assumptions to the CBA model or modifying existing assumptions. For example, the yield rate of an agricultural program might be estimated as a function of the acres of forest within a given distance from the site, to account for pollination and pest control services. The analyst can then test the sensitivity of the conclusions to this new assumption through simple sensitivity and scenario tests, or advanced risk analysis methods such as Monte Carlo simulations. This said, advanced approaches require access to and proficiency in tools that may not be available to all practitioners.

Knowledge Gaps

During the above process, in addition to selecting priority interactions and integrating them into a CBA, the analyst may also have generated a list of knowledge gaps as described above in Step 2. These represent interactions that are potentially significant but for which there is insufficient evidence to include them in a CBA. Items excluded from the analysis due to knowledge gaps may be of major interest to stakeholders and should be discussed in the narrative accompanying a CBA. In addition, if one major impact has been excluded, an analyst may be able to estimate a defensible minimum value or range of values that would be acceptable to many stakeholders. The analyst can then show whether the alternatives with the most favorable net present value in the CBA were changed by inclusion of this minimum value or range of values (Figure 1).

FIGURE 1: DEFENDING THE CONCLUSION OF CBA DESPITE THE KNOWLEDGE GAPS ABOUT A KEY IMPACT

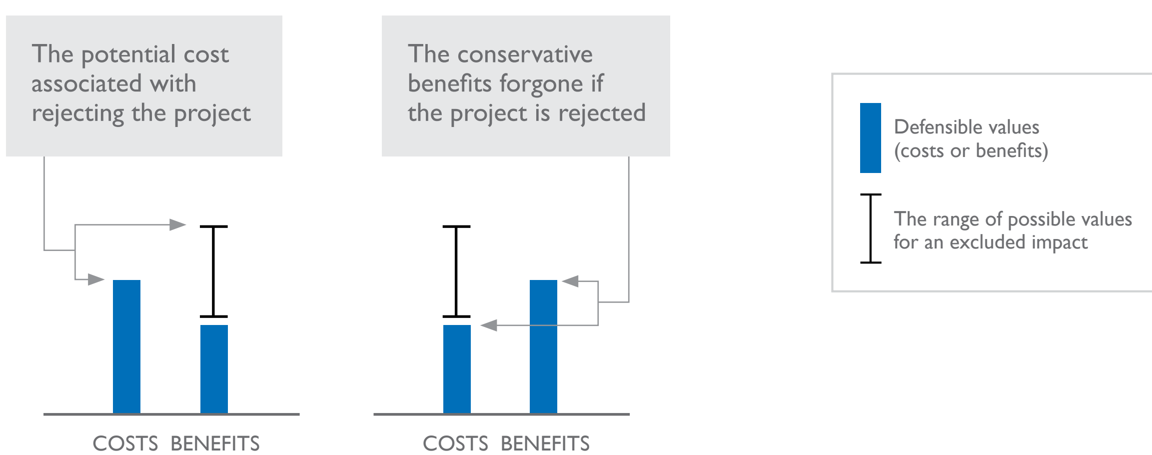


If the recommendation of the CBA is sensitive to the range of values that can be assigned to the dominant excluded impact, the analyst can still consider three additional steps to assist the decision-making process. First, it is possible to report the potential costs or forgone benefit caused by rejecting the programming, as illustrated in Figure 2. This provides decision makers with a clear picture of tradeoffs to be considered for the final decision.

Second, it is sometimes possible for slight adjustments in the technical design to remove a questionable yet potentially important impact from the analysis of the programming. In such a case, the analyst may compare the cost of the design change with the range of estimated benefits. It is often less expensive over the long term to avoid or mitigate an impact than allow it to happen. This also eliminates the need to estimate the costs of the negative impact.

When uncertainty is high, many analysts may consider the option of conducting probabilistic analysis using advanced risk analysis tools such as Monte-Carlo simulations. Probabilistic analysis is only useful, however, when uncertainty is well understood and evidence is available to estimate a probability distribution for the value in question. When faced with uncertainties of unknown distributions, advanced risk analysis tools may not be useful. For example, a meta-analytical database of hundreds of relevant primary studies might provide the evidence required to estimate a probability distribution for a particular value. Barring this type of evidence, an educated guess at defensible range is most likely the preferable option for an analyst.

FIGURE 2: THE COST OF REJECTING PROGRAMMING BASED ON CONSERVATIVE MEASURES OF IMPACT



GENERAL RECOMMENDATIONS FOR INCLUSION OF ECOSYSTEM SERVICE VALUATIONS IN CBA

Based on the above steps, following are general recommendations for the inclusion of ecosystem services into USAID CBA:

1. Ecosystem interactions with programming includes both impacts and dependencies. Although the primary focus in CBA has traditionally been on including programming impacts on ecosystem services, it is also important to measure the program's dependence on ecosystem services.
2. Impacts or dependencies in the CBA model should be associated with a stakeholder or group of stakeholders that are included in the analysis. When an analysis is performed at the country level, impacts on stakeholders beyond the borders of the country may be lower priority for quantification and should not be associated with in-country stakeholders.
3. Analysts should not attempt to introduce an external environmental impact using a conversion factor. While this may be feasible for a given market price and quantity, the relationship will not follow the same relative pattern if the market price or the quantity consumed change over time.
4. Multiple impacts on ecosystem services from the same financial transaction should be added as new line items in the CBA model, rather than combining them into one direct or indirect attachment. Combining impacts can hide important details that may hinder analysis and affect the decision-making process. For instance, individual valuation approaches may vary in their rigor and acceptability, or their applicability to stakeholders, and their combination into one value eliminates the option to separate them in later stages of the analysis.
5. Ecosystem service values should not be called financial impacts unless they affect the decision of one of the stakeholders that has direct financial interest in the program, such as an investment partner, financier or public utility. While labeling ecosystem services as financial impacts does not introduce any logical error into the analysis, it can be a source of confusion in communication. It is common for practitioners not to call an impact an "environmental impact" once it enters the financial cash flow statement.

MONGOLIA: Wildlife Conservation Society members discuss the Daurian Steppe project in the field.
Photo by Matthew Erdman for USAID.

SECTION II INSTITUTIONAL RECOMMENDATIONS

This section provides recommendations for USAID as an institution for incorporating ecosystem services into CBA. As described in the introduction, interviews with USAID staff identified four primary needs in promoting this work at the institutional level: Agency guidance, data sources, training and champions. In addition, this section offers two further institutional recommendations on closing the evidence gaps on ecosystem service valuation at USAID and conducting CBAs on biodiversity conservation programs. These recommendations are intended as a starting point for further discussion and are provided for USAID management staff, technical staff and CBA practitioners who are interested in initiating those discussions and advocating for ecosystem service valuations in USAID CBAs.

Guidance

During interviews, USAID staff consistently identified guidance on ecosystem service valuations and their incorporation into CBA as a key need. This document provides a general process for identifying and incorporating ecosystems services (Recommendations for Practitioners), but is intended as a starting point for more detailed guidance based on experience and experimentation within the Agency. Future guidance, which should be developed by both USAID and its partners, might include:

- Sector-specific guidelines for common impacts and dependencies
- Guidelines for common ecosystem service valuation methods, including both primary studies and benefit transfer
- USAID case studies on integration of ecosystem service valuations into CBA

More detailed guidance will require the participation and endorsement of key USAID offices, staff and other stakeholders.

Data

USAID staff also cited a perceived lack of data on ecosystem service values and the difficulty of generating new data as a barrier to conducting integrated CBAs. These recommendations provide a first attempt to meet this need by reviewing data sources for ecosystem service valuation and the literature underlying these data (Annexes I, II and III). The primary intent of these reviews is to explain principles, provide examples of primary studies (i.e., using revealed or stated preferences approaches) that might be duplicated during program-specific CBAs and provide a good set of resources for carrying out valuations.

This document recognizes that USAID economists may lack the time and financial resources to conduct primary studies and may need to rely on benefit transfers. As noted below, however, benefit transfer may yield invalid results and should be conducted carefully and after consideration of other options (Annex I). As such, this document makes two recommendations for data collection and application at USAID:

- When USAID or its partners use benefit transfers from existing studies, databases, modeling platforms and meta-analyses, information should be collected on the data sources used, the programs to which they are applied, the success of that application and any lessons learned.
- Where USAID and its partners conduct new primary studies of ecosystem valuation, information should be documented on the program context, methods, outcomes and lessons learned.

These data could be collected by a designated USAID operating unit or implementing partner, and might be made available to other USAID CBA practitioners to enable collaboration, learning and adaptation during ecosystem service valuation and its incorporation into Agency CBAs. Identifying and recording USAID experience in ecosystem valuation will be essential in enabling future CBAs and closing key evidence gaps (see below). As with the recommended guidelines for including ecosystem service valuation into CBAs, Agency data sources and guidance can be improved over time as they are applied in the field.

Training

The USAID Office of Economic Policy provides regular training in CBA methods for USAID missions around the world. Interviews indicate that Agency staff have generally received limited training on ecosystem service valuation and its integration into CBA. The successful application of the methods and data described here, plus their refinement based on application, will thus benefit from a range of capacity building activities, both for Agency staff and for implementing partners. Such capacity would increase the ability of Agency staff to carry out, guide, interpret and apply the findings of CBA analyses that integrate ecosystem service values. Both the present and future, more detailed guidance may serve as the basis for future training materials, and a non-exhaustive list of potential subjects for training includes:

- Primary valuation of ecosystem services
- Ecosystem service valuation using benefit transfer methods
- Selecting ecosystem service links to value for CBA
- Integrating ecosystem services values into CBA

It is recommended that these training materials be developed following field testing of the guidance presented in this document so as to best understand the needs of USAID users. In addition, beyond the topics discussed in this document, a broader effort is being made to build capacity at USAID for CBA (Belt and Zukevas, 2014). Interviewed USAID staff agreed that trainings for economists have helped them design more effective and sustainable programs. This capacity building is expected to create increased demand for CBAs that incorporate ecosystem services. This document thus recommends an institution-wide effort that builds on existing CBA training to promote the integration of ecosystem service valuations into CBA.

Champions

Achieving the above recommendations will require Agency champions to secure the funding and commitment needed to implement these recommendations, and to provide examples of the importance of including ecosystem services in Agency CBAs. Champions could be identified during training and outreach activities, and provided with both the guidance and data needed to conduct their work and the evidence needed to convince decision makers of its worth. Champions among agency leaders might be identified during briefings on these recommendations and new CBA opportunities, and provided with the examples needed to support allocation of Agency resources. Tracking of CBAs over time may be used to produce evidence of the role of ecosystem service valuation in identifying, designing and implementing better programs. Once such data are available, USAID could consider a "CBA of CBAs," to compare the relative success of programming conducted with and without ecosystem service valuation, and use the results to promote best practices.

Closing the Evidence Gap

Despite the substantial body of evidence for the valuation of ecosystem services (see Annexes II and III), significant gaps remain and closing them will take time. USAID can play an important role in facilitating this process by:

- Consistent identification and reporting of knowledge gaps
- Prioritization of knowledge gaps for efficient use of scarce research resources
- Management of accumulated knowledge for ease of access and future reference (see also Data, above)

If CBA is used during the project or activity design process, Agency staff that are engaged in the analysis might identify knowledge gaps that limit their ability to integrate ecosystem service valuations into their analysis (see Step 4, above). These gaps might feed a pipeline of questions regarding the magnitude of physical interactions or the value of a particular ecosystem service. Other parts of the Agency, such as monitoring and evaluation teams or research units, might use this pipeline as a menu of questions to be addressed. Through this process USAID staff could prioritize knowledge gaps and look for opportunities to answer them or collaborate with others to do so.

CBA of Biodiversity Programming

CBA of biodiversity conservation programming has in some cases been perceived as ineffective due to the challenges presented by non-use values, the choice of discount rate and uncertainties around long-term impacts. Despite these challenges, CBA can often be effective in improving allocation of funds to the most efficient programming. Conducting CBAs for conservation programs that are typically justified for intangible benefits can add an important additional argument if ecosystem service values outweigh the costs.

Two examples are the return on investment in enforcement activities to protect elephants in Africa (Naidoo, Fisher, Manica and Balmford, 2016) and the argument for global support of management and compensation programs for an expanded protected area system in Madagascar (Hockley and Razafindralambo, 2006). In the first of these examples, the authors modeled the expected decline in protected area visitation due to elephant poaching and estimated a loss of approximately $25 million per year in economic activity across Africa. Losses were unevenly distributed, as were costs of avoiding further decline, but in the region that offered the greatest return on investment (Southern Africa), the benefits of enforcement activities were approximately twice their costs. As noted by the authors, this return on investment compares favorably with the return on education, agriculture, electricity and energy.

In the second example, the authors found a positive global return of $330 million to protected area expansion in Madagascar (net present value in 2006). However, the authors also found that forest frontier communities suffered a net present value loss of approximately $1,400 from protected area expansion, and that at that national level, the benefits of expansion were ambiguous. Accordingly, the authors argued that although there is a compelling global economic case for protected area expansion, significant increases in the scope of benefit sharing are required for the choice to make sense nationally and locally (Annex II provides a more detailed review).

PHILIPPINES – 2017: Ecotourism at the mangroves near Sabong beach provides an economic alternative to traditional forest livelihoods. Photo by Jason Houston for USAID.

ANNEX I
KEY CONCEPTS

This annex provides an introduction to key concepts in the field of ecosystem service valuation, including the need for valuation, approaches to ecosystem service valuations and some considerations when conducting these valuations. This is intended to provide the reader with the information needed to implement this document's recommendations, with a focus on valuation techniques and their application to Agency CBAs. This annex is intended both to provide guidance for USAID economists and environment staff that are participating in cost-benefit analyses and to help non-specialists recognize which approaches to valuation are credible and what adjustments must be made when extrapolating results from one time and place to another.

ECOSYSTEM SERVICES AND MARKET FAILURES

A central principle of economic analysis is that free markets will produce efficient outcomes when markets are perfectly competitive, complete information is available to all participants and the decisions of producers and consumers yield no uncompensated effects on other participants. Failures to meet these conditions are known as market failures, and often result in an inefficient allocation of goods and services and a net loss of social welfare.

Biodiversity and ecosystems often lack appropriate management because ecosystem services are externalities and not included in market calculations (Naidoo and Adamowicz, 2005; TEEB, 2010; Guerry et al., 2015, Scorse, 2010). Externalities are a key cause of market failure and arise when the person who is responsible for creating a benefit or cost does not receive all the benefits or incur all the costs of their actions. Examples include uncompensated damage to fisheries due to agricultural pollution of fishing waters, or uncompensated improvements that increase fishery catch due to improved waste treatment. Although a full discussion of market failures related to the environment is beyond the scope of this paper, it is important to note that other issues such as information failure, public goods, and tenure rights may also affect biodiversity and ecosystem service valuation (see Scorse, 2010).

Ecosystem services range from tangible and local services, such as the provisioning of food and clean water, to intangible and global services, such as ethical or spiritual enrichment. Numerous categorization schemes for ecosystem services have been proposed, and USAID's Biodiversity Policy (2014) uses the classification developed by the Millennium Ecosystem Assessment (2005), the most widely cited of these schemes (U.S. EPA 2017). This system divides ecosystem services among:

1. **Provisioning goods and services**, or the production of basic goods such as food, water, fish, fuels, timber and fiber
2. **Regulating services**, such as flood protection, purification of air and water, waste absorption, disease control and climate regulation
3. **Cultural services** that provide spiritual, aesthetic and recreational benefits
4. **Supporting services** necessary for the production of all other ecosystem services, such as soil formation, production of oxygen, crop pollination, carbon sequestration, photosynthesis and nutrient cycling

The fourth of these categories, supporting services, is problematic for the purposes of valuation, as it can cause double-counting of ecosystem service values (see below for more information on double-counting). For example, the value of wild-harvested food might be counted both in the value of the food itself and in the value of a supporting service such as soil formation (TEEB, 2010). Following the consensus in the literature, this Annex I and the associated literature review (Annex II) focus on the first three categories of ecosystem services: provisioning, regulating and cultural services.

ECOSYSTEM SERVICE VALUATION

Ecosystem service and biodiversity valuations improve decision-making by allowing overlooked but significant costs or benefits to be incorporated into economic planning. Failure to measure and incorporate these values can have negative consequences, particularly for development donors whose beneficial work in one sector may place gains in other sectors at risk. For example, application of pesticides might increase agricultural production and food security, but these benefits may be offset by pollution of waterways and impacts on fisheries. Understanding the effects of programming upon ecosystem services, and vice versa, thus provides opportunities to mitigate negative impacts and capitalize on previously unrecognized benefits.

The principles of economic valuation for biodiversity and ecosystem services are generally the same as they are for other goods and services, but differ in that ecosystem services are often "non-market goods"[5] (Polasky, 2008; Hanley and Barbier, 2009). Some ecosystem services, like wild-caught food or forest products, are frequently bought and sold in markets. However, as described above, the majority of biodiversity and ecosystem services generally do not pass through markets. Even when they contribute to the production of goods that are sold in markets (e.g., fish or agricultural output), the underlying services themselves (e.g., wild pollination, pest control or flood protection) are generally not commercialized.

Because their value cannot be read from market prices, a variety of approaches have been developed for incorporating ecosystem services into decision-making. This annex begins with an introduction to some fundamentals principles of economic valuation of ecosystem services, and then reviews three approaches: revealed preferences, stated preferences and benefit transfer.

Fundamentals of Economic Valuation

The concepts of supply and demand illustrate how the quantity of a product that producers choose to provide and consumers choose to acquire varies with its price. Typically, as the price of a product increases, the supply of that product will increase and demand will decrease. This relationship between supply, demand and price can be represented in supply and demand curves (Figure 3). A supply curve relates the

5 Some authors suggest that "extramarket goods" is a more appropriate term to reflect the institutional considerations that determine when markets are established (Ciriacy-Wantrup 1969). As "non-market goods" is much more widely used, it is used here.

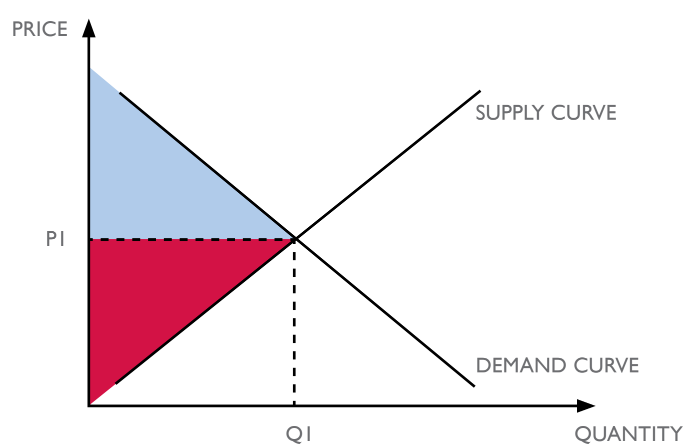
quantity of a product its producer would offer for sale at a given price and is generally positive in slope; in contrast, a demand curve demonstrates the quantity sought by consumers at a given price and is typically negative in slope.

The two shaded triangles in Figure 3 represent a consumer surplus (blue) and producer surplus (red). The concept of producer surplus may be more familiar to non-economists as profit:[6] the difference between the revenue a seller receives for a product and what it costs them to make it. The total revenue received by selling a product is equal to price times quantity (Figure 3, P1 x Q1), and the area beneath the supply curve up to the quantity supplied is the cost to produce that quantity. A producer will offer a good for sale so long as the price they receive for each unit is at least as much as it costs them to produce that good. The cost to produce one more unit of a good is referred to as marginal cost. As shown in Figure 3, marginal cost typically increases with quantity: the more of a good a supplier produces, the more it costs them to produce an additional unit. So, subtracting the area under the marginal cost curve at Q1 from the total revenue (P1 x Q1) yields the area of the red triangle, producer surplus.

The blue triangle in Figure 3 is the benefit to consumers, known as consumer surplus. A consumer might be willing to pay a large amount for a good if its supply is very restricted. However, as supply increases, the willingness to pay for that good declines as reflected in reduced demand (i.e., the negative slope of the demand curve). A demand curve shows the consumer's maximum willingness to pay for the good: typically a high price for the first unit, and successively lower prices for each additional unit. The area beneath the demand curve but above what is paid for the good represents consumer surplus, the difference between the maximum amount a consumer would have been willing to pay to acquire the entire quantity they buy and the amount they actually pay for that quantity. Economists use the sum of producer and consumer surpluses as a measure of economic welfare. An increase in consumer surplus means that a consumer is, in essence, "getting more than they paid for." Similarly, an increase in producer surplus means that producers need to incur fewer costs to produce something than they would have had to otherwise.

The provisioning or elimination of ecosystem services can have substantial effects on supply and demand. For example, consider fruit farmers whose trees are pollinated by insects, with fruit production increasing

FIGURE 3: SUPPLY AND DEMAND CURVES, WHERE Q_1 INDICATES THE QUANTITY OF A PRODUCT THAT WILL BE PRODUCED AT THE PRICE P_1.



6 Note that producer surplus consists of both profit and the fixed costs of production.

in the number of pollinators. All else being equal, if an area of habitat is set aside that increases the number of insects that pollinate their crop, their farm will yield more fruit for a given cost of production. This is reflected in a rightward shift in the supply curve (Figure 4), which results in an expansion of consumer and producer surplus, as indicated the purple-shaded area in Figure 4. Conversely, if pollinator habitat is eliminated, the supply curve would shift left, reducing the supply of fruit. Modeling these supply curve responses to change in ecosystem services, and thus the change in production, is a key technique in inferring the actual value of ecosystem services, as described in the following sections.

Changes in ecosystem services, in addition in changing the supply of a product, can also shift demand. For example, if a wetland that filters and purifies water were restored, a consumer might be willing to buy more water than they would have previously at the same price per liter. They may now choose to use water both for its usual use, washing, and for a new use, drinking. This is depicted in Figure 5 as a rightward shift in the demand curve. Note again that the benefits of improved water quality may be shared between both consumers and producers.

FIGURE 4: SHIFT IN SUPPLY CURVE WITH AN INCREASE IN AVAILABLE ECOSYSTEM SERVICES

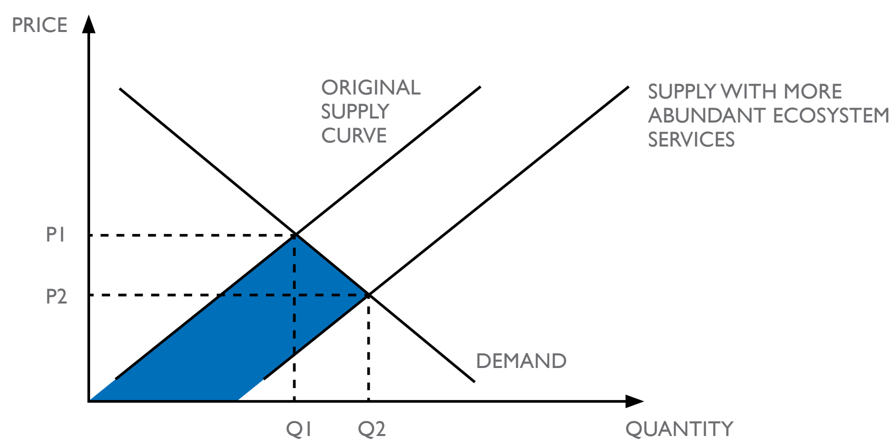
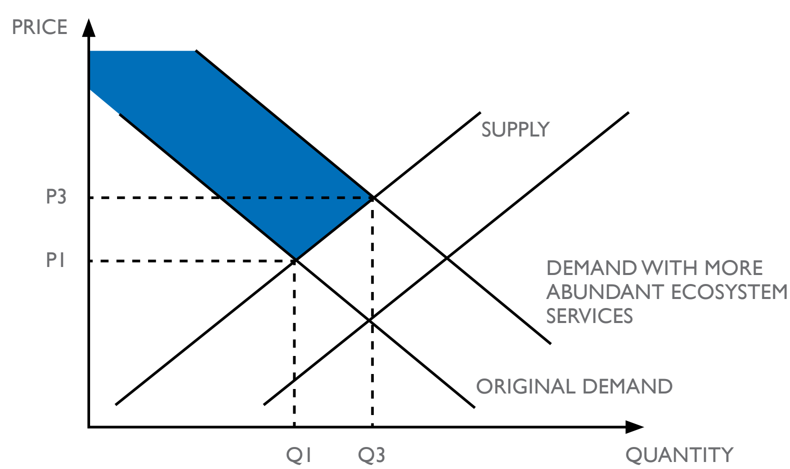


FIGURE 5: SHIFT IN DEMAND WITH MORE ECOSYSTEM SERVICES



Despite the simplicity of the above examples, valuation often requires multiple steps in a causal chain. In the case of pollination and fruit production, understanding how fruit production changes with pollinator habitat availability requires an understanding both of the relationship between the quality of habitat and pollinator populations, and the relationship between quantity of pollinators and amount of fruit production. Despite these complications, it is useful to be conscious of the implied supply and demand curve shifts described here when applying or assessing the valuation methods described in the following sections.

Revealed Preference Valuation

The first category of approaches to ecosystem service valuation is revealed preference valuation, as conducted through primary study. Preferences and thereby values for non-market goods are said to be "revealed" when they can be inferred from the markets for other goods. This does not mean that ecosystem services are themselves bought and sold in markets. Instead, if the products of those services, such as fruit and water, are sold in markets, it may be possible to infer the value of ecosystem services that contribute to their provisioning based on the value of those market goods. Below are the major categories of revealed preference valuation.

Market values. When an ecosystem generates a product that is sold to consumers, such as honey or nuts, the value of that service can sometimes be inferred by the net earnings collectors realize (i.e., producer surplus). For example, the provisioning value of an additional hectare of forestland for sustainable collection of forest products might be inferred from earnings for those products. This said, only net earnings should be recorded, such that the costs of collection—including the value of the time they spend collecting—must be subtracted from gross receipts. In addition, when the collector consumes some of the products they collect, the portion they consume is valued at the prices at which they could have sold them. As a last note, changes in consumer surplus should also in principle be included in this valuation, but to the extent that changes in quantity are marginal, these are sometimes reasonably assumed to be insignificant.

Production function. In this approach, shifts in the supply curve may be used to measure ecosystem service values. As an increase in ecosystem services results in increased production, supply curves shift rightward (Figure 4). Using statistical methods or other models, researchers can estimate a production function that will estimate the relationship between an increase in output and an increase in inputs. For example, this approach might be used to model how total quantity of fruit production varies as a function of pollinators or pollinator habitat. From this researchers can estimate the value of the ecosystem service, and how it might increase or decrease in response to a policy or project.

Avoided costs. Ecosystem services can often be used to offset costs of production that would otherwise be valued in markets, and can be valued on the basis of these avoided costs. For example, by maintaining habitat for wild pollinators, famers may avoid the costs incurred by the rental of beehives. This said, an avoided cost is only a valid measure of benefit if beneficiaries would in fact, choose to bear the cost in the absence of the ecosystem service. In the case of wild pollinators, the avoided cost of renting honeybees to pollinate a crop would not measure the benefits of wild pollination services if, in the absence of wild pollinators, farmers would plant a different crop that does not require insect pollination rather than rent honeybees (Ricketts, Daily, Ehrlich and Michener, 2004; McCauley, 2006). Avoided cost approaches are typically used to value a change in either provisioning or regulating services.

Avoided damages. Ecosystem services can also often serve to prevent damage to property, goods, livelihoods or other assets, and can be valued on the basis of these avoided damages. For example, coastal mangrove forests may provide protection against storms by reducing the intensity of waves, and the reduction in costs from this expected damage may be inferred as the value of the mangrove's protective service. This approach is typically used to value maintaining or improving regulating services.

Hedonic pricing. The underlying principle of hedonic pricing is that the value of something is a function of multiple attributes, including environmental attributes. For example, the value of a home depends both on the attributes of the house and property (e.g., numbers of rooms, quality of construction), and on its ecological attributes (e.g., vulnerability to natural hazards or proximity to a national park). The value of these ecological attributes may thus be determined from the variation in prices of homes with varying ecological conditions, therefore avoiding the need to estimate production functions. For example, rather than using physical models of how mangroves reduce wave energy and protect property, it may be possible to observe the extent to which, all other things held equal, properties protected by coastal mangroves are more valuable than those that are not protected. Similarly, if a hectare of land is more productive due to ecosystem services like pollination, those benefits should be capitalized in the price of the property. One limit of hedonic analysis is that it requires detailed and reliable data on property values that may not be available in the places where USAID works.

Travel cost. The value of a place may also be estimated from the costs that a person incurs to visit a site, including the expense for fuel and the time spent in travel to that place. Estimating value on the basis of these costs is known as the travel cost method. For example, if improvements in ecological conditions at a site make it more attractive to visit, people will be willing to travel a greater distance to reach it, and the increased costs of travel can provide an estimate of the value of those improvements. Travel cost methods are of particular use for valuing recreational services, including both non-consumptive (e.g., photo safari tourism) and consumptive (e.g., diving for abalone) recreation.

Key considerations. Some additional important considerations for implementing the above approaches are:

- Production function, market value, avoided cost and avoided damage approaches generally require careful statistical modeling or detailed understanding of natural processes to evaluate the effects of marginal changes in ecosystem service provisioning. These approaches may be useful in a development context, although estimates of the prices and costs needed to implement them may be challenging to identify.
- Hedonic pricing methods typically involve complicated econometric procedures to ensure that results are not biased by omission of important variables. Moreover, they assume that buyers and sellers have very sophisticated understandings of the factors that determine values they obtain through property ownership. Property values may not be available or reliable for assets like homes and farmland in a development context, however, and it may be incorrect to assume that property holders are fully aware of the benefits that ecosystems provide.
- Travel cost studies rely on measurements of the opportunity cost of travelers' time to estimate value. Researchers generally use a fraction of the wage rate as a measure of the opportunity cost of a traveler's time, but the legitimacy of this approach may vary between individuals and depend on considerations such as how much they enjoy time spent in travel. Travel cost studies may be useful in a development context, for example when estimating increased earnings of local people from foreign travelers as a result of improving ecological conditions. It is important, however, to verify that such benefits do in fact accrue to local people.

Stated Preference Valuation

A second approach to non-market valuation is the stated preference approach, also as conducted through primary study. In contrast to revealed preference approaches, in which consumers' valuations of non-market goods are revealed by the choices they make through the goods they purchase or the ways in which they allocate their time, stated preference approaches ask people to state what they prefer. The main criticism of this method is that stated preferences do not have a financial consequence for consumers—that is, they are never required to "put their money where their mouth is." This represents a significant departure from what many economists consider a basic principle:

that economics is the study of how people make choices under real-world constraints, not how they say they would make such choices in hypothetical circumstances (Nordhaus and Kokkelenberg, 1999).

This said, stated preference-based studies are common and in some cases essential. First, stated preference methods are the only means of estimating non-use values. The value that people assign to the survival of endangered species or the preservation of inaccessible landscapes may have nothing to do with uses they might make of them, the possibility that they might see them, or the possibility that their descendants or other people might use or see them. They may be based solely in ethical precepts. These values are separate from the demand for any market good, and the preferences for them can neither be observed nor revealed in markets.

In addition, stated preference studies are also conducted for reasons of speed, convenience or cost. For example, when estimating the value of tourism to a protected area system, it may be time consuming to trace the origin of visitors, measure the distance they traveled, account fully for their spending and quantify site characteristics. An alternative is to ask visitors the maximum that they would be willing to pay to visit the protected area. Finally, in some cases, the service that needs to be valued may not yet exist. Maldonado et al. (in press), for instance, used a stated preference approach to assess the potential value to birders of birding trips to Colombia following the signing of recent Peace Accords.

At least two variants of stated preference estimation are commonly used. In ***contingent valuation*** of ecosystem services, survey respondents are asked about their maximum willingness to pay for a specific environmental improvement, or their willingness to accept payment for a decline in environmental quality. Another common approach is ***choice experiments***, in which respondents select their preferred option between scenarios that vary in multiple attributes, including the quality of the ecosystem good or service, and amount they would need to pay to ensure that quality. For instance, diving tourists might be asked to select among scenarios that vary water clarity, distance to dive site, reef biodiversity and price of the dive. In both cases, econometric models are used to infer the value of the relevant change in ecosystem service from respondents' choices among discrete options.

Conducting stated preference studies using best practices is technically difficult and can be expensive, despite being relatively simpler than revealed preference valuation in some cases. The questions that are given to respondents and the context in which respondents address them must be as real and consequential as possible. This means that respondents should be given adequate information with which to form a judgment on the things they are being asked to value. They should also be asked questions about their economic and demographic characteristics so individuals' responses can be used to extrapolate values to the broader population. Design and implementation of good surveys takes time and careful consideration.

Benefit Transfer

Primary studies of ecosystem service valuation through revealed and stated preference approaches require time, expense and expert judgment. When these resources are in short supply, benefit transfer may be considered, although with caution. In benefit transfer, an estimate of value derived at one time or place is used to estimate value at a different location or time. Due to the appeal of this approach, the application of benefit transfer to ecosystem valuation has received considerable academic and policy interest (Kaul, Boyle, Kuminoff, Parmeter and Pope, 2013; Johnston, Rolfe, Rosenberger and Brouwer, 2015), as has benefit transfer for ecosystem service valuation (Johnston and Wainger, 2015; Boyle and Parmeter, 2017).

Unit and Function Transfer

Two types of approaches can be used for benefit transfer: "unit value transfer" and "function transfer." In unit value transfer, a monetary value derived in one setting is applied directly to another, although adjustments might be made for currency exchange rates and monetary inflation over time. In function transfer, a mathematical function that was found to describe values in one place and time is combined with data for a different place and time to estimate a value for the new scenario. Examples of both cases are provided below.

In benefit transfer, the original valuation is referred to as a ***study case***, and the time and place to which this valuation is applied is referred to as a ***policy case*** (Boyle and Parmeter, 2017). There need not be a one-to-one correspondence between study cases and policy cases—the results of one original study might be applied to multiple policy cases, and multiple original studies may be combined to inform one or more policy cases, through a process known as meta-analysis (see below; e.g., Brander, Florax and Vermaat, 2006).

Two factors determine the validity of a benefit transfer. The first is the accuracy of the study case—i.e., whether it follows both the basic principles described above and specific best practices for each method. If a study case is not accurate, then the resulting value estimate will not be accurate, regardless of how sophisticated the mechanism for transferring values from study to policy cases. For this reason, searching public databases for thematically related work and simply transferring those values to a policy case can yield poor results if the study cases are not checked for quality (Blomqvist and Simpson, 2017).

The second factor that determines the validity of a benefit transfer is the degree of difference between the study and policy case, and methods to account for this difference (Johnston and Wainger, 2015; Boyle and Parmeter, 2017). When study and policy case scenarios match very closely, unit value transfers are feasible, but under all other conditions, function transfer approaches are preferred. In addition, function transfers should account for variations in both the area and location of study and policy cases. Increases in ecosystem area typically result in diminishing returns in ecosystem service values, and this should be addressed through a transfer function expressing a non-linear relationship between area and value. Furthermore, the location of an ecosystem relative to economic activity is also critical in estimating value. For example, a riparian buffer will not provide a valuable pollution treatment service if it is not located downhill of a pollution source and upstream of an area that is vulnerable to pollution. A prominent example of unit value transfer in violation of these principles is the well-known work of Costanza et al. (1997), which attempted to value all of the Earth's ecosystem services but did not account for the critical differences between locations (Bockstael, Freeman, Kopp, Portney and Smith, 2000; Pearce 1998).

Function transfer is typically preferred to unit transfer, except in cases of severe constraints on time and resources. In these cases, unit value transfers might be employed conservatively, particularly to make lower-bound estimates. For example, if one well-conducted study finds that the value of a 10-hectare wetland that serves purified water to a community of 1,000 people is $10,000, it would be reasonable to surmise that a 20-hectare wetland serving a community of 2,000 people in otherwise similar circumstances would provide a service valued for a minimum of $10,000. It is not reasonable to assume that a 20-hectare wetland would provide a 1,000-person community with twice the water purification service of a 10-hectare wetland due to diminishing returns.

Meta-Analysis

One approach to function transfer is meta-analysis. A meta-analysis may be thought of as a "study of studies," such that it treats the value identified by a specific ecosystem service study as a variable that is to be explained by the conditions under which the study was conducted (see also Annex III). The strength of meta-analysis is that it combines studies to more accurately estimate an ecosystem value. For example, if multiple hedonic valuation studies estimate how much a hectare of nearby forest area enhances the value of a home, a meta-analysis that combines data across studies while accounting for the factors that varied between them might provide a more robust estimate of value (see Nelson and Kennedy, 2009 for a technical treatment of issues in combining studies). When this is the case, meta-analyses can be used for benefit transfer (e.g., Brander et al., 2006; Ghermandi, van den Bergh, Brander, de Groot and Nunes, 2010), and the transfer function that emerges from the meta-analysis can be estimated using data from policy cases and used to estimate values. A meta-analysis may also reveal that different studies are not comparable, indicating that one or more of the studies is flawed, or that different studies are estimating fundamentally different values and should not be combined.

Modeling Platforms

Function transfer may also be implemented as part of modeling platforms. Modeling platforms use a combination of ecological production functions and economic models to estimate the change in ecosystem service values due to interventions (see also Annex III). In economics, a production function is a relationship describing how inputs are converted into outputs. An ecological production function is a production function that describes how ecological inputs are converted into ecological output in processes that do not require human agency. These platforms capture the chain of effects that link changes in ecosystems, to changes in the provisioning of ecosystem services, and eventually to changes in human welfare. For example, the crop pollination model in the InVEST platform (see Annex III) first estimates the abundance of pollinators based on the availability of the food sources on which they depend. It then estimates how these pollinators are distributed over fields and their densities at specific locations. It last relates the number of pollinators that visit fields to crop yield. The user may then be able to link agricultural production to societal well-being through data on crop prices and costs of production. In addition, the Natural Capital Project has created a suite of 17 models of ecological services including pollination, coastal protection and water purification for use in economic analysis (Natural Capital Project, 2017). These models have been used in a variety of settings relevant for USAID, including Kenya (TNC, 2015), Nepal (Vogl et al., 2017) and Belize (Arkema et al., 2015).

Recommendations for Benefit Transfer

Benefit transfer, although imprecise, may thus be useful in cases where analysts have insufficient time and resources to conduct an original valuation. If that is true, it is important that:

- Unit transfers should not be conducted when there are substantive differences between study and policy cases, although they may be used to provide lower-bound estimates as described above. Function transfer will be necessary when conservative estimates do not suggest a clear choice among alternatives.
- Even where function transfer is used, the case study case and policy case should be as similar as possible.
- Because of concerns related to diminishing returns with increases in area and variations in value due to location, transfer functions should allow values to vary as appropriate with ecosystem size, scarcity, proximity to economic activity and other relevant spatial variables. This variation is ideally accomplished by applying tested mathematical relationships.[7] Expertise in relevant natural science issues may be required to identify appropriate mathematical models.
- A benefit transfer is no more reliable than the study or studies on which it is based. There are many databases and procedures, both free and proprietary, that users can use to conduct benefit transfer. Analysts should try to "look inside the black box" rather than accepting results, and ask questions such as "are accepted principles of economic valuation followed? Were study cases chosen carefully?"

7 Many ecological production functions have been found to follow declining exponential forms, including Simpson, Sedjo and Reid's (1996) work on new product development from biodiverse natural sources, Acharya and Barbier's (2002) work on crop growth and Mander's (2008) work on nutrient retention.

GENERAL CONSIDERATIONS IN ECOSYSTEM VALUATION

Below is a discussion of additional considerations that should be kept in mind when implementing or using the results of any ecosystem service valuation approach. These include the importance of variations in wealth between locations, diminishing returns to ecosystem services, the perils of double-counting and the fact that protecting ecosystem services may not protect biodiversity.

Wealth and Value in Developing Countries

Economic valuation is often characterized as an exercise in determining "willingness to pay." What something is worth to someone is determined by the tradeoffs they would accept to acquire or retain it. Valuation may also be conducted on the basis of "willingness to accept" a change in circumstances, as estimated from a minimum payment for that change. In both cases, however, a limitation of all valuation exercises is that responses are affected by the distribution of income and wealth. The willingness of impoverished households to pay for or accept a reduction in ecosystem goods and services will be substantially lower than that of their wealthier neighbors or wealthier countries. This can also be true for variations in wealth by gender and age. As such, the principle that value is measured as willingness to pay or accept payment underscores an important limitation of both ecosystem service valuation and cost-benefit analysis: in development applications, it is particularly important to understand disaggregated benefits and costs, and to consider disparate impacts on different income, gender, age and geographical groups.

Diminishing Marginal Returns and Non-Linear Relationships

Diminishing returns are a near-universal feature of economic processes and most ecosystem services. Under diminishing returns, each incremental increase in the area of an ecosystem under consideration generates less of the desired ecosystem service than the previous increase. It is generally wrong to extrapolate ecosystem services values per hectare of natural habitat in a linear way. This is illustrated by the ecosystem service of water purification (Plummer, 2009; Simpson, 2017; Mander, 2008): although a 20-meter buffer might remove 50 percent of the fertilizer draining from an agricultural field, a 100-meter wide buffer will not remove 250 percent of nutrients. A failure to consider diminishing returns may result in spectacularly large errors, as noted above in the case of Costanza et al. (1997).

A related caution is that when values are estimated for areas that are larger than those that would likely be affected by a program, the results may be difficult to apply to that program. For example, a recent USAID valuation of the services provided by the Páramo De Santurbán wetlands in Colombia estimated values for the full 800 square kilometer area of the wetlands (Garcia et al., 2013). A future USAID intervention that influences a fraction of that area would only affect a fraction of the total value, and the effect would likely not vary linearly with the area.

Double-Counting of Ecosystem Services

Double-counting occurs when ecosystem service valuations overlap, such that the sum of these values overestimates the value of the ecosystem or associated losses. Double-counting might occur for several reasons. First, benefit estimates may overlap when an analyst estimates both the benefits an ecosystem service provides to another economic activity, and the benefits that activity derives from an ecosystem service. For example, an analyst might estimate either how much fishers are willing to pay for cleaner water because it enhances fisheries, or the market value of enhanced fisheries production resulting from cleaner water, but not both. Double-counting is particularly a risk in evaluating the supporting functions of ecosystem such as nutrient recycling, as these valuations may overlap with many of the provisioning or other services provided by that ecosystem (see, e.g., MEA, 2005). Valuing supporting functions directly is thus often both problematic and unnecessary.

Second, some approaches might measure equivalent values using different methods. For example, increases in ecosystem service provisioning may be represented either by increased production or by reduction in production costs, and using both methods would result in double-counting. For instance, if a new forest area is protected, the ecosystem service provided by native pollinators can be estimated as the avoided costs to rent bee colonies, or the value of additional production if the farmer continues to rent bee colonies. Summing the two values would be incorrect.

Third, some approaches may capture the results of other approaches. For example, a hedonic price study may capture the advantages of location, including flood protection provided by adjoining forests and pollination potential. Reporting the results of studies of both hedonic prices and avoided costs of flooding or benefits of pollination would be double-counting. This said, although double-counting should be carefully avoided, overlapping results can be used to check each other and improve the valuation used in cost benefit analysis.

Protecting Ecosystem Services May Not Always Protect Biodiversity

It is conceivable that many of the services described in this document might be provided equally well by human-managed ecosystems designed for specific purposes. For instance, carefully managed forest plantations might generate similar ecosystem service values as a natural forest in terms of sediment regulation or even opportunities for hunting. In addition, Kareiva and Ruffo (2009) note that infrastructure programs might be more effective than natural ecosystems in adapting to climate change, and that monoculture plantations might be more effective in mitigating it. Furthermore, while evidence suggests that some ecosystem services might be produced in greater quantities by more diverse ecosystems, the relationship between diversity and function often shows strongly diminishing returns (Balvenera et al., 2014; Harrison et al., 2014).

Furthermore, some conservation advocates question whether an emphasis on ecosystem services promotes biodiversity conservation at all. Indeed, preserving relatively small isolated areas of "natural" habitats to provide ecosystem services in otherwise human-dominated landscape may not advance broader conservation objectives (Soulé, 2013; see also Kloor, 2015). This does not suggest that ecosystem service valuation is not important, only that USAID analysts should not assume that biodiversity objectives are necessarily met through ecosystem service valuation. Biodiversity conservation objectives, especially as defined by the Agency, may require additional or alternate actions than those encouraged by valuation processes.

PHILIPPINES – 2015: The mangrove forest of the Del Carmen landscape protects against coastal erosion and storm surges. Photo by Sam Harold K. Nervez.

ANNEX II
LITERATURE REVIEW

Decades of work on ecosystem service valuations has generated a large body of original research, much of which is relevant to USAID's work. This annex reviews this literature, as organized by USAID program areas, and provides examples of valuation techniques and outcomes from the primary literature. Although in limited cases it may be possible to apply the values identified here to new CBAs, this is not recommended without caution (see Annex I, Benefit Transfer), and Annex III provides additional information about data sources for USAID studies. It should be noted that this annex is not meant to provide a complete review of the valuation literature, but rather to provide good examples from primary studies that illustrate important themes, approaches, implications and caveats.

The following studies are presented with several caveats. First, the valuations described here were not typically conducted as part of a cost-benefit analysis, and represent examples of ecosystem service valuation approaches that USAID and its partners could include in a cost-benefit analysis. In addition, all values are reported in U.S. dollars and have not been adjusted by inflation, and thus represent the values as reported in the corresponding studies. Lastly, due to the lack of reliable valuation studies in development contexts, many of the studies reported below are from developed nations. Despite this difference in context, these examples provide useful examples of successful valuations that might be replicated in USAID work.

Table 4 presents the ecosystem services for which case studies are provided, organized by the USAID program areas that typically depend on them. Some of the included services apply to more than one USAID sector, in which case they are listed for the most relevant sector. Annex IV provides some additional examples of project impacts or dependencies on ecosystem services, organized by USAID program areas.

TABLE 4: ECOSYSTEM SERVICES DISCUSSED AS CASE STUDIES, ORGANIZED BY USAID PROGRAM AREAS AND ORDERED AS PRESENTED IN THE TEXT

USAID Program Area	Ecosystem Service	Ecosystem Service Category
Food Security	• Wild fisheries and other wild foods[8]	Provisioning
	• Pollination • Pest control	Regulating
Global Climate Change	• Climate change mitigation • Climate change adaptation	Regulating
Water, Sanitation and Hygiene	• Water provision	Provisioning
	• Water purification	Regulating
Economic Growth	• Recreation and tourism	Cultural
	• Forest products	Provisioning
Energy and Infrastructure	• Water provision and silt reduction for reservoirs	Provisioning/Regulating
	• Protection from flooding	Regulating

FOOD SECURITY

Modern agricultural value chains depend on ecosystem services for their productivity. In addition, food supplies may be complemented by value chains built on wild foods. Below are examples of ecosystem service valuations for pollination and pest control provided for agricultural crops, and for wild foods and particularly wild-harvested fish. Watershed management and soil conservation, which are also important to food security, are discussed below under Water.

Crop Pollination

Many agricultural value chains are enhanced by or dependent upon pollination by animals. In many cases this ecosystem service is sustainably provided, either partly or entirely, by wild pollinators. The value of pollination to agricultural value chains may usefully be included in cost-benefit analyses of actions that affect pollinators and their habitats. Some examples of efforts to value pollination services include:

- ***Forests, pollinators and coffee production***: Using production function methodology, Ricketts et al. (2004) conducted careful experiments to determine the effects of native pollinators on coffee production in a plantation in Costa Rica. The researchers hypothesized that coffee trees planted closer to remaining areas of native forest would benefit from increased visitation by pollinators. To test this hypothesis, they compared output between trees that did and did not receive visits from forest pollinators. The researchers found that coffee visited by forest pollinators produced about 20 percent more output. From these findings they

8 The distinction between "wild" food systems and managed farms is sometimes tenuous. In keeping with the definition proposed above of ecosystem services as things provided by "natural" ecosystems, wild foods are ecosystem services to the extent that they are provided by generally unmanaged systems.

inferred that forest areas harboring pollinators contributed about $130 per hectare per year to the value of production. Such a value might be included in cost-benefit analysis as a benefit of retaining, rather than felling, forests in the vicinity of crops requiring pollination, or, conversely, as part of the opportunity cost of clearing land for farming.

In another study of the contributions of pollinators to coffee production, also using the production function approach, Priess et al. (2007) found that fruit set (i.e., the fraction of a crop that is successfully pollinated) was substantially lower in areas 1,500 meters or more from natural forests, as compared to coffee-producing areas adjoining such forests. Fruit set was roughly 60 percent in the more distant areas, but roughly 85 percent in those adjoining the forest. The researchers then used statistical procedures to relate fruit set to distance. By estimating this relationship, they were able to infer the value of a hectare of forest as a source of pollinators at approximately $46 per hectare. Values such as these might be included in CBA as the value lost if forest is cleared, or used to design an alternative landscape matrix that maximizes production and other values.

- ***Pollinators and watermelon***: Unlike coffee, which can still produce, although less prolifically, in the absence of insect pollinators, watermelon is dependent on insects for pollination.[9] Winfree, Gross and Kremen (2011) also used production function methods to study the value of both native pollinators and rented commercial honey bees for watermelon farming in Pennsylvania and New Jersey. Watermelon requires pollination, but each fruit requires only a certain amount of pollen, such that insects who deliver pollen after the requirement is met contribute nothing more to production. This implies that native pollinators would contribute little to fruit that was already served by a sufficient number of honey bees, and vice versa. The authors found that the contribution of native pollinators to watermelon production in Pennsylvania and New Jersey would be about $3.4 million per year if rented honey bee colonies were not available to pollinate the crop, but, because honeybees are, in fact, used, the native pollinators' contribution is only on the order of $500,000 per year.

Implications and caveats: Modeling of pollination underscores a point stressed throughout this document: that diminishing returns are a near-universal phenomenon. Pollinators can do no better than to pollinate the entire crop that has been planted, and thus the more pollinators are available, the less likely it is that each would pollinate a plant that has not already been served by another (Winfree et al., 2011), so the marginal product of pollinators falls as the number of pollinators increases. On the other hand, the opportunity cost of setting aside area for native pollinators grows linearly with the size of such areas, such that the optimal area to protect for pollination may be small. If large areas are required to provide pollination services, a farmer may thus be better off planting different crops or renting honeybees where local economies are sufficiently sophisticated to provide that service. For crops that do not benefit from native pollinators, the value of this ecosystem service is zero, regardless of the presence of habitat or healthy populations of insects (Kareiva and Ruffo, 2009).

In addition, crops that benefit from the services of wild pollinators tend to be grown in remote locations where such pollinators remain abundant (Ghazoul, 2005). To the extent that biodiversity is more likely to persist in these places, there is a potential overlap between areas where native pollinators are most important to food security and where conservation is important for biodiversity.

Although authors such as Priess et al. (2007) have related the success of pollination to proximity to areas of native forest, other ecosystem services such as pest control (reviewed below) or local climate moderation can also vary with distance to forest. If so, valuing production as a function of proximity to the forest may give a more accurate measure of ecosystem service values.

9 This is also true for seedless watermelon varieties, which produce minute inviable seeds and require pollination to trigger fruit production.

It should be noted that no USAID study in our review included pollination. Given both the relevance of this work to food security sector work and the state of the science, pollination could usefully figure in future USAID cost-benefit analyses.

Pest Control for Crops

Agricultural pests are frequently held in check by wild predators, such as bats and birds, who are often dependent on intact ecosystems for survival and reproduction. By preying on crop pests, native species can increase crop quantity or quality, or reduce the costs of avoiding damage. The value of the services these ecosystems and their predators provide might therefore be estimated either in terms of the damage they prevent or the cost of the pesticides whose purchase and use they avoid (but not both, see discussion of double-counting, Annex I). Some examples are:

- ***Bats and cotton production***: Cleveland et al. (2006) estimated that Brazilian free-tailed bats' consumption of agricultural pests is worth $741,000 to cotton producers in eight Texas counties, where average annual cotton production from about 4,000 hectares of land is valued at $4.6 million. Estimates were made by combining the following to quantify how much damage an adult bat prevents: field studies of bats' consumption of pests; pest abundance estimates, drawing from literature on cotton reproduction and susceptibility to other predators; and a literature-derived function that estimates pest consumption of cotton at different times in the growing season. The valuation itself was based on the net value of avoided damage to crops, and, for comparison (not additionally), the avoided cost of applying pesticides accounting for farmers' preferences.
- ***Birds and coffee production***: Karp et al. (2013) found that pest control by birds and other animals prevented damage of $75-$310 per hectare per year on coffee farms in Costa Rica. This value was estimated using field assessment of pest infestation, damage to crops, and the resulting changes in value to crop production. An analysis of bird droppings showed that more pest-consuming species were present on farms with greater forest cover.

Implications and caveats: Pollination and pest predation are similar in some important respects: both are provided by animals whose survival may be enhanced by preservation of natural habitats and restrictions on pesticide use and other practices that may have impacts on the animals' health. As such, agricultural interventions that rely on insecticides and other chemicals may cause a reduction in pest control at the same time as crop pests are killed, resulting in reduced net gain from the intervention. This implies that caution should be used to estimate increased long term production from the use of chemicals, and that farmers who maintain native populations of these animals may realize net financial benefits, including health and other benefits, from reduced reliance on potentially dangerous pesticides. One farmer's application of chemicals may also affect other farmers' output through negative impact on pest predation.

Fisheries and Other Wild Foods

Wild foods, such as wild-caught fish, wild-harvested nuts or honey, edible plants or similar goods, are food supplies that replenish independent of human intervention. When these resources are harvested directly, the estimation of the local value of current harvest per hectare or per family is relatively straightforward. Projecting change in ecosystem service value resulting from interventions, for example those that regulate harvest to improve sustainability, may add complexity. Services provided by aquaculture, mariculture and agriculture are often excluded from ecosystem services considerations as they do not originate from primarily natural ecosystems.

- ***Mangroves and fisheries***: The interlaced roots of coastal mangrove forests provide protection and refuge for fish and shrimp reproduction. In Thailand, the value of nearshore mangroves to fisheries was estimated at between $33 and $110 per hectare per year for mangrove loss (Sathirathai, 1998). This estimate was derived by positing a production function in which fish catch depended on both effort and the area of coastal mangroves maintained for the reproduction of target species. The author estimated a model to find the relative contributions of these factors, in effect developing an empirical representation of the shift in the supply curve (see Figure 4). An interesting feature of this analysis is that the range of values depends on the institutional governance of the fishery (see below).

- ***Water quality and fisheries***: In the Chesapeake Bay, implementation of water quality regulations could generate benefits worth almost $13 million per year due to enhanced fisheries production (Moore and Griffiths, 2017). This result was developed from a detailed model illustrating both the consumer and producer benefits that arise from improvements in water quality. The authors also considered how much more fish and other seafood such as oysters might be caught as a result of cleaner water. Note that benefits arise from both increased harvests and consumers' perceptions of enhanced quality.

Implications and caveats: Even when the ecosystem services provided by gathering, hunting or fishing are computed correctly, conducting a cost-benefit analysis of an intervention requires that these values be related to the extent and quality of the expected change in habitat, and the sustainability of the intervention. Bioeconomic and related models can help understand and model this relationship (Ellis and Fischer, 1987; Natural Capital Project, 2017). McNamara et al. (2016), for instance, used an empirical analysis to link the size and composition of bushmeat harvest to the condition of local forests. These authors were able to combine the estimated volume of sustainable harvest with economic data on revenues and costs to value bushmeat under different forestry management scenarios. Robinson and Redford (1991) also provided a simpler, much-used model for the sustainable quantity of bushmeat.

In addition, spatial and temporal issues in modeling wild food harvest are particularly important. The effect of food security interventions strongly depends on the quality of the area that is protected or compromised for food production (e.g., see Gell and Roberts, 2003; Aburto-Oropeza et al., 2011 for fishing; Fa et al., 2014 for hunting) and when it is impacted (Erisman et al., 2012). For example, agricultural production can often impact fisheries production through runoff into streams, eutrophication and pollution, and reduced habitat quality. By modeling a variety of approaches and locations, studies have found that if agricultural interventions are well designed in terms of approach and location, improved production is possible with little externality in terms of downstream ecosystem services (e.g., Butler et al., 2013; Polasky, 2008; Smith et al., 2016).

A last observation is that governance conditions matter greatly. Under open-access conditions, in which anyone can exploit a resource, people may do so until competition among them exhausts any benefits of participation. Under such circumstances, enhancing ecological conditions alone will do little to help the people using these resources (Freeman, 1991). The range of values Sathirathai (1998) reports in the work cited above arises from alternative assumptions concerning management of the fishery. Barbier and Strand (1998) also illustrate the importance of access management in their study of a shrimp fishery in Mexico, finding that while protecting mangroves would have a small effect on profits, better-regulated fishing efforts would have a much larger effect. Such governance work can generate or preserve considerable ecosystem service value, and this has been demonstrated in USAID's work with the Northern Rangelands Trust in Kenya (Gangelhoff, Gregory and Smith, 2015) and with the customary forest management program in Kalimantan Timur, Indonesia (NRM/EPIQ, 2000).

CLIMATE CHANGE

Natural ecosystems provide the globally valuable service of sequestering carbon dioxide, and their conservation may contribute to climate change mitigation objectives. Similarly, natural ecosystems can increase resilience to extreme weather and climate events, contributing to climate change adaptation objectives. Following are examples of ecosystem service valuations in regards to these two approaches to addressing climate change.

Climate Change Mitigation

Plants absorb carbon dioxide as they grow, sequestering atmospheric carbon, and emit carbon dioxide when they are burned or decomposed, releasing atmospheric carbon. The maintenance or regeneration of ecosystems can thus contribute to climate change mitigation goals by preventing the release of or potentially increasing sequestration rates of carbon dioxide. Valuing the mitigation services provided by an ecosystem usually requires estimating the present and future baselines of carbon content, and then estimating carbon content under land use change scenarios. This applies to programs that may mitigate emissions (e.g., Reducing Emissions from Deforestation and Degradation programs), reverse emissions (e.g., reforestation programming), or cause emissions (e.g., through deforestation or flooding). Examples of climate change mitigation valuation include:

- ***Carbon sequestration in coastal mangrove forests***: Estrada, Soares, Fernadez and de Alemida (2015) estimated the value of yearly incremental carbon sequestration in mangrove ecosystems in southeastern Brazil. The total carbon stored by these ecosystems was initially estimated from Estrada, Soares, Chaves and Cavalcanti (2013), and carbon sequestration rates (i.e., growth per year) were obtained by measuring plots from 2003 to 2012. Carbon in biomass was then converted to equivalent amounts of carbon dioxide, and rates of carbon sequestration were obtained in tons of carbon dioxide per hectare per year. Two monetary values were obtained, one that considered carbon sequestration (based on the Clean Development Mechanism) and another that considered carbon storage in a protected area (based on reduced emissions for deforestation and degradation). Monetary values from carbon sequestration varied from US$19 ± $10 per hectare per year in basin forests to $82 ± $32 per hectare per year in fringe forests. The range depends on both the price of carbon used and the incremental growth per forest type. These values were derived from above-ground biomass only and ignore below ground biomass and soil carbon storage. Additional estimates of carbon storage in mangrove systems are also reported by Smith, Hyman, Foley and Mack (2018).
- ***Carbon sequestration in temperate hardwood forests***: Studying hardwood forests in the United Kingdom, Valatin and Starling (2012) found a value of about $360 per hectare per year. The study used a carbon accounting model that included a simplified treatment of living biomass (including above and belowground biomass), litter and soil. U.K. Government guidance on valuing carbon suggested a value of $76 per ton of carbon dioxide (2009 prices) for the non-traded sector (i.e., not included in the EU emissions trading scheme).
- ***Carbon sequestration in marine seagrass beds***. Carbon can also be stored in freshwater and marine ecosystems. Cole and Moksnes (2016) estimated carbon storage values in eelgrass beds off Sweden's coast at $280 per hectare per year, considering both live eelgrass and sediment. The non-market values associated with carbon were based on a transfer of existing values in the literature. The price of carbon, $127 per ton, was based on the global value associated with economic damages arising from carbon emissions.

Implications and caveats: These variations in estimates illustrate some key considerations for valuing carbon sequestration. Some studies consider only carbon in above-ground biomass, while others include carbon both below the ground, as roots, and in soil, as decaying biomass or microorganisms. Furthermore, some studies focus on annual sequestration of carbon, the amount by which the carbon stock increases from year to year, while others focus on the stock itself, the total net amount that has been sequestered in all previous years. Any of these concerns might be important in a cost-benefit analysis. The value of carbon stock would be most relevant if an action under contemplation would result in its short-term release—if, for example, trees were felled and burned. Conversely, in valuing a reforestation program, an analyst would want to account for the year-on-year sequestration it provides. Furthermore, removing aboveground biomass by cutting vegetation might have a delayed effect or no effect on belowground biomass.

Most studies adopt one of two approaches to assigning a monetary value to sequestered carbon. The first of these, the "social cost of carbon," is an example of the avoided damages approach and can be defined as the net present value, globally, of climate change damages associated with incremental increases in carbon emissions (Heyes, Morgan and Rivers, 2013). In cost-benefit analysis, the social cost of carbon is appropriate where the beneficiary considered is society as a whole. Estimation of the social cost of carbon requires considerable amounts of data and complex models, bringing much uncertainty into the calculations (Smith and Braathen, 2013). The United States Interagency Working Group on the social cost of carbon proposed values of between $5 and $61 per ton, with the range depending on assumptions made on the discount rate applied and the likelihood of extreme outcomes. While the range of candidate values for the social cost of carbon varies widely, each value can be applied anywhere in the world, as global carbon damages should be the same regardless of their source.

A second approach to assigning a price to carbon is the marginal abatement cost of emissions reductions. Marginal abatement cost is the marginal cost of reducing carbon emissions, and the marginal abatement cost curve is the "supply curve" for carbon reductions (as in Figures 3 to 5). When nations or international organizations set up trading markets, such as the European Union's Emissions Trading Scheme, the price of carbon is determined by the point at which the demand for carbon reductions as set by the regulatory body meets the supply. The price of emissions reductions in such a market is, then, the marginal abatement cost of carbon. The marginal abatement cost would be equal to the social cost of carbon if the regulator set the demand at the appropriate level, but this may not always be the case. Nonetheless, for most cost-benefit analysis at USAID, use of prevailing "market" prices are likely the appropriate value in that they capture income foregone from not participating in carbon markets. In countries in which there is an opportunity to participate in carbon markets, prices in those markets should be used.

For their work with USAID, Narayan, Foley, Haskell, Cooley and Hyman (2017) estimated values of carbon stocks at $117,867 per hectare at a carbon price of $8 per metric ton of carbon for mangrove forests in Mozambique. They based their marginal abatement cost estimates on prices recorded in U.S. regional or voluntary carbon markets. Estrada et al. (2015) derived their range of values from assumptions of carbon prices between $6 and $20 per ton, focused on marginal abatement costs as estimated from existing carbon markets or costs incurred to abate carbon. Valatin and Starling (2012) and Cole and Moksnes (2016) used substantially higher estimates of $293 and $127 per ton, respectively. Valatin and Starling employed the social cost of carbon estimate published by the U.K. Department of Energy and Climate Change, while Cole and Moksnes used an average of estimates of the social cost of carbon from the academic literature.

Climate Change Adaptation

Natural ecosystems can also help human communities adapt to the impacts of climate change. Increasing temperatures, rising sea levels and extreme weather events like droughts and floods present serious threats to human development, economic growth and poverty reduction. Ecosystem-based adaptation is a nature-based method for climate change adaptation that can offer cost savings compared with other approaches, as well as additional benefits, such as the provisioning of wild foods, carbon sequestration and biodiversity conservation. While there is a growing body of research that supports the environmental, social and financial benefits of these approaches, many programs do not adequately capture data on the economic value of these benefits. Following are several examples of ecosystem services that can be valuable as part of an ecosystem-based adaptation approach:

- ***Mangroves and storm protection***: Mangrove ecosystems on the coast of Thailand were found to yield a net present value for storm protection of between $8,966 and $10,821 per hectare over a 20-year time horizon at a 10 percent discount rate, based on an avoided damage approach (Barbier, 2007). In contrast, Narayan, Foley, Haskell, Cooley and Hyman (2017) considered the damage that inland structures would suffer in the event of a storm, and the reduction in the likelihood of that damage from restoring a 22 hectare area of mangroves in Mozambique. They found only modest benefits from storm protection of structures in the study area due to the low value of the informal sector housing, the paucity of other built infrastructure, and the ten-year period before newly planted mangroves reached maturity. Under these conditions, the benefits of mangrove restoration from reduced damage to these houses was estimated at only $26 per hectare per year.

- ***Wetlands and hurricane protection***: Wetlands in the United States were estimated to reduce damage from hurricanes by anywhere from $250 to $51,000 per hectare of wetland (Costanza et al., 2008). These results were calculated from a statistical model that relates damage from 34 major U.S. hurricanes to the intensity of the storm and the extent of coastal wetland area.
- ***Coastal ecosystems and loss of life***: Das and Vincent (2009) analyzed how the number of fatalities during a 1999 cyclone in Orissa, India varied as a function of the width of coastal mangrove forests. While they did not assign monetary value estimates to lives saved per unit area of mangroves, this extension might be conducted if appropriate by assigning the "value of a statistical life" derived from other studies.

Implications and caveats: The extensive literature on coastal protection illustrates several issues of relevance to USAID's potential inclusion of ecosystem service valuations in CBA. The first of these is diminishing returns to investments in coastal protection services. As described by Barbier et al. (2008), despite high average values per hectare of coastal vegetation for storm protection in Thailand, the economically optimal landscape in this environment requires the protection of only a coastal strip of mangroves and significant conversion of the landscape to shrimp ponds.

Second, as discussed above, the ability of ecosystems to provide adaptation services depends on the location of the structures to be protected. Narayan et al. (2017) found that low mangrove values are driven by a low average value of structures immediately inland. This is particularly the case when facilities are deliberately located inland to avoid climate damage. A recent study by Reddy et al. (2016) found that the value of coastal vegetation in protecting an industrial facility on the U.S. Gulf Coast was low primarily because the company owning the facility chose to locate it where it would not be vulnerable to coastal storms.

Third, ecosystem service values must be compared with the opportunity cost of providing them. Costanza et al. (2008) found that coastal ecosystems might provide hurricane protection benefits as high as $51,000 per hectare. Despite the magnitude of this value, it is frequently exceeded by coastal land prices, indicating that preserving ecosystems to provide hurricane protection might be less preferable than alternative uses of this land.

WATER, SANITATION AND HYGIENE

Natural ecosystems play a fundamental role in ensuring the purification and provisioning of fresh water for human use. Following are examples of valuations of both purification and provisioning services, and their associated caveats and implications. The services described here are also relevant to food security objectives at USAID, and any other programming that depends on the reliable provisioning of clean water.

Water Purification

The essential role of natural ecosystems in purifying water is well known in developed countries, and has been recognized in some cases through protected status for the lands that feed reservoirs and other water sources. A seminal contribution on ecosystem services was a short letter to Nature (Chichilnisky and Heal, 1998) arguing that New York City had avoided the substantial cost of building a new drinking water treatment facility by paying considerably less to restrict agriculture and construction in the Catskills Watershed that supplied the city's water. Others have estimated water treatment service values in a variety of settings. Following are some examples:

- ***Municipal water purification:*** Emerton and Kekulandala (2003) used an avoided cost approach to estimate that the Muthurajawela Wetland in

Sri Lanka provided water purification services worth about $1 million per year, based on the anticipated investment in water purification facilities.

- ***Nutrient retention***: Simpson (2017) demonstrated that the value of nutrient retention services afforded by a hectare of riparian buffer in the Chesapeake Bay Watershed may be on the order of $25,000 per year. This value is estimated through the combination of a production function approach and estimation of the avoided cost of marginal treatment at publicly owned water treatment plants.
- ***Food processing waste treatment***: Plummer (2009) used avoided cost methods to estimate that a six-acre wetland in Louisiana provided water treatment services worth $86,000 per hectare per year.
- ***Municipal water supply***: In USAID's work, Garcia et al. (2013) used a stated preference approach to infer the willingness to pay for quantity and quality of water supply among residents near the Páramo De Santurbán moor in Colombia. They found an overall value of $3.50 per person for watershed preservation. Although this number may seem small, the overall willingness to pay would exceed US$8 million based on the 2.3 million consumers in the area.

Implications and caveats: Although these examples are drawn from different parts of the world and use different methods, they each point to large values of water purification services. In some cases, the water purification services provided by natural ecosystems have been demonstrated to justify the costs of forgoing alternative land use. This said, location and size of the lands providing these services remain key considerations. The wetland in Plummer's example was particularly valuable because it is adjacent to a food processing facility that needs its services. The Muthurajawela Wetland in Sri Lanka that Emerton and Kekulandala (2003) studied is similarly valuable because it is situated where it can process concentrated urban waste. Furthermore, the riparian areas described by Simpson (2017) are valuable on the margin precisely because rather narrow strips suffice to provide the service. In each case the ecosystem service is valuable because it is located near a high value area that may benefit from these services or because the area providing it can do so with relatively little land. When ecosystems are located far from these valuable areas, or require large amounts of land to provide services, the value of ecosystem services is less likely to outweigh the value of alternative uses.

In addition, the study by Garcia et al. in Colombia is an outlier among this group due to its use of a stated preference approach. Respondents were asked: "To preserve the quantity and quality of the water you receive, it is necessary to protect its sources in the Páramo de Santurbán, which implies increased funding by users. How much more are you willing to pay on each water services bill, in addition to what you currently pay?" While answers to this question would indicate how much people would be willing to pay for water quality and quantity, the survey did not relate quantity and quality to an incremental change in the extent or condition of the Páramo de Santurbán moors. This makes it difficult to estimate the value of incremental losses or protection for the moors—information that is often essential to CBA.

Water Provisioning

In addition to improving water quality, ecosystems can also increase the quantity of water that is available at the times it is most needed, or reduce flow when water is in excess. Some examples include:

- ***Groundwater recharge***: Wetlands retain precipitation, which gradually recharges groundwater. As the water table rises, households need to spend less time and effort acquiring water for domestic and agricultural use. In their study of the Hadejia-Jama'are Floodplain in Nigeria, Acharya and Barbier (2002) used a model of "household production"—a depiction of how households combine their own labor and other resources—to acquire the water they need for their own use. When there is more groundwater recharge, the water table will be higher, meaning that household workers, often women, benefit from spending less time and effort raising it from wells. The authors also consider households' demand for water. Combining the production and consumption aspects of their analyses, the authors estimate that local communities' welfare from water provisioning increases in aggregate by some $60,000 per year. This results in a value of approximately $10 per hectare per year for the Hadejia-Jama'are wetland.

- ***Soil moisture retention***: Natural vegetation retained at the perimeter of farmland is a strong determinant of resistance to soil erosion and retention of soil and moisture. Using a simplified representation of agricultural production, Vogl et al. (2017) estimate benefits of increased water retention in soils downhill from areas of forest or other native vegetation as between $68 and $479 per hectare per year in the Upper Tana River Basin, Kenya, depending on the crop grown. Furthermore, when farmers maintain upland vegetation cover, they not only reduce losses from sediment washing off their land, they maintain benefits from organic material-rich sediment that remains on their land.

Implications and caveats: Water storage and provisioning services are among the most intensively studied ecosystem services, and this work has yielded very well established hydrological models such as the Soil and Water Assessment Tool (Arnold et. al, 2012). Furthermore, extensive meteorological data and detailed modeling capabilities may facilitate the development of precise and reliable estimates of ecosystem service values. This said, it remains technically demanding to estimate water provisioning benefits from intact ecosystems, as it requires physical modeling of water flows and economic modeling of crop production. Estimating ecosystem service values under a range of assumptions is one useful response to this complexity.

ECONOMIC GROWTH

By definition, all ecosystem services contribute to economic growth. Furthermore, some services provided by intact ecosystems—such as ecotourism, recreation and non-timber forest products—may also serve as the basis for economic growth programming. Following are examples of these services.

Ecotourism and Recreation

Areas that support more biodiversity or offer more attractive natural amenities can attract more visitors, both domestic and international. Some examples of the value of ecosystem services in the provisioning of recreational amenities are:

- ***Wetland maintenance and tourism***: In USAID's work, Garcia et al. (2013) used a travel cost model to estimate that travelers from Colombia's major cities could generate $300,000 and $650,000 in spending on trips to the Páramo de Santurbán. This amount would be the equivalent of $3.75 to $8.00 per hectare per year.
- ***Wildlife corridors and tourism***: Studying a wildlife corridor in Madagascar, Hockley and Razafindralambo (2006) estimated a tourism value of about $33 per person per year, based on direct benefits of ecotourism (e.g., from current entrance fees charged at existing national parks), combined with projections for future growth in tourism at the regional level. The authors also transferred indirect benefits of $55 per person from a previous study. Although this is an example of benefit transfer from data collected in very similar circumstances, this example does raise the question of whether adding another destination might reduce visitors' willingness to pay for either area individually.
- ***Avian diversity and park visitation***: Naidoo and Adamowicz (2005) used a stated preferences approach to estimate that quadrupling the number of bird species seen during a visit to a Ugandan National Park could more than double park revenues per hectare of area. Despite this result, the value of bird diversity as measured by willingness to pay to visit the park would remain low, translating into a total of approximately $1.35 per hectare of park area. In addition, this value represents the consumer surplus of largely foreign visitors, and Uganda could reasonably expect to capture only a fraction of this value in increased fees.

- ***Water quality and beach visitation***: Krietler, Papenfus, Byrd and Labiosa (2013) estimated changes in beach visitation rates in Washington State based on water quality, using a statistical approach similar to travel-cost models. Although this study focused only on the probability of visitation rather than valuation in dollar terms, it did identify a relationship between quality of ecosystem and quantity of tourists, and thus is a useful illustration of a key step in determining the economic value of ecosystem quality.

Implications and caveats: Despite the above findings, there is limited evidence that enhanced ecosystem quality translates into increased tourism and recreational values. Furthermore, some of the values reported are small, as in the birdlife diversity case studied by Naidoo and Adamowiczs (2005). In addition, as illustrated by Garcia et al. (2013) study, average values per hectare do not imply a similar size marginal gain or loss to tourist surplus from adding or reducing park size, or amenity quality. This is also emphasized by Hockley and Razafindralambo (2006), who noted that failing to protect a specific site would probably not dissuade tourists from visiting Madagascar, but might instead cause them to go to a different destination within the country.

These observations underscore the conclusion that estimates of recreation values must be performed carefully. A variant of the travel cost method—a multi-site, as opposed to a single site, recreational demand model—is often more appropriate for estimating the demand from international travelers. In addition, it should also be noted that benefits accruing to international tourists may not be of as much interest to USAID as the fraction of such benefits that might be appropriated by the country hosting them. This last observation underscores the importance of distributional considerations: travelers and lodging owners might be expected to benefit more from programming that enhances recreational destinations than unskilled local laborers.

Non-Timber Forest Products

Low-income people around the world continue to rely on forests for food to supplement agricultural production and local markets, and for forest products such as medicinal plants and construction materials for sale in markets. These goods are known as non-timber forest products, and following is one example of this service.

- ***Household collection***: Foods and other forest products are estimated to be worth $18-47 per hectare per year to local communities in Bolivia and Honduras (Godoy et al., 2002). These products included bushmeat, fish, edible plants, construction materials and medicines. It should be noted, however, that this value represented the consumption of forest products and gross earnings from their acquisition, and costs such as the time required for harvesting have not been subtracted. As such, these values are not net values.

Implications and caveats: While examples such as this illustrate the application of ecosystem service valuation to non-timber forest products, other studies have revealed potential pitfalls. Peters, Gentry and Mendelsohn (1989) reported that harvested food and other non-timber forest products in the Peruvian Amazon generated a gross value excess of $3,000 per hectare, an amount that is competitive with the revenues from one-time logging of high-value timber. However, the correct measure in both cases is the net value, not the gross value, and subsequent studies such as that carried out by Godoy and colleagues, have often found lower values for non-timber products.

ENERGY AND INFRASTRUCTURE

Natural ecosystems may both complement built infrastructure and constitute "green infrastructure" that can sometimes provide necessary public services at a lower cost than constructed alternatives. At USAID, these services are most relevant for the Agency's work in supporting renewable energy and sustainable infrastructure. An example of each is considered below.

- ***Reducing hydroelectric reservoir siltation***: Strategically retaining natural land cover in catchments can reduce the flow of sediments into hydroelectric, irrigation, or drinking water reservoirs, either increasing water availability or decreasing costs of reservoir dredging. Saenz, Mulligan, Arjona and Gutierrez (2014) valued the restoration of cloud forests around the Calima hydroelectric dam in Valle del Cauca, Colombia, using detailed models of the effect of landscape protection measures on erosion, sediment deposition and water provisioning. Using this information they estimated the value for electricity generation. The authors found, under a conservation scenario that considers restoration of 18,000 hectares of cloud forest, a reduction in sediment deposition from 277,000 to 85,000 cubic meters per year, and an increase in water quantity of 5.9 percent. This translated into an average increase in the value of energy production of $1.03 million per year, and an increase of up to $1.92 million per year in dry years. The resulting per-hectare value for cloud forests is $60 and $120 per year in normal and dry years, respectively. This type of analysis reveals the hidden value of standing forests, and the importance of investing in ecosystem protection for hydroelectric dams, irrigation or drinking water programming.
- ***Wetlands and flood protection***: Studying wetlands in the northeastern United States, Watson, Ricketts, Galford and Polasky (2016) found that wetlands provide an average value of between $30 and $70 per hectare per year in flood protection benefits. To arrive at these values, the authors used a hydrological model to estimate high-water levels with and without wetlands, based on ten major storm events over a roughly 80-year period. They then related damages to the height of water. Tan-Soo and colleagues (2016) conducted similar work in Peninsular Malaysia, finding that tropical forests significantly reduced the number of days of flooding as compared to areas converted to plantations (Tan-Soo et al., 2016). These types of values might be included in cost-benefit analysis to estimate the opportunity cost of draining or clearing wetlands for other uses. As in the case of reservoirs, they can also be used to assess the protection of natural ecosystems as a means to contribute to goals typically addressed by engineering solutions.

Implications and caveats: Habitat conservation can yield significant benefits to, or serve as a substitute for, infrastructure, but location and habitat type are important determinants of the value provided by habitat. Furthermore, these ecosystem values suggest that payments for the preservation of natural ecosystems can yield benefits to both biodiversity conservation and infrastructure development. Such payments have been initiated in many parts of the world, including lower and middle income countries (Pagiola and Platais, 2002; Ezzine-de-Blas, Wunder, Ruiz-Pérez and Moreno-Sanchez, 2016).

ANNEX III
DATA CATALOG

This data catalog highlights sources of data and models that USAID economists, implementing partners and other practitioners can use for ecosystem service valuation and its incorporation into CBA. As such, this catalog reviews an illustrative set of resources rather than providing an exhaustive list. The applicability of the data sources described here to specific CBAs will vary between programs, and the reviews of key concepts and primary literature (Annex I and II) may assist readers in evaluating these data sources and identifying additional sources of information.

OVERVIEW

The catalog covers three categories of data sources and decision tools: databases, modeling platforms and meta-analyses. This overview provides a brief description of each of these sources, followed by an example that compares these three categories and explains their relationships to each other.

Databases

Databases are compilations of studies and data from the ecosystem service valuation literature and vary in their organization and ease of use. In some databases, results from multiple studies are presented in a single spreadsheet and users need only find the results of interest to them. Other databases consist of a single text document whose contents are not as easily used as a spreadsheet. Still others exist as online searchable databases, where the user may select a region or country, an ecosystem service and a method for its valuation, and then view a collection of pertinent resources. Some databases also provide abstracts and summary information for the studies they list.

Databases typically provide either estimates of value in monetary units, or a guide to data sources that provide estimates. Monetary amounts are often provided on a per hectare basis for units of habitat providing a service, or on a per person basis for individuals receiving a service. Databases usually also include geographical location, study date and bibliographical information for the data they provide. Based on these data, databases can be used either to perform unit benefit transfers (with caution; see Annex I), as the sources of functions for function transfer or as data sources for meta-analyses. Databases also provide a guide to available literature and can be used to identify studies of interest.

Modeling Platforms

Modeling platforms combine ecosystem service production functions with economic models to estimate the impact of specific actions on ecosystem services and the resulting changes in economic value (see Annex I for more information). To use a modeling platform, an analyst typically selects the services they wish to value, enters location-specific data and then specifies the state of vegetation and other indicators of ecosystem health. These analyses are performed both with and without program intervention, and the modeling platform uses these variables to estimate values. For example, the crop pollination model in the InVEST platform (below) first relates the abundance of pollinators to the availability of the food sources on which they depend. A second model then depicts how pollinators disperse over fields. Lastly, a third model relates the number of pollinators that visit farm fields to crop yield. The user can then link agricultural production to societal well-being through data on crop prices and costs of production.

Modeling platforms differ in the degree and type of user interaction they require. Some platforms require that the user insert data and parameters to calibrate the model to the appropriate setting. Other platforms query users' desired features and provide models that meet their criteria. In all instances, however, the platform is intended to provide modeling capabilities that the user does not have the time, resources or expertise to develop themselves. Although users may rely on platforms to provide modelling capabilities, it is important to understand the platform's methods and outputs to ensure they are appropriate for the context.

Meta-Analyses

A meta-analysis uses estimates of ecosystem service values collected in databases, as described above, to generate a function that explains the estimates in terms of the attributes of the studies from which they came (see Annex I for more information). This function can then be used to predict values in other locations—that is, a meta-analysis transfer function can be used to predict the value that a study would find for a set of ecosystem services in a new location of known physical, social and economic characteristics. The attributes that must be known to produce this transfer function are often separated into two broad categories. The first category is the methods used by the primary study—for example, production function, avoided cost, hedonic valuation, travel cost, stated preference or other method (see Annex 1). The second category is the attributes of the ecosystem providing the service—for example the local climate, wealth of the surrounding populace and other characteristics. Meta-analyses may also record whether values were published in a peer-reviewed journal, the date they were published and authorship information.

Example Illustrating the Differences Between these Data Sources

The differences and relationships between these three approaches can be illustrated by the case of water purification by wetlands. For example, fertilizer application for agricultural production may result in increased discharge of nutrients into streams. As the nutrient-laden water passes through a wetland, however, some of this pollution is removed. This water purification function reduces the impacts of this pollution on fishery productivity, human health and water treatment costs. Water purification is thus an ecosystem service provided by the wetland, and can be valued accordingly.

Researchers may have estimated the monetary value of this purification service through a variety of techniques including the avoided costs for water treatment, increased profits from fisheries, increased recreational benefits as reflected in travel cost models and increased housing values as reflected in hedonic models. These estimates can be collected in a **database**, and used by a cost-benefit analyst to predict the water purification service value in a new situation of interest. In the best case, the analyst will find a high-quality study that was conducted near the area for which they want to estimate values and which closely resembles the area, allowing benefit transfer. If this is not the case, the analyst can use the database to identify analytical methods for their own valuations.

After a sufficient number of studies have been collected, researchers might be able to define an ecological production function that expresses the water purification services provided by a wetland as a function of its size, configuration and conditions. This ecological production function may be made available as part of a **modeling platform**. To use this platform, the analyst calibrates the model using location-specific parameters, for example soil composition or temperature. Next, the analyst would provide the conditions of the program site to estimate change in purification services, both with and without the program intervention. Some modeling platforms will also estimate the change in value associated with the change in services, while other platforms will require that the analyst estimate this change using primary study or benefit transfer (see Annex I).

After a sufficient number of studies have been collected, researchers might also use them as part of

TABLE 5A: DATABASES

Name	Geographic Coverage	Relevance to USAID Sectors	Ecosystem Services Considered	Valuation Methods Employed / Included
Ecosystem Services Valuation Database	Global	FS, GCC, WASH, EG	All	Market pricing, revealed preference, stated preference
Environmental Valuation Reference Inventory	Global	FS, GCC, WASH, EG	All	Market pricing, revealed preference, stated preference
Coastal and Marine Ecosystem Services (Torres and Hanley 2017)	Global (coastal and marine)	FS, GCC, EG	Fisheries production, recreation, coastal protection, non-use values	Market pricing, revealed preference, stated preference
National Ocean Economics Program Valuation Studies Search	Global (coastal and marine)	FS, GCC, EG	Fisheries, tourism and recreation, option value, existence value, bequest value	Market pricing, revealed preference, stated preference
Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Knowledge Center	Botswana, Colombia, Costa Rica, Guatemala, Indonesia, Madagascar, the Philippines, Rwanda, Zambia	FS, GCC, WASH, EG	Water, carbon, fisheries, forest products, ecotourism, erosion, flood control, waste treatment	Market pricing, revealed preference, stated preference

a **meta-analysis**. This analysis expresses the value of nutrient retention services provided by wetlands as a function of the characteristics of the studies estimating them (e.g., method of valuation, date of study) and the attributes of the areas in which the studies were conducted (e.g., size and location). The meta-analysis can then be used to predict the value of wetland nutrient retention services these studies might collectively estimate for a new location based on its climate, wealth and area. In contrast to modeling platforms, meta-analysis does not use ecological production functions to predict the impact of an intervention on ecosystem properties and services prior to arriving at a valuation, and instead links the interventions directly to valuations. This approach can potentially reduce the steps required by an analyst to arrive at a valuation, but may not allow insight into the assumptions behind the valuation.

Table 5 summarizes the databases, modeling platforms and meta-analyses reviewed in this Annex. The USAID program areas discussed in this Annex are food security (FS); global climate change (GCC); water, sanitation and hygiene (WASH); and economic growth (EG).

TABLE 5B: MODELING PLATFORMS

Name	Geographic Coverage	Relevance to USAID Sectors	Ecosystem Services Considered	Valuation Methods Employed / Included
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)	Global	FS, GCC, WASH, EG	Carbon, coastal protection, pollination, fisheries, habitat quality, recreation, water yield, scenic quality, sediment retention, water purification	Market pricing, revealed preference
Artificial Intelligence for Ecosystem Services (ARIES)	Global	FS, GCC, WASH, EG	Carbon, scenic quality, coastal protection, flood protection, sediment retention, fisheries, recreation, water purification	Benefit transfer
Multiscale Integrated Models of Ecosystem Services (MIMES)	Global	FS, GCC, WASH, EG	Carbon, flood protection, coastal protection, genetic resources	Market pricing, benefit transfer
Toolkit for Ecosystem Service Site-based Assessment (TESSA)	Global (but for specific sites)	FS, GCC, WASH, EG	Coastal protection, carbon, harvested wild goods, recreation, pollination, water purification, non-use values	Market pricing, benefit transfer

TABLE 5C: META-ANALYSES

Name	Geographic Coverage	Relevance to USAID Sectors	Ecosystem Services Considered	Valuation Methods Employed / Included
Forests (Siikamäki et al. 2015)	Global	FS, GCC, WASH, EG	Forest products, recreation, water purification and regulation, carbon	Market pricing, revealed preference, stated preference
Wetlands (Chaikumbung et al. 2016	Global	FS, GCC, WASH, EG	Recreation, food protection, water supply, sediment retention, carbon, water purification, non-use values	Market pricing, revealed preference, stated preference
Lakes (Reynaud & Lanzanova 2017)	Global	FS, GCC, WASH, EG	Sediment retention, flood protection, water purification, recreation non-use values	Revealed preference, stated preference
Coastal protection (Rao et al. 2015)	Global	GCC, WASH, EG	Coastal protection	Market pricing, revealed preference, stated preference
Coastal recreation (Ghermandi & Nunes 2013)	Global	EG	Recreation	Revealed preference, stated preference
Coral reef recreation (Brander et al. 2007)	Global	GCC, WASH, EG	Recreation	Market pricing, revealed preference, stated preference

DATABASES

The following section reviews five prominent databases that vary in their included studies, update rate, search functionality and quality requirements. As such, no one database can be considered the best; this document recommends that users use multiple databases when searching for valuation studies.

Ecosystem Services Valuation Database

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Global

Ecosystem services considered: All

Number of records: 1,300+

Updated: 2010

Background: The Ecosystem Services Valuation Database was originally developed as part of The Economics of Ecosystems and Biodiversity (TEEB) project, and contains 1,310 estimates of values from more than 300 studies. The sources for this database include peer-reviewed papers published in economics journals, peer-reviewed work from natural science and other journals, reports submitted to international and advocacy organizations and student theses.

Advantages: This database is among the most comprehensive sources of estimates of ecosystem service values, and is a good place to begin a search for published studies. Researchers conducting meta-analyses often consult this database.

Disadvantages: First, the average age of the estimates in this database is 20 years old, the database itself has not been updated since 2010, and its earliest cited work was conducted more than 50 years ago. Due to the evolution of methods and best practices for valuation, these estimates may not meet current expectations. Second, many studies included in this database use flawed methods such as replacement costs. Lastly, more than one-third of the estimates reported in this database are based on benefit transfer rather than primary study. Users should thus consult the original study for all entries in this database in order to assess their validity.

Getting started: The database is available on a downloadable Excel spreadsheet, and it is easily accessed and searched.

Website: https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/

Full reference: Van der Ploeg, S. and R.S. de Groot. "The TEEB Valuation Database – a searchable database of 1,310 estimates of monetary values of ecosystem services." Foundation for Sustainable Development, Wageningen, the Netherlands, 2010.

Environmental Valuation Resource Inventory

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Global

Ecosystem services considered: All

Number of records: 4,000+

Updated: Continuously

Background: The Environmental Valuation Resource Inventory was initiated in the early 1990s by Environment and Climate Change Canada, the department of the Canadian government responsible for coordinating environmental policies and programs. This database was developed in collaboration with both international partners such as the U.S. Environmental Protection Agency and individual environmental economists. The database now contains more than 4,000 entries, of which more than 1,500 address "ecological functions," largely synonymous with ecosystem services. Although the majority of the entries in the database originate from relatively wealthy nations, many developing country studies are included.

Advantages: This database is comprehensive and frequently includes abstracts and annotations for individual studies, allowing the user to determine if a study meets their purposes. In addition, this database is curated by a group of advisors, which provides additional credibility for the included studies.

Disadvantages: More than half of the ecosystem service studies in this database are more than ten years old. This said, the under-representation of newer papers may reflect the selectivity of this resource, such that studies are only included after they have gained credibility among practitioners.

Getting started: The database and its accompanying information, including search menus, is available online. Users first create a free account, and can then use search parameters to identify studies of interest. Users that are specifically interested in ecosystem services can open the "Type of Value/Usage" tab and choose "ecological functions" from the drop-down menu. Additional descriptors including "passive uses" allow users to refine their search. Other menus allow the user to cross-tabulate results by the study area "medium" (e.g., water, land) and the source of the study (e.g., peer-reviewed articles, reports, student theses).

Website: http://www.evri.ca/en

Torres and Hanley (2017) Coastal and Marine Ecosystem Services Database

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Coastal and marine ecosystem services globally

Ecosystem services considered: Fisheries production, recreation, coastal protection, non-use values

Number of records: 196

Updated: 2016

Background: The Torres and Hanley coastal and marine ecosystem services database (Torres and Hanley, 2017) was developed as part of the European Union's 2000 Water Framework Directive and subsequent Directives concerning water and marine resources. The database includes coastal and marine ecosystem services from both wealthy and developing countries around the world. The database only includes peer-reviewed journal publications published since 2000.

Advantages: The chief advantage of this database is that it has been curated by experts. Although users must use discretion when applying the results, they may feel confident knowing that the studies have been vetted twice: once by the referees for the publications in which the study first appeared and again by the authors of the database. Torres and Hanley also include annotations that can help users in interpreting and determining whether and how to apply results.

Disadvantages: This database exists only as a working paper and is less easily searched than other sources.

Getting started: The paper containing the database can be accessed and downloaded from the University of Stirling. The table of contents provides an overview of the document.

Website: https://www.stir.ac.uk/media/schools/management/documents/workingpapers/SEDP-2016-01-Torres-Hanley.pdf

Full reference: Torres, Cati and Nick Hanley. "Communicating research on the economic valuation of coastal and marine ecosystem services." *Marine Policy* 75: (2017) 99-107. https://doi.org/10.1016/j.marpol.2016.10.017.

National Ocean Economics Program Valuation Studies Search

Relevance to USAID sectors: GCC, EG

Geographic coverage: Coastal and marine waters

Ecosystem services considered: Fisheries, tourism and recreation, option value, existence value, bequest value

Number of records: 779

Updated: Continuously

Background: This large database of valuation studies is maintained by The National Ocean Economics Program, which is affiliated with the Center for the Blue Economy at the Middlebury Institute of International Studies at Monterey (USA).

Advantages: This searchable database allows users to filter its content by eight categories, including publication year, source, methods, assets valued and geographical location. Although most studies are from the United States, there is an extensive collection of studies from other countries. The National Ocean Economics Program database is useful for analysts who are focusing on coastal and marine ecosystem services.

Disadvantages: The chief disadvantage of this database is that it is limited to ecosystem services in coastal and marine ecosystems. Users should also consult the original studies to determine if they are appropriate for their purposes.

Getting started: The database can be searched at its website, which features multiple menus to refine searches. The database categorizes entries by U.S. states and foreign countries, and multiple countries can be selected by highlighting them in the "location" drop-down menu. If the user requires summary descriptions for the studies, the "include" option may be used to identify "only entries with an abstract." In searches where location is not specified, international studies are marked by three red asterisks.

Website: http://www.oceaneconomics.org/nonmarket/NMsearch2.asp

Wealth Accounting for the Valuation of Ecosystem Services Knowledge Center

Relevance to USAID sectors: FS, GCC, WASH, EG

Geographic coverage: Botswana, Colombia, Costa Rica, Guatemala, Indonesia, Madagascar, the Philippines, Rwanda, Zambia

Ecosystem services considered: Water, carbon, fisheries, forest products, ecotourism, erosion, flood control, waste treatment

Number of records: 448

Updated: Continuously

Background: The World Bank's Wealth Accounting for the Valuation of Ecosystem Services (WAVES) program focuses on incorporating ecosystem services and natural capital in national economic accounts. The methods used for this purpose can also be used to estimate benefits for cost-benefit analyses. This program is primarily funded by European donors and works with partners in Botswana, Columbia, Costa Rica, Guatemala, Indonesia, Madagascar, the Philippines, Rwanda and Zambia.

Advantages: The Knowledge Center is a database of several hundred documents with convenient search capabilities that allow users to select from 14 topics ranging from agriculture to water, and a WAVES partner country or geographical region. The database also allows the user to specify document type including articles, blog posts, country reports and presentations.

Disadvantages: Value estimates can be difficult to locate in this database, and studies may be regarding the theory and practice of valuation rather than specific benefit estimates. A further disadvantage is the focus of this database on economic accounting rather than cost-benefit analysis. The former often uses gross numbers (e.g., the total value of non-timber forest products collected) while net figures are more appropriate for cost-benefit purposes (e.g., value of collections less cost of labor and inputs expended in collection; see Annex I, Revealed Preference valuation).

Getting started: The database can be accessed from the WAVES webpage's Knowledge Center. Menus on the right side of the screen allow the user to filter entries by topic, country or region, and type of document. In addition, the user may specify key words or phrases.

Website: https://www.wavespartnership.org/en/knowledge-center-search?field_kc_type_tid=All&title=&field_kc_author_fname_value=&field_kc_standfirst_value=&op=Search

MODELING PLATFORMS

The following section describes four modeling platforms of which one, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), is significantly more commonly cited in the academic literature. For this reason, this platform is described in greater detail than the other platforms. In addition, ecosystem service quantification and valuation platforms are evolving rapidly, and the reader may consult the following reviews for a more extensive overview of existing platforms, their uses, their strengths and their limitations:

- Bagstad, K.J., D.J. Semmens, S. Waage and R. Winthrop. "A comparative assessment of decision-support tools for ecosystem services quantification and valuation." *Ecosystem Services* Vol 5: 27-39. (2013). https://doi.org/10.1016/j.ecoser.2013.07.004.

- Cristin, Z.L., K.J. Bagstad and M.R. Verdone. "A decision framework for identifying models to estimate forest ecosystem values from restoration." *Forest Ecosystems* 3(3): 1-12. (2016). https://doi.org/10.1186/s40663-016-0062-y
- Turner, K.G., S. Anderson, M. Gonzales-Chang, R. Costanza, S. Courville, T. Dalgaard, E. Dominati, et al. "A review of methods, data and models to assess changes in the value of ecosystem services from land degradation and restoration." *Ecological Modelling* Vol 319: 190-207. (2016). https://doi.org/10.1016/j.ecolmodel.2015.07.017.

In addition, the following websites maintain descriptions and reviews of modeling platforms:

- The ValuES Methods Database, maintained by ValuES project: http://aboutvalues.net/method_database/
- The Tool Assessor website maintained by the U.K.-based Ecosystem Knowledge Network: https://ecosystemsknowledge.net/resources/guidance-and-tools/tools/tool-assessor

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Models may be applied globally

Ecosystem services considered: Carbon, coastal protection, pollination, fisheries, habitat quality, recreation, water yield, scenic quality, sediment retention, water purification

Updated: Continuously

Background: The InVEST modeling platform is maintained by the Natural Capital Project, a consortium of the Woods Institute at Stanford University, the University of Minnesota, the Nature Conservancy and the World Wildlife Fund. The first modules of the InVEST suite of models were developed in 2009; it now includes 17 modules addressing a wide variety of ecosystem services. These modules differ in both the problems they address and methods they employ, making a simple summary difficult. In general, however, these modules adopt a spatially explicit, process-based approach such that they divide the landscape into small cells where the service provided in one cell depends both on its ecological and physical attributes, and the inputs it receives from adjoining cells. These variables are then used as inputs for ecological production functions that estimate the provisioning of services based on the size, condition, configuration and/or location of ecosystems. These estimates can then be used as the basis for valuations. The platform is regularly updated, and due to its breadth and accessibility, it may be considered an industry standard.

Advantages: This platform has many advantages: it is free to use, multiple modules are available, and it is supported by a useful online support system. The platform is particularly useful when users are seeking spatially explicit information (e.g., where an investment in catchment restoration will produce the greatest return in reduced sediment runoff), and also wish to understand and provide inputs to underlying ecological production functions. This platform is particularly useful to CBA since the input to most modules is a *change* in natural conditions, which could be specifically that change brought about by the program in question.

Disadvantages: A first limitation of this platform is that not all modules yield economic values; several modules report only the change in physical quantities. The analyst is then required to translate these values into dollar amounts through benefit transfer or primary study. Second, becoming proficient in its use and tailoring models to project circumstances requires a significant investment of time. Third, the documentation of this platform's models is complex and mathematically demanding, although a mathematically skilled user can develop a more sophisticated understanding of its modeling procedures than of the other platforms described here. Fourth, the modules of this platform do not always use detailed models, limiting the usefulness of their results. For example, water yield calculations are reported in total annual quantity rather than seasonal flow change. A last disadvantage, particularly for spatially explicit analyses, is that running some models requires basic knowledge of geographic information systems.

Getting started: This platform and its manuals can be accessed through the Natural Capital Project website.

Website: https://www.naturalcapitalproject.org/invest/

Artificial Intelligence for Ecosystem Services (ARIES)

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Models may be applied globally

Ecosystem services considered: Carbon, scenic quality, coastal protection, flood protection, sediment retention, fisheries, recreation, water purification

Updated: Continuously

Background: ARIES was initiated in 2007 by the University of Vermont with initial funding from the National Science Foundation. It has since expanded to support multiple ecosystem modeling approaches, in collaboration with Conservation International and Earth Economics. Although ARIES has focused on Europe and North America, the ARIES team has conducted projects in North and sub-Saharan Africa and in the Himalayan region. The developers of ARIES argue that a "one-model-fits-all" approach to ecosystem service valuation will not adequately treat all situations of interest. ARIES thus uses algorithms to match user needs to a "model base" of studies, choosing the most relevant results from among those it has assembled based on criteria supplied by the user. In matching models to needs, the ARIES algorithm develops an estimate of the likelihood that a particular model is appropriate for specific circumstances and weights findings by these probabilities.

Advantages: The primary advantage of this platform is its ability to link users with a variety of ecological production functions and economic valuation models, and allow them to identify those that are most pertinent to their needs. Its method for matching users to models also gives the user a better understanding of the confidence they should have in their results.

Disadvantages: The chief concern with ARIES is its lack of publicly accessible documentation about the models it uses. Reviewers have found that ARIES "provides no specific information on the models that are available…The system is currently a black box with no online documentation on how values are derived" (Mulligan et al., 2010). In addition, the ARIES website provides little information about its sources, quality control or screening measures that might assure its reliability. Given the lack of information regarding these models and methods, this document recommends that USAID users make use of this platform cautiously, and not without verifying its results through alternate methods.

Getting started: More information on ARIES can be found online. New users can submit requests for access to ARIES but are advised by the platform's developers to participate in training before using the platform. In the future, the platform is expected to develop a more user-friendly interface.

Website: http://aries.integratedmodelling.org/

Multiscale Integrated Models of Ecosystem Services (MIMES)

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Models may be applied globally

Ecosystem services considered: Carbon, flood protection, coastal protection, genetic resources

Updated: Continuously

Background: MIMES is one of the oldest platforms described here and was initially developed during the 1980s at Louisiana State University as the Global Unified Metamodel of the Biosphere (GUMBO) platform. This platform links models of atmosphere, geology, oceanology, hydrology, biology and economics to predict the effect of land use change on ecosystems and human well-being.

Advantages: This platform is relatively comprehensive, and is able to provide estimates for 17 ecosystem services in 11 biomes, ranging from oceans to mountaintops and including natural and managed land uses. In addition, this platform provides estimates of economic values based on changes in the provisioning of ecosystem service due to landscape change. Lastly, these models include dynamic responses, allowing users to understand how the effects of landscape change evolve over time based on feedback effects. One of MIMES's developers compares the platform to a flight simulator (Boumans et al. 2015): its purpose is not so much to predict results in specific instances with precision as to illustrate potential outcomes under a variety of assumptions.

Disadvantages: MIMES may be more appropriate for large-scale "what-if" analysis than smaller scale program evaluation. In addition, this platform incorporates a variety of feedback effects and may not be practical when evaluating relatively small-scale programs. Lastly, this platform has not yet been widely applied to developing countries.

Website: http://www.afordablefutures.com/home

Full reference: Boumans, R., J. Roman, I. Altman and L. Kaufman. 2015. "The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems." *Ecosystem Services* 12: (2015) 30-41, https://doi.org/10.1016/j.ecoser.2015.01.004.

Toolkit for Ecosystem Service Site-based Assessment (TESSA)

Relevance to USAID sectors: FS, GCC, DRG, WASH, EG

Geographic coverage: Global (but for specific sites)

Ecosystem services considered: Coastal protection, carbon, harvested wild goods, recreation, pollination, water purification, non-use values

Updated: Continuously

Background: TESSA is the youngest of the platforms described here and was developed by a consortium of universities, NGOs and international organizations for the rapid assessment of ecosystem services. In addition, this platform was designed to be used in the field; TESSA guides users through simple methods for measurements of ecological and physical parameters, and questionnaire-based approaches to valuation.

Advantages: The primary advantage of this platform is that it allows field-based and non-technical assessment of changes in ecosystem services based on policy decisions, requiring substantially less time and expense than required by the above platforms.

Disadvantages: This modeling platform gains its simplicity and ease of use by avoiding ecological and physical models linking an intervention to a change in ecosystem services, and assuming that practitioners can accurately predict how programming will alter ecosystems and services. As a result, errors are easily introduced into these analyses, especially by non-expert users. This said, TESSA is a relatively young platform and may continue to evolve and improve over time, and currently remains as an important tool for conducting scoping exercises or where field-based assessment of local effects is a priority.

Getting started: Users can submit a request for access at the TESSA website.

Website: http://tessa.tools/

Full reference: Peh, Kelvin S. H., A. Balmford, R.B. Bradbury, C. Brown, S.H.M. Butchart, F.M.R. Hughes, A. Stattersfield, et al. "TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance." *Ecosystem Services* 5 (2013): 51-57. https://doi.org/10.1016/j.ecoser.2013.06.003.

META-ANALYSIS DERIVED TRANSFER FUNCTIONS

The following sections present meta-analyses as organized by the ecosystems they address, including forests, lakes, wetlands, mangroves and other coastal ecosystems. Analysts can use these meta-analyses to transfer benefits by combining the estimated parameters from an individual meta-analysis with data from the area of interest. For example, using recreational use values in 86 different forest areas around the world, results Siikamäki et al. (2015) estimated that[10]:

> ln(recreational value per hectare of forest) = -8.375 + 0.562 · ln(population density) + 0.566 · ln(GDP per capita) + 0.0178 · ln(mean annual temperature) + 1.133 · ln(species richness)

In an area in which the population density is 500 people per square kilometer, GDP is $4,000 per person, the mean annual temperature is 15 degrees Celsius, and that contains 200 species of vertebrates, an analyst would derive a recreational use value of approximately $350 per hectare of forest. In addition, the analyst could also use the standard errors reported by Siikamäki et al. to generate confidence intervals for the results.

It is important to remember, however, that a meta-analysis will predict what a study might show in a unstudied area based on what studies have shown elsewhere. If the studies conducted elsewhere yielded biased estimates of value, transferring the results of the meta-analysis would also yield a biased estimate of value. In addition, using a meta-analysis to predict values for an unstudied area will be unreliable if characteristics of the policy site were not represented in the sample. Therefore, it is important to assure that the primary studies on which the meta-analysis is based are credible and related to the polity site to which they will be transferred.

Forests

Relevance to USAID sectors: FS, GCC, EG, WASH

Coverage: Global

Number of original studies: 186

Ecosystem services considered: Forest products, recreation, water purification and regulation, carbon

Background: Siikamäki, Santiago-Ávila and Vail (2015) conducted a meta-analysis for the World Bank to update the Bank's approach to the estimation of forest ecosystem service values. This team assembled a dataset of 186 observations on recreational, water service, non-wood forest product and habitat or species protection values, using estimates from the Ecosystem Services Valuation Database and Environmental Valuation Reference Inventory Database (see above). These values were supplemented by searches of the academic and gray literature for other useful values. Their study included estimates from a variety of stated and revealed preference methods, including travel cost, production function and avoided cost approaches.

The results of this work are estimates for four categories of services: recreation (86 observations), habitat or species protection (54), non-wood forest product (30) and water service values (16). Due to the small sample sizes for non-wood forest products and water services, Siikamäki et al.'s findings for these services may be less reliable than the other categories. In general, Siikamäki and his colleagues found substantially higher values for forested areas than prior estimates used by the Bank.

Full reference: Siikamäki, Juha, Francisco J. Santiago-Ávila and Peter Vail. "Global Assessment of Non-Wood Forest Ecosystem Services: Spatially Explicit Meta-Analysis and Benefit Transfer to Improve the World Bank's Forest Wealth Database." World Bank Project on Forests (ProFor) Working Paper. 2015.

10 Where "ln(x)" refers to the natural logarithm of x, and "species richness" refers to the number of species in a given area.

Wetlands

Relevance to USAID sectors: FS, GCC, EG, WASH

Coverage: Global

Number of original studies: 379

Ecosystem services considered: Recreation, food protection, water supply, sediment retention, carbon, water

Chaikumbung and colleagues (2016) assembled more than 1,400 value estimates from approximately 400 wetlands in 50 developing countries in Latin America, Africa, the Middle East, Asia and the Pacific. These original studies used a variety of stated and revealed preference approaches, with the latter focused on travel cost or production function methods. More than one-sixth of all estimates, however, used the problematic replacement cost method, limiting their utility. In general, the authors found strong evidence of diminishing returns: the larger the area of a wetland studied, the lower the estimated benefits it provides per hectare.

This meta-analysis combines valuations for multiple ecosystem services, estimated in multiple environments and employing several different methods. Despite this range of conditions, the authors found a relatively low mean transfer error of approximately 31 percent. Unsurprisingly, benefit transfer using this meta-analysis was more accurate when a subset of similar studies was used; the authors also conducted individual meta-regressions for revealed and stated preference methods and for coastal and inland wetlands. Based on the greater accuracy of these restricted meta-analyses, transferring the results of these meta-analyses to new settings in developing countries might reasonably yield estimates that are comparable to original studies at a fraction of the cost.

Full reference: Chaikumbung, Mayula, Hristos Doucouliagos and Helen Scarborough. "The economic value of wetlands in developing countries: A meta-regression analysis." *Ecological Economics* Vol 124: (2016) 164–174. https://doi.org/10.1016/j.ecolecon.2016.01.022.

Lakes

Relevance to USAID sectors: FS, GCC, EG, WASH

Coverage: Global

Number of original studies: 133

Ecosystem services considered: Sediment retention, flood protection, water purification, recreation, non-use values

Freshwater lakes provide multiple ecosystem services including sediment retention, flood protection and water purification. Of these services, the most commonly considered are recreational opportunities and visual amenities. These services depend on, among other variables, water quality and the abundance of fish and other aquatic organisms. To understand the valuation of lake ecosystem services, Reynaud and Lanzanova (2017) conducted a meta-analysis of water quality ecosystem service values in lakes using 669 value estimates from 133 studies. These studies were located primarily in North America and Western Europe, but also included Latin America, Africa, the Middle East and India. The product of this study were two meta-analyses: one focusing on hedonic values (values expressed per parcel of property) and the other focusing on stated preference values (values expressed per respondent). The authors report not only the effects of lake sizes on values, but also on the interaction between variables such as water quality and use, underscoring that values depend on context.

Full reference: Reynaud, Arnuad and Denis Lanzanova. "A Global Meta-Analysis of the Value of Ecosystem Services Provided by Lakes." *Ecological Economics* 137: (2017) 184-194. https://doi.org/10.1016/j.ecolecon.2017.03.001.

Mangroves, Coral Reefs and Coastal Wetlands (Coastal Protection Values)

Relevance to USAID sectors: GCC, EG, WASH

Coverage: Global

Number of original studies: 54

Ecosystem services considered: Coastal protection

Rao, Ghermandi, Portela and Wang (2015) conducted a meta-analysis to identify where coastal protection services from mangroves, coral reefs and coastal wetlands might be most valuable, including a total of 54 studies, 92 estimates and 27 countries. In contrast to many meta-analyses, studies from Asia represented over half of the included studies, followed by Latin America and the Caribbean, and studies from the United States and Europe were in the minority. One reason for this emphasis on studies from Asia, Latin America and the Caribbean is the importance of coastal storm protection in areas vulnerable to tropical storms.

The analysis found that coastal protective services are more valuable in wealthier countries because more expensive assets are at risk. This study also observed diminishing returns to ecosystem area to coastal protection services. In addition, the authors incorporated data on storm frequency and maximum wind speed into their analyses, and found that the value of protective services increases with the frequency and severity of threats.

Full reference: Rao, N.S., A. Ghermandi, R. Portela and X. Wang. "Global values of coastal ecosystem services: A spatial economic analysis of shoreline protection values." *Ecosystem Services* 11: (2015) 95-105. https://doi.org/10.1016/j.ecoser.2014.11.011.

Mangroves, Coral Reefs and Coastal Wetlands (Recreation Value)

Relevance to USAID sectors: EG

Coverage: Global

Number of original studies: 79

Ecosystem services considered: Recreation

Coastal ecosystems also provide the service of attracting domestic and foreign tourists, as demonstrated by Ghermandi and Nunes (2013). This study assembled 253 value estimates from 79 studies of recreational values. These studies were focused on North America, Western Europe and Australia, but also included Latin America, Africa, the Middle East and Southeast Asia.

This study comes with two important caveats. First, dollar-per-hectare estimates in this study ranged from less than one to more than US$10,000 per hectare. This indicates that the results of this study should be treated with care, and that the results of this analysis for countries in the middle of the distribution might be more useful than those at the lower end. Second, this meta-analysis measures visitors' willingness to pay to visit a site, but CBA analysts may be more interested in the specific factors affecting willingness to pay. For example, how much might willingness to pay increase if water clarity was improved or native species were better protected? If available, this information could be used to improve programs that aim to increase local benefits from tourism.

Full reference: Ghermandi, Andrea and Paulo A.L.D. Nunes. "A global map of coastal recreation values: Results from a spatially explicit meta-analysis." *Ecological Economics* 86 (2013): 1-15. https://doi.org/10.1016/j.ecolecon.2012.11.006.

Coral Reefs (Recreation Value)

Relevance to USAID sectors: GCC, EG, WASH

Coverage: Global

Number of original studies: 52

Ecosystem services considered: Recreation

Focused on the recreation values of coral reefs, Brander, Van Beukering and Cesar (2007) identified 166 studies of which 52 were selected due to data limitations, yielding a total of 100 values for analysis. From their analysis, these authors determined that recreational value was a function of the accessibility of ecosystems, and the size and wealth of populations who might visit. The authors, however, found substantial variation in estimates between studies, suggesting that the source studies may not be sufficiently comparable for a meta-analysis. In addition, Brander and colleagues also found evidence of "authorship effects" in their source studies, such that authors consistently produced high or low estimates over multiple studies, even after controlling for variations in the places the studies were conducted and the tools that were used. This feature may explain why the Brander et al. study found a substantially higher mean transfer error, 186 percent, than many other studies.

For this reason, it is recommended that this study not be used to estimate the recreation value of coral reefs. This study has been included, however, to demonstrate that meta-analyses can be used not only for benefit transfer, but also as diagnostic tools to determine if original studies are credible or if the science is consistent. The finding of these authors that different studies of similar issues yielded very different predictions underscores the importance of examining a study's research methods. In addition, these findings indicate that benefit transfer may be a risky method for quantifying the recreational value of coral reefs.

Full reference: Brander, L.M., P. Van Beukering and H.S.J. Cesar. "The recreational value of coral reefs: A meta-analysis." *Ecological Economics* 63, no. 1 (2007): 209-218. https://doi.org/10.1016/j.ecolecon.2006.11.002.

SOURCES OF ADDITIONAL INFORMATION

This catalog provides a snapshot of current ecosystem valuation efforts. Because this field is expanding rapidly, however, the following additional sources of information may be used to follow new developments.

- The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative hosted by the United Nations Environment Programme in Geneva, Switzerland, and publishes both major reports and sector and country-specific case studies on an ongoing basis. (http://www.teebweb.org/)
- The World Bank's Wealth Accounting for the Value of Ecosystem Services program is a global partnership that promotes the inclusion of natural capital values and ecosystem services in national economic accounts. The WAVES' Knowledge Center provides both country case studies and broader resources on ecosystem services. (https://www.wavespartnership.org/en)
- The Ecosystem Services Partnership serves as a central clearinghouse for information from its partners. It has links to ten resources for valuation information (including the NOEP database, the InVEST modeling suite, and the ARIES modeling platform), as well as a dozen sources of case studies, including TEEB. (https://www.es-partnership.org/about/)
- ValuES is a project implemented by the German Corporation for International Cooperation, Helmholtz Centre for Environmental Research and Conservation Strategy Fund, on behalf of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in Germany. ValuES maintains a database that provides a wide range of methods, tools and sources for integrating ecosystem services into policymaking, planning and project implementation. (http://aboutvalues.net/)
- The British government established Ecosystem Services for Poverty Alleviation as a consortium of its Department for International Development, Natural Environments Research Council and

Economic and Social Research Council. ESPA maintains an extensive database of publications and project descriptions. (http://www.espa.ac.uk/about/espa)

- The Natural Capital Coalition grew from the TEEB for Business activity, and focuses on private sector actions as they relate to ecosystem services. The "Hub" tab on the Natural Capital Coalition homepage describes reports and resources relevant for those with an interest in private sector or joint public-private programs involving ecosystem services. (https://naturalcapitalcoalition.org/)
- The Federal Resource Management and Ecosystem Services project is conducted under the auspices of the National Ecosystem Services Partnership, a group of federal agency staff, academics, NGO staff and other practitioners organized by Duke University's Nicholas School of the Environment. FRMES has produced a guidebook that can be accessed from its website detailing the experiences of several U. S. federal agencies in incorporating consideration of ecosystem services in their operations. This guidebook also presents an assessment framework suggesting approaches to, and best practices for, analyzing ecosystem services. (https://nicholasinstitute.duke.edu/focal-areas/online-guidebook)
- The Ecosystems Knowledge Network is based in the United Kingdom. Many of its resources focus on the U.K. but it also includes a number of more general studies and tools. (https://ecosystemsknowledge.net/)
- Two academic journals of particular relevance are *Ecological Economics* and *Ecosystem Services*. *Ecological Economics* is the official journal of the International Society for Ecological Economics and has published many of the studies included in databases and incorporated in meta-analyses. *Ecosystem Services* was established in 2012 and has published a number of influential papers on the science and economics of ecosystem services.
- Lastly, when searching for additional research, the Journal of Economic Literature's classification code "Q57" (ecological economics and ecosystem services) may help identify ecosystem service literature and can be used in combination with other keywords. Universities, private research organizations and government agencies that produce pre-publication research papers typically include keywords and the "JEL code" for indexing purposes.

NEPAL – 2017: Tourists view a Greater One-horned Rhinoceros (Rhinoceros unicornis) from an elephant.
Photo by Jason Houston for USAID.

ANNEX IV
EXAMPLES OF INTERACTIONS BETWEEN USAID PROGRAMMING AND ECOSYSTEM SERVICES

The following tables present potentially relevant interactions between USAID's program areas and those ecosystem services that can be reasonably quantified. For each program area, a table is provided for potential impacts of the programming on ecosystem services, and potential dependencies of the programming on ecosystem services. As noted, sector specialists should regard these tables as a starting point rather than a definitive list, and the ecosystem services listed here are not meant to be exhaustive.

FOOD SECURITY

Impacts on Ecosystem Services

Activity	Ecosystem	Ecosystem Service	Cause of Impact	Impact
Fertilizer or pesticide application	Rivers and coast	Wild harvested food	Chemical inputs reduce water quality and negatively affect fisheries	Reduced fishery yields
Fertilizer or pesticide application	Rivers	Water purification	Chemical inputs reduce water quality for human populations	Increased water treatment cost
Land conversion	Forests	Climate change mitigation	Forest conversion to agricultural land releases carbon dioxide	Lost opportunity to participate in emerging carbon markets
Land conversion	Savannah	Tourism	Reduced habitat reduces wildlife and causes a decline in visitation	Lost tourism income
Land conversion	Forests	Non-timber forest products	Forest conversion reduces opportunities to gather forest products	Cost of purchasing formerly "free" goods

Dependencies on Ecosystem Services

Ecosystem Service	Ecosystem	How Ecosystem Provides Service	Dependency
Pest control	Forests	Nearby natural ecosystems support insects and bats that consume crop pests	Crop yield rate, pesticide cost
Pollination	Forests	Nearby natural ecosystems support insects that fertilize crops	Crop yield rate, rental cost of mobile bee colonies
Wild harvested food and feed	Rivers and coast	Freshwater and marine ecosystems provide fish protein and aquaculture feed	Fishery yields, aquaculture yields and costs
Water provisioning	Forests and wetlands	Upstream ecosystems capture and store water that is used for irrigation	Crop yield rate, cost of substituting irrigation
Water quality	Streamside vegetation	Riverside ecosystems prevent sediment from entering water used for irrigation	Crop yield rate, cost of unclogging irrigation systems

GLOBAL CLIMATE CHANGE

Impacts on Ecosystem Services

Activity	Ecosystem	Ecosystem Service	Cause of Impact	Impact
Participation in carbon trading program	Forests	Non-timber forest products	Promotion of reforestation for carbon sequestration increases forest product availability	Increased income from forest products
Mangrove planting for coastal protection	Coast	Climate change mitigation	Mangrove planting for coastal protection increases carbon sequestration potential	Increased income from participation in carbon markets
Construction of reservoir for hydropower generation	Rivers	Wild harvested food	Dams block migration routes and reduce fish stocks	Reduced fishery yields

Dependencies on Ecosystem Services

Ecosystem Service	Ecosystem	How Ecosystems Provides Service	Dependency
Climate change mitigation	Forests	Intact forests sequester carbon	Carbon sequestration rates
Climate change adaptation	Coral reefs	Intact coral reefs absorb wave energy and protect coastal populations from storms	Storm protection rates

WATER, SANITATION AND HYGIENE

Impacts on Ecosystem Services

Activity	Ecosystem	Ecosystem Service	Cause of Impact	Impact
Wastewater treatment	Rivers, coastal	Wild harvested foods	Treatment improves water quality in aquatic/marine habitats	Increased harvest of aquatic and marine species
Agricultural water management	Rivers, groundwater	Wild harvested foods	Reduced water use improves aquatic habitats	Increased harvest of aquatic species

Dependencies on Ecosystem Services

Ecosystem Service	Ecosystem	How Ecosystem Provides Service	Dependency
Water provision	Forests or wetlands	Upstream ecosystems capture and store water for human use	Water security; water transport cost
Water quality	Streamside vegetation	Riverside ecosystems prevent sediment from entering drinking water	Cost of water treatment, cost of dredging
Wastewater treatment	Wetlands	Wetlands capture and treat human waste	Health costs; costs of waste capture and treatment

ECONOMIC GROWTH

Impacts on Ecosystem Services

Activity	Ecosystem	Ecosystem Service	Cause of Impact	Impact
Promotion of cacao production	Forest	Climate change mitigation	Forest clearing for cacao results in a net carbon release	Reduced ability to participate in global carbon markets
Improved credit for strawberry production	Rivers, coast	Wild harvested food	Intensification of strawberry production results in increased fertilizer in rivers	Reduced fishery yields
Transportation infrastructure	All terrestrial	Multiple	Improved transport and access drive deforestation	Reduction in mulitple ecosystem services, location dependent

Dependencies on Ecosystem Services

Ecosystem Service	Ecosystem	How Ecosystem Provides Service	Dependency
Tourism	Coral reef	Tourist revenue depends on intact coral reef ecosystem	Income from tourism
Non-timber forest products	Forests	Non-timber forest product revenue depends on intact forests to generate products	Income from forest products

ENERGY AND INFRASTRUCTURE

Impacts on Ecosystem Services

Activity	Ecosystem	Ecosystem Service	Cause of Impact	Impact
Construction of transmission lines	Mountain forests	Ecotourism	Transmission lines decrease attractiveness of views that draw tourists	Reduced tourism income
Reservoir construction for hydropower generation	Rivers	Wild harvested food	Dams block migration routes and reduce fish stocks	Reduction in fishery yields
Promotion of clean power	Forests	Climate change mitigation	Reduced reliance on wood and charcoal	Increased opportunity to participate in carbon markets
Transportation infrastructure	Forests	Climate change mitigation	Improved access to forests drives deforestation	Reduced opportunity to participate in carbon markets

Dependencies on Ecosystem Services

Ecosystem Service	Ecosystem	How Ecosystem Provides Service	Dependency
Water provision	Forests or wetlands	Upstream ecosystems capture and store water that is used for hydroelectric power generation	Power generated, especially in dry season
Water quality	Streamside vegetation	Riverside ecosystems prevent sediment from entering water used for hydroelectric power generation	Power generated; cost of dredging reservoirs
Wastewater treatment	Wetlands	Wetlands capture and treat urban and agricultural waste	Water treatment costs; fishery yields; health costs
Protection from flooding	Wetlands	Wetlands absorb floodwaters and protect built infrastructure	Sustainability of infrastructure investment

ANNEX V
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DOMINICAN REPUBLIC – 2011: Bats hang on a cave's roof in Los Haitises National Park.
Photo by Jerry Bauer, U.S. Forest Service, for USAID.

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