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Evaluating the Ecosystem Services and Benefits of Wetland Restoration by Use of the Rapid Benefit Indicators Approach

Marisa Mazzotta[*,†], **Justin Bousquin**[‡], **Walter Berry**[†], **Claudette Ojo**[§], **Rick McKinney**[†], **Kristen Hyckha**[//], and **Caroline Gottschalk Druschke**[#]

[†]US Environmental Protection Agency, Office of Research and Development, Atlantic Ecology Division, Narragansett, Rhode Island [‡]US Environmental Protection Agency, Office of Research and Development, Gulf Ecology Division, Gulf Breeze, Florida [§]New York State Department of Environmental Conservation, Long Island City, New York, USA [//]Center for Environmental Science, University of Maryland, Solomons, Maryland, USA [#]Department of English, University of Wisconsin-Madison, Madison, Wisconsin, USA

Abstract

Wetlands in urban and urbanizing areas are often smaller, more degraded, and subject to more stressors than those in undeveloped locations. Their restored level of functioning may never equal that of a site in an undisturbed landscape. Yet, the social benefits from restoring these wetlands may be significant because of the relative scarcity of wetlands and natural areas in urban settings and also the large number of people who may benefit. In this study, we have outlined a systematic approach to compiling nonmonetary indicators of wetlands restoration benefits: The Rapid Benefit Indicators (RBI) Approach. The RBI approach is grounded in economic theory and compatible with methods used by environmental economists to value ecosystem services. We illustrate the RBI approach with a comparison of 2 sites within the Woonasquatucket River Watershed in Rhode Island. As an urbanizing watershed, the Woonasquatucket illustrates how decisions may differ when based primarily on evaluations of ecological functioning versus those that incorporate benefits to people. It demonstrates how small urban sites with relatively low ecological function can provide large social benefits. *Integr Environ Assess Manag* 2019;15:148–159. Published 2018. This article is a US Government work and is in the public domain in the USA.

Keywords

Benefits; Ecosystem services; Indicators; Urban wetlands; Ecological restoration

[*]Address correspondence to mazzotta.marisa@epa.gov.

This article includes online-only Supplemental Data.

Disclaimer—The authors declare no conflicts of interest.

Data Accessibility—All data used for case study examples in this paper are publicly available spatial data sets, either state- or national-level data. We did not create or collect any original data. The data files used for the case study are listed in the Supplemental Data.

SUPPLEMENTAL DATA
Table S1. Spatial Data Sets Used in Case Study Analysis.
Postprocessing. Results of additional postprocessing of RBI Spatial Analysis Tool results.

INTRODUCTION

Despite the important ecosystem services (ESs) that wetlands provide, the extent of wetlands in North America has declined substantially, particularly in urban areas (Dahl and Allord 1996; Millennium Ecosystem Assessment 2005). Wetland restoration is one way to try to recover some of these losses. Many communities and citizens' groups are interested in restoring wetlands, with a variety of motivations, including regulatory requirements to mitigate losses, reconstruction of filled wetlands, creation or enhancement of green infrastructure for stormwater or wastewater management, or simply as proactive and voluntary restoration to provide ESs.

When making decisions about where to invest resources in restoration, managers and funders often need to balance competing aims and outcomes. Not all restorations provide the same functions, services, or values; while some sites may be undeniably better candidates for restoration, usually tradeoffs will need to be weighed. To take advantage of fleeting funding opportunities, restoration decisions often must be made rapidly, leading to opportunistic decisions rather than decisions based on more detailed analysis of tradeoffs.

Compared to ecological restoration in rural or undeveloped settings, restoration in urban and suburban settings may have different ecological, social, and economic characteristics and outcomes. Wetlands in urban and urbanizing areas are often smaller, more degraded, and subject to more stressors, so that their restored level of functioning may never equal that of a site in a more remote area or undisturbed landscape (Ehrenfeld 2000; Ingram 2008; Hobbs et al. 2009; Gobster 2010). Yet, social benefits from a restored wetland in an urbanizing area may be significant because of the relative scarcity of wetlands and other natural areas in urban settings and because of the large number of people who may benefit (Manuel 2003; Platt 2006; Elmqvist et al. 2015). While restoring wetland functioning is important, and wetlands in more remote areas can provide important and often unique functions, focusing solely on ecological functioning, as is often done in restoration planning, can lead to missed opportunities to provide social benefits (Manuel 2003; Platt 2006; Elmqvist et al. 2015; Martin 2017), pointing to the need for methods to evaluate the cultural benefits of urban wetlands.

The ESs paradigm provides a framework that stresses the connections between wetland functions, the goods and services those functions provide, and how people benefit from those goods and services (Mahan et al. 2000; Turner et al. 2000; Boyer and Polasky 2004; Fisher et al. 2008; Mitsch et al. 2014; Stelk and Christie 2014). Yet, few metrics exist to easily compare the potential ESs and benefits to people from wetland restoration projects in situations in which there is little time, money, or expertise to conduct detailed analysis. While there are many existing wetland functional assessment tools, they typically do not estimate ESs and benefits explicitly (for reviews, see Carletti et al. [2004] and King and Price [2004]). Some consider social benefits or values (Mitsch and Gosselink 2000; Turner et al. 2000), in the form of a judgment regarding the "social significance" of each function, but these typically are not well-developed measures and do not address wetland values in ways consistent with accepted economic concepts or practices (King et al. 2000; Wainger et al. 2001; King and Price 2004; Wainger et al. 2004).

Alternatively, economic valuation approaches monetize the value of wetlands to people, but such estimates are context and location specific and can require substantial resources to conduct (Heal 2000; Fisher et al. 2008; Turner et al. 2010). Those who restore wetlands may want to evaluate dollar values but doing so at the site or even watershed level can be difficult —there are many variations across sites and the ESs they provide and in who benefits from different sites and in what ways. A generic value per hectare of wetland restored will not capture these differences, and even values based on metaanalyses of existing studies (Brander et al. 2006; Moeltner and Woodward 2009; Ghermandi et al. 2010) may not contain enough variation to be appropriate for making decisions within a watershed (Plummer 2009; Wainger and Mazzotta 2011). This often leads to local decisions based solely on either functional assessments or on economic benefit transfer of somewhat generic wetland values.

Recognizing the limitations of monetary economic valuation, indicator-based studies have been used to assess the benefits and values of mitigation trades or compensatory restoration, in situations where wetlands are restored to compensate for losses due to development or environmental damage (King et al. 2000; Wainger et al. 2001; King and Price 2004; Wainger et al. 2004; Wainger et al. 2010). It is possible to use economic principles to capture important aspects of value without calculating monetary values. These factors that affect value can be compiled into a set of benefit indicators.

In this study, we have outlined a systematic approach to compiling nonmonetary indicators of wetlands restoration benefits: the Rapid Benefit Indicators (RBI) approach. Existing work (King et al. 2000; King and Mazzotta 2000; Wainger et al. 2001; Boyd and Wainger 2002; Boyd and Wainger 2003; Boyd 2004; King and Price 2004; Wainger et al. 2004; Wainger and Boyd 2009; Wainger et al. 2010; Wainger and Mazzotta 2011; Olander et al. 2015; Boyd et al. 2016; Olander et al. 2018) provided benefit indicator concepts and applications that we drew upon in developing the RBI approach. The RBI approach is intended to be used in conjunction with functional or ecological production function assessments and is designed to use widely available data and to be flexible in its data requirements and transferable to other ES and types of ecosystems. It is useful as a screening tool when used with basic data, but more data can support more detailed analyses. The RBI Guidebook (Mazzotta et al. 2016) provides a full description of the entire process, while this paper presents the general rationale and approach.

We illustrate the RBI approach with a comparison of 2 sites within the Woonasquatucket River Watershed in Rhode Island. As an urbanizing watershed, the Woonasquatucket illustrates how decisions may differ when based primarily on ecological functioning versus those that incorporate benefits to people. It demonstrates how small urban sites can provide large social benefits, though they may not rank well under ecological criteria alone.

METHODS

Identifying and selecting indicators for ES benefits

Indicators can inform decisions and actions when direct metrics are unavailable, overly complex, or otherwise inadequate (Meadows 1998; Bossel 1999; Layke 2009). Desirable indicator variables have a strong relationship to the phenomena of interest yet are simple enough to be effectively monitored and/or modeled (Dale and Beyeler 2001). The RBI are based on factors considered by basic economic theory to be important determinants of economic value.

Economics defines value in terms of scarcity, the result of the interaction of supply and demand (Turner et al. 2010). The greater demand is relative to supply, the greater the scarcity of a good or service. Thus, indicators of value are based on the important factors that affect supply and demand functions, by shifting them relative to one another. We incorporated these factors into a set of user-answered questions that offer a big picture of ES benefits provided by a site (Wainger et al. 2010; Wainger and Mazzotta 2011). To develop indicators from these questions, we selected a set of metrics based on empirical studies in the literature.

The ES cascade depicts the relationship of supplied ESs to demand for ESs (Potschin and Haines-Young 2011; Figure 1). The ES cascade illustrates the linked flows from the ecologically focused biophysical structure and functions to the economically focused benefits and value. Bridging the 2 perspectives, in the center of the cascade model, are ESs, the aspects of nature that contribute to people 's health, well-being, and enjoyment (Wainger and Mazzotta 2011; Munns et al. 2015).

For the RBI proof-of-concept application, we focused on 5 ESs provided by vegetated wetlands in urbanized areas—flood water regulation, scenic landscapes, learning opportunities, recreational opportunities, and birds—and their associated benefits (Figure 2). We selected these 5 because they may be provided by relatively small, urban vegetated wetland sites, they are relevant to our example watershed, and they were mentioned in our interviews with managers conducting restoration in Rhode Island (Druschke and Hychka 2015; Hychka and Druschke 2017). Wetlands can provide other services, and multiple types of benefits may result from each service. For more detailed information about defining and classifying ESs, see the reports by Landers and Nahlik (2013) and USEPA (2015). In selecting these particular ESs, we have chosen to focus on cultural services of particular relevance in urban settings. We recognize that this set of services may not capture other ESs that may be relevant to more remote sites, especially their ability to provide sometimes-unique undisturbed habitats. We have made this choice in order to illustrate and evaluate opportunities for providing social benefits to often underserved populations.

We are using the term “benefit” to refer to human interactions with ESs, although in economics, the term is generally synonymous with economic value. We have chosen this usage in order to capture a nuance that is sometimes important in ES assessments. As shown in Figure 1, ESs are defined in biophysical terms (for example, flood regulation or fish that people can catch), and benefits capture the intersection of biophysical and human inputs that is often needed for people to actually derive a benefit (for example, reduction in damage to property or a day of recreational fishing).

The RBI approach

The RBI approach provides a framework for compiling information on tradeoffs in a systematic way to inform decisions. The result is a set of benefit indicators that may be used as a first step toward monetary valuation or toward a single score but can be used in disaggregated form in participatory decision making. The RBI's ES benefit indicators are compiled using 5 questions, some with subquestions, to guide the process of indicator selection and measurement. Each of these questions and subquestions may be answered with 1 or more metrics. Some metrics may be measured by mapping or modeling approaches, as described below and illustrated in the example application using the RBI Spatial Analysis Toolset (Bousquin et al. 2017); others require local knowledge and best professional judgment.

The RBI questions

1) Are people able to benefit?—By definition (Fisher et al. 2009; Wainger and Mazzotta 2011; Munns et al. 2015), ESs require use or appreciation by people and thus are distinguished by the interaction of supplied ecological outputs and demand for those outputs by people. Question 1 requires the user to evaluate 3 things. First, for a service to be supplied, wetland functioning must meet thresholds, such as a minimum size or capacity to retain water, required to provide benefits to people. Second, people must care about, or demand, the service in the location being evaluated. Third, for some ESs, other inputs or conditions may be necessary for people to benefit. These may include physical supports that enable enjoyment of the ES, such as built infrastructure allowing physical access to recreational services, or institutional supports or constraints, such as regulatory limits to harvest (Olander et al. 2015; Olander et al. 2018). This first set of questions serves as an initial screening, using yes or no responses. If these criteria are not met, there is not a benefit, and nothing further needs to be assessed for that service at that site.

2) How many people benefit?—This question assesses the number of people who benefit, the most basic measure of the magnitude of benefits. The aggregate social value of a change can be more sensitive to the size of the beneficiary pool than the magnitude of value for each individual (Bateman et al. 2006). Thus, the total benefits of an ecosystem change depend, to a large extent, on how many people stand to benefit. As long as the average value to individuals is expected to be positive, the number of beneficiaries alone can provide an indication of the overall magnitude of benefits.

Potential beneficiaries can be counted with various approaches, including direct counts, user surveys, spatial estimation approaches, or modeled estimates based on 1 or more of these approaches (White et al. 2007; Garcia and Smith 2013; Mazzotta et al. 2015; Allan et al. 2015; Leggett 2017; Tourangeau et al. 2017). The RBI use a spatial approach, which requires an understanding of how people and services interact within the landscape. This interaction includes the relationships among the area where a service is generated, the area where people can benefit from the service, and the area where people who benefit are located. In general, services originate at a particular site, and either services move beyond that site to interact with people, people travel to the site to interact with services, or both.

Three general categories, illustrated in Figure 3, describe these relationships (Fisher et al. 2009; Johnson et al. 2010; Bagstad et al. 2013):

a. Services are generated and must be enjoyed within a particular geographic area or site (Figure 3a). People must be located at or travel to that site to benefit. When evaluating these on-site services, the most important consideration in determining who benefits is how far people will travel to the site.

b. Services are generated at a site and flow in all directions to a surrounding area (Figure 3b). People who are within the area where services flow will be able to benefit. This relationship is true for services such as wildlife moving within a certain range of useful habitat (e.g., birds, mammals, pollinators), scenic views, and microclimate regulation. When evaluating these services, it is important to consider how far the ESs travel, whether those travel paths are blocked in any direction, and how those travel paths overlap with people who might benefit.

c. Services are generated at a site, and flow in a single or restricted direction to a surrounding area (Figure 3c). People within that area will be able to benefit. This is true for services that flow downstream, such as water retention or purification that affects downstream flood risks or water quality. When evaluating these services, it is important to consider how far the ESs travel, whether anything impedes or assists that flow, in what direction, and how the travel path overlaps with people who might benefit.

Nonuse services (those ESs that people value although they do not directly interact with them, such as simply for the knowledge that they exist and may continue to exist for the benefit of future generations) are a special case in which people do not have to be in any particular location to benefit but simply need to be aware of the service and value it. These services can benefit people at varying distances, not requiring any contact with people. We do not discuss the complexities of evaluating nonuse services with benefit indicators in this paper. A highly simplified indicator of potential nonuse values is whether the site provides any rare or particularly unique flora or fauna.

The extent of the relevant boundaries will vary based on local conditions, including ecosystem attributes and attributes of beneficiaries (Vajjhala et al. 2008). Many services experience a “distance decay” in provision, where the service level decreases with distance from the source (Fisher et al. 2009; Bagstad et al. 2013). Benefits also may have a distance decay, in which people’s values diminish with increasing distance from the service provision area (Hanley et al. 2003; Bateman et al. 2006; Campbell et al. 2007; Campbell et al. 2008; Johnston and Rosenberger 2010). To account for decreasing magnitude of benefits with distance, for some ESs it may make sense to count beneficiaries within different distance bands and give those farther away lower weight if the indicators are aggregated.

3) By how much do people benefit?—This question assesses the magnitude of benefits to affected individuals or households. It may incorporate a number of measures, including the quality of the service, the availability and quality of substitutes, the availability and quality of any associated complementary inputs, and strength of preferences for the service. Some of these measures may not be relevant for every ES, and those that are relevant may have 1 or more indicators. Each factor is evaluated by assuming a positive or negative influence on value, holding all other factors equal. In reality, it is possible that there are more complex interactions among these factors that will not be captured by individual indicators. This possibility highlights the importance of considering local stakeholder knowledge.

A. Quality of the service: This indicator evaluates the quality of a service, assuming that higher quality services have greater value. An indicator of quality might be based on scores from a functional assessment, on location-specific models or expert elicitation (Radford and James 2013; Bousquin et al. 2015), or on literature that relates people's preferences to services and benefits (Van Herzele and Wiedemann 2003; Wolf 2003). For example, when comparing the scenic quality of 2 locations, quality indicators could be based on factors such as the presence of open water, an attribute that people often say adds to scenic beauty, or presence of industrial buildings, a feature that detracts from scenic beauty (Gobster and Westphal 2004; Dramstad et al. 2006).

B. Substitutes for the service: This indicator evaluates the availability and quality of substitutes for the service—either other sites or technological substitutes nearby that provide the same service—assuming that fewer substitutes and/or lower-quality substitutes lead to greater value. For example, other nearby wetlands might provide natural substitutes for the flood risk reduction services of a site being evaluated; levees, dams, or storm sewers might provide technological substitutes.

C Quality of complements.: This indicator evaluates quality of infrastructure or other conditions that complement the service, assuming that higher quality complements lead to greater value. This step is only important for services that are enhanced by complementary factors, such as recreation or education. For example, a handicap-accessible entrance can increase benefits from a recreational or educational site; a higher quality boat launch area can increase boating benefits; or the availability of a viewing platform can increase bird watching benefits.

D. Strength of people's preferences: This step evaluates how much people care about the service, assuming that stronger preferences lead to greater value. How strongly people prefer a service in a particular location can be inferred, such as through their demonstrated interest (for example, by participating in public programs or meetings or writing letters to the editor) or by talking with the public. This step may also examine people's willingness or ability to adapt to changes in the service, by evaluating aspects such as how much people who benefit depend on the service. The strength of people's preferences can be difficult to measure in an indicator context and thus may often be omitted from the assessment.

4) What are the social equity implications?—The social equity assessment supplements these economically focused indicators by looking more closely at the groups who benefit to assess concerns related to environmental justice and potential effects on particularly vulnerable populations. This indicator is evaluated for each site, rather than for the individual services, although vulnerability may be more important for specific services such as flood risk reduction. One method for assessing social equity is the Social

Vulnerability Index (SoVI; Cutter et al. 2003). The SoVI combines a set of statistically relevant demographic variables summarizing information on race, class, wealth, age, ethnicity, and other factors into an index. It is intended to indicate the capacity for preparedness and response to environmental hazards.

5) How reliably will services be provided over time?—This step assesses temporal reliability of ESs provision by a site and is evaluated at the site level rather than for individual ESs. It considers factors that affect the probability that the wetland will continue to function at a sufficient level to provide services over time. The reliability of service provision is important to consider when comparing restoration sites because 2 sites may provide identical benefits in the short run, but if one of the sites is threatened by stressors, it may not continue to provide services into the future, resulting in a lower total stream of benefits for that site. For example, a site in a location where there is strong development pressure may be at higher risk than a site surrounded by protected land. Thus, projected development around the site can indicate lower reliability, and protected land surrounding a site can indicate higher reliability.

Using the results for decision making

The indicators outlined above provide information on who benefits, where benefits occur, and which factors determine the potential magnitude of benefits. However, this process is not an endpoint for making a decision but an approach to gathering, organizing, and presenting information. In order to rank and choose among sites, decision makers must weigh the resulting tradeoffs.

With monetary valuation, dollar values are used as a common measure of people's preferences over different services and benefits, facilitating aggregation and comparisons. Indicators do not allow for a simple method of aggregation. A set of indicators may be used in disaggregated form as a basis for discussions, to inform participatory or consensus-type decisions, or they may be aggregated with Multi-Criteria Decision Analysis (MCDA) methods (Belton and Stewart 2002; Gregory et al. 2012). In other work, we illustrate the application of MCDA aggregation approaches to the RBI (Martin and Mazzotta 2018a, 2018b; Martin et al. 2018).

Example application

As an illustration, we applied the RBI approach to 2 filled former wetland sites within the Woonasquatucket River Watershed (sites A and B in Figure 4; see Mazzotta et al. [2016] for full details of the application). The 31-km Woonasquatucket River, a river with a long history of cultural and industrial development, flows from mixed suburban and agricultural settings in its headwaters into highly urbanized neighborhoods downstream. Its 132 km^2 watershed encompasses portions of 8 municipalities, with a wide range of demographics. Growth projections suggest that the watershed will continue to urbanize in years to come (Rhode Island Statewide Planning Program 2006).

Table 1 shows the RBI for the example sites. We evaluated the sites by using the automated processes in the RBI Spatial Analysis Toolset (Bousquin et al. 2017), which uses a geographic information system (GIS) to calculate most of the indicator values. The Toolset uses readily available spatial datasets (see Supplemental Data for data sources). Some values cannot be calculated by GIS; these metrics require local knowledge and best professional judgment, including stakeholder values and site-specific features or attributes of the planned restoration.

The process used to answer the benefit indicator questions for flood risk reduction in Table 1 demonstrates how spatial data can be processed by the RBI Toolset to produce many of the RBI values. For the purposes of the example, we made 2 assumptions that would, in practice, be answered by people familiar with the sites being evaluated: we assumed that both sites are able to retain enough water for people to be able to benefit and that both sites when restored would have features that can increase water retention. To answer the other questions, we used spatial data and our Toolset models. The spatial models provide a count of the number of homes in the floodplain within 4 km downstream of the sites. To conduct these calculations, the Toolset uses the NHDPlus V2 data set (McKay et al. 2012) to determine each site's catchment and catchments within 4 km downstream. The downstream floodplain is delineated by using these catchments to subset the FEMA 100-year Flood A Zones. The number of homes is determined by overlaying the downstream floodplains with an e911 address data set. While this data set is state specific, data such as spatial census data sets available at the national scale can be substituted in the Toolset. To assess site quality, the Toolset uses the size of the polygon defining the site to determine the size (ha) of each site. The Toolset also determines the number of dams and levees within 4 km downstream by limiting the dams and levees input data set, in this case dams defined by a statewide data set, by the same downstream catchments used to determine the number of affected homes. The Toolset determines the percentage of area within a 4-km radius that is wetlands by subsetting a user-defined wetlands input data set, in this case the National Wetlands Inventory (USFWS 2016), by a 4-km radius buffer around the site and determining the percentage of that buffer area that is covered by wetlands.

The first site (Figure 4, site A) is 1.55 ha, located in a forested area in the upper watershed, in a relatively rural area (North Smithfield, Rhode Island; population density = 192.1/km^2). The second site (Figure 4, site B) is 0.22 ha and is located in an urban area (Johnston, Rhode Island; population density = 469.3/km^2). It is currently an unused, previously paved area on the west bank of the Woonasquatucket River. There is a restored mill with residential units directly across the river. With a rapid functional assessment, site A received an overall functional score of 10/10 and ranked second of 77 sites evaluated in the watershed; site B's overall functional score was 4.5/10, and it ranked 33rd of 77 sites (Miller and Golet 2001; Golet et al. 2003).

RESULTS

Table 1 shows the RBI for each site. Even though site A scored much higher in the functional assessment, it generally scores lower than site B in terms of benefits to people. This result is because site A is farther from people and in an area where other wetlands and green spaces are more abundant. For flood risk reduction, site B has more homes in the downstream floodplain and fewer substitute wetlands, although site B does have more dams and levees downstream that can provide substitute flood protection services. Site A, because it is not visible from homes or roads, does not provide scenic view benefits. Similarly, site A is not near any educational institutions and is not easily accessible, so it is unlikely to provide educational benefits.

For potential recreation benefits, site B is located near almost 3 times as many people as site A and has bus stops and a proposed bike path nearby. It is also in an area with less nearby green space that might provide substitutes. However, it is a much smaller site with much less adjacent greenspace, and so, based on those criteria, site B is a lower-quality site. For potential bird watching benefits, site B is near more people, so potentially provides higher benefits, assuming that the species mix at both sites is similar. Site B serves a more socially vulnerable population than site A. Site A, however, is likely to function more reliably over time because it is less susceptible to development pressure.

In summary, this example illustrates the types of tradeoffs that must be considered when selecting sites to restore. While additional location- and stakeholder-specific factors may play into an actual decision, this simple illustration shows that even sites that score lower with a functional assessment alone can provide important benefits to many people.

DISCUSSION AND CONCLUSIONS

In this paper, we have presented the RBI approach: a rapid approach to compiling nonmonetary indicators of ES benefits. We illustrated the application of the RBI with a comparison of a small urban site (B) to a larger site in a more rural location (A) within the same watershed. The illustration shows that site B (the small urban site) provides important benefits to many people in an area with a large portion of the population falling into the medium or high social vulnerability categories. However, it has lower ecological functioning and may be more susceptible to stressors over time. These results point to the need to carefully evaluate and consider the various tradeoffs involved in selecting sites for restoration, in light of both ecological and social goals.

Restoration is often more expensive at urban sites owing to a variety of constraints, including industrial pollutants, population density, and infrastructure (Hychka and Druschke 2017) and may not greatly improve some wetland functions. But urban restoration can provide real opportunities, as demonstrated through the RBI approach, to address environmental justice issues and deliver wide-reaching benefits to an increasingly urban populace (Pickett et al. 2001; Platt 2006; Elmqvist et al. 2015). Further, restoration sites that score high with the RBI approach can act as “ambassador sites” to other restoration efforts and can garner support for watershed-scale changes needed to address nonpoint source problems that ultimately improve ecological conditions on a broader scale (Palmer et al. 2014; Yocom 2014; Smith et al. 2016; Hychka and Druschke 2017).

The RBI approach relies on a compilation of factors based on economic principles that, all else being equal, lead to higher potential benefits. It does not incorporate complexities associated with potential interactions among the factors or other context-specific considerations that may be important. By simplifying, precision and thoroughness are sacrificed in order to provide an approach that is relatively easy to apply quickly with readily available data. We assume that users will incorporate their own local knowledge and judgment to modify or supplement this information as appropriate.

The approach is useful for rapid assessments at the site level, where it allows users to consider who may benefit and by how much. Using an indicator approach, such as the RBI, can promote transparency by presenting a set of systematically compiled information. Restoration site selection often lacks transparency, but transparency is critical, especially for publicly funded projects (Yocom 2014). However, we would caution users that, in any indicator approach, intended or unintended bias may be introduced by selecting a subset of easy-to-measure indicators and by selecting indicators that support a particular outcome.

We view the primary advantage of the RBI or similar approaches to benefit indicators as providing an easily applied method to incorporating benefits to people, in addition to evaluations of ecological functioning, into decisions about ecological restoration or conservation. This approach may be especially useful in urban settings, for providing a way to compare urban sites to less urban sites on the basis of benefits and to foster important discussions about benefits. When functional comparisons alone would lead to low rankings of urban sites, considering benefits puts them on a more equal footing with rural sites by providing valuable additional information.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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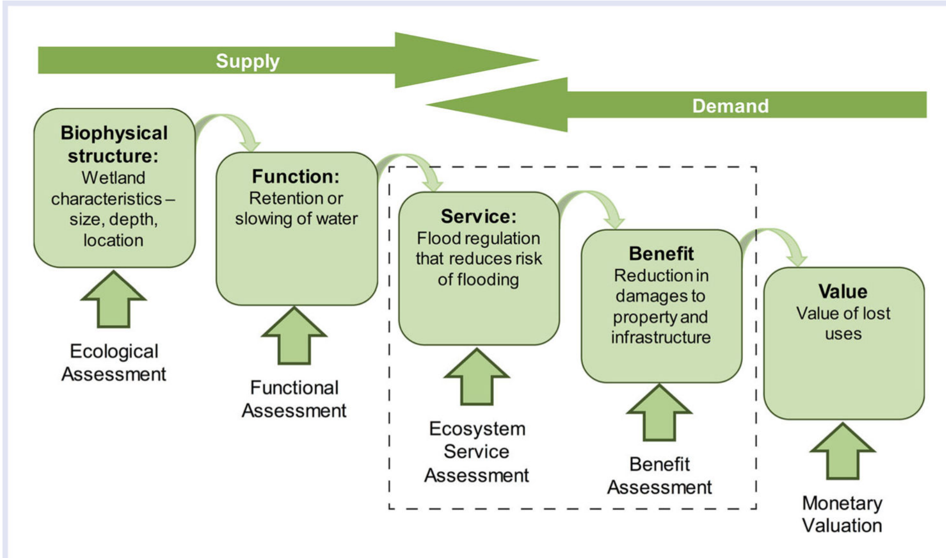

Figure 1.

The ecosystem service cascade (adapted from Potschin and Haines-Young 2011), depicting an example of the service of flood risk reduction. The cascade shows the relationship between supply of and demand for ecosystem services and illustrates how the ecosystem's structure and processes affect its functioning, leading to the provision of ecosystem services to people who benefit from and value those services.

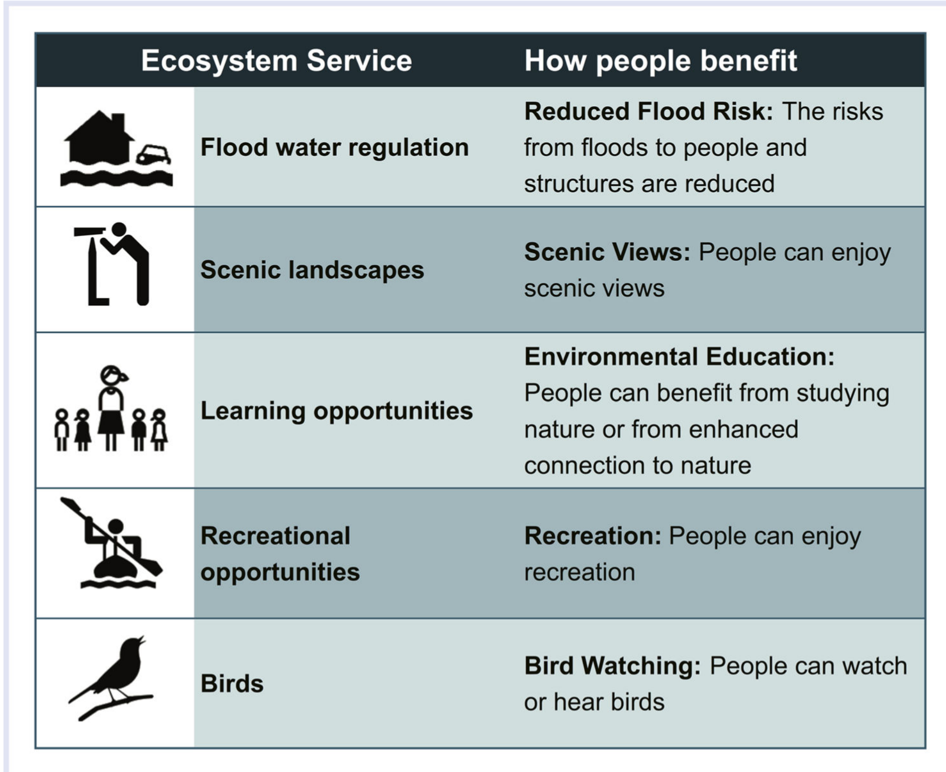

Figure 2.

Ecosystem service and associated benefits included in our proof-of-concept application. (Icons are from thenounproject.com; flood and view icons are public domain; credits for other icons: teacher © Piotrek Chuchla; kayaking © Luis Prado; warbler © Matt Steele; all licensed under Creative Commons.)

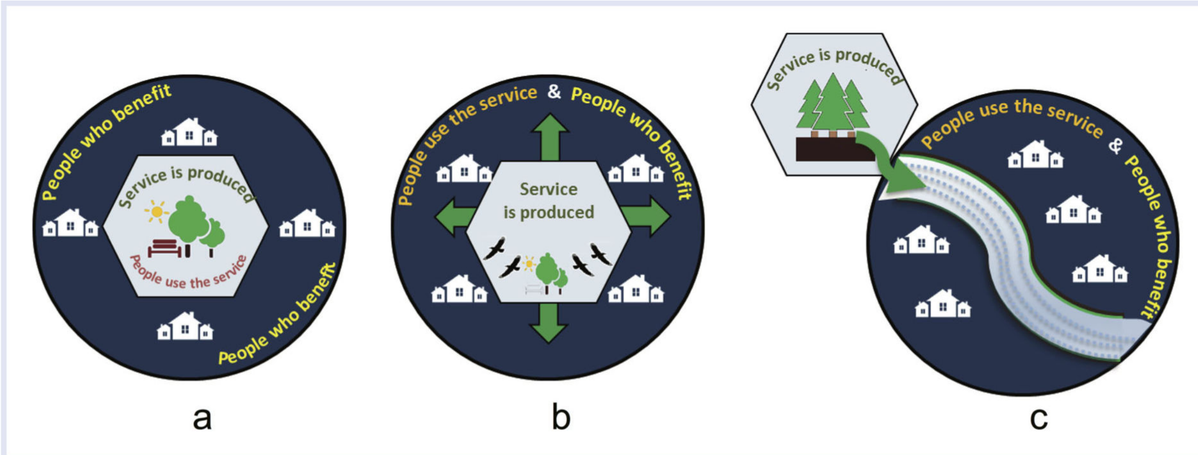

Figure 3.

Three types of spatial relationships between ecosystem service and beneficiaries: (**a**) services are generated and must be enjoyed at a particular site; (**b**) services are generated at a site and flow in all directions to beneficiaries; (**c**) services are generated at a site and flow in a particular or restricted direction to beneficiaries.

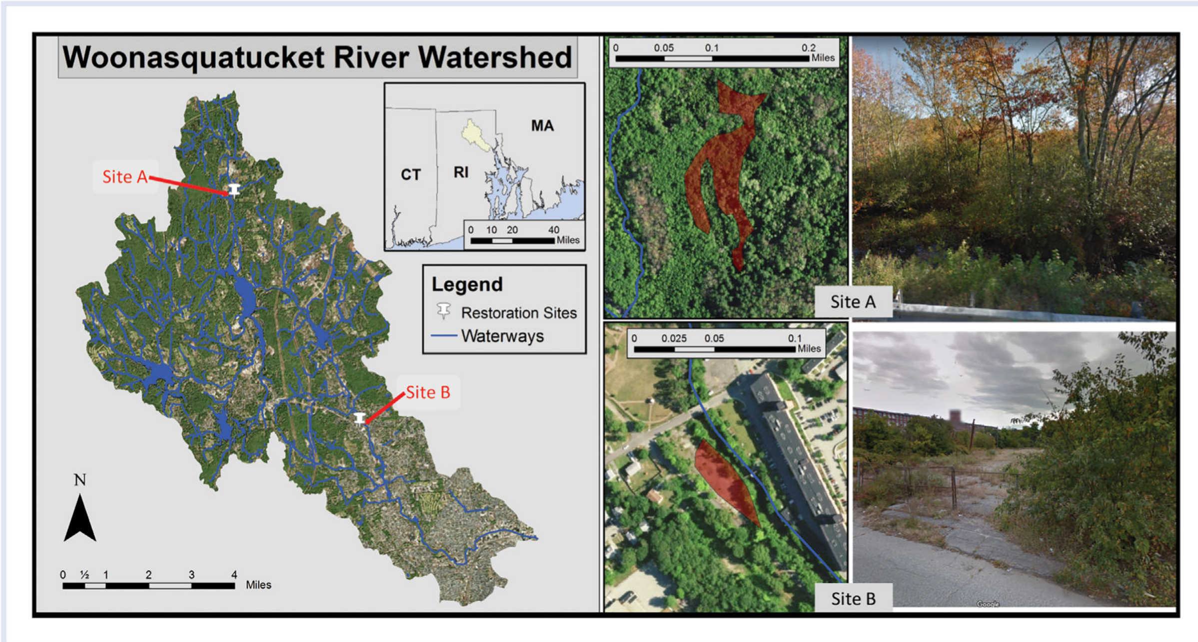

Figure 4.

Example restoration sites in the Woonasquatucket River Watershed. (**Left**) Map showing the watershed and locations of the 2 sites; (**Top**) aerial photo with site A in orange and a Google street view image of the area adjacent to the nearest road; (**Bottom**) aerial photo with site B in orange and a Google street view image showing the site and apartment building across the river. The Woonasquatucket River is shown in blue in the aerial photos.

Table 1.

Benefit indicators and measurements for example restoration sites[a]

Benefit indicator question	Indicator metric(s)	Site A	Site B
Flood risk reduction			
Q1 Are people able to benefit?			
1.1 Is functioning sufficient?	Can the site retain water that will affect floodplain? (Y/N)[b]	Y	Y
1.2 Is there demand?	Are there people in floodplain within 4 km downstream?	Y	Y
Q2 How many people benefit?	Number of homes in floodplain within 4 km downstream	4	25
Q3 By how much do people benefit?[c]			
3.1 Quality of the ecosystem service	Size (ha) of site	1.55	0.22
	Features that increase water retention? (Y/N)[b]	Y	Y
3.2 Availability and quality of substitutes[d]	Number of dams and levees within 4 km downstream	1	3
	Percentage of area within 4 km radius that is wetlands (%)	13.4	9.0
Scenic views			
Q1 Are people able to benefit?			
1.1 Is functioning sufficient?	Does site have scenic features? (Y/N)[b]	Y	Y
1.2 Is there demand?	Is the site visible from homes, roads, or trails?	N	Y
Q2 How many people benefit?[e] (divided into distance bands to account for distance decay of benefits)	Number of homes within 50 m of site	0	1
	Number of homes between 50 and 100 m of site	0	9
	Roads or trails within 100 m of site	N	Y
Q3 By how much do people benefit?[c]			
3.1 Quality of the ecosystem service	Does the site have features or characteristics of scenic interest? (Y/N; note features)[b]	NA[e]	Y
3.2 Availability and quality of substitutes[d]	Percentage of area within 200 m of site that is wetlands	NA[e]	7.9
3.3 Availability and quality of complements	Number of natural land use types within 200 m of site	NA[e]	5
Environmental education			
Q1 Are people able to benefit?			
1.1 Is functioning sufficient?	Will the site support features of educational interest? (Y/N)[b]	Y	Y
1.2 Is there demand?	Is there demand for environmental education in this location? (Y/N)[b]	N	Y

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Benefit indicator question	Indicator metric(s)	Site A	Site B
Q2 How many people benefit?[e]	Number of educational institutions within 400-m radius of site	0	2
Q3 By how much do people benefit?[c]			
3.1 Quality of the ecosystem service	Does the site have features of educational interest? (Y/N; note features)[b]	NA[e]	Y
3.2 Availability and quality of substitutes[d]	Percentage of area within 800 m of site that is wetlands	NA[e]	4.9
3.3 Availability and quality of complements	Will the site have complementary infrastructure (educational signs, etc.)? (Y/N; note features)[b]	NA[e]	Y
Recreation			
Q1 Are people able to benefit?			
1.1 Is functioning sufficient?	Could the site support recreational activities? (Y/N)[b]	Y	Y
1.2 Is there demand?	Are there nearby people who might use the site for recreation? (Y/N)[b]	Y	Y
1.3 Will required complementary features be available at the site?	Does the site have appropriate access and facilities for recreation? (Y/N)[b]	N	Y
Q2 How many people benefit? (divided into distance bands to account for distance decay of benefits)	Walking: Number of homes within 500 m of site	34	766
	Driving: Number of homes between 500 and 800 m of site	90	787
	Number of homes between 0.8 and 10 km of site	38992	102518
	Access: Bike trails within 500 m of site	N	Y
	Bus stops within 500 m of site	N	Y
Q3 By how much do people benefit?[c]			
3.1 Quality of the example site	Size of site and adjacent green space (ha)	16872	18.2
3.2 Availability and quality of substitutes[d]	Percentage area of green space within 1000 m	69.6	31.2
	Percentage area of green space between 1000 and 1600 m	81.5	51.3
	Percentage area of green space between 1.6 and 20 km	66.9	57.4
3.3 Availability and quality of complements	Quality of access and facilities (L/M/H; note features)[b]	NA	M
Bird watching			
Q1 Are people able to benefit?			
1.1 Is functioning sufficient?	Will the site support bird species of interest? (Y/N)[b]	Y	Y
1.2 Is there demand?	Are nearby people interested in bird watching? (Y/N)[b]	Y	Y
Q2 How many people benefit?	Number of homes within 300m of site	8	298
	Roads or trails within 300m of site	Y	Y

Benefit indicator question	Indicator metric(s)		Site A	Site B
Q3 By how much do people benefit?[c]				
3.1 Quality of the ecosystem service	Will the site support rare or unique species? (Y/N)[b]		N	N
3.2 Availability and quality of substitutes[d]	Without additional expert input, this question may be beyond the scope of a rapid approach, because nearby sites may support rather than substitute for additional habitat.		NA	NA
3.3 Availability and quality of complements	Are there features such as viewing platforms available? (Y/N; note features)[b]		N	N
Social equity and reliability[f]				
Q4 What are the social equity implications?	Measured with the Social Vulnerability Index: values are % of people falling in low-, medium-, or high-vulnerability category, based on demographics and other factors.	Low	81.3	16.6
		Medium	0	72.3
		High	18.7	11.0
Q5 How reliably will services be provided over time?	Assurance that a site will continue to provide benefits overtime, in the face of development stressors. Measured in portion (percentage) of property within 150 m of site designated with conservation, parks and open space, reserve, or water land use categories.		64.5	19.9

[a] Data sources are listed in Supplemental Data.

[b] These indicators are not calculated with GIS but need to be determined with best professional judgment. We have made assumptions regarding the answers for the purposes of illustration.

[c] Additional information could be added to assess people's strength of preference for this example site, if available, as part 4 of this question.

[d] Higher numbers for substitutes indicate lower relative value for the site.

[e] Because site A is not within visible range of homes or roads and is not accessible to school children, it will not provide scenic view benefits or educational benefits.

[f] Evaluated at the site scale rather than for each service.

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