A Systematic Approach to Incorporating Multiple Ecosystem Services in Landscape Planning and Design

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ABSTRACT This paper uses a contemporary perspective on ecosystem services to propose a method by which projects designed for sustainability may more fully capture or enhance ecosystem services. A comprehensive Ecosystem Services Evaluation Matrix is used to evaluate three designed landscapes, at different scales. The matrix is then incorporated into a revised sustainable landscape planning and design process. This approach uses evaluative tools within a decision making process to incorporate a broader range of ecosystem services in landscape planning and design.

KEYWORDS Landscape architecture, landscape planning, ecosystem services, sustainability, landscape performance

INTRODUCTION

While most landscapes are suitable for multiple purposes and can be shaped by people to provide a diverse array of material and immaterial goods, services, and benefits (known hereafter as ecosystem services) (Wiggering et al. 2006; Musacchio 2009; de Groot 2006), design and land-use decision making often does not fully consider or assess these services. Consequently, highly productive, multifunctional landscapes become less valuable, single-function landscapes (de Groot and Hein 2007; Wallace 2007). Similarly, in site planning and landscape design, the range of ecosystem services that may accrue from the landscape is often not fully considered or realized. Application of an ecosystem services approach to landscape planning decision making (de Groot, et al. 2010) reverses ecosystem degradation. It facilitates the conservation and enhancement of ecosystem services as well as the creation of positive synergies among ecosystem services (Millennium Ecosystem Assessment 2005).

After examining multiple approaches to defining ecosystem services and their integration into landscape management, this article proposes the Ecosystem Services Evaluation Matrix as a tool for a systematic integration of multiple ecosystem services into sustainable landscape planning and design. Conceptual development of the approach evolves from an examination of contemporary literature on ecosystem services and landscape design, planning, and management. The approach proposes the use of a kit of evaluative tools to assess diverse ecosystem services created through landscape planning and design. After applying the Matrix in evaluating three Canadian design case studies, the article proposes revisions to the sustainable landscape planning and design process to more explicitly integrate ecosystem services evaluation into the design process. Case studies evaluated in this article

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include: the Southeast False Creek Community Public Realm in Vancouver, British Columbia; Fisherman's Wharf Park and Rain Garden in Victoria, British Columbia; and Riparian Corridors in the Fraser River Valley in British Columbia.

CONTEMPORARY PESPECTIVES ON THE APPLICATION OF ECOSYSTEM AND ECOSYSTEM SERVICES APPROACHES TO LANDSCAPE MANAGEMENT

In an attempt to increase the sustainability of designed landscapes, a number of new evaluation methods have evolved in recent years. These include SITES (Sustainable Sites Initiative 2009a) and The Landscape Architecture Foundation's Landscape Performance Series (LPS) (Landscape Architecture Foundation 2012). Both SITES and LPS seek conservation and enhancement of ecosystem services in site design and landscape planning.

This paper offers a complementary yet alternative process to that of SITES and LPS. Based on both the Ecosystem Approach and the Ecosystem Services Approach to landscape management, the process incorporates collaborative social learning through a public participatory process to identify key ecosystem services of concern in landscape development. It is site-adaptive in that it allows the practitioner, in concert with key stakeholders, to identify and incorporate a broad range of best practices that facilitate realization of synergies of ecosystem services that are most closely associated with a site's context, condition, and program.

The Ecosystem Approach

In 2000, the United Nations initiated an assessment of the health of global ecosystems and their ability to support human needs (Haines-Young and Potshin 2010). While the resulting Millennium Ecosystem Assessment report (MEA) concluded that the substantial gains to human economic development of the previous 50 years had been achieved through extensive alteration of global ecosystems, it also reported that 60 percent of the global ecosystem services examined, including potable water, fisheries, and air and water purification, were degraded and continuing to decline (Millennium Ecosystem Services Assessment 2005).

The idea that human actions impair the ability of the planet to support human needs evolved in the 1970s (Daily 1997; Gómez-Baggethun et al. 2010). This recognition led to the evolution of an ecosystem approach to landscape management. The ecosystem approach is based on the idea that human needs are central to biodiversity management (Haines-Young and Potschin 2010) and that ecological knowledge provides a basis for landscape decision making and governance (Kay and Schneider 1994; Waltner-Toews, Kay, and Lister 2008). This new form of ecosystem management posits that:

- Ecosystems operate on multiple scales, and principles of landscape management need to be developed and applied at the landscape level rather than being ecosystem specific;
- Landscapes operate as open systems;
- Humans and cultural diversity are inherent components of the landscape, and management needs to incorporate a range of economic, social, and cultural as well as biophysical ecosystem services;
- The public and stakeholders need to be part of the decision making process;
- Adaptive management strategies that fluctuate in response to changing ecosystem conditions and requirements should be part of ecosystem management (Risser 1999).

The intent of the Ecosystems Approach to landscape management is to maintain or enhance ecosystem processes to preserve ecological integrity, which is the ability of the ecosystem to absorb change without being permanently altered (Kay and Schneider 1994; Christensen et al. 1996). The method seeks sustainability by avoiding thresholds of change that result in a deterioration of ecological integrity. This process requires a biophysical understanding of the ecosystems in question as well as an understanding of the social, political, and economic dimensions that drive demands for alternative uses and establish a framework for governance of the systems. A collaborative and transdisciplinary process engaging knowledge bases from lay as well as expert perspective integrates these understandings in the generation of spatial scenarios

Table 1. Classification of Ecosystem Services (after de Groot et al., 2010b)

Ecosystem Service category	Main service types
Provisioning services	Food (e.g. fish, game, fruit) Water (e.g. for drinking, irrigation, cooling) Raw materials (e.g. fiber, timber, fuelwood, fodder, fertilizer) Genetic resources (e.g. for crop-improvement and medicinal purposes) Medicinal resources (e.g. biochemical products, models and test-organisms) Ornamental resources (e.g. artisan work, decorative plants, pet animals, fashion)
Regulating services	Air quality regulation (e.g. capturing fine dust, chemicals, etc.) Climate regulation (including carbon sequestration, influence of vegetation on rainfall, etc.) Moderation of extreme events (e.g. storm protection and flood prevention) Regulation of water flows (e.g. natural drainage, irrigation and drought prevention) Waste treatment (especially water purification) Erosion prevention Maintenance of soil fertility (including soil formation) and nutrient cycling Pollination Biological control (e.g. seed dispersal, pest and disease control)
Habitat services	Maintenance of life cycles (including nursery services) Maintenance of genetic diversity (especially through gene pool protection)
Cultural and amenity services	Aesthetic information Opportunities for recreation and tourism Inspiration for culture, art and design Spiritual experience Information for cognitive development

of intended futures. The Ecosystem Approach stresses the need for adaptive management and governance as a basis for maintaining ecological integrity (Kay et al. 1999; Christensen et al. 1996).

Ecosystem Services

Ecosystem services are the material and immaterial goods, services, and benefits that people receive from functioning ecosystems (Wiggering et al. 2006; Termorshuizen and Opdam 2009; Selman 2012). They include services that are necessary for our survival, such as climate regulation, water purification, and pollination, as well as those that enhance our wellbeing, such as aesthetics (Kremen 2005).

The Millennium Ecosystem Assessment (MEA) (2005) provided a typology of ecosystem services, dividing them into provisioning, regulating, supporting, and cultural services. Provisioning services are ecosystem goods and services that provide direct utilitarian value to people and include fuel, timber, medicinal resources, and potable water. Regulating services include climate regulation, regulation of air quality, erosion control, and water purification. Supporting services maintain the production of other services and include soil formation and oxygen production. Such services are also referenced as habitat services (de Groot et al., 2010b). Many cultural services provide non-material benefits such as cognitive functioning, recreation, and aesthetic experience (Hassan, Scholes, and Ash 2005; Millennium Ecosystem Assessment 2005). (Table 1).

The Ecosystem Services Approach

In addition to identifying a method for assessing ecosystem services, the Millennium Ecosystem Assessment report established an Ecosystem Services Approach to landscape design, planning, and management. As does the Ecosystem Approach, from which it evolved (Haines-Young and Potschin 2009), the Ecosystem Services Approach engages stakeholders and experts in two aspects: a) assessing user needs for both ecosystem services and human well-being; and b) developing future options that deliver ecosystem services to fulfill identified human needs. The process involves four stages. The exploration, design, and implementation stages yield possible alternative futures, which are subject to expert peer review and stakeholder response in the review stage. In the design stage, governance,

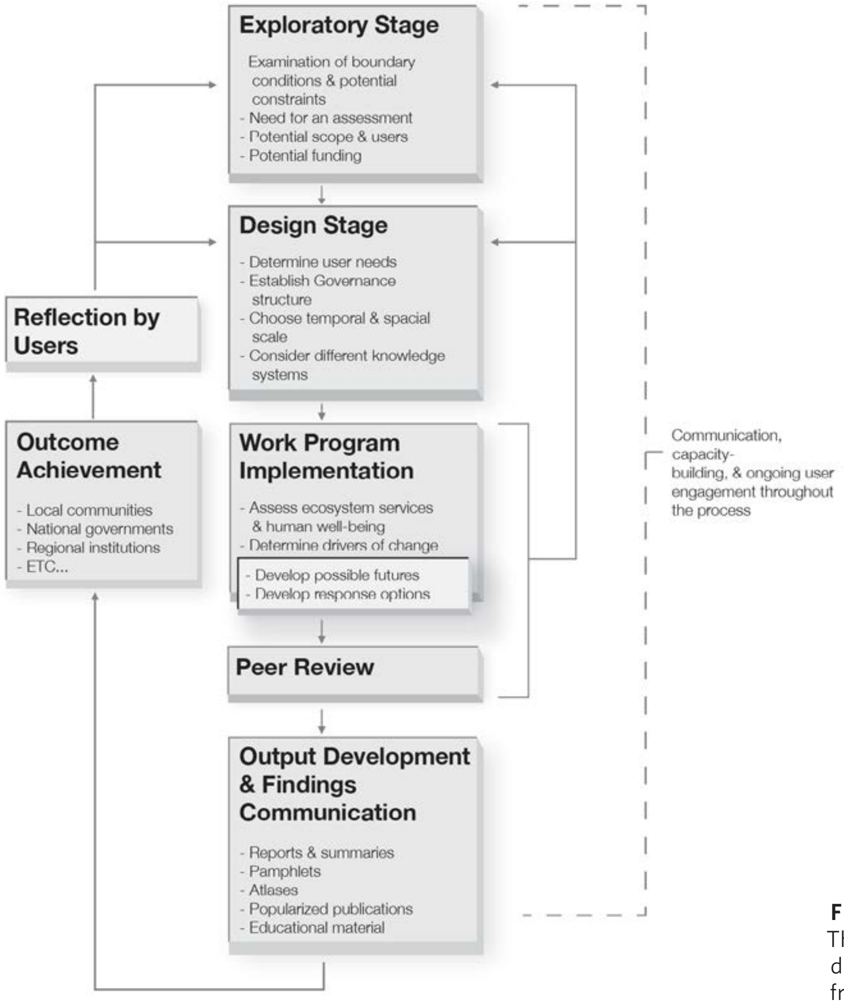

Figure 1
The Ecosystem Services Approach to landscape design, planning, and management (adapted from Ash et al., 2010).

which often consists of a technical steering committee, is established, and all stages involve continuous stakeholder engagement (Figure 1). The final phase focuses on communicating outcomes of the ecosystem assessment process to stakeholders and institutions at multiple levels of governance.

The Ecosystem Services Approach encourages the adoption of institutional policy and management frameworks that foster, maintain, and enhance positive synergies between multiple ecosystem services (Millennium Ecosystem Assessment 2005). It differs from the Ecosystem Approach in the use of ecosystem services to: a) assess the contribution of landscape to human well-being; and b) to develop and evaluate the performance of alternative land use scenarios. Comparative evaluation of scenario performance is based on the array of ecosystem services that will be delivered by each scenario. The Ecosystem Services Approach assumes that highest levels of sustainability will be provided by landscapes that maximize production of ecosystem services. The range and magnitude of ecosystem services delivered by a landscape indicates its overall health and value. Multifunctional landscapes include those that provide multiple ecosystem services.

SUSTAINABLE APPROACHES TO LANDSCAPE DESIGN AND PLANNING

Sustainable Landscape Planning

Landscape planning is defined as a "process of choice based on knowledge about people and land" (Steiner 1991, 520) for the attainment of sustainable use of natural and cultural resources (Ahern 1999). Substantive theories derived from social and natural science research inform planners about relationships between cultural and natural processes as well as the implications of planned interventions in landscape structure

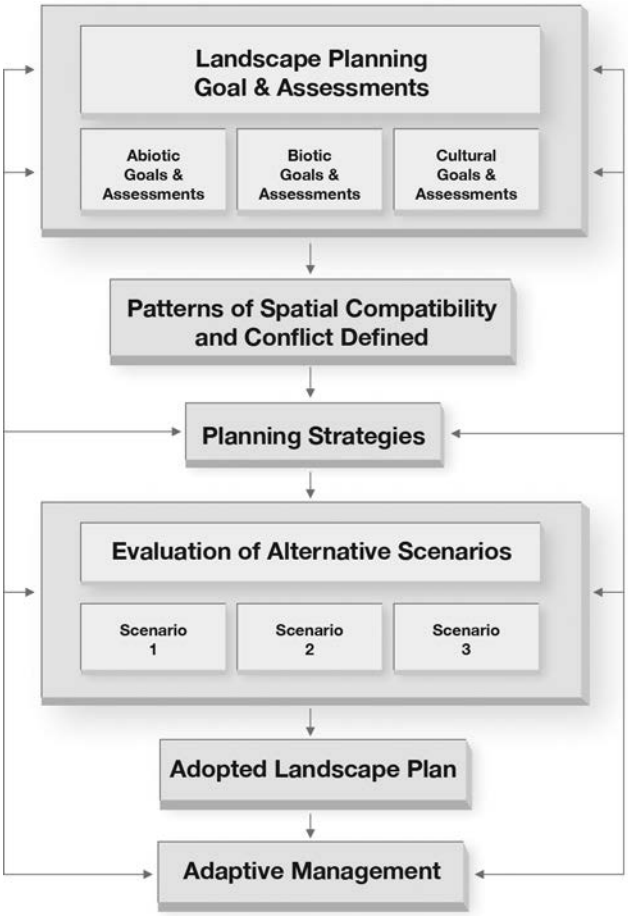

Figure 2
A Framework Method for Landscape Ecological Planning (adapted from Ahern, 2006).

on maintenance of ecological process. Procedural theories also inform the definition and operation of the planning process (Ahern 2006).

In a review of planning methodology, Ahern (2006) compared three widely known planning methods: his own method for landscape ecological planning (Figure 2), Steiner's ecological planning model, and Steinitz's method for landscape planning (Ahern 2006; Steiner 1991; Steinitz 1995). The three methods incorporate substantive knowledge derived from the humanities and natural and social science research, including island biogeography, landscape ecology, meta-population dynamics, and human ecological theory (Steiner 1991; Ahern 2006; Mörtberg, Balfors, and Knol 2007). Application of this substantive information varies, depending on the overarching goals of the planning exercise. Substantive theory derived from the natural sciences, such as island biogeography and meta-population dynamics theory, could inform conservation or regional planning that attempted to maximize biodiversity or plan for survival of an endangered species. A landscape planner might use human ecological theory to support an emphasis on meeting human needs while also maintaining ecological integrity.

Landscape planning methodology readily incorporates new understandings of landscape processes, and it is adaptable across differences in scales and intended outcomes. Landscape planning methods advocated by Ahern, Steiner, and Steinitz use a defined but flexible method, address multiple goals related to natural and cultural processes, are transdisciplinary, evaluate alternative future spatial scenarios, and are adaptable in multiple contexts. In addition, Ahern advocates the use of adaptive management to implement landscape plans.[1] Such an approach allows management strategies to change with the availability of new knowledge concerning landscape characteristics and performance

Table 2. Attributes of Sustainable Landscape Planning

Its purpose is to foster sustainability.
It is informed by substantive and procedural theories.
It requires the simultaneous achievement of multiple abiotic, biotic, and cultural goals.
Planning is becoming more interdisciplinary and transdisciplinary. Thus, academics, the public, stakeholders, and professional experts are all involved in landscape planning decision making.
Its outcomes include spatially defined alternative future scenarios.
The method should be flexible and adaptive to different situations, goals, and scales.
It will increasingly incorporate methods of adaptive landscape management to achieve its ends.

or changes in the geographic scale of concern or intended outcomes of management.

Among the three methods, Table 2 summarizes the commonalties that Ahern argues are necessary attributes of sustainable landscape planning.

From Sustainability to Adaptive, Regenerative, Resilient, and Multifunctional Landscapes

There is no widely accepted definition of sustainability in research and practice, and the term is suspect in many forums. In landscape planning and design, function, performance, and sustainability have been interpreted and variably applied in different jurisdictions and at different scales (Musacchio 2009). The applications have generally been defined in the context of the Brundtland Commission Report (World Commission on Environment and Development 1987) admonition to provide "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs." Additionally, sustainability seldom inspires design (Steiner 2013). Hence, the concept of sustainability has never been widely adopted within the landscape architecture community (Meyer 2008).

In the face of responding to climate change, society is now in a period characterized by: global ecosystem decline, growth in population and urbanization, and increasing demands for food, water, and energy (Beddington 2009). The recognition that landscape reflects the inextricable coupling of human and natural systems (Liu et al. 2007) requires a shift in emphasis from sustaining a steady state to one of adaptation and the fostering of resilience in the face of change. Sustainability has become redefined as creating and maintaining resilience, or the adaptive capacity of landscapes to maintain themselves in the face of change in underlying natural or human systems (Gunderson and Holling 2001).

Human systems generate demands for manipulation of landscape structure that is actuated through design, planning, and management. Human induced changes in landscape structure affect resilience of natural system functions, processes, and outcomes in both positive and negative ways. They may lead to the enhancement or diminishment of a landscape's capacities for regeneration. In turn, structural changes that enhance resilience of these functions, processes, and outcomes may inform opportunities for design, planning, and management. Measuring the impacts and effects of these reciprocal relationships between human and natural systems in a changing landscape requires a systematic means of evaluating feedback between the systems. In other words, creating self-renewing, regenerative landscapes that enhance resilience of biophysical systems in the landscape and generate human well-being, including enhanced aesthetics (Steiner 2013), requires a means of measuring and evaluating performance of both human and natural systems in the face of change that is the eventual product of design, planning, and management.

The array and magnitude of ecosystem services, be they provisioning, regulating, habitat or supporting, or cultural, that emanate from a planning recommendation become metrics for measuring landscape performance. Modeling the potential range and magnitude of ecosystem services that might be delivered by a landscape design and planning scenario holds the promise of creating an adaptive design process that operates *a priori* to implementation of the scenario. Comparative *a priori* evaluation of ecosystem services likely to be delivered by a design or planning scenario would serve as a companion to the *post hoc* institution of adaptive management strategies. It would allow stakeholders to render decisions relating to alternative design and planning scenarios that are informed by the ecosystem services likely to be produced by each scenario.

Application of the Ecosystem Services Approach to Design and Planning of Sustainable Multifunctional Landscapes

The advent of sustainability science in the early 2000s made apparent the need to understand the effects of human interventions on ecosystem functioning. Integrating these understandings into the design and planning of landscapes for intentional human use pointed to the need for explicit measurement of these effects (Musacchio 2009). This led to the development of a wide range of performance indicators for use in evaluating delivery of ecosystem services in designed landscapes. It also suggested the redefinition of sustainable landscapes as those that are multifunctional and capable of delivering a multitude of ecosystem services (O'Farrell and Anderson 2010). The heterogeneity required to deliver diverse services suggests that multifunctional landscapes also possess high resilience (Liu et al. 2007). Ecosystem services are now increasingly used as the metric of both multifunctionality and sustainability (Selman 2012).

Systems to evaluate the array and magnitude of ecosystem services emanating from the implementation of landscape design and planning proposals evolved in response to the desire of landscape architects and allied professionals to enhance the multifunctional performance of their work. The two most widely used systems for this are the Sustainable Sites Initiative (SITES) (Sustainable Sites Initiative 2009a, 2009b, 2013) and the Landscape Architecture Performance Series (LAPS), developed by the Landscape Architecture Foundation (Landscape Architecture Foundation 2012). SITES was developed by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and other partner and stakeholder institutions to foster sustainable landscape design, construction, and management (SITES 2009a). It is similar to the LEEDS (Leadership in Energy and Environmental Design) program developed by the US Green Building Council and is intended to provide standards for sustainable landscape design (Brown and Mooney 2013). One of its stated purposes is to "restore or enhance the ecosystem services" in built landscapes (SITES 2009b, 5). It uses a rating system to award points for 15 required and 51 additional best design practices for enhancing delivery of ecosystem services. While the practices used in the SITES and LAPS programs are based on the prospective delivery of ecosystem services, SITES measures the intent of designers and planners to create multiple ecosystem services as a product of design implementation. While the LAPS program espouses use of metrics emanating from heuristic or stochastically based performance modeling, the link between a design practice and the delivery of its associated ecosystem services is often not explicitly apparent. In addition, in neither SITES nor LAPS is there a basis for identifying and selecting those ecosystem services that necessarily attend to the specificity of program and biophysical characteristics of site or stakeholder and institutional considerations existing in a given locale.

The spate of literature following publication of the MEA advanced the use of ecosystem services in research and their application as performance indicators in designed landscapes (Termorshuizen, Opdam, and Van den Brink 2007; Lovell and Johnston 2009; Sustainable Sites Initiative 2009a). Multiple authors have since attempted to incorporate ecosystem science as well as ecosystem services into landscape planning and design (Nassauer and Opdam 2008; Lovell and Johnson 2009; Musacchio 2009; Termorshuizen, Jolande, and Opdam 2009; de Groot, et al. 2010a; O'Farrell and Anderson 2010; Wu 2010). A broad range of individuals, stakeholders, and institutions is espousing a requirement that designed landscapes be multifunctional and capable of delivering diverse ecosystem services (Termorshuizen, Jolande, and Opdam 2009).

Difficulties in Applying the Ecosystems Services Approach to Landscape Design and Planning

Designed landscapes include those that have been altered spatially or functionally to achieve human benefits (Musacchio 2009). Examples include urban and suburban areas, parks of varying sizes and use intensities, and agricultural areas. The execution of design interventions to accommodate human function may either increase or decrease the range of ecosystem services provided by a designed landscape. For example, agricultural areas based on a monocultural cropping system may adversely affect ecosystem services related to regulation of hydrologic flows and water quality as well as delivery of supporting services relating to soil formation and biological diversity. The implications of specific design or planning actions on enhancing landscape resilience and multifunctionality can be assessed by measuring the array and magnitude of services that will emanate from a specific design or plan. However, the use of the ecosystem services approach to assess, plan, design, and manage landscapes is fraught with problems. These include:

- Managing ecosystem services is as difficult as managing ecosystems, and competence is lacking in that domain (Kremen 2005);

- No coherent, integrated approach to the practical application of ecosystems services in landscape planning, management, and design is yet available (de Groot, et al. 2010a , 260);

- As developed by the MEA, the ecosystem services approach is prohibitively costly, in both time and money, and requires transdisciplinary expertise;

- The MEA decision to define both the processes and functions of ecosystems and the goods and services they produce as ecosystem services is confusing and hampers application (de Groot and Hein 2007). This problem has been partially solved by the cascade diagram developed by Haines-Young and Potschin (2010) and adopted by The Economics of Ecosystems and Biodiversity (TEEB) initiative (Kumar 2010, de Groot, et al. 2010). The cascade diagram clarifies that ecosystem functions and processes produce the ecosystem services that benefit people. As illustrated in Figure 3, in a designed landscape the ecological structure (or design action) might be creation of a rain garden, the process might be purification and infiltration of stormwater runoff, and the service might be improved marine habitat with the benefits to the public being health and food;

- The existing typologies for cultural services have been very general in nature. Broad terms, such as opportunities for recreation and cognitive development, fail to recognize many of the cultural benefits of designed landscapes (Brown and Mooney 2013);

- The application of ecosystem services has mostly been done in large and less developed landscapes. The measurement of the ecosystem services in smaller, more disturbed landscapes and in designed landscapes is not yet clear. Assessment methods need to be suitable for the scale, ecosystem processes, and landscape type to which they are applied (Millennium Ecosystem Assessment 2003).

THE ECOSYSTEM SERVICES EVALUATION MATRIX AS A BASIS FOR LANDSCAPE AND SITE SCALE PLANNING AND DESIGN

This section develops an Ecosystem Services Evaluation Matrix as a means of identifying and evaluating the ecosystem services to which planners and designers should attend in specific settings and with a specific set of design program objectives. It recognizes and has the capacity to respond to the social and institutional environment within which the design is pursued. This section discusses the matrix in terms of its conceptual basis, development, and use in specific design settings. A subsequent section of the paper examines use of this Matrix in three design studies at multiple scales.

Conceptual Basis of the Matrix

The author hypothesized that the difficulties inherent in incorporating ecosystem services into landscape planning and design could be overcome by itemizing the range of services that might be incorporated into existing planning and design processes. The hope was that by assisting practitioners in identifying and evaluating the ecosystem services of either existing or proposed landscapes, planners and designers would be more inclined to incorporate and maintain a broader range of ecosystem services in their work.

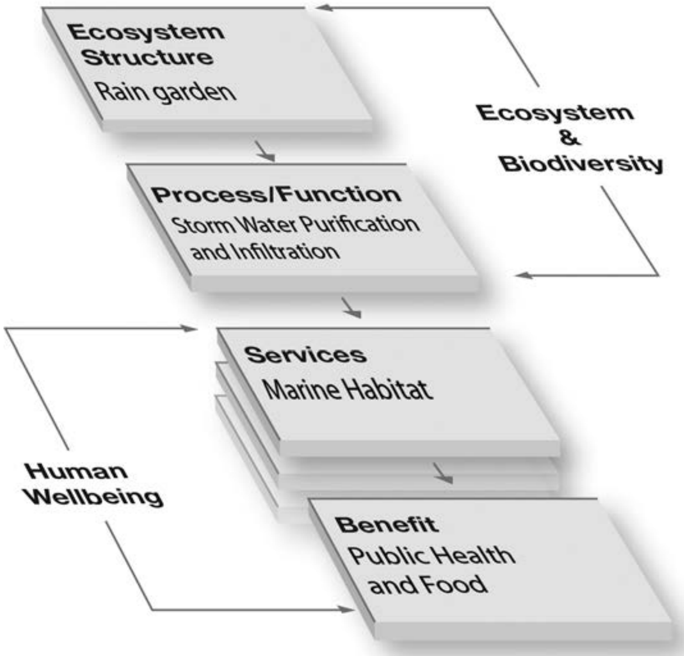

Figure 3
Cascade Diagram showing the relationship of ecosystem structure, functions, services and benefits (adapted from Haines-Young and Potschin, 2010).

Use of the Ecosystem Services Evaluation Matrix allows planners and designers to identify, in conjunction with key stakeholder groups, the nature of ecosystem services to which attention must be directed. Identification of key services is based on the social and institutional context in which the design has been proposed as well as the biophysical and programmatic characteristics of the spatial setting to be created. The matrix is based on the topology of ecosystem services initially developed in the MEA (Millennium Ecosystem Assessment 2005). However, the range of ecosystem services actually examined in a particular design situation is negotiated in conjunction with an array of key stakeholders after careful evaluation of the biophysical and socio-cultural characteristics of the site as well as the programmatic objectives of the design. One evaluates resiliency and multifunctionality of the designed site based on the array and magnitude of relevant ecosystem services that are delivered. In using the Matrix, relevancy of ecosystem services to a design is defined on the basis of social, institutional, and stakeholder perspectives, biophysical and socio-cultural dimensions of the setting, and programmatic objectives of the proposed design. A feedback mechanism exists such that determination of ecosystem service relevancy in a given setting may also alter the definition of the design program that may necessitate revisions in the range of services to be considered.

Development of the Matrix

Development of the Ecosystem Services Evaluation Matrix evolved from a study of the ecosystem services provided in the Southeast False Creek Community (SEFC) in Vancouver, Canada. Based on The Economics of Ecosystems and Biodiversity (TEEB) Manual for Cities (TEEB 2011, 17), the author developed a checklist of questions that may be used to identify existing ecosystem services provided by the site. Individuals possessing local and expert knowledge evaluated these questions in personal interviews and stakeholder workshops conducted by the author.

Identification of a candidate ecosystem service triggered conduct of on-site surveys and literature reviews as well as review of project drawings to further refine and support its inclusion in the list of ecosystem services for SEFC. Because ecosystem services are highly specific to site characteristics and design program objectives, fixed guidelines or checklists such as the Matrix, *per se*, are insufficient tools for assessing ecosystem services. Engagement with a variety of knowledgeable stakeholders who contribute substantive expert and local knowledge is necessary to reveal priorities among the ecosystem services that flow from a given designed landscape.

Conduct of a wider literature review also facilitated expansion of the site–level cultural services category of ecosystem services as defined in the MEA (Millennium Ecosystem Assessment 2005) that certain types of landscapes can provide. Multiple cultural ecosystem services were recorded for urban parks, urban street trees, forests, grasslands, wetlands and riparian corridors. In compiling this list of cultural services for urban areas, it became apparent that one may qualitatively infer an ecosystem service from the presence of a particular landscape type or attribute. For example, peat bogs sequester high levels of carbon (Strack 2008) and riparian corridors are critical habitats for a wide variety of vertebrates (Ewing and Hodder 1998). Relying on the inferred presence of an ecosystem service based on literature citations from other similar sites is critical to the application of the matrix to a particular site.

The literature review examined the MEA and the TEEB methods that were used in developing a more detailed typology of ecosystem services (Millennium Ecosystem Services Assessment 2005; de Groot, et al. 2010b). The Ecosystem Services Evaluation Matrix integrated these two typologies for use at the site scale (Tables 3, 4, 5). The categories and types of ecosystem services in the evaluation matrix reflect an application at the site scale. For example, existing ecosystem services typologies list climate regulation and modification of extreme weather events as ecosystem services. At the site scale, weather related ecosystem services might include compensation for summer drought or microclimatic modification.

The typology of ecosystem services used in the evaluation matrix also differs from existing typologies in the category of cultural services. The physical and mental health benefits that urban dwellers receive through contact with urban green spaces, including social cohesion and sense of identity, are widely documented (Frumkin and Louv 2007; Kuo 2010). Aesthetic response, recreation, and property values are also important ecosystem services that may be found in constructed landscapes (Konijnendijk et al. 2013). These and other research reports helped define the cultural services included in the evaluation matrix.

The Role of Biodiversity

Biodiversity, although not an ecosystem service, plays a significant role in the provision of those ecosystem services that flow from the interactions of living organisms and their environment (Haines-Young Potschin 2010). Research supports a clear linkage between biodiversity and supporting and regulating ecosystem services (Balvanera et al. 2006). For example, bioproductivity, or primary productivity, is an important supporting ecosystem service that has been shown to be highly related to biodiversity (Costanza et al. 2007). A more productive forest would have higher precipitation interception and infiltration and could have better flood control services (Haines-Young Potschin 2010). Thus, loss of biodiversity in the forest might also reduce its bioproductivity and flood control ecosystem services.

As the threshold at which declining biological diversity produces a collapse of a particular ecosystem service is unknown, it is in society's collective self-interest to maintain biological diversity (Kremen 2005). For these reasons, biological diversity and ecosystem services are both components of the Matrix and are considered in each of the case studies.

Use of Matrix to Evaluate a Specific Site

The Ecosystem Services Evaluation Matrix used in the following case studies is a conceptual approach used to identify the ecosystem services of three existing landscapes and to propose design, planning, and management policies to sustain or enhance those ecosystem services. The matrix used in the three case studies provides a model for use in other studies. Modifications of the matrix and specific information for using the matrix may be gleaned from The Economics of Ecosystems and Biodiversity (TEEB) Manual for Cities (TEEB 2011) as well as assessment manuals created by Ash et al. (2010) and Karieva et al. (2011). The examples documented in the Landscape Architecture Foundation's Landscape Performance Series (LPS) may also be helpful (Landscape Architecture Foundation 2012).

The matrix can be completed by an individual. Ideally, it would involve interviewing experts from different disciplines, the project's designers, and public officials, as well as engaging relevant stakeholders. Other supporting materials such as site surveys and project design drawings are useful in documenting the existence of nominated ecosystem services. Initial completion of the matrix could involve conducting workshops with local experts and stakeholders.

Following preparation of a first draft of the matrix, a literature review of the nominated ecosystem services (possibly including references cited earlier in this article) is useful in documenting the decision to include a particular ecosystem service in the Matrix. Ecosystem services for which no satisfactory empirical evidence or scholarly citations supporting their inclusion should be omitted from the Matrix. It is useful to include the full range of project stakeholders in selecting services listed on the Matrix.

Qualitative versus quantitative evaluation. Unlike the LPS, which seeks quantitative evaluation of ecosystem service presence (Myers 2013), in using the Matrix, documenting the presence of ecosystem services may involve both quantitative and qualitative means. In some of the case studies, such as the Southeast False Creek Community case (SEFC), ecosystem service evaluation relied heavily on quantitative performance evaluation tools. In contrast, in the Riparian Corridors in the Fraser River Valley (FRC) case, the nominated ecosystem services were confirmed only through literature review of studies conducted in similar ecosystem types.

The application of the method for evaluating ecosystem presence in the Ecosystem Services Evaluation Matrix accepts the use of both qualitative and quantitative findings, adapting the level of certainty to the available resources. The premise is that it is more important to identify the existence of a particular ecosystem service than to omit it simply because it cannot be fully quantified. Acceptance of this limitation is due, in part, to the desire to enable landscape practitioners to incorporate more ecosystem services into designed landscapes without using a process as cumbersome and expensive as the Ecosystems Services Approach. Where site conditions have been quantified, for example the number of street trees is known, quantitative performance indicators may be used. Where there is little such information, for example the breeding season bird count for the area is not known, a more qualitative method of assessment can be applied. In using the matrix to evaluate ecosystem services in the three case study landscapes, the absence of a particular ecosystem service is indicated by the entry of "None" in the pertinent matrix.

Importance of the Ecosystem Service. The Matrix for each case study (see Tables 3, 4, and 5) includes a column headed "The change in the ecosystem service in this study" in which a rating of high to low is given. This rating indicates the relative enhancement of each ecosystem service in a particular case. In evaluations for the SEFC (Table 3) and the Fisherman's Wharf Park (FWP) (Table 4) cases, ratings in this column represent an estimate of the degree of change in each ecosystem service included in the matrix. In the Riparian Corridors (FRC) case presented in Table 5, ratings in this column represent the services that would be supported by an intact riparian corridor.

APPLICATION OF THE ECOSYSTEM SERVICES EVALUATION MATRIX

Development of the Ecosystem Services Evaluation Matrix focused on identifying a broad range of ecosystem services in designed landscapes. Demonstration of this capacity is examined in this section by applying the matrix to each of three case studies of designs in Canada. The case studies were selected from a pool of over 100 such studies conducted as part of an earlier evaluation (Brown and Mooney 2012). The three selected cases reflect variability in scope and completeness. All three cases consider landscape management, the application of best practices for sustainability, and the relationship between those practices and ecosystem services. To illustrate the versatility of the Matrix in application, the three examples include disparate contexts, design programs and site conditions and sizes ranging from the agricultural landscape to an inner city brownfield.

The cases incorporated use of a full range of case study methods, (Preiser, Rabinowitz, and White 1988; Francis 1999) including site observations and surveys, stakeholder interviews and workshops, interviews

Figure 4
Aerial view of the southeast False Creek Community, showing green roofs, the community center and plaza in the center, the continuous waterfront walkway, with Hinge Park and the habitat island in the upper photo.

with project designers and biologists, review of project drawings supplied by project firms and development of specific performance measurement tools.

Case One: Southeast False Creek Sustainable Community

Southeast False Creek (Figure 4) is a new LEED Platinum certified community, situated on a former brownfield, adjacent to the central business district in Vancouver, Canada (City of Vancouver Mayor 2012).[2] When complete in 2020, the development will contain more than 1.5 million square feet of built space and house 11,000 to 13,000 people. The site will contain 10 hectares (24.7 acres) in public parks and a public waterfront walkway to make the entire waterfront accessible to pedestrians.

This case evaluated the first phase of the development, which contains 7 hectares (17.3 acres) of the 32 hectare (79 acre) site. Working with the landscape architecture firm of PWL Partnership, designers of the site's public realm, best practices related to landscape design were evaluated as generators of ecosystem services using the Ecosystem Services Evaluation Matrix.[3] The process included interviewing the lead landscape architect, review of the City of Vancouver's web resources and related literature (City of Vancouver 2007; City of Vancouver 2013; Bayley 2014), survey and mapping of site habitats, interviews with the biologist monitoring the adjacent marine habitat, calculating the percentage of native plants used, and calculating CO_2 sequestration, pollution removal, and oxygen production for all street trees over their expected lifespan. Overall ecosystem services of the site are shown in Table 3.

Vancouver's vision, as specified in the SEFC Official Community Plan, was to create "a place where people, live, work, play, and learn in a neighborhood designed to maintain and balance the highest possible levels of social equity, livability, ecological health and economic prosperity" (Bayley 2014). The following material discusses these services under the general headings of the livable neighborhood, carbon sequestration, enhancements of site habitats and biodiversity, and the cultural landscape.

The livable neighborhood. Several ecosystem services are provided pertaining to enhancement of livability in the SEFC project. These include the opportunity for increased active living, enhanced social equity, provision of recyclable gray water and regulation of water quality, and regulation of air quality.

Increased active living. The SEFC project is a transit-oriented, high density development with pedestrian and cycle connectivity to transit and to the mixed-use commercial and civic center. A fine-grained network of on-street and off-street sidewalks and narrow, pedestrian-friendly streets support a walkable neighborhood. In addition to biking and walking, alternative transit modes include streetcar, bus, monorail, and pedestrian/bike ferry.

This transportation network produces a highly walkable neighborhood that enhances the realization of healthful benefits associated with active living (Cook et al. 2013). As evidenced in on-site observations in the summer of 2012, the site is intensively used by a wide demographic of ages and ethnicities. Numerous opportunities for cycling, walking, kayaking, park use, and socializing exist in the public realm. The community provides extensive access to attractive water views from its park, community center plaza, and seawall walkway. Vancouver is experiencing increased bicycle tourism, and the public seawall is an important destination for cyclists in the city (Duncan 2012).

Enhanced social equity. The twenty percent of the housing units in the SEFC that will be subsidized for low income households and the community garden on the site support provision of cultural ecosystem services relating to social equity.

Regulation of water flows. The landscape design also incorporates extensive water management strategies. Collection of precipitation from rooftops in underground cisterns provides water for toilet flushing as well as for high-efficiency drip irrigation of specific ornamental plantings. Native plants and/or drought tolerant plants are used to reduce water demand. Stormwater is filtered in wetlands and/or bioswales before entering the ocean inlet that is False Creek. As all irrigation water is collected on-site, this landscape is a net-zero water landscape.

Regulation of air quality. Generally, street trees in the City of Vancouver are planted in 1.8 m^3 (64 ft^3) of soil. The City reports that these trees survive an average of 13 years and achieve a minimal tree canopy. Through the use of soil cells, the landscape architects were able to increase the available soil volume per tree to 19.6 m^3 (692 ft^3) and extend the lifespan of the trees to 50 years (Long 2012), dramatically increasing the ecosystem services of carbon sequestration, air pollution removal and oxygen generation by each tree.

Trees remove both gaseous and particulate air pollutants. Gaseous pollutants enter the leaf via the stomata during photosynthesis and may be adsorbed or interspersed in intercellular spaces. Particulate pollutants are intercepted by the plant surface and held until they are removed by wind or rain or they drop to the ground as leaf- and twig-fall. Pollutants removed by trees include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter less than 10 μm in diameter, with the greatest reductions occurring in particulate matter, ozone, and sulfur dioxide (Nowak, Crane, and Stevens 2006).

Since pollutant removal increases with leaf area (Bolund and Hunhammar 1999), older, larger trees with larger total leaf area will deliver greater benefits than younger, smaller trees (Beckett, Freer-Smith, and Taylor 2000; City of New York Parks and Recreation 2014). The leaf area of a tree may be estimated by multiplying the area of the tree canopy by 4. Where r = the radius of the tree canopy, the leaf area of a tree may be calculated as $4\pi r^2$ (Coder 2014). Using this formula, the leaf area of a 50 foot diameter tree canopy is 2.77 times greater than that of a tree with a 30 foot diameter canopy. The older tree has proportionally 2.77 times more capacity to generate oxygen, remove pollutants, and absorb CO_2.

Trees having stem diameters of less than 8cm reduce air pollution by 0.02 kg/yr. (Nowak 1994). Using this figure for young trees and multiplying by 2.77 for mature trees, the average pollution removal of a single tree over its lifetime is:

$$\text{(Benefit of Year One + Benefit of Year Fifty)}/2 \times \text{Years lived}$$

$$= (0.02\text{ kg} + (0.02 \times 2.77))/2 \times 50\text{ years}$$

$$= 1.88\text{ kg}$$

Thus, the total pollution removal benefit per tree over fifty years is estimated as 1.88 kg (4 lb) and 568 kg (1253 lb) for all 302 street trees onsite over 50 years.

The amount of oxygen produced annually by a tree will vary with the location, size, and health of the tree. Using an average annual oxygen production figure of 118 kg/tree/year (Environment Canada 2014), the amount of oxygen produced on site over 50 years is equal to 118 kg/year × 50 = 5,900 kg per tree or 1,781,800 kg (1964 short tons) of oxygen produced by all 302 street trees over fifty years.

Table 3. Biodiversity and Ecosystem Services of the Southeast False Creek Community (SEFC), Vancouver, British Columbia

Biodiversity and Ecosystem Services of the Site		The change in the ecosystem service in this study	Element(s) Supporting the Ecosystem Service Rationale and supporting citation(s)	Ecological function or landscape element necessary to preserve ecosystem service
Biodiversity				
	Biodiversity (marine and aquatic) Maintain or increase	High	1) Bioswale and wetland 2) Bioswales removing silt and other pollutants. Constructed wetlands are particularly effective in removing pollutants (Wise, et al. 2010). Polluted storm water is harmful to freshwater and marine organisms (Schiff, Bay, and Stransky 2002).	Bioswale and wetland
	Biodiversity (terrestrial)	Moderate	1) Multiple habitat types 2) Research has shown that avian diversity increases with site habitat heterogeneity (Mooney 2011). Ecosystems that support high avian diversity are likely to have higher general biodiversity (Gaston and Blackburn 1995).	Multiple habitat types
Provisioning Services				
	Food	Low	1) Rooftop Gardens and the Community Garden 2) The rooftop gardens and community garden provide local people with organic produce.	Maintain urban agriculture
	Raw Materials	Low	1) Native plants 2) Native plants provide resources that may be used by native peoples for crafts and ceremonies.	Maintain high proportion of native plants
	Fresh water	High	1) Rooftop capture and underground water storage for irrigation 2) This system reduces the per capita potable water use on site.	Maintain water collection and irrigation system
	Medicinal Resources	None	None	None
	Ornamental Plants	None	None	None
Regulating Services				
Climate and Atmosphere	Carbon sequestration and storage	Moderate	1) Site vegetation, especially trees 2) Woody plants sequester significant carbon (Nowak and Crane 2002). Well-designed and maintained constructed freshwater wetlands can provide a carbon sink (Kayranli et al. 2010).	Maintain site woody vegetative cover of all types
	Moderation of Extreme Events	None	None	None
	Pollution Mitigation (Air)	Low	1) Site canopy trees 2) Street trees uptake gaseous and particulate pollutants and all plants release oxygen (Bernatzky 1983).	Maintain site tree cover
	Pollution Mitigation (Water)	Moderate	1) Bioswale and wetland 2) All surface runoff is cleansed in bioswales and the wetland before being released into False Creek (Wise et al. 2010).	Retain and restore bioswales as needed
	Pollution Mitigation (Soil)	None	None	None
	Local Climate and Air Quality regulation	Moderate	1) Neighborhood energy system 2) The neighbourhood is heated with heat extracted from sewage which reduces CO_2 emissions (Bayley 2014).	Maintain community heating system
	Moderation of impacts of weather extremes	None	None	None
Pollination	Maintain or increase pollination	Moderate	1) Native plantings 2) Native plantings support native pollinator species (Morales and Traveset 2009).	Habitat for native pollinators

Hazard Regulation	Reduction in Landslide potential	None	None	None
	Reduced Flooding	None	None	None
	Noise Reduction	None	None	None
	Disease and pest Regulation	None	None	None
Water	Seasonal drought mitigation	High	1) Irrigation system 2) Summer irrigation offsets summer drought.	Maintain irrigation with collected water
	Waste-water Treatment	None	None	None
Soil	Maintenance of Soil Fertility	None	None	None
	Reduced Erosion	None	None	None
Supporting Services				
	Primary Productivity	Low	1) Site vegetation 2) The dramatic increase in vegetative cover of the site will result in increased biomass production (Coastal Carolina University 2014).	Maintain site vegetation of all types
	Preservation and generation of soils	Moderate	1) Leaf litter 2) In many of the plantings, leaf litter will provide organic matter build up in the soil over time (Melillo et al. 1989).	Where possible, allow leaf litter to decay in place
	Nutrient Cycling	Moderate	1) Leaf litter 1) Leaf litter will also provide nitrogen cycling that will increase soil fertility (Melillo et al. 1989).	Where possible, allow leaf litter to decay in place.
	Water Cycling (hydrologic flows)	High	1) Water collection system, wetland and riparian system, bioswale and irrigation system 2) A number of site systems purify, collect and reuse precipitation (Bayley 2014).	Maintain all site water systems
Cultural Services				
	Social Cohesion	Moderate	1) The entire public realm 2) Site is highly used by a wide demographic. On-site observations suggest that this is a result of the site plan and design. Studies have shown that parks moderately support Social cohesion (Peters and de Haan 2011).	The entire publically accessible landscape
	Sense of Identity	None	None	None
	Mental and physical well-being	High	1) The Public Realm 2) Significant access to urban nature will give these benefits (Kuo 2010).	Maintain site plan and design
	Recreation	High	1) The public realm 2) Numerous opportunities for cycling, walking, kayaking, park use and socializing exist in the public realm.	Maintain site plan and design
	Tourism	High	1) Sea Wall public walkway 2) Vancouver is experiencing increased bike tourism. The public seawall is an important destination for cyclists in the city (Alan Duncan 2012).	Public pedestrian and cycle paths especially along the seawall
	Aesthetic Appreciation/ Spiritual/ Religious	High	1) The Public Realm 2) People frequently report a high appreciation of the beauty of nature in urban green spaces (Matsuoka and Kaplan 2008) and a feeling of spirituality or unity with nature (Chiesura 2004).	The Public Realm

Figure 5
The stormwater outflows of these two catchment areas adjacent to Fishermen's Wharf Park are now treated by the large rain garden within the park.

Carbon sequestration. Estimated annual carbon sequestration of medium sized deciduous trees in the Pacific Northwest region is 133.7 kg/yr (295 lb/yr) (McPherson and Simpson, 1999, 174). The street trees on site are deciduous and medium to large in ultimate size. Using the CO_2 sequestration of medium size trees, the 302 trees on site will sequester 2,018,870 kg (2225 short tons/yr) of carbon over their 50-year lifespan.

Enhancement of site habitats and biodiversity. The SEFC site contains native, drought-tolerant plants. They provide increased habitat for pollinators and avian species. In Hinge Park, the waterfront, and the habitat island, the plantings are comprised of 88%, 86%, and 96% native plants respectively. Seven different habitat types, including the habitat island, were identified and mapped in SEFC. Avian diversity is directly proportional with habitat diversity increases, and sites with a variety of habitat types will increase biodiversity (Bolund and Hunhammar 1999; Mooney 2011). The south coast region of British Columbia has more birds than any other region in Canada in winter. Bird counts in downtown Vancouver show a total of 77 species in winter (Nature Vancouver 2012). This represents 16% of the 484 bird species known to occur in British Columbia (Campbell et al. 1990) and is high for an urban center. While summer figures are unknown, the high winter bird counts indicate that the different habitats in SEFC will attract a significant number of bird species.

In 2010, one year after project completion, herring spawned on the shores of the habitat island, after an

80-year absence of spawning in False Creek. Biologists monitoring the False Creek shoreline and waters reported the unusual appearance of a grey whale in 2010 as well as healthy intertidal plant life and shellfish populations and five different species of juvenile salmon in the waters of False Creek (McFarland 2012).

The Cultural Landscape. The Cultural Landscape is comprised of Hinge Park, the waterfront walkway, courtyards, plazas, roof decks, and green roofs of the building sites (Figure 4). These areas provide flexible use, promote social interaction, and give the site a regional identity. Urban agriculture in the community garden and on roof tops supports food production and social interaction. Significant access to urban nature also nurtures mental and physical well-being (Kuo 2010).

Case Two: Fisherman's Wharf Park and Rain Garden, Victoria, British Columbia

Victoria, British Columbia is a popular tourist destination and retirement community due, in part, to its sunny climate characterized by distinct wet and dry seasons. Approximately two-thirds of annual precipitation occurs between November and February, and summers are very dry. Annual precipitation is 158 cm (62 in.).

The Rain Garden. The City of Victoria asked the landscape architecture firm of Murdoch de Greeff Inc., in collaboration with KWL Engineering, to develop a plan to daylight a large storm drain to create a stream flowing through Fisherman's Wharf Park (FWP) and emptying into Victoria Harbor. Site analysis revealed that due to the existing elevations of the stormwater drains, the proposed stream would be at the bottom of a deep and shady ravine, providing little, if any, water-cleansing effect. Murdoch de Greeff therefore proposed that the stormwater flows from two smaller catchment areas surrounding the park (with shallower storm drains) be directed to a large rain garden (352 square metres or 3,789 square feet) within the 1.83 hectare or 4.5 acre park (Figure 5).

Installed in 2012, the FWP rain garden intercepts storm flow from two drains at an approximate depth of 3m. The rain garden treats rainwater runoff from two catchment areas adjacent to the park, totaling 1.42 ha (5.52 ac) of impervious surfaces comprised of roads and buildings.The garden annually treats an estimated 8,500 cubic meters or 2.29 million US gallons of runoff. The rain garden holds standing water for 48–72 hours after rainfall events, and it is dry for most of the summer.

Native plantings. Rain garden plantings thrive under conditions of alternating flood and drought, while remaining attractive throughout the year. They include native *Juncus effusus* (Common Rush), *Myrica gale* (Sweet Gale), and *Cornus stolonifera* (Red Osier Dogwood). These and other native plantings in the park will support terrestrial biodiversity and pollination. Because they are not large and because the surrounding area is densely urban, this contribution was rated as low.

Cultural ecosystem services. Fisherman's Wharf Park and the adjacent Fisherman's Wharf are located near the tourism center of Victoria's Inner Harbor and provide views and public access to the urban waterfront. The park incorporates a variety of use areas, including natural play spaces, unprogrammed active use areas, a contemplative garden and a variety of sitting and viewing locations, while the wharf area contains food outlets, shops and ecotourism businesses, as well as a floating houseboat community. Due to the park's location and the variety of opportunities it offers, it is well-used by both tourists and residents. As a result, FWP provides a number of cultural ecosystem services that accrue from contact with urban green space, including aesthetic experience, support for tourism, recreation opportunities and the physical and mental wellbeing (Table 4).

Evaluation of on-site ecosystem services involved interviews with project designers, review of project drawings, and site observation. The Ecosystem Services Evaluation Matrix developed for FWP identified ecosystem services of the park using both quantitative as well as qualitative methods of accounting. In this example, estimates of stormwater treatment involved use of quantitative modeling. The literature citations provided in Table 4 identified other ecosystem services of the park.

The ecosystem service benefits of the Rain Garden include water cycling and water pollution mitigation. Both of these services promote improved marine biodiversity in the adjacent harbor. The native plantings

Table 4. Biodiversity and Ecosystem Services of Fisherman's Wharf Park and Rain Garden (FWP), Victoria, British Columbia

Biodiversity and Ecosystem Services of the Site		The change in the ecosystem service in this study	Element(s) Supporting the Ecosystem Service Rationale and (supporting citation(s))	Ecological function or landscape element necessary to preserve ecosystem service
Biodiversity				
	Biodiversity (marine) Maintain or increase	Moderate	1) Rain Garden 2) The rain garden will support aquatic life in the harbour (Schiff, Bay, and Stransky 2002; Davis et al. 2009).	Stormwater purification
	Biodiversity (terrestrial) Maintain or increase	Low	1) Native plantings 2) Native planting provide habitat for native species and increase genetic diversity while loss of native vegetation negatively impacts native animal species (McKinney 2002; Burghardt, Tallamy, and Shriver 2009).	Native plantings for habitat
Provisioning Services				
	Food	None	None	None
	Raw Materials	None	None	None
	Fresh Water	None	None	None
	Medicinal Resources	None	None	None
	Ornamental Plants	None	None	None
Regulating Services				
Climate and Atmosphere	Carbon sequestration and storage	Moderate	1) Trees 2) Urban trees sequester carbon (Nowak and Crane 2002).	Plant growth, especially trees
	Moderation of Extreme Events	None	None	None
	Pollution Mitigation (Air)	Moderate	1) Vegetation 2) Trees in urban parks can filter as much as 85% of air pollution (Bernatzky 1983).	Vegetation, especially trees
	Pollution Mitigation (Water)	Moderate	1) Rain Garden 2) The rain garden will capture and treat particulate and dissolved pollutants in the stormwater from the urban catchment area that previously went untreated (Davis et al. 2009).	Stormwater detention and infiltration
	Pollution Mitigation (Soil)	None	None	None
	Local Climate and Air Quality regulation	Low	See pollution mitigation (air) above	Park vegetation especially trees.
	Moderation of impacts of weather extremes	None	None	None
Pollination	Maintain or increase pollination	Low	1) Native plantings 2) Plantings support native pollinator species (Morales and Traveset 2009).	Habitat for native pollinators
Hazard Regulation	Reduction in Landslide potential	None	None	None
	Reduced Flooding	None	None	None
	Noise Reduction	None	None	None
	Disease and pest Regulation	None	None	None
Water	Seasonal drought mitigation	None	None	None
	Waste-water Treatment	None	None	None

Soil	Maintenance of Soil Fertility	None	None	None
	Reduced Erosion	None	None	None
Supporting Services				
	Primary Productivity	Low	1) Park vegetation 2) Since plants are the primary producer of biomass, which is the measure of primary productivity, increasing vegetation in a given area increases the primary productivity of that area (Coastal Carolina University 2014).	Plant growth
	Preservation and generation of soils	None	None	None
	Nutrient Cycling	None	None	None
	Water Cycling (hydrologic flows)	Moderate	1) Rain Garden 2) The rain garden maintains the water flows to the marine environment (Davis et al. 2009).	Rain Garden
Cultural Services				
	Social Cohesion	Moderate	1) The entire park 2) Studies have shown that parks moderately support social cohesion (Peters and de Haan 2011).	The park and its surrounding context.
	Sense of Identity	None	None	None
	Mental and physical well-being	Moderate	1) The entire park 2) Studies have shown that urban green space contributes to mental and physical wellbeing (Kuo 2010; Konijnendijk et al. 2013).	The park
	Recreation	Moderate	1) The entire park 2) Parks support a variety of recreational opportunities. (Weber and Anderson 2010).	The park
	Tourism	Low	1) The entire park 2) The local attractions mean that the park will be frequented by tourists. Urban parks contribute to tourism (Chaudhry and Tewari 2009).	The park
	Aesthetic Appreciation/ Spiritual/ Religious	High	1) The Public Realm 2) People frequently report a high appreciation of the beauty of nature in urban green spaces (Matsuoka and Kaplan 2008) and a feeling of spirituality or unity with nature (Chiesura 2004).	The park

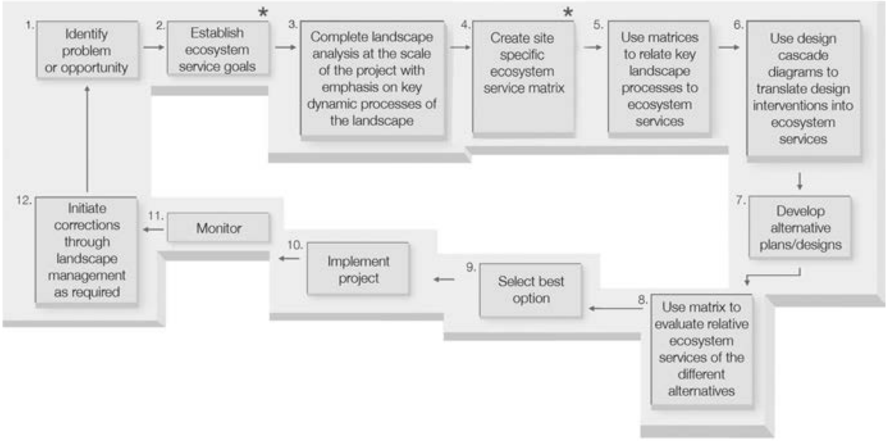

Figure 6
The Ecosystem Services Framework (ESF) for Design/Planning: A process for incorporating ecological services into landscape planning and design (adapted from Steiner, 2008).
*Steps 2 and 4 are key points to establish the range of ecosystem services that may be provided on a given site, to communicate these to the stakeholders and to determine, with the stakeholders, those ecosystem services that will be supported by the design.

in the park improved pollination by providing pollinator habitat. Vegetation in the park increased ecosystem services related to primary productivity, air pollution mitigation, and carbon sequestration while the design and location of the park supported a number of cultural ecosystem services (Table 4).

Case Three: Biodiversity and Ecosystems Services of Riparian Corridors in the Fraser River Valley

The Fraser River Valley is a fertile, agricultural valley east of the Metropolitan Vancouver Region of British Columbia, Canada abutting the United States border. The Fraser River produces some of the world's largest salmon runs and over 50% of the salmon in British Columbia (BC). The land base of the Fraser Valley is less than 5% of the 220,000 square kilometer (85,000 square mile) Fraser River watershed, yet it supports approximately 80% of the Fraser River's total production of commercial salmon stocks (Fraser River Action Plan 1998; Rosenau and Angelo 2005). There is widespread concern that negative effects of farming, such as stream eutrophication and nitrate contamination of groundwater, may be affecting biological diversity in salmonid populations in the Fraser Valley (Berka, Schreier, and Hall 2001; Rosenau and Angelo 2005).

These concerns led to an investigation of the ecosystem services of riparian corridors in the Fraser River Valley with the Fraser Valley Watershed Coalition (FVWC), a local non-governmental organization focused on watershed management. Riparian corridors were selected for review because their contributions to water quality and fish habitat have been well documented (Hanson, Groffman, and Gold 1994; Vought et al. 1994; Bowler et al. 2012). Although corridor quality in the Fraser Valley is considered moderately good overall, it is very poor to absent in some areas due to existing farming practices (Pearson 2012). The FVWC hoped that demonstrating other important ecosystem services of riparian corridors might foster better corridor stewardship and improved aquatic habitat quality. Through a series of four workshops, members of the FVWC identified the ecosystem services presented Table 5.[4]

A literature review validated the extension of many of the ecosystem services nominated though the FVWC workshops to the riparian corridors of the Fraser Valley. Inferences drawn from this review suggested that the corridors help to: a) maintain or increase aquatic and terrestrial biodiversity and provide habitat for native pollinator species (Naiman, Decamps, and Pollock 1993; Ewing and Hodder 1998; Parkyn et al. 2003; Greenleaf and Kremen, 2006; Olson et al. 2007; Bowler et al. 2012); b) supply the services of fresh water (Woessner 2000; Bharati et al. 2002; Lee, Isenhart, and Schultz 2003); c) sequester carbon (Hernandez et al. 2008); d) moderate high winds to protect agricultural crops (Lowrance, Leonard, and Sheridan 1985); e) mitigate air and water pollution (Hanson, Groffman, and Gold 1994; Vought et al. 1994; Nowak, Crane, and Stevens 2006; Lovell and Sullivan 2006; Dobbs, Escoedo, and Zipperer et al. 2011); and f) reduce local flooding (Table 5). The management implication of the case investigation was that maintaining well-vegetated, continuous riparian corridors would support these ecosystem services.

The Fraser River Valley Riparian Corridor case was also informative of how the ecosystem services matrix may be used in a stakeholder or public participation process. Stakeholders helped articulate the ecosystem services that flow from healthy riparian corridors. Thus, developing the matrix with the FVWC helped to define what was possible. The matrix was also used in a daylong workshop with local agricultural producers, the BC Agricultural Research and Development Corporation, and the BC Ministry of Agriculture, where it served as a communication tool to a wider range of stakeholders and fostered discussion of landscape management. The workshop presentations and discussion focused on the statement "Agricultural lands do much more than grow our food. They also provide valuable 'ecosystem goods and services' that serve the local community and society. While clean air, soil, and water, and habitat for fish and wildlife are highly valued, society has not compensated agricultural producers for providing these benefits to society." This workshop led to ongoing discussions between the FVWC, local municipalities, and agricultural producers.

Summary

These three case examples illustrate that use of the Ecosystems Services Evaluation Matrix can reveal the range of ecosystem services provided by a designed landscape. Such a process can also be used to communicate a defensible, evidence-based design process to stakeholders, including politicians and the public.

AN ECOSYSTEM SERVICES FRAMEWORK FOR DESIGN/PLANNING

This section of the article presents an argument for integrating the Ecosystem Services Evaluation Matrix into sustainable landscape planning and design. A sustainable landscape planning and design process that integrates the evaluation of ecosystem services using the Ecosystem Services Evaluation Matrix must be rational and defensible, incorporating both science and critical thinking. It needs to encourage and enable use of the designer's creativity and best professional judgment. It must also be responsive to the conditions and processes found on any site and program. Finally, it must recognize that even small and simple landscape designs have multiple possible outcomes (Lyle 1985) that generate ecosystem services.

The integration of the Ecosystem Services Evaluation Matrix into an Ecosystem Services Framework (ESF) design process for use by design practitioners and decision makers is offered here. This process is flexible enough to incorporate the reality of current design practices and its mechanics are not so cumbersome as to preclude its use. The process makes use of the Ecosystem Services Evaluation Matrix and another tool called the Design Cascade Diagram in a systematic design process (Figure 6). In using this process, the planning problem or opportunity is identified in step 1. The designer or consultant team sets preliminary goals for provision of ecosystem services and conducts a traditional site inventory and analysis suitable to the problem and goals identified in steps 2 and 3. Because the analysis is going to be translated into the language of ecosystem services and since ecosystem services are derived from landscape structure, function, and processes, it is imperative that site processes (for example patterns of surface and subsurface hydrologic flow) be inventoried and assessed rather than simply its elements (for example, soil type). In step 4, the designer determines what ecosystem services are currently available on the site and develops the site's Ecosystem Services Evaluation Matrix as discussed above. This process seeks answers to questions such as what services can be maintained, increased, or added to the site? Both existing and proposed ecosystem services are recorded in the matrix.

As in the Ecosystem Services Approach, it is important to engage stakeholders and/or experts throughout the Ecosystem Framework Process (EFP). The intent is to first involve stakeholders in identifying the range of ecosystem services that may be actuated on a particular site and to invite their participation in determining the services that will be provided. Steps 2 and 4 of the EFP are critical for engaging stakeholders. In step 2, potential goals for the project should be developed with stakeholders through a collaboratively-based public participatory process. The designer should communicate to the public/stakeholders the landscape interventions that will be required to meet these goals and the resultant ecosystem services that are likely to result. The site analysis in step 3 would identify the biophysical structures and processes of the site and the ecosystem services that they deliver. This would allow, in step 4, the refinement of possible ecosystem service enhancements and lead to the joint development, with key stakeholders of a site-specific matrix of intended ecosystem services. Such a process

Table 5. Biodiversity and Ecosystems Services of Riparian Corridors in the Fraser River Valley (FRC) of British Columbia

Biodiversity and Ecosystem Services of the Site		The change in the ecosystem service in this study	Element(s) Supporting the Ecosystem Service Rationale and (supporting citation(s)	Ecological function or landscape element necessary to preserve ecosystem service
Biodiversity				
	Biodiversity (aquatic) Maintain or increase	Moderate	1) Riparian vegetation removes sediment from runoff (Vought et al., 1994) and reduces water temperature supporting fish, amphibians and invertebrates (Bowler et al. 2012).	Riparian Vegetation
	Biodiversity (terrestrial) Maintain or increase	Moderate	1) Riparian Vegetation 2) Riparian corridors are used by approximately 70 % vertebrates (Ewing and Hodder 1998) and support regional biodiversity (Naiman, Decamps, and Pollock 1993).	Riparian Vegetation
Provisioning Services				
	Food	Medium	1) Native and non-native berries 2) Native peoples, the public and professional foragers use this resource (Pearson 2012).	Berry Plants
	Raw Materials	Low	1) Riparian vegetation 2) Foragers use Western Recedar, Thuja plicata for crafts (Pearson 2012).	Riparian Vegetation
	Fresh Water	Moderate	1) Riparian vegetation 2) Streams in riparian corridors contribute significantly to groundwater purification and recharge (Woessner 2000; Lee, Isenhart, and Schultz 2003).	Riparian Vegetation
	Medicinal Resources	None	None	None
	Ornamental Plants	Medium	1) Riparian corridors 2) Nurseries harvest of seeds and plants and take live wood cuttings of willow Salix sp. and Red-osier dogwood Cornus stolonifera (Pearson 2012).	Riparian Vegetation
Regulating Services				
Climate and Atmosphere	Carbon sequestration and storage	Moderate	1) Riparian vegetation 2) Riparian corridors sequester carbon (Hernandez et al. 2008).	Riparian Vegetation
	Moderation of Extreme Events	Moderate	1) Riparian vegetation 2) Riparian areas dissipate wind energy that can damage agricultural land and are sometimes used as windbreaks (Lowrance, Leonard, and Sheridan 1985).	Riparian Vegetation
	Pollution Mitigation (Air)	Low	1) Riparian vegetation 2) Like all woody plants riparian vegetation adsorbs air pollutants (Nowak, Crane, and Stevens 2006).	Riparian Vegetation
	Pollution Mitigation (Water)	Moderate	1) Riparian vegetation 2) Vegetated buffers, like riparian corridors, can remove up to 100% of nitrogen and phosphorus. This effect is increased in wider buffers (Vought et al. 1994).	Riparian Vegetation
	Pollution Mitigation (Soil)	None	None	None
	Local Climate and Air Quality regulation	None	None	None
	Moderation of impacts of weather extremes	None	None	None

Pollination	Maintain or increase pollination	Moderate	1) Riparian vegetation 2) Provides habitat for wild pollinators such as bees and wasps. Pollination services increase in proximity to natural habitats, including riparian areas (Greenleaf and Kremen 2006).	Riparian Vegetation
Hazard Regulation	Reduction in Landslide potential	None	None	None
	Reduced Flooding	Low	1) Riparian vegetation 2) Increasing shade reduces the above ground biomass of Reed Canarygrass, Phalaris arundinacea (Kim, Ewing, and Giblin 2006). This would improve drainage and reduced local flooding (Pearson 2012).	Riparian Vegetation
	Noise Reduction	None	None	None
	Disease and pest Regulation	None	1) Riparian vegetation 2) Pest control by predator species is facilitated by on- farm vegetation around drainages and ponds (Zhang et al. 2007).	Riparian Vegetation
Water	Seasonal drought mitigation	None	None	None
	Waste-water Treatment	None	None	None
Soil	Maintenance of Soil Fertility	None	None	None
	Reduced Erosion	None	None	None
Supporting Services				
	Primary Productivity	Moderate	1) Riparian vegetation 2) Many riparian wetlands have higher rates of primary production than adjacent upland systems (Lowrance, Leonard, and Sheridan 1985).	Riparian Vegetation
	Preservation and generation of soils	Moderate	1) Riparian vegetation 2) Riparian tree roots improve stability of river banks even under worst-case hydrological conditions (Abernethy and Rutherfurd 2000).	Riparian Vegetation
	Nutrient Cycling	High	1) Riparian vegetation 2) Riparian areas have high rates of denitrification and commonly maintain enriched nitrogen zones as sinks for upland-derived nitrate (Hanson, Groffman, and Gold 1994).	Riparian Vegetation
	Water Cycling (hydrologic flows)	None	None	None
Cultural Services				
	Social Cohesion	None	None	None
	Sense of Identity	Moderate	1) Agrarian landscape 2) The physical appearance of the landscape is closely linked to people's sense of their local community and personal identity (Manzo and Perkins, 2006).	Agrarian landscape
	Mental and physical well-being	Moderate	1) Agrarian landscape 2) Direct contact with nature leads to increased mental and physical well-being (Kuo 2010).	Agrarian landscape
	Recreation	Moderate	1) Agrarian landscape 2) The Fraser Valley provides multiple recreation opportunities (Schwichtenberg 2012).	Agrarian landscape
	Tourism	High	1) Agrarian landscape 2) The Fraser Valley contains numerous regional Parks, tourist attractions and events many of most of which are landscape dependent (Found Locally 2014).	Agrarian Landscape
	Aesthetic Appreciation/Spiritual/ Religious	Low	1) Agrarian landscape 2) Forty-five percent of general population said that the beauty of nature had led to an intense spiritual experience (Greeley 1974).	Agrarian landscape

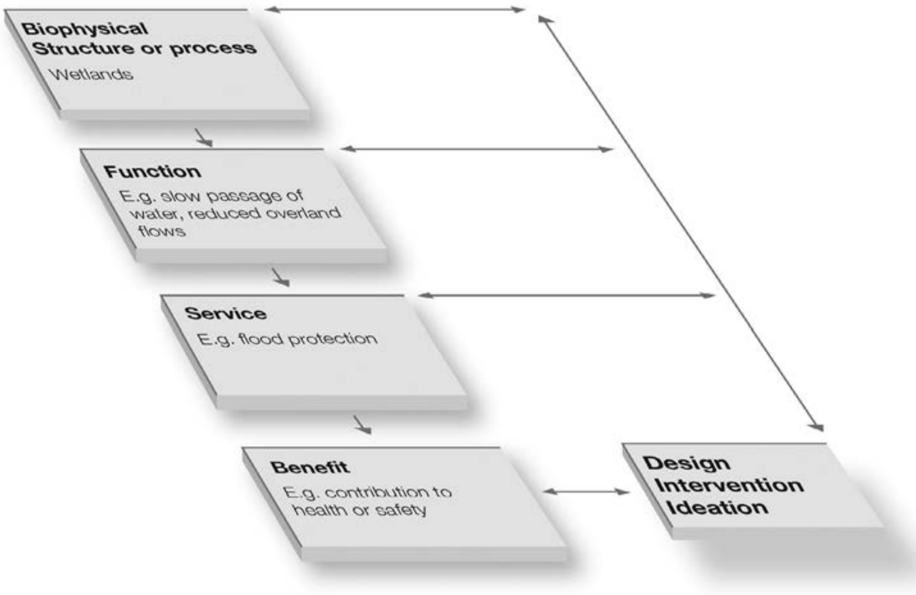

Figure 7
The Design Cascade Diagram can be used to relate design interventions to desired ecosystem services during project programming and design evolution.

must be responsive to the institutional context of the site as well as its biophysical condition. It should enable creation of a design program attuned to the production of multifunctional and regenerative landscapes that are feasible given the biophysical and sociocultural realities of the setting.

In step 5 of the process, the existing and proposed ecosystem services on site are related to specific landscape attributes, such as forest cover, or elements, such as a constructed wetland, and these are added to the Matrix. These relations can then be recorded in a cascade diagram similar to Figure 3. In step 6, the designer proposes design interventions to maintain, increase, or introduce ecosystem services to the site. This process integrates the creative-intuitive mind of the designer with rational site evaluation. The intention is to maximize the range of ecosystem services and make explicit judgments about what is appropriate on the site.

After developing alternative design solutions in step 7, step 8 asks the designer to use a modified cascade diagram of ecosystem services, called the Design Cascade Diagram (see Figure 7) to evaluate which landscape attributes can be manipulated to add or maintain a particular ecosystem service. In this diagram, a new step of design ideation is added to the ecosystem services cascade diagram. The designer develops the design intervention that will yield the desired benefit to people. The use of this method is a form of backcasting[5] where the designer needs to decide what benefits are possible, then backcasts how the structure and function of the landscape could be altered to create these benefits. At that point, the proposed design intervention becomes part of the potential program for the site but is not accepted until step 9 when the best option is selected.

DISCUSSION

There are numerous commonalities in method and intent among the Ecosystems Approach, the Ecosystem Services Approach, and Ahern's framework of sustainable landscape planning. All three methods focus on sustainability. They show a convergence of transdisciplinary development and evaluation of future scenarios, and they all use a form of adaptive management and ongoing development of substantive knowledge. The insertion of ecosystem services into landscape planning and design represents an innovation in the type of substantive knowledge considered in developing designed landscapes.

The case examples and the Ecosystem Services Framework for Design/Planning offered here use a mixture of qualitative and quantitative evaluation of ecosystem services. While services such as carbon sequestration or volumes of water purified were quantified, most of the ecosystem service claims were inferred from expert knowledge and relevant research publications. For example, the habitat values and cultural services of SEFC were inferred and supported by site observation and literature review, but they were not quantified. The method accepts inferred as well as quantified metrics in order to evaluate and incorporate the broadest range of ecosystem services into designed landscapes.

The Ecosystem Services process may be considered an alternative and/or complementary process to the existing LPS methods. The Landscape Performance Series case studies quantitatively evaluate built projects and demonstrate at least one ecological, economic, and social performance benefit (Deutsch 2014). The Ecosystem Services Matrix can be used to rapidly identify and assess a broad range of ecosystems services produced by a built landscape and evaluate them qualitatively or quantitatively. It could be a useful first step in an LPS case study development to identify a broad range of ecosystem services and determine candidate services for quantitative evaluation in the LPS.

The Ecosystem Services Framework for Design/Planning uses the tools of the Ecosystem Services Evaluation Matrix and the Design Cascade Diagram within a systematic process to incorporate the ecosystem services into a proposed landscape design. What is critically different from the SITES method is the Ecosystem Service Framework, which is based on programmatic and site/landscape characteristics. It is site-adaptive and responsive to program objectives rather than being prescriptive. Further, it allows the designer to "think through" the design process, understanding how programmatic concerns and site interventions will influence the delivery of ecosystem services. Conversely, feedback from ecosystem provision can inform development program objectives and the need for specific interventions. Given the wide range of ecosystem services that may be identified using the Ecosystem Services Evaluation Matrix, there is an increased possibility that a greater number of these services will be realized in the designed landscape. The process requires the designer to identify the desired ecosystem services and to determine what must be done to maintain or add those services to a site.

The Ecosystem Services Evaluation Matrix records the degree to which services emanating from the system can be increased by a particular design intervention. This information is necessary to the design team (consisting of designer and relevant stakeholders) in order to decide which ecosystem services are important and should be supported by the proposed design. For example, pollination was an important service that supported the native plantings integrated into the design of the rain garden in the Fisherman's Wharf Park and Rain Garden (FWP) case in Victoria, British Columbia (Case Two). However, because the surrounding landscape was predominantly urban, the pollination increase on the site would not be regionally significant. Water purification, the ecosystem service selected to be maximized, was efficiently achievable and regionally significant.

The three cases discussed in this article demonstrate that the Ecosystem Services Evaluation Matrix (Tables 3, 4, and 5) is a useful tool for assessing and designing existing landscapes across scales ranging from broader agricultural settings to smaller, more urban neighborhoods and parks when activated by an integrated base of expert and local/stakeholder knowledge. The Matrix deals with the setting in terms of its biophysical and design program reality, and it is adaptable to varying levels of site complexity. For example, in FWP (Case Two) the design interventions of the rain garden, native and other plantings and design for human use generated a narrower set of ecosystem services than was found in SEFC (Case One). The programming of the larger SEFC site as a new community allowed a wider range of goals. Additionally, the City of Vancouver established an ambitious sustainability program which led the consultants to incorporate a wider variety of BMPs (Long 2012). These multiple and complex design interventions produced a more complex site that provided a broader array of ecosystem services than was feasible at FWP.

The multiplicity of landscape and anthropogenic processes occurring in the riparian corridor systems of the Fraser Valley agricultural landscape of Case Three make it very complex but also very different from the two urban site case studies. Development of the Matrix for FVC yielded a number of ecosystem services that were not found in either of the two urban sites, including provision of ornamental plants, modification of weather events, a wider variety of pollution mitigation, and disease and pest regulation. The larger agricultural landscape produced cultural ecosystem services, such as sense of identity and opportunity of a spiritual experience that were not assigned to the two urban cases.

The ability to apply the Ecosystem Services Evaluation Matrix to the three diverse cases demonstrates its flexibility and adaptability. In *post hoc* evaluations of ecosystem performance, the Matrix facilitates the consideration and evaluation of the full range of ecosystem services that may have been implemented regardless of the type and size of the site. In *a priori* evaluation of ecosystem services, it allows the designer to respond to the site socioeconomic and biophysical conditions and to determine which aspects of site and program need recognition in design development. Consideration of the full array of possible ecosystem services before implementing the design should produce more multifunctional, resilient and sustainable designed landscapes emanating from the Ecosystem Service framework for landscape planning and design. Incorporation of stakeholders in the process should ensure the appropriateness of the design to meeting human needs.

CONCLUSIONS

The three cases illustrate that use of the Ecosystem Services Evaluation Matrix can reveal the ecosystem services provided by a designed landscape. Given that it is often not possible to afford equal weight to the enhancement of all possible ecosystem services associated with a site, the Matrix provides a systematic process whereby an established prioritization among services can be emphasized in selecting design actions. It provides information that can be used to establish priorities among prospective ecosystem services fostered in a specific design. Such a process can also be used to communicate a defensible, evidence-based design process to stakeholders, politicians, and the public.

High density urban sites such as SEFC are generally considered to support low levels of biodiversity. The evaluation of SEFC revealed that site planning and design may make a significant contribution to both ecosystems services and biological diversity. The best practices implemented at SEFC supported biological diversity and enhanced delivery of multiple ecosystem services. Most notable was the wide range of cultural ecosystem services. A key finding is that while good ecological design may support provisioning, regulating, and supporting ecosystem services, site planning and design that responds to the needs of people can contribute more to cultural ecosystem services than most natural sites of equivalent size.

In both the SEFC (Case One) and the FWP (Case Two), the Ecosystem Service Evaluation Matrix identified a larger array of ecosystem services whose provision could be enhanced by the use of best management practices (BMPs). The wider the array, or greater magnitude of those BMPs, the greater was the diversity and magnitude of the ecosystem services produced. In the FVC case (Case Three), a single BMP, the provision of intact riparian corridor vegetation, was considered. When applied at the landscape scale, this single BMP will produce an abundance of diverse ecosystem services.

The proposed Ecosystem Service Evaluation Matrix method is not meant to substitute for rigorous empirical research on the delivery of ecosystem services as a means of enhancing landscape resilience and multifunctional performance. However, there is a place in both practice and research for qualitative evaluation of ecosystem services. Similarly, qualitatively inferred as well as quantitatively measured services can both be integrated into landscape design and planning to enhance the diversity and magnitude of ecosystem services produced. Failure to recognize the value of documenting ecosystem services delivery through qualitative methods may result in a reduction of multifunctionality and a decreased level of landscape resilience. Finally, the Ecosystem Services Evaluation Matrix may be used to identify and communicate ecosystem services in a public participatory process and to nominate ecosystem services within the design process to maximize landscape performance.

NOTES

1. Adaptive management is explicit in Ahern's and Steiner's methods but not in the Steinitz method. However in implementing his planning method, Steinitz expresses the necessity of incorporating adaptive landscape management to successfully complete the plan's implementation (Steinitz et al. 2005).
2. Leadership in Energy and Environmental Design (LEED) is a voluntary certification system for projects seeking to meet environmental performance standards and is administered by the Green Building Council in Canada (Bayley 2014).
3. The public realm is comprised of the public spaces of the city that are shared by people who are not personally

acquainted. It has an important role as the social space of the city (Lofland 1989).

4. FVWC participants included farmers, environmentalists, professional biologists and ecological restorationists who were able to bring detailed local and scientific knowledge to the discussion.

5. Backcasting is a form of prediction that involves defining a desired future and then working backwards to identify the strategy to achieve that future (Dreborg 1996). This is common practice in environmental design. In this case the designer determines the ecosystem service they would like to incorporate into a site and then determines the landscape structure that must be maintained or put in place to achieve that goal.

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