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A research agenda for ecosystem services in American environmental and land use planning

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ABSTRACT

We assess pathways for integrating the ecosystem services concept into American land use and environmental planning. Ecosystem services are the beneficial products that functioning ecosystems provide to human society. Building on Ian McHarg's influential ecological planning work, we argue that ecosystem service-based planning frameworks may improve our understanding of the consequences of planned actions in urban-ecological systems. Using evaluations of four diverse and innovative comprehensive plans, we examine how ecosystem service information can enhance plan specificity, investment strategies, and prioritization for policy implementation. Finally, we present a research agenda for evaluating how the use of ecosystem services in planning could improve assessment and communication of planning tradeoffs and outcomes.

1. Introduction

In 2001, the United Nations Environmental Program convened over 1350 experts from 95 countries to review the state of Earth's ecosystems and the consequences of human activity on environmental functions (Millennium Ecosystem Assessment; MEA, 2005). They found that alterations to the world's ecosystems over the past 50 years outpaced those of any other point in human history. Growing demands for clean water, food, and fuel threaten to inflict irreversible losses to global ecosystems. Ecosystem services (ES) – defined as the beneficial functions supplied to human society by ecosystems – served as the organizing framework for the UN initiative and now serve as the primary theoretical construct for vast research literature spanning many disciplines, including an entire area of ecological inquiry that focuses on the linkages between human well-being and ecological function (Seppelt, Dormann, Eppink, Lautenbach, & Schmidt, 2011).

As demonstrated by the MEA initiative, ES offer a conceptual framework for explaining and understanding the connection between human activities and the complexities of environmental degradation (Yap, 2011). Building on this, numerous communities across the United States have begun to analyze ES to better understand the role and functioning of their natural resources, and thereby improve urban decision-making processes. For example, King County, Washington performed an analysis of potential development futures for Maury Island, determining that certain zoning decisions could have disproportionately extensive impacts on the ecological benefits of coastal, riparian, and freshwater wetlands, leading to stability problems in beaches, sedimentation, reductions in wildlife abundance, and other impacts (Herrera Environmental Consultants et al., 2004). This analysis allowed King County to move beyond vague discussions about resource quantity and location, and talk more directly about what, where, and how those ecosystems provided benefits to surrounding residents.

In the United States, the profession and practice of city and regional planning contributes to the creation and implementation of policies that help govern urbanized and rapidly urbanizing environments (Berke, Godschalk, Kaiser, & Rodriguez, 2006). Although the planning profession is far from the last voice on regulatory, conservation, or development decisions, the profession's role in the translation of community goals into policies is an opportunity to influence decision-making within the urban land development process. The connection between the ecosystem service and planning professions, however, has been predominately unidirectional (BenDor & Doyle, 2010; Berke, Spurlock, Hess, & Band, 2013). Ecosystem service studies frequently reference planning efforts and the impacts of urban decisions on ecological functions, but – save for several examples, such as those above – it is rare for this information to be fed back into planning practice as a mechanism for development and land-use decisions (e.g. Chan, Shaw, Cameron, Underwood, & Daily, 2006). While there is a long history of planning recognizing the benefits of functioning ecosystems, there are few examples in the U.S. of plans explicitly using an ES framework (Wilkinson, Saarne, Peterson, & Colding, 2013).

Most land use and comprehensive plans are based on inventories of land uses, types, and resources (Berke et al., 2006; Kaiser & Godschalk,

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1995) that consist of basic assessments of quantity, such as open space acreage, miles of trail resources, or wetland acreage. While useful, these coarse measurements can neglect the quality and health of ecosystems (Mertes & Hall, 1995) and do not differentiate based on the type or provision of services to people (the MEA (2005) delineates ES into provisioning, regulating, supporting, and cultural services). For example, instead of looking merely at forest acreage or wetland classification during a planning process, using ES-based analysis might investigate stormwater storage, nutrient uptake, or air quality improvements, which are dependent on vegetation level and type.

High resolution, disaggregated environmental data can facilitate measures of ecological quality, analysis of tradeoffs, and exploration of complex spatial relationships during decision-making process (Benedict & McMahon, 2006). In the planning context, ES based approaches may pave the way towards development designs and plans that maintain ES, while meeting other objectives for economic development, transportation, agricultural production, and other needs. It's important to note that, while many ES investigations often lead to valuation efforts as a means to differentiate between different decisions (e.g. King County; [Herrera Environmental Consultants et al., 2004]), the recognition of ES benefits does not need to be restricted to quantification and valuation in order to provide distinct advantages to decision processes. (Olander, Boyd, & Schieffer, 2015; Olander et al., 2015). Although an ES approach may be more data heavy, this information is theoretically much more applicable to the public in conveying tradeoffs associated with different courses of action (e.g. discussing "flood water reductions" with a non-expert may be easier than explaining "hectares of wetlands.")

Both Ian McHarg's work and more recent research support the explicit incorporation of ES into planning. Design with Nature provided an early example of how ecological information could be incorporated into land-use and design decisions without the explicit label of ES. More recent studies propose the modification of existing frameworks such as multi-criteria decision analysis and the development of new frameworks to integrate ES into land-use planning and decision-making (Albert et al., 2016; Biggs, Schlüter, & Schoon, 2015; Langemeyer, Gómez-Baggethun, Haase, Scheuer, & Elmqvist, 2016; Nin, Soutullo, Rodríguez-Gallego, & Di Minin, 2016). Yet, studies that explore the integration of ecological information into comprehensive plans suggest that the inclusion of ecological data is woefully inadequate (Berke et al., 2013; Brody, Highfield, & Carrasco, 2004). Additionally, few studies on urban ES provide recommendations to policy makers about how to implement an ES framework into decision-making (Haase et al., 2014). These findings suggest there are opportunities to provide explicit guidance on how to incorporate ES into planning with the goal of balancing urbanization and environmental degradation.

A focused examination of how planning can integrate ES information, theories, and models is necessary. While multiple initiatives seek to integrate ES into decision-making such as *The Economics of Ecosystems and Biodiversity* (TEEB, 2011) and the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES; Díaz et al., 2015), questions remain about what an ES framework would look like for planning and the benefits of such an approach to planning practice. In this paper, we assess the potential for integrating the ecosystem services concept into land use and environmental planning in the United States[1] and explore the potential opportunities and negative consequences presented by this approach. By "ES framework," we reference the use of ecosystem service concepts, measurements, theories, and models as a major factor in analyzing planning decisions, engaging in planning processes, and making recommendations for future action. In particular, we seek to explore several key questions, including:

1) What would it entail to incorporate a significant amount of ecosystem service information into land use and environmental planning? How could an ES framework differ from existing paradigms for incorporating environmental quality measures into planning?

2) Could the ES paradigm be constructed as an organizing framework for analyzing tradeoffs in alternative decisions during the land use and environmental planning process? What are the benefits and consequences of utilizing ES as an input into the land use and environmental planning process?

We begin the paper by reflecting on Ian McHarg's ground-breaking push for urban designs that harmonize with environmental features, and then contrast his work with recent advances in analysis of ecosystem service tradeoffs. In the 46 years since McHarg's (1969) Design with Nature, ecological science has advanced our scientific understanding of – as well as our ability to discriminate, weigh, and model – the environmental implications of urban land use choices. We reflect on McHarg's observations to address the first research question in light of the growing body of measurements and methods for weighing the importance accorded to different services by different stakeholders.

To investigate the second question, we analyze comprehensive plans from four communities, which were selected on the basis of their representation of and acknowledged leadership in four fields: a hazard-mandated land use plan (New Hanover County, NC), a major metropolitan land use plan (Philadelphia, PA), an ecosystem-service based plan (Damascus, OR), and a county plan in a heavily regulated watershed (Baltimore County, MD). We compared these plans on three factors (quality of ES information, tradeoff analysis, and stakeholder engagement) to illustrate the shortcomings of existing planning approaches and the potential advantages of an ES framework. These cases help highlight the multitude of obstacles that may prevent the incorporation of ES into the planning profession.

Finally, drawing on the previous sections, we propose a focused research agenda that will inform and guide the integration of ES as a vector for promoting better decisions in environmental planning practice. In this agenda, we explore a number of lingering questions that stand between planners and the widespread use of ES as a supporting framework for modern land use and environmental planning.

2. Ecosystems in planning: McHarg and beyond

There is a long history of exploring stronger and more sophisticated integration of environmental considerations into planning policy and decision-making. In his 1969 book, Design with Nature, Ian McHarg, articulated design approaches and planning processes to shape urbanizing landscapes while promoting protection of natural resources. While many additional frameworks for 'ecological' planning have been advanced (e.g. Roseland, 1997; Vasishth, 2008), McHarg's work remains an authoritative contribution with an enduring influence at the interface of the ecology, planning, landscape architecture, and architecture fields (Steiner, 2006). We will therefore draw on McHarg's opus as a proxy for much of the subsequent direction of the ecological planning literature.

In his most famous example, McHarg focused on the important role dunes play in protecting coastal areas in New Jersey from storm surge. He first vividly described the ecological processes that create and maintain dunes and then investigated the tolerance of dune environments to development. Accounting for the tolerance of the dune system, McHarg provided a loose outline for the design of a built environment that balanced the protective services of dunes with other human benefits such as recreational access. His takeaway message from the dune and other examples, was that the many social values provided by nature can be balanced through the use of ecological data during the process of designing the built environment: "…[I]t is enough to observe that [the ecological view] could considerably enhance the present mode of

[1] We limit our analysis in this document to the American planning process, which observes various procedural, cultural, and legal hallmarks, including mandated public participation, budgetary and legal federalism, property rights concerns, constitutional obligations to due process and equal protection, and a consistent focus on local-government obligations to protect health, safety, and welfare.

planning, which disregards natural processes all but completely…" (p. 65).

In a real-world illustration of the "indifference to the natural process" in cost-benefit analyses, McHarg lambasted the traditional route selection methods for highway systems, which accounted only for easily quantified engineering factors such as traffic, volume, design speed, capacity, pavements, horizontal and vertical alignment (p. 31). Noting the neglect of impact to ecological and social systems, McHarg sought to reshape the equations used in decision-making by including additional factors to better optimize "…maximum social benefit at the least social cost" (McHarg, 1969, p. 32).

To begin placing social and ecological benefits on the same quantitative footing as more traditional engineering variables, McHarg developed a ranking protocol based on new data inputs. He argued we could avoid damage to important ecosystems by using ecological information such as surface drainage and susceptibility to erosion, as well as the value of land, recreation, and residential and institutional developments when we plan highway locations. Under this type of early landscape suitability analysis (e.g. Steinitz, Parker, & Jordan, 1976), ranking occurs within each factor based on three levels of variation with darker areas (as visualized using shaded Mylar sheets; McHarg, 1964) representing higher values. As the various variables are layered on top of one another, areas with higher ecological and social values become darker (Fig. 1).

These two examples from McHarg's seminal work outline both the absence (the initial route selection variables) and explicit inclusion

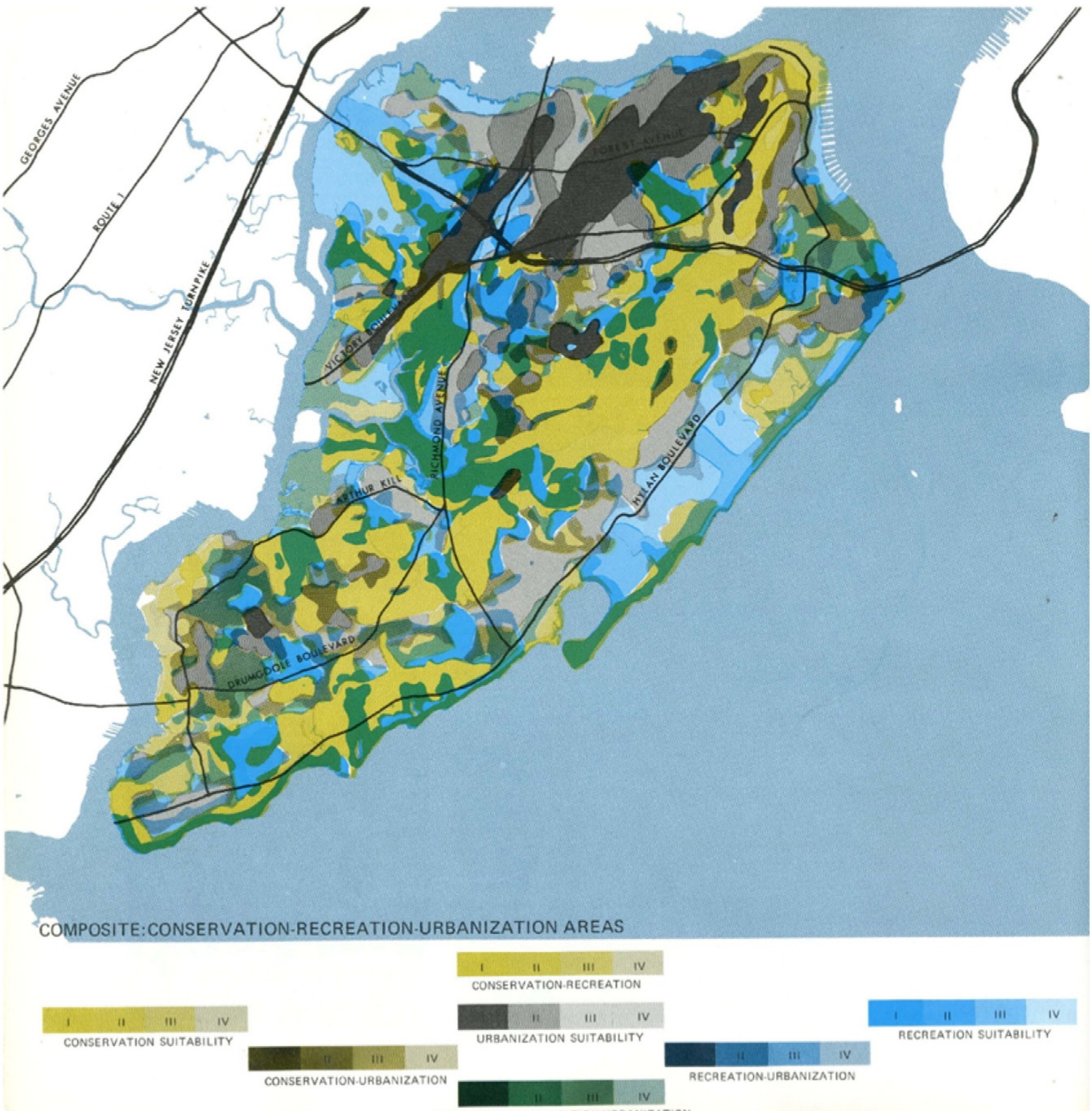

Fig. 1. The composite map created when McHarg (1969) applied his overlay technique using colored Mylar sheets to determine high value conservation, recreation, and urbanization areas in Staten Island, NY. Reprinted with permission from John Wiley & Sons, Inc.

(development within a dune environment) of ES in planning decisions. Throughout *Design with Nature*, McHarg emphasized the benefits of an ecological approach to planning, in which decisions are based on an understanding of environmental processes – the values they provide to society and their tolerance to development – rather than simplified metrics, such as broad-brush standards for open space acreage per capita (e.g. Mertes & Hall, 1995). McHarg's evaluation process, while imprecise and incomplete by his own admission, represents an early precursor of ecosystem service analysis (Nelson et al., 2009), wherein carefully measured ecological data is modeled to allow the evaluation of tradeoffs among different ecosystem and social factors and outputs. Thus, returning to the first research question, an ES-based framework for land use and environmental planning would build on McHarg's approach, but would depart from this existing framework by 1) exploiting methodological advances and the availability of ecological data at a finer scale, 2) enhancing the inclusion of societal values through stakeholder participation, and 3) combining the enhanced ecological data and stakeholder input into more sophisticated methods to analyze the tradeoffs among economic development, social equity, and environmental protection. The following section delves into each of these conceptual enhancements to McHarg's approach.

3. Applying an ES framework to planning

3.1. Information in planning

A strong literature argues that planning is a powerful center for drawing together data to inform urban decision-making (Berke et al., 2006; Innes, 1998; Fig. 2). Building on McHarg's work with respect to information means taking advantage of the increased availability of ecological data. Instead of rough approximation using Mylar sheets and three broad categories of quality, advances in technology and data availability increase the amount, quality, and scale of data available to inform planning decisions.

Ecosystem service analysis requires nuanced metrics and indicators of ecosystem features (physical landscape objects), functions (what those features do), and benefits (if those features are beneficial to people; de Groot, Alkemade, Braat, Hein, & Willemen, 2010). These metrics may entail complex spatial relationships at a variety of scales (e.g. site, neighborhood, watershed), which can be very difficult to understand without sophisticated models. Substantial efforts (e.g. Benedict & McMahon, 2006) have focused on promoting landscape ecology concepts, such as integration, spatial connectivity, multi-functionality, and scale, as integral elements for enhancing what green infrastructure can deliver in urban landscapes. For example, the strategic spatial arrangement of green infrastructure elements – in terms of their position within a network and relative connectivity to one another – can be more important to ecological function improvements than gross measures like total area, count, or plant density (Jongman, Külvik, & Kristiansen, 2004; Jongman & Pungetti, 2004).

Implementing an ES approach for planning will require defining, delineating, measuring, and modeling ecosystem service provision at the local level, which has significant implications for both the *quantity* and *quality* of data used in the planning process. This begs several important questions; specifically, to what extent does the real-world use of an ES framework increase the amount collected and/or enhance the quality of ecological information used in the planning process? What are the implications for planning policy and practice, given the bounded rationality of policy-makers (i.e., information overload in decision-making with limited time and expertise)?

3.2. Participatory engagement with plan information

McHarg assumes that residents value avoidance of damage to erosive soils, historic and habitat zones, and high quality forests and marshes, and thereby receive increased ecological values through his designs. This assumption about project goals and community values occurs without involvement from the public, or any decision-making body, illustrating a distinction between ecological design and planning informed by ES. Design processes – while frequently information-rich – have historically been reluctant to allow democratic input from the communities inevitably affected by design decisions (Goodman, 1971; Sanoff, 2000). For example, in his route selection for a new highway in Richmond, VA McHarg ranks residential areas using market value, which undervalues lower income areas (p. 38). This seemingly objective process could easily, and inadvertently, result in very inequitable

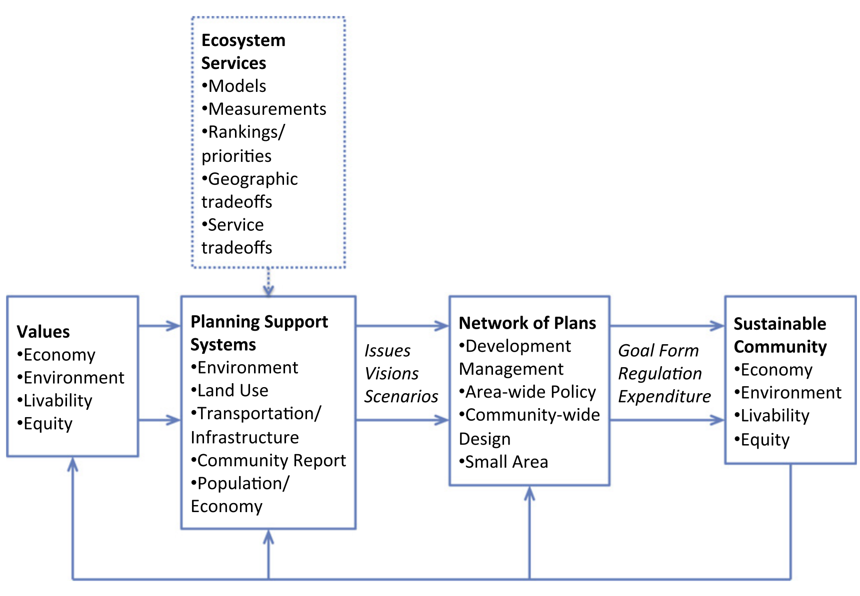

Fig. 2. The modern comprehensive land use planning process, based on the classic (rational) model of information use in land-use planning, which demonstrates the interplay between information and planning support systems that digest and analyze that information (Brail & Klosterman, 2001). Adapted from Berke et al. (2006).

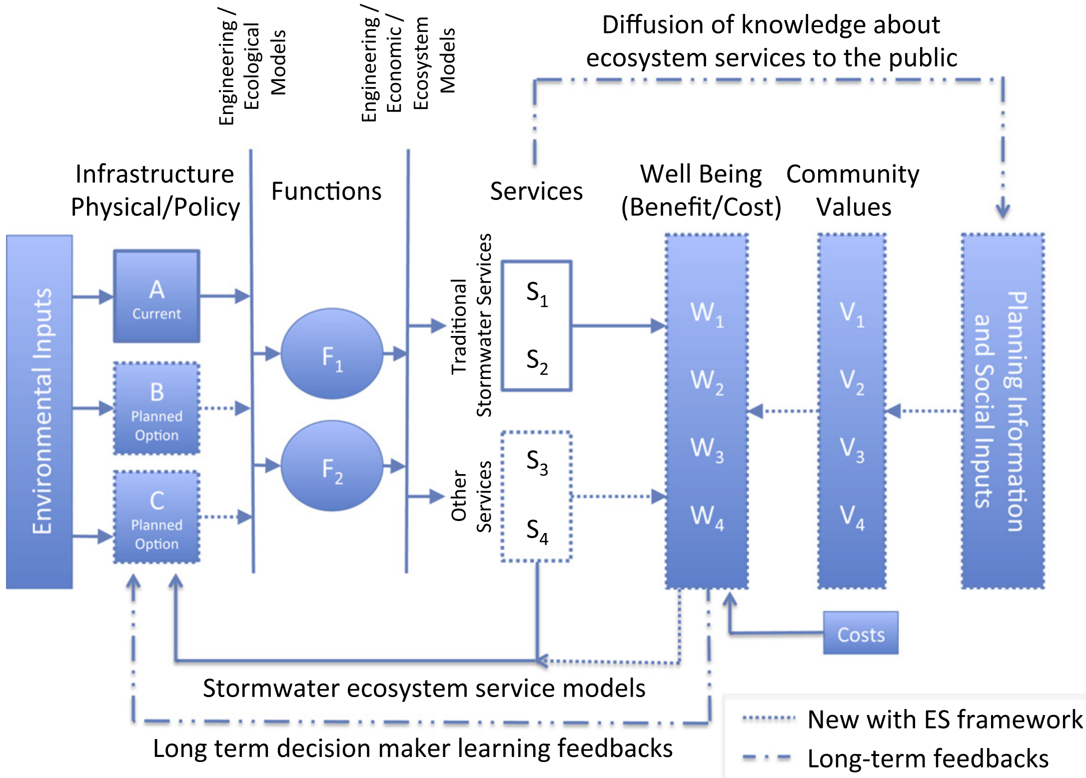

Fig. 3. Expansion of traditional stormwater service assessment to fully integrate additional ecosystem-services and community values (expansions shown with dotted lines/borders). Left to right: engineering models translate Best Management Practice (BMP) features into ecological functions, engineering and ecosystem models translate functions into services, and services are weighted using community values to determine the well-being (a cost/benefit ratio) created by the services of a given array of BMPs. Optimization of BMP system (both structural and non-structural; left side inputs) is now calculated based on additional services (i.e. "other services"), as weighted by community (right side inputs). Measures of community well-being created by certain ES are calculated based on community values expressed in public planning and policy processes (e.g. visioning, survey focus groups). Double dotted lines represent slow formation of knowledge feedbacks to decision-makers and the public regarding the effects of certain BMPs on services, and the effects of services on public well-being, respectively.

outcomes and risk community conflict as it signals planning practices associated with Urban Renewal.

Newer planning practices specialize in exploring the specter of multiple viewpoints with the hope that the inclusion of multiple voices will counteract less inequitable outcomes (Brody, Godschalk, & Burby, 2003; Forester, 1999; Innes, 1996). Thus, an ES framework in planning should intentionally incorporate the values of multiple stakeholders into decision-making, but must balance the plethora of actors involved in the planning process (e.g. developers, community members, elected officials, staff, environmental NGOs, non-profit organizations), different methods of collecting or measuring social preference information, and how these prioritizations can be injected into the decision-making process.

To illustrate this possibility, Fig. 3 depicts an example of a stormwater planning framework where ES function as a tool for matching green stormwater infrastructure features and functions as weighted through a lens of community values, which are derived through participatory and deliberative planning processes. By identifying variations in the constituencies concerned with each ecosystem service, planners can 1) create opportunities to better understand community stakeholders, 2) create situations where power imbalances do not silence certain groups, 3) create mechanisms for better weighing tradeoffs to promote win-win scenarios, and 4) identify policy levers and planning implementation guidelines that clearly delineate the ecological services to be valued by the community in the future. In the European context, Fürst, Opdam, Inostroza, and Luque (2014) analyze two planning processes that integrate ES and demonstrate that ES can enhance public participation by facilitating knowledge sharing, incorporating local data, creating a shared vision of the future, and building networks.

3.3. Analytical tradeoffs

An ES-centered framework for environmental planning implies more than just an increased use of information; it needs to explicitly combine ecological information and community values as the basis for environmental planning decisions. As a result, planning informed by an ecosystem service framework could inject ecological information into decision-making processes that account for multiple viewpoints while focusing attention on equity and economic tradeoffs (Ahern, Cilliers, & Niemelä, 2014; Albert, Aronson, Fürst, & Opdam, 2014). McHarg's composite map would become one that is colored not only by the production of services, but weighted by the values of each type of service desired by the community.[2]

For example, decisions to route a highway through a sensitive wetland complex may damage certain ES (e.g. water quality and flood attenuation). An alternative possibility – routing the highway around the complex – may preserve these services, while damaging others (e.g. habitat connectivity and air quality). By quantifying the ES impacts of proposed actions, ES frameworks can create systems of 'currencies' (or metrics extending between decision alternatives; e.g. NESP, 2014; Salzman & Ruhl, 2000) that facilitate weighting of different actions on the ES generated locally and regionally (e.g. downstream or affecting

[2] While this statement will undoubtedly invite continuations of longstanding, equity-centered debates over issues such as how values can be determined from diverse communities, how to deal with widely divergent views within a community, who gets to determine these values, etc., we leave these questions open and point to them in our call for further research.

environmental dynamics in other locations). An ES planning framework would make these factors, weights, and tradeoffs explicit to more accurately demonstrate how community values factored into land suitability analyses to express alternative urban futures.

This explicit inclusion of ecological information weighted by community social values could, in theory, help diffuse (or at least identify) community conflict. However, there are lingering questions about bias towards services that are more easily quantifiable. Insufficient knowledge of how the form, location, and scale of urban development will affect ES will influence the factor weighting and accuracy of tradeoff analyses (Theobald et al., 2005; Norgaard, 2010; Robertson et al., 2014).

4. Case selection to analyze ES in planning today

The previous section explored how an ES framework for planning could build on the work of McHarg by utilizing ecological informational advances, enhancing stakeholder participation, and explicitly considering tradeoffs. To explore how this extended framework could be applied to current planning practice, we used two criteria to select four comprehensive plans for evaluation. First, we wanted to examine plans in jurisdictions with widely acknowledged environmental leadership and where environmental constraints and regulations have acutely affected planning efforts. Given the extensive role that water quality, flooding, and coastal hazards (e.g. sea level rise, storm surges) now play in driving American urban planning efforts, we selected leading plans whose environmental focus falls primarily on water-related issues (Berke, 2014; van Leeuwen, 2015).

Our second criterion was to select a wide array of plan types that exist within the "family tree" of American land use planning, as described by Kaiser and Godschalk (1995). We aimed to select plans created under a diverse subset of planning frameworks and processes, including countywide comprehensive planning, major metropolitan area master planning, focused new town planning, and hazard-related coastal area management planning. Using these two criteria, we deliberatively sampled (Yin, 2008) four well-known plans in diverse urban and environmental settings: New Hanover County, NC; Baltimore County, MD; Philadelphia, PA; and Damascus, OR.

In all cases, environmental issues, particularly around water quality and flooding, have been major topics that have partly motivated plan creation. New Hanover County, North Carolina lies in a hurricane-exposed area, contains the highest population density along the North Carolina coast, and faces immense environmental pressure from both growth and climate-related coastal change. New Hanover County is the most visible result of well-established state coastal planning requirements across the Southeastern United States (NCDENR, 2015). Baltimore County's master plan builds on Ian McHarg's previous work in the region (*The Plan for the Valleys*) and was created in direct response to unique and expansive federal and state water quality regulations affecting Chesapeake Bay, which are now some of the most stringent and comprehensive water regulations in the United States (Tango & Batiuk, 2013). Chesapeake Bay's water quality protection efforts are widely viewed as an example that will guide future water quality management efforts for many of the other 130 estuaries across the US (Chesapeake Bay Program, 2010).

Philadelphia has implemented major planning innovations due to water quality conditions, and is now widely acknowledged as a the leader in green infrastructure planning in the United States (Clements et al., 2012). Finally, Damascus, Oregon is the only known example of a set of explicitly ecosystem service-based planning initiatives (public facilities plan, comprehensive plan, and market-based planning initiative).[3] Given the novelty and creativity surrounding this set of plans, Damascus represents an important case for exploring ES as a basis for future land use and environmental planning activities (Yin, 2008).

While these four plans are by no means representative of the overall state of planning – in fact they are deliberately selected based on the leading role of their respective jurisdictions in managing water quality, ES, or coastal hazards, they do represent an illustrative set of high-visibility cases that extend across a wide range of planning contexts and can help identify gaps between traditional planning practice and an ES framework. In these four plans, we find archetypical examples of divergent planning regimes throughout the United States. We focus on the quantity and quality of ecological information used in the plan, how ES are used to engage stakeholders, and analytic methods to weigh tradeoffs (Table 1).

4.1. Wilmington – New Hanover County joint coastal area management plan

With over 200,000 residents in 2010, New Hanover County is the most populous coastal county in North Carolina and their continued growth is an important issue to residents. In preparing their 2006 plan, New Hanover County surveyed over 600 voters and found that two-thirds believed the county was growing too fast with environmental issues (e.g., open space preservation and the incorporation of natural areas in new developments) ranked among the most important issues to residents (Wilmington – New Hanover County, 2006, p. 10).

These concerns emphasize the legislative goals of the Coastal Area Management Act (CAMA; CSA §113A-100, et. seq.), which requires coastal counties to prepare, adopt, and enforce land use plans that manage growth and protect valuable environmental resources.[4] CAMA, established in 1974, recognizes the recreational, esthetic, and economic value of coastal natural resources and the threat that uncontrolled development poses to these resources. As such, CAMA delineates guidelines for county land use planning including conducting a land suitability analysis, mapping natural resources, and assessing environmental conditions. This framework requires county governments to consider factors such as coastal hazards and water quality in their land use decision-making.

New Hanover County adopted their first CAMA plan in 1976 and the current *2006 Wilmington – New Hanover County Joint Coastal Area Management Plan* is the fifth update to this original plan. The 2006 plan builds upon the county's past CAMA plans to ensure wise development and minimize further degradation and loss of the natural landscape.

4.2. Baltimore County, MD master plan

Between 1950 and 1960 the population of Baltimore County nearly doubled, increasing from 270,000 to 492,000, prompting strong planning and growth management initiatives to help retain the county's rural character. In 1964, *The Plan for the Valleys* became the first long-range development plan based on McHarg's approach of using ecological information to guide development (Valleys Planning Council, 1964). The plan, for which McHarg acted as a consultant, has had a lasting impact. In 1967, the county established an urban growth boundary and, since then, has successfully guided development into a concentrated urban area. Today, over 90% of the County's residents live within urban growth boundary that covers just a third of the county's land area (Baltimore County, 2010).

Baltimore County's *Master Plan 2020* (Baltimore County, 2010) reflects the influence of this early plan by relying heavily on growth management policies to address environmental issues. For example, to comply with federal and state programs like the Chesapeake Bay Critical Area Act of 1984 (MDDNR, 1984) to restore water quality in the Chesapeake Bay, Baltimore County concentrates on compact development

[3] See Woodruff and BenDor (2016) for comprehensive and comparative plan quality evaluations of Damascus plans.

[4] CAMA requires local governments in the 20 coastal counties to prepare land use plans that help to protect, preserve, manage, and provide for orderly development.

Table 1
Plan performance on principles of ES framework.

	Principles of ES framework		
	Ecological information	Stakeholder participation	Consideration of tradeoffs
Baltimore County, MD	Recognizes services, but ES data does not inform policies	ES information not used to engage stakeholders	No tradeoff analysis
Damascus, OR	Uses ES quantification to guide development	Techno-centric process, did not engage the public	Creates ES market to incorporate ecological tradeoffs into upfront development cost
New Hanover County, NC	Traditional use of ecological information, focusing on resource existence and extent	ES information not used to engage stakeholders	No tradeoff analysis
Philadelphia, PA	Uses data to determine areas where restoring ES would have greatest benefit	Green infrastructure projects require community support	No tradeoff analysis

and preservation of undeveloped land with policies encouraging redevelopment within the urban growth boundary.

4.3. City of Philadelphia comprehensive plan

In contrast to the population increases observed in New Hanover and Baltimore Counties, Philadelphia followed the trajectory of many industrial cities in the U.S. Industrial output and population in Philadelphia peaked in 1950, and then dramatically declined during decades of de-industrialization that resulted in migration to the suburbs, closed factories, vacant land, and urban decay (City of Philadelphia, 2011). Although these trends are beginning to reverse for the first time in 50 years, the City of Philadelphia continues to struggle to maintain public facilities and services designed for 2 million in a city with only 1.5 million residents.

At the same time, it is confronting new environmental challenges related to water quantity and quality. In particular, a high percentage of impervious surface (52%; City of Philadelphia, 2011, p. 175) combined with an industrial-era combined sewer system, which carries both sewer and storm water in one pipe, results in the release of too much untreated wastewater into neighboring rivers during rain events. To address this issue, the *Citywide Vision for Philadelphia 2035* supports the use of green infrastructure as a cost effective way to manage stormwater runoff while providing additional social and environmental benefits (City of Philadelphia, 2011).

The plan recommends expanding the tree cover within the city to reduce stormwater runoff and, at the same time, improve air quality, increase energy savings, improve traffic safety, and provide additional sociological benefits. These strategies are drawn from the Philadelphia Water Department (PWD) *Green City*, *Clean Water* plan that established an ambitious green infrastructure program to reduce combined sewer overflows and meet compliance with the Federal Clean Water Act. Philadelphia has embraced green infrastructure as a tool to restore ecological functions and at the same time revitalize the city by improving public health, recreation, and housing (PWD, 2011).

4.4. Damascus, OR comprehensive plan and public facilities plan

Damascus, OR is a new municipality that incorporated in 2004 after the Portland Metro Urban Growth Boundary was expanded to include the area (City of Damascus, 2010). Due to the rapid growth in the Portland region, Damascus anticipates an increase in population from approximately 10,000 residents in 2010 to 35,000 in 2030. To accommodate this growth in an environmentally responsible way, Damascus proposed an ES approach in their very first comprehensive plan, *Envision Damascus Comprehensive Plan* (City of Damascus, 2010). As the city develops drinking, storm, and wastewater infrastructure, it foresaw utilizing ES to lower costs and protect environmental resources. However, the 2010 comprehensive plan was quickly rescinded after being adopted due to a political shift in the town board.

Instead, goals related to ES are implemented by the Damascus' *Public Facilities Plan* (CH2MHill, 2009), which includes ES along with more traditional infrastructure such as parks and transportation. The *Public Facilities Plan* quantifies ES provided by parcels across the community to support policies that use ecosystem services as a basis for land use decisions. In addition, Damascus explores the potential of an ES market to help better represent the cost of development.

4.5. Information quantity

The Wilmington – New Hanover County (2006) CAMA plan provides an example of a traditional use of ecological information to inform planning recommendations. The plan identifies 100-year and 500-year flood zones. Based on this information – almost entirely centered on the *existence* and *extent* of floodplains – the plan devises a plan-policy framework (see Berke et al., 2006), offering recommendations focused on 'discouraging' development in floodplains.

In contrast, the application of an ES framework would integrate floodplain existence and extent with information about other floodplain services such as removing nitrogen, reducing sedimentation, or water storage capacity during floods to inform recommendations. Although New Hanover's plan voices concerns over fecal coliform levels, it neglects to examine how different floodplain areas 1) currently help to reduce coliform, or 2) could be selectively enhanced to contribute to even further reductions. The collection of additional ecological data would enable these types of highly directed planning recommendations.

Baltimore County's plan makes a stronger connection between natural environments and the ES they provide. For example, the plan recognizes that forests provide multiple water management services: reducing stormwater runoff, cleansing stormwater runoff of pollutants, reducing erosion and soil loss, replenishing soil nutrients, and maintaining stream temperatures (Baltimore County, 2010, p. 167). While the plan references the collection of data to measure these services – abundance and biodiversity of aquatic species in streams, pollutant loads, stream stability, and forest community structure (p. 170) – proposed policies are not based on this information. Rather, preservation of forest is quota driven. The plan ambitiously sets a goal of preserving 80,000 acres of farm and natural resource space (p. 181), but the location or type of resources preserved is not informed by ES. Similarly, the plan proposes a no-net loss of forest policy based on area, rather than services, which has been widely critiqued in the ES market literature for producing a net loss of services (de Groot et al., 2010; Salzman & Ruhl, 2000, 2004; Wainger, King, Salzman, & Boyd, 2001). In summary, the plans of New Hanover County and Baltimore County demonstrate the missed opportunity for ecological information to shape specific policies to protect ES from future development.

In contrast, Philadelphia's plan illustrates how ecological information *could* be used to restore and bolster ES. With only 5% of its land area vacant, Philadelphia has little, if any, undeveloped natural areas to preserve. Rather, the city is seeking opportunities to create green infrastructure that can restore ecological functions, especially stormwater management, at schools, parks, vacant lots, or underutilized properties. The plan maps impervious surface coverage, as well as where the city is served by a combined sewer system, in order to identify areas within the city that would benefit most from green infrastructure projects. An ES approach would go even further by incorporating additional information such as flood damages and impaired streams to allow for more specific planning recommendations, as demonstrated by the Damascus plan (CH2MHill, 2009).

As a component of their *Public Facilities Plan*, the City of Damascus performed a net environmental benefit analysis (NEBA), an approach that shares the same theoretical foundation as cost-benefit analysis, to identify and value the primary ES an area provides under different land uses (CH2MHill, 2009). For each parcel of natural space, ecosystem types and conditions were used to calculate discounted service-acre-years (DSAYs), a measure of services currently provided relative to a reference fully functioning ecosystem.[5] This information allows the city to take a more targeted approach to development decisions. By quantifying ES provided by the community's natural resources, Damascus' plan demonstrates how additional information can be incorporated into planning decisions. In contrast to broad policies to discourage development in floodplains or preserve natural space found in New Hanover and Baltimore County's plans, Damascus' plan includes recommendations such as: "The City shall associate parks with ecosystem services targeting the protection and conservation of high quality ecosystems while meeting recreation needs" (City of Damascus, 2010, p. 164). The comprehensive plan also includes multiple policies that use ES to guide development and the location of public facilities in particular (City of Damascus, 2010).

Damascus not only uses ecosystem service information as a basis for siting development, but also requires development that does occur in sensitive environmental areas to offset the impacts to ES. In Damascus's *Ecosystem Service Market Program Component* (CH2MHill, 2011), planners attempt to incorporate the ecological tradeoffs associated with development into upfront development cost. This report explores the possibility of creating a community-wide ES market in which each parcel would be assigned a given number of ecosystem service credits. Landowners could either sell these credits or, if they wish to develop the parcel, purchase an equivalent number of credits to the parcel being developed.

Both the comprehensive plan and the *Ecosystem Service Market Program Component* discuss the potential of the city to enhance ES by siting parks and restoration efforts in degraded environments, creating ecosystem credits that could offset impacts elsewhere (City of Damascus, 2010, p. 164; CH2MHill, 2011, p. 14). Their efforts are based on the idea that a well-designed ecosystem service market would make it more costly to develop areas that provide critical ES by requiring more offsets and, as a result, guide development away from sensitive environmental areas (BenDor, Brozovic, & Pallathucheril, 2008). This approach moves beyond traditional planning approaches of incorporating environmental information by creating metrics that enable a discussion of the tradeoffs between the services (and their locations, resource types, and neighborhoods served) being lost due to development and the services created by conservation and restoration projects.

4.6. Information quality

If we look closely at the Wilmington – New Hanover County CAMA plan, we see that the plan's treatment of wetland areas, similar to floodplains, is primarily centered on *existence* and *extent*. While wetland delineation requires ecological information to differentiate wetland types, there is little information on wetland quality or ecological benefit. The plan recommends the avoidance of impacts, the creation of buffers, and wetland restoration efforts. The information needed to support these recommendations, however, is never collected. Similarly, the Baltimore County's comprehensive plan recommends stream and shoreline restoration (Baltimore County, 2010, p. 146), the preservation and enhancement of functional open spaces (p. 169), and projects to re-establish forests (p. 169), but does not outline where these actions should take place to maximize the impact on ES. We lack information on the location of degraded ecologically valuable resources and what types of actions should be taken *and* prioritized to improve specific services.

Measuring and modeling ES can, in theory, increase the *quality* of the information used in the planning process, particularly with regards to a jurisdiction's historic, current, and trending ecological conditions. Instead of the gross quantities or generalized impacts that characterize current resource inventories, the higher resolution and data integrity yielded by using ES concepts could allow ecological quality to enter into strategic decision-making. For example, instead of forest acreage or wetland classification, an ES-based measurement framework could look at specific levels of stormwater storage, nutrient uptake as a result of vegetation levels and types within the wetland, or air quality improvements due to forest establishment.

4.7. Stakeholder engagement

An ES approach should enhance planning's incorporation of multiple stakeholder viewpoints and values with ecological information (Fig. 3) to better identify and weigh tradeoffs. While the decision to use an ES approach in Damascus included extensive stakeholder engagement and visioning exercises, the ES planning process was highly technical with no community input. CH2MHill, a contractor outside the community, wrote the Public Facilities Plan and conducted the ES quantification and modeling. The plan briefly mentions the need to gauge community preferences moving forward (CH2MHill, 2009, p.240), especially when developing preservation targets and mitigation ratios. Specifically, the plan raises the concern that the public may prefer one service to another, but it did not include the public when determining which services should be included in the quantification or how the services should be weighted. This exclusion may be one of the reasons that the Damascus plan was quickly rescinded after its initial adoption, and signals that major improvements can be made in stakeholder involvement in the face of ES quantification and modeling efforts during the planning process.

Of all the communities we considered, Philadelphia's planning process included the strongest stakeholder engagement. As part of its green infrastructure program, community groups may propose locations for green infrastructure projects, which are then prioritized by the PWD if the green infrastructure projects are recommended by community groups, supported by community partnerships, have undergone a community-based planning process, and include community outreach and engagement (PWD, 2015). By focusing on the need for green infrastructure investments to revitalize the community and better manage stormwater, Philadelphia's approach may better account for community values and concerns.

4.8. Tradeoff analysis

Efforts to integrate planning and ES do not (and should not) end with the provision of information. Whether collected through measurement or modeling, ES data can help to assess the impacts of planned future actions, facilitating improved analysis of 'alternative futures', or alternate planning decisions. The first step in this integration involves recognizing the ever-present calculus of tradeoffs inherent in development decisions.

Damascus' approach of quantifying ES provided by different parcels and requiring offsets for loss of ES demonstrates how an ES framework could help identify tradeoffs associated with development. Further examination of the methods to quantify ES in the *Public Facilities Plan*, however, raises concerns about the quality of data. Quantification was

[5] Damascus used a habitat equivalency analysis methodology that "…values natural resource assets in terms of the discounted sum of valued ecological service flows over time. [The analysis] uses indicators to measure the functionality of the ecosystem as a percentage of maximum functionality per acre (or an alternate spatial measure). (CH2MHill, 2009, Pg. 4–4)"

based on two factors: ecosystem type and quality. Quality is assumed to be representative of ecosystem function and level of services provided, but this relationship does not necessarily hold true (Salzman & Ruhl, 2000). Although the *Public Facilities Plan* states, "Habitat quality assessments were based on collection of field data related to provision of specific ecosystem services," (CH2MHill, 2009, p. 79) it is not clear which or how services were measured. The plan assigns parcels letter grades A to C based on ecosystem quality, which fails to provide specific information about how quality and provision of services truly differs across the landscape. Admittedly, this is an initial assessment to identify the relative level of services provided across the landscape (CH2MHill, 2009, p. 78) and additional analyses, using site-specific data, were planned at later stages when the need for higher resolution data would emerge.

5. Challenges with the ES framework

These cases demonstrate the missed opportunities to incorporate ES in planning and illustrate how an ES framework could advance planning goals. While these plans certainly are not representative of all planning efforts, they are at the forefront of plans to manage water quality and coastal hazards. The limited use of ES data and concepts in these particular plans can help identify the larger limitations to incorporating ES into planning.

In general, the incorporation of more information into a planning process is considered beneficial and ES represent an increase in scientific information available for decision-making. However, it is not clear how much and at what level of precision ES data should be provided to inform decision-making and balance trade-offs. An ES framework may represent such an information-heavy burden on the planning profession that it is impossible to implement. For example, Baltimore County identifies ES information about the multiple benefits associated with forests (i.e., improving the quality and quantity of stormwater runoff, reducing erosion and soil loss, replenishing soil nutrients, and maintaining stream temperatures), but reverts to a quota system around forest preservation and restoration, which suggests a gap between the availability of ES data and its incorporation into local policy. In other instances, data may not even be available to make informed decisions about how to structure local regulations (Rose et al., 2015).

Further, the Baltimore County's's (2010) plan recognizes that, "when considered alone, the impact of any single development project may be negligible but when combined with all other development impacts within a watershed over time, may threaten fragile waterfront resources and diminish the quality of life" (p. 103). Consequently, a case-by-case analysis or authorization presents a significant barrier to the adoption of ES as an organizing framework because it fails to account for impacts across the "service shed," or the areas that provide specific ecosystem services to specific beneficiaries (see Tallisa, Kennedy, Ruckelshaus, Goldstein, & Kiesecker, 2015). In this case, we find two embedded issues: 1) the absence of sufficient – either in terms of scientific precision or usability for practicing planners – ecological "production" models that link physical features in the landscape to the services they provide and 2) the need to consider cumulative effects, rather than each planned action independently. In other words, we do not have strong, and easily used, models for explaining how a development or planning action will change the provision of services.

Even as scientific advancements and technological improvements facilitate more accurate, high-resolution data, numerous planning scholars point to imperfect data, limited cognitive capacity, and political power as complicating factors to the role of technical information in the planning process (Beauregard, 1991; Flyvbjerg, 1998; Forester, 1989; Goldstein, 1984; Harper & Stein, 1995; Hoch, 2007; Innes, 1998). For example, despite long-term and widespread water quality impairment in the B. Everett Jordan Lake Reservoir in the rapidly-growing research triangle region of North Carolina, the implementation of an adopted nutrient management strategy, which would alter land development practices, encountered long delays due to legislative calls for additional data including a demonstration project to study in-lake, long distance circulators (NCDENR, 2013).

As data collection delays stalled action, many argued for a stronger strategy, even if it was informed by flawed, low-resolution data. Moreover, the investigation of end-of-pipe solution instead of the implementation of adopted land use strategy occurred within a political climate hesitant to limit development in one part of the watershed in order to protect water resources in other areas (see Berg & BenDor, 2010). This situation speaks to additional issues; to what extent does the precautionary principle (Foster, Vecchia, & Repacholi, 2000) play a role in ecosystem service assessments? Should effective land use interventions that demand large scale buy-in be delayed until we have better data on the effectiveness of a fully range of strategies?

An ES approach could inform public discourse by providing more specific information about development tradeoffs, but translating ES information into a recognizable value system the public can digest remains challenging. Simply put, ES is helpful, but it adds complexity, making it often very difficult to communicate ecosystem service concepts (Metz & Weigel, 2010). Using ES information should, in theory, allow planners to communicate environmental information more easily, as they would be able to more specifically address issues that residents care about, like reduced flooding or increased groundwater availability. However, trying to assess tradeoffs with ES can be difficult if we are not able to convey different ES services and their benefits using the same units (e.g. dollar values), which is often extremely difficult.

Planners will need to determine to what extent an expanded ES framework could balance increased data and public communication. For example, it is unclear how subjective valuations like public input should be interpreted. Public input is necessary to determine which ES hold great value to a community at large, but may be ranked or weighted differently by different stakeholder groups.[6] For example, what if the construction of a highway by-pass in one neighborhood will decrease idling time and improve air quality, but residents in an adjoining neighborhood will see diminished flood control from wetlands? How can planners resolve stakeholder disagreements about how to measure and quantify services? While ranking systems are simplistic, it is immediately evident that prioritization will be necessary to address the quantity and quality of data as well as the cognitive and practical decision-making limits to considering an infinite array of weighted tradeoffs.

Berke et al. (2013) found wide variation in the quality of comprehensive plans with respect to water resource protections for jurisdictions within the same watershed. This study highlights that even with many calls for watershed or regional approaches to environmental management (BenDor & Doyle, 2010), the scale of most planning decisions remains local (Berke et al., 2006). It has yet to be explored how these inter-jurisdictional issues affect the value of an ES approach, and how to handle the spatial mismatch between the regional coordination necessary to protect ES and the jurisdictions that are actually empowered to regulate.[7]

Finally, in prior efforts to shift environmental paradigms, such as 'adaptive management' regimes, issues of uncertainty are typically countered with iterative processes of robust decision-making that take advantage of comprehensive system monitoring (Allan & Stankey,

[6] Tools like the US Environmental Protection Agency's's (2014) EnviroAtlas are being developed to provide uniform, nationwide ecological information. This data infrastructure will be critical to creating mainstream considering of ES in planning.

[7] Understanding ecosystem service relationships across administrative boundaries may motivate cross-jurisdictional solutions to environmental conflict (Heal, Daily, Ehrlich, & Salzman, 2001). For example, Raleigh NC is investing in land protection that will help water quality in Falls Lake, an impoundment that is major source of drinking water for Raleigh, yet is surrounded by the City of Durham, NC (Monti, 2014). Additionally, investments in US Forest Service's efforts to manage headwaters to reduce fire risk will help the City of Denver, CO to avoid costly fire-related pulses of sediment into their water system (Denver Water, 2014).

2009). This simple idea ("figure out failures of our previous ideas, fix previous problems") is commonly met with institutional barriers, like limited budgets for monitoring, and entrenched interests fighting against management changes. As we saw in the Damascus, OR, a major hurdle to the an ES framework is the institutional barriers to the implementation of new environmental management paradigms.

6. Extending ES into planning: a call for research

The incorporation of ES into the land use and environmental planning process necessitates an outlay of resources (i.e., staff time, outside expertise, data resources). Thus, it will be essential for proponents to articulate a clear set of arguments to justify this investment in the often-limited financial reality of planning departments. We have identified possible synergies between ecosystems services and urban planning processes in the plans discussed above, but additional research is necessary in order to tailor the data generation, measurement, and modeling processes to the needs and potential uses of ES in real-world planning processes. We propose a three-part research agenda for the environmental planning research community to explore a fundamental question: how can ecosystem service frameworks *measurably* and *verifiably* improve planning outcomes?

This question could ideally be answered through quasi-experimental designs that analyze situations where ES are considered and used in planning situations, as well as counterfactuals where ES are not considered. Researchers could then assess the planning process and variations in the expected outcomes of the plan with and without ES incorporated and assess the role of ES across 1) jurisdictions, 2) types of plans, and 3) types of services.

6.1. Current state of ES in urban planning

In the first stage of this agenda, we call for reviews of existing comprehensive planning processes to assess how ES concepts (whether or not these concepts are presented using "ecosystem service" terminology) are already incorporated. For example, while green infrastructure emergence in many cities has not typically been driven by an ES perspective, considerations of cost and public perception have played a major part in the adoption of green infrastructure stormwater management practices. Many plans already assess various aspects of ecological functioning and community valuation. If they incorporate information on the use of recreational lands and the way the public values them, or if plans consider the air quality and temperature benefits of street trees by looking at reduction in health related costs, then they are inherently considering ES. At the far end of this continuum, the City of Damascus, OR explicitly used an ES approach to quantify the ecological services associated with selected parcels (Yap, 2011). It is critical to first understand how jurisdictions are already using ES information and valuation and how these practices may be extended.

6.2. Improving the use of ES in planning

The second facet of our agenda calls on researchers to develop techniques (e.g. checklists, tools, models) that allow planners to better incorporate ES measurements and models into plan development and implementation efforts. Existing research has been primarily theoretical in proposals for improved ES use in decision-making (Bateman et al., 2013; Cowling et al., 2008; de Groot et al., 2010; Fisher, Turner, & Morling, 2009; Grêt-Regamey, Celio, Klein, & Wissen Hayek, 2013; Jordan & Russel, 2014), with efforts only starting to focus on using ES for influencing actual decision-making processes (Posner, McKenzie, & Ricketts, 2016; Ruckelshaus et al., 2015; Spangenberg, Görg, & Settele, 2015).

The potential outcomes of this part of the research agenda could be evaluated by examining how these tools might change existing plans and their implementation. A thorough research design would involve working with groups of planners and ecosystem service experts in selected cities who apply these tools and changes to the planning process or implementation of plans. Future work should delve deeper into determining how and where inclusion of ES information can occur in different types of *planning processes*, seeking qualitative understanding of the specific process for incorporating environmental values in different planning contexts. One potential approach, developed by Wensem et al. (in press), involves using three criteria for evaluating the extent of ES use in decision-making processes, including 1) creating clear connections bridging ecosystem change and human well-being, 2) consideration of a holistic and relevant set of ES affected by decisions, and 3) comparisons between well-being changes in different groups of stakeholders.

Additionally, there is currently an extensive debate in several fields around measuring and modeling ES, such as urban forestry (National Research Council, 2013), where current models have major shortcomings in characterizing and quantifying the benefits of urban trees (e.g. Pataki, McCarthy, Litvak, & Pincetl, 2011; Pincetl, Gillespie, Pataki, Saatchi, & Saphores, 2013). While work has begun to improve techniques for integrating of ES into planning processes – e.g. Hilde and Paterson's (2014) efforts to integrate specific street tree benefits into scenario planning processes – on-going efforts need to continue to improve ecosystem service model validity, usability, and applicability in the urban context.

6.3. ES measurement and communication

The third area of research seeks to understand how ES information can best be measured, visualized, and communicated during urban planning processes. In the federal decision making context, many agencies require a formal trade-off or cost-benefit analysis (wherein all costs and benefits are monetized) for use in a formal multi-criteria decision process. In other cases, it may be sufficient to have measures of the potential impact on the provision of services or benefits received that are not dollar values. For an ES framework, we might measure different scenarios based on a change in the risk of flooding for a number of people (e.g., a 10% reduced risk of flooding for 300 people). This approach implies the need for a system for gauging the level of effort for providing services, the necessary data and models for measuring those services, and a test of implementation feasibility for different levels of services based on this effort.

Beyond commonly used techniques employing GIS layers that show green space and non-green space in a binary fashion, ES information may best be represented as flows of services from area of provision to areas where they are used or appreciated. Visualizations and data sharing tools developed as part of this research program could be tested directly with focus groups of urban planners. As above, researchers would work with a group of planners in selected cities who review the new visualizations and weigh changes the planning process or implementation of plans.

7. Conclusions

ES represent a potential new platform for including ecological information in planning. By drawing on a system that explicitly facilitates tradeoffs among environmental outcomes, an ES-based platform may be able to fundamentally reframe many challenges that 21st century planners face in environmental decision-making. In this paper, we have addressed several questions, including how ES can be constructed as an organizing framework for land use and environmental planning and how such an approach could become a central consideration in urban planning processes.

Planning policies and actions are typically informed by data with low temporal and spatial resolutions. An ES approach involves the integration of more, higher quality ecological and social data as planners and policy-makers balance tradeoffs. Planning, decision-making, and implementation occurs within a complex system where regulations and, institutional structures complicate the adoption of ES. Our exploration lays out a research agenda to address whether an ES framework yields a net benefit to planning and if it is worth pursuing. Significant work remains to further develop current ES data resources, models, and decision making processes.[8] Improving the extent of ecological data collected for decision-making during the planning process could have profound consequences for the consideration of the interplay of multiple, alternative planned actions or policies.

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References

Ahern, J., Cilliers, S., & Niemelä, J. (2014). The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation. *Landscape and Urban Planning*, *125*, 254–259.
Albert, C., Aronson, J., Fürst, C., & Opdam, P. (2014). Integrating ecosystem services in landscape planning: Requirements, approaches, and impacts. *Landscape Ecology*, *29*, 1277–1285.
Albert, C., Galler, C., Hermes, J., Neuendorf, F., von Haaren, C., & Lovett, A. (2016). Applying ecosystem services indicators in landscape planning and management: The ES-in-planning framework. *Ecological Indicators*, *61*, 100–113.
Allan, C., & Stankey, G. H. (2009). *Adaptive environmental management: A practitioner's guide*. Springer.
Baltimore County (2010). *Master plan 2020.* (In. Baltimore, MD: Baltimore County, MD).
Bateman, I. J., Harwood, A. R., Mace, G. M., Watson, R. T., Abson, D. J., Andrews, B., ... Dugdale, S. (2013). Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science*, *341*, 45–50.
Beauregard, R. (1991). Without a net: Modernist planning and the postmodern abyss. *Journal of Planning Education and Research*, *10*, 189–194.
BenDor, T., & Doyle, M. W. (2010). Planning for ecosystem service markets. *Journal of the American Planning Association*, *76*, 59–72.
BenDor, T., Brozovic, N., & Pallathucheril, V. G. (2008). Exploring the social impacts of wetland mitigation policies in the United States. *Journal of Planning Literature*, *22*, 341–357.
Benedict, M. A., & McMahon, E. T. (2006). *Green infrastructure. Linking landscapes and communities*. Washington, D.C.: Island press.
Berg, H. E., & BenDor, T. K. (2010). A case study of form-based solutions for watershed protection. *Environmental Management*, *46*, 436–451.
Berke, P. (2014). Rising to the challenge: Planning in the age of climate change. In B. Glavovic, & G. Smith (Eds.), *Adapting to climate change: Lessons from natural hazards planning*. London: Springer.
Berke, P., Godschalk, D., Kaiser, E., & Rodriguez, D. A. (2006). *Urban land use planning* (5th ed.). Urbana, IL: University of Illinois Press.
Berke, P., Spurlock, D., Hess, G., & Band, L. (2013). Local comprehensive plan quality and regional ecosystem protection: The case of the Jordan Lake watershed, North Carolina, U.S.A. *Land Use Policy*, *31*, 450–459.
Biggs, R., Schlüter, M., & Schoon, M. L. (2015). *Principles for building resilience: Sustaining ecosystem services in social-ecological systems*. Cambridge University Press.
Brail, R. K., & Klosterman, R. E. (2001). *Planning support systems: Integrating geographic information systems, models, and visualization tools*. Redlands, CA: ESRI Press.
Brody, S. D., Godschalk, D. R., & Burby, R. J. (2003). Mandating citizen participation in plan making: Six strategic planning choices. *Journal of the American Planning Association*, *69*, 245–264.
Brody, S., Highfield, W., & Carrasco, V. (2004). Measuring the collective planning capabilities of local jurisdictions to manage ecological systems in southern Florida. *Landscape and Urban Planning*, *64*, 33–50.
CH2MHill (2009). *Public facilities plan.* (Damascus, OR: City of Damascus, OR).

[8] The technical literature is often critical of current tools used to evaluate ES; for example, models often do a very poor job of representing benefit transfers (e.g. extrapolating value of a forest from individual trees). Furthermore, tools that are commonly used by planners, like GIS, typically are bad at representing the three-dimensional functions of ecosystems (Hopkins, 1999).

CH2MHill (2011). *Ecosystem service market program component.* (Damascus, OR: City of Damascus, OR).
Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation planning for ecosystem services. *PLoS Biology*, *4*, e379.
Chesapeake Bay Program (2010). Why is the Chesapeake Bay so important? *Chesapeake Bay News*. Annapolis, MD: Chesapeake Bay Program.
City of Damascus (2010). *Envision Damascus: Comprehensive plan.* (Damascus, OR: City of Damascus, OR).
City of Philadelphia (2011). *Citywide vision: Philadelphia 2035.* Philadelphia, PA: City of Philadelphia.
Clements, J., Shafer Raucher, R., Neukrug, H., Mills, D., Cromwell, J., Horsch, E., & Deck, L. (2012). The Philadelphia story-A triple-bottom-line assessment of traditional and green infrastructure options for controlling CSO events in Philadelphia's watersheds. *Water Environment and Technology*, *24*, 28.
Cowling, R. M., Egoh, B., Knight, A. T., O'Farrell, P. J., Reyers, B., Rouget, M., ... Wilhelm-Rechman, A. (2008). An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences*, *105*, 9483–9488.
de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, *7*, 260–272.
Denver Water (2014). *From forests to faucets: U.S. Forest Service and Denver water watershed management partnership.* (Denver, CO: Denver Water).
Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., ... Báldi, A. (2015). The IPBES conceptual framework—Connecting nature and people. *Current Opinion in Environmental Sustainability*, *14*, 1–16.
Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, *68*, 643–653.
Flyvbjerg, B. (1998). *Rationality and power: Democracy in practice*. Chicago, IL: University of Chicago Press.
Forester, J. (1989). *Planning in the face of power*. Berkeley: University of California Press.
Forester, J. (1999). *The deliberative practicioner. Encouraging participatory planning processes*. Cambridge, MA: MIT Press.
Foster, K. R., Vecchia, P., & Repacholi, M. H. (2000). Science and the precautionary principle. *Science*, *288*, 979–981.
Fürst, C., Opdam, P., Inostroza, L., & Luque, S. (2014). Evaluating the role of ecosystem services in participatory land use planning: Proposing a balanced score card. *Landscape Ecology*, *29*, 1435–1446.
Goldstein, H. (1984). Planning as argumentation. *Environment and Planning B*, *11*, 297–312.
Goodman, R. (1971). *After the planners*. New York, NY: Simon & Schuster.
Grêt-Regamey, A., Celio, E., Klein, T. M., & Wissen Hayek, U. (2013). Understanding ecosystem services trade-offs with interactive procedural modeling for sustainable urban planning. *Landscape and Urban Planning*, *109*, 107–116.
Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., ... Hansen, R. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*, *43*, 413–433.
Harper, T., & Stein, S. (1995). Out of the post-modern abyss: Preserving the rationale for liberal planning. *Journal of Planning Education and Research*, *14*, 233–244.
Heal, G., Daily, G. C., Ehrlich, P. R., & Salzman, J. (2001). Protecting natural capital through ecosystem service districts. *Stanford Environmental Law Journal*, *20*, 333–364.
Herrera Environmental Consultants, Northern Economics, & Spatial Informatics Group (2004). *Ecological economic evaluation: Maury Island, King County, Washington*. Seattle, WA: King County Department of Natural Resources and Parks.
Hilde, T., & Paterson, R. (2014). Integrating ecosystem services analysis into scenario planning practice: Accounting for street tree benefits with i-Tree valuation in central Texas. *Journal of Environmental Management*, *146*, 524–534.
Hoch, C. (2007). Making plans: Representation and intention. *Planning Theory*, *6*, 16–35.
Hopkins, L. D. (1999). Structure of a planning support system for urban development. *Environment and Planning B*, *26*, 333–343.
Innes, J. E. (1996). Planning through consensus building: A new view of the comprehensive planning ideal. *Journal of the American Planning Association*, *62*, 460–472.
Innes, J. (1998). Information in communication planning. *Journal of the American Planning Association*, *64*, 52–63.
Jongman, R. H. G., & Pungetti, G. (2004). *Ecological networks and greenways: Concept, design, implementation*. Cambridge, England: Cambridge University Press.
Jongman, R. H. G., Külvik, M., & Kristiansen, I. (2004). European ecological networks and greenways. *Landscape and Urban Planning*, *68*, 305–319.
Jordan, A., & Russel, D. (2014). Embedding the concept of ecosystem services? The utilisation of ecological knowledge in different policy venues. *Environment and Planning C: Government and Policy*, *32*, 192–207.
Kaiser, E. J., & Godschalk, D. R. (1995). Twentieth century land use planning: A stalwart family tree. *Journal of the American Planning Association*, *61*, 365–385.
Langemeyer, J., Gómez-Baggethun, E., Haase, D., Scheuer, S., & Elmqvist, T. (2016). Bridging the gap between ecosystem service assessments and land-use planning through Multi-Criteria Decision Analysis (MCDA). *Environmental Science & Policy*, *62*, 45–56.
McHarg, I. (1964). The place of nature in the City of man. *The Annals of the American Academy of Political Science*, *325*, 1–12.
McHarg, I. (1969). *Design with nature*. New York, NY: John Wiley and Sons, Inc.
MDDNR (1984). *Critical Area Act.* (Annapolis, MD: State of Maryland).
MEA (2005). *Ecosystems and human wellbeing: Biodiversity synthesis*. Washington, D.C.: World Resources Institute.
Mertes, J. D., & Hall, J. R. (1995). *Park, recreation, open space, and greenway guidelines (Vol. Lubbock, TX)*. National Recreation and Park Association.
Metz, D., & Weigel, L. (2010). *Key findings from recent national opinion research on "ecosystem services"*. Washington, D.C.: The Nature Conservancy.

Monti, A. (2014). *Development in the watershed: Growth vs policy*. Raleigh, NC: Raleigh Public Record.
National Research Council (2013). *Urban forestry: Toward an ecosystem services research agenda: A workshop summary*. Washington, D.C.: National Academies Press.
NCDENR (2013). *The Jordan Lake rules*. Raleigh, NC: NC Department of Environment and Natural Resources.
NCDENR (2015). *Coastal area management act*. Raleigh, NC: North Carolina Department of Environment and Natural Resources.
Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., ... Kareiva, P. M. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, *7*, 4–11.
NESP (2014). *National ecosystem service partnership Guidebook*. Durham, NC: National Ecosystem Service Partnership.
Nin, M., Soutullo, A., Rodríguez-Gallego, L., & Di Minin, E. (2016). Ecosystem services-based land planning for environmental impact avoidance. *Ecosystem Services*, *17*, 172–184.
Norgaard, R. B. (2010). Ecosystem services: From eye-opening metaphor to complexity blinder. *Ecological Economics*, *69*, 1219–1227.
Olander, L., Boyd, J., & Schieffer, E. (2015). Integrating ecosystem services into federal resource management. *Federal resource management and ecosystem services guidebook*. Durham, NC: National Ecosystem Services Partnership, Duke University.
Olander, L., Johnston, R. J., Tallis, H., Kagan, J., Maguire, L., Polasky, S., ... Palmer, M. (2015). Best Practices for Integrating Ecosystem Services into Federal Decision Making. *Durham: National Ecosystem Services Partnership*. Duke University. http://dx.doi.org/10.13016/M2CH07.
Pataki, D. E., McCarthy, H. R., Litvak, E., & Pincetl, S. (2011). Transpiration of urban forests in the Los Angeles metropolitan area. *Ecological Applications*, *21*, 661–677.
Pincetl, S., Gillespie, T., Pataki, D., Saatchi, S., & Saphores, J. -D. (2013). Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. *GeoJournal*, *78*, 475–493.
Posner, S. M., McKenzie, E., & Ricketts, T. H. (2016). Policy impacts of ecosystem services knowledge. *Proceedings of the National Academy of Sciences*, *113*, 1760–1765.
PWD (2011). *Amended Green City clean waters: The city of Philadelphia's program for combined sewer overflow control project summary*. Philadelphia, PA: Philadelphia Water Department.
PWD (2015). *Community input for green stormwater infrastructure: Project criteria*. Philadelphia, PA: Philadelphia Water Department.
Robertson, M., BenDor, T. K., Lave, R., Riggsbee, A., Ruhl, J. B., & Doyle, M. (2014). Stacking ecosystem services. *Frontiers in Ecology and the Environment*, *12*, 186–193.
Rose, R. A., Byler, D., Eastman, J. R., Fleishman, E., Geller, G., Goetz, S., ... Wilson, C. (2015). Ten ways remote sensing can contribute to conservation. *Conservation Biology*, *29*, 350–359.
Roseland, M. (1997). Dimensions of the eco-city. *Cities*, *14*, 197–202.
Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., ... Wood, S. A. (2015). Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics*, *115*, 11–21.
Salzman, J., & Ruhl, J. B. (2000). Currencies and the commodification of environmental law. *Stanford Law Review*, *53*, 607–694.
Salzman, J., & Ruhl, J. B. (2004). "No net loss" and instrument choice in wetland protection. *National Wetlands Newsletter*, *26*(3–4), 16–20.
Sanoff, H. (2000). *Community participation methods in design and planning*. New York, NY: Wiley.
Seppelt, R., Dormann, C. F., Eppink, F. V., Lautenbach, S., & Schmidt, S. (2011). A quantitative review of ecosystem service studies: Approaches, shortcomings and the road ahead. *Journal of Applied Ecology*, *48*, 630–636.
Spangenberg, J. H., Görg, C., & Settele, J. (2015). Stakeholder involvement in ESS research and governance: Between conceptual ambition and practical experiences–risks, challenges and tested tools. *Ecosystem Services*, *16*, 201–211.
Steiner, F. (2006). *The essential Ian McHarg: Writings on design and nature*. Washington, D. C.: Island Press.
Steinitz, C., Parker, P., & Jordan, L. (1976). Hand-drawn overlays: Their history and prospective uses. *Landscape Architecture*, *66*, 444–455.
Tallisa, H., Kennedy, C. M., Ruckelshaus, M., Goldstein, J., & Kiesecker, J. M. (2015). Mitigation for one & all: An integrated framework for mitigation of development impacts on biodiversity and ecosystem services. *Environmental Impact Assessment Review*, *55*, 21–34.
Tango, P. J., & Batiuk, R. A. (2013). Deriving Chesapeake Bay water quality standards. *JAWRA Journal of the American Water Resources Association*, *49*, 1007–1024.
TEEB (2011). *TEEB manual for cities: Ecosystem services in urban management*. In: TEEB - The Economics of Ecosystems and Biodiversity.
Theobald, D. M., Spies, T., Kline, J., Maxwell, B., Hobbs, N. T., & Dale, V. H. (2005). Ecological support for rural land-use planning. *Ecological Applications*, *15*, 1906–1914.
US Environmental Protection Agency (2014). *EnviroAtlas*. Washington, D.C.: U.S. Environmental Protection Agency.
Valleys Planning Council (1964). *The plan for the valleys*. Towson, MD: The Valleys Planning Council.
van Leeuwen, K. (2015). Too little water in too many cities. *Integrated Environmental Assessment and Management*, *11*, 171–173.
Vasishth, A. (2008). A scale-hierarchic ecosystem approach to integrative ecological planning. *Progress in Planning*, *70*, 99–132.
Wainger, L. A., King, D. M., Salzman, J., & Boyd, J. (2001). Wetland value indicators for scoring mitigation trades. *Stanford Environmental Law Journal*, *20*, 413–478.
Wensem, J. V., Calow, P., Dollacker, A., Maltby, L., Olander, L., Tuvendal, M., & Houtven, G. V. (in press). Identifying and assessing the application of ecosystem services approaches in environmental policies and decision-making. Integrated Environmental Assessment and Management. http://dx.doi.org/10.1002/ieam.1836.
Wilkinson, C., Saarne, T., Peterson, G. D., & Colding, J. (2013). Strategic spatial planning and the ecosystem services concept—An historical exploration. *Ecology and Society*, *18*, 37.
Wilmington – New Hanover County (2006). *Wilmington — New Hanover County joint coastal area management plan*. (Wilmington, NC: Wilmington – New Hanover County).
Woodruff, S. C., & BenDor, T. K. (2016). Ecosystem services in urban planning: Comparative paradigms and guidelines for high quality plans. *Landscape and Urban Planning*, *152*, 90–100.
Yap, A. (2011). Is ecosystem services implementable by municipalities at the landscape level? *Oregon Planners Journal*, 13–18.
Yin, R. K. (2008). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.