

# Service Path Attribution Networks (SPANs): A Network Flow Approach to Ecosystem Service Assessment

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## ABSTRACT

*Ecosystem services are the effects on human well-being of the flow of benefits from ecosystems to people over given extents of space and time. The Service Path Attribution Network (SPAN) model provides a spatial framework for determining the topology and strength of these flows and identifies the human and ecological features which give rise to them. As an aid to decision-making, this approach discovers dependencies between provision and usage endpoints, spatial competition among users for scarce resources, and areas of highest likely impact on ecosystem service flows. Particularly novel is the model's ability to quantify services provided by the absence of a flow. SPAN models have been developed for a number of services (scenic views, proximity to open space, carbon sequestration, flood mitigation, nutrient cycling, and avoided sedimentation/deposition), which vary in scale of effect, mechanism of provision and use, and type of flow. Results using real world data are shown for the US Puget Sound region.*

*Keywords: Ecosystem Service Assessment, Environmental Planning, Flow Criticality, Flow Density, Flow Modeling, Network Flow, Service Flows, Service Path Attribution Network (SPAN), Spatial Decision Making*

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## INTRODUCTION

The concept of Ecosystem Services (ES) provides a cohesive scientific view of the many mechanisms through which nature contributes to human well-being (Daily, 1997). From the

more well-known services, such as the provision of food, clean water, medicine, and raw materials to the more ephemeral services of natural systems regulation, aesthetics, and cultural preservation, ecosystem services both directly and indirectly impact the quality of life of people around the globe (Daily, 1997; National Research Council (NRC), 2005; Millennium Ecosystem Assessment (MA), 2005).

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Ecosystem service assessment, as an application of ecological and economic principles, is the task of quantifying the values conferred by natural systems to their human counterparts for the purpose of improving spatial decision making around land management. Focusing on both the biophysical mechanisms of ES provision and the economic implications of ES use can allow our societies to balance the sides of the “nature vs. economy” equation, leading ultimately to better management and governance (Millennium Ecosystem Assessment (MA), 2005).

Since analyzing ecosystem services requires modeling coupled human-natural systems, an ongoing hurdle in this field is properly combining techniques from both socio-economics and the physical sciences so as to capture both sides of the service dynamics. However, these fields often make use of quite different modeling techniques, underlying assumptions, and spatio-temporal scales. Furthermore, even with an optimal integration of modeling techniques, many of the interactions between humans and their environments remain clouded by uncertainty or completely unknown to science (Limburg, O’Neill, Costanza, & Farber, 2002).

For these reasons, concrete techniques for supporting quantification, spatial mapping and economic valuation of ES have lagged behind the popularity of the concept, making it difficult to productively use ES as a basis for scientific investigation and accurate decision-making (Boyd & Banzhaf, 2007; Wallace, 2007). Virtually all methodologies employed or proposed (Costanza et al., 1997a; Farber et al., 2006; Nelson et al., 2009; Tallis & Polasky, 2009) to quantify ES and their values convert proxy categorical information, chiefly land cover type, into coarse assessments of value or potential provision through the use of aggregated coefficients. Such approaches ignore the complex, multi-scale dynamics of ES provision, use, and flow, and are insufficiently precise to enable detailed scenario analyses or inform spatial planning decisions. Current approaches tend to address the following four points unsatisfactorily:

1. **Scalability:** Ecosystem services are provided and used at a wide variety of spatial and temporal scales (Hein, van Koppen, de Groot, & van Ierland, 2006; Fisher & Turner, 2008). However, most current spatial ES models are calibrated to operate on one fixed scale. A more robust model would be able to adapt its scale and associated complexity to match each problem and have some means of automated or semi-automated recalibration in conjunction with these scale changes.
2. **Generalizability:** When different ES models are developed using entirely independent assumptions and abstractions, comparison of their results for the purpose of decision-making, particularly around tradeoff analysis, becomes very difficult. The development of a unified framework for quantifying many different ecosystem services with the same (or comparable) parameters is sorely lacking but has the potential to make ES assessment a much more useful tool in spatial decision-making contexts.
3. **Benefit-Centrism:** Although earth system simulation modeling is a well established field, especially with respect to climate and hydrologic modeling, such models focus largely or exclusively on describing and predicting how physical environmental systems behave under varying conditions. In order to describe ecosystem services, the effects of the environmental system on the human economic system (and vice versa) should be central to the model rather than an addendum to a separate analysis (Boyd & Banzhaf, 2007; Wallace, 2007; Bagstad, Johnson, Villa, Krivov, & Ceroni, 2012).
4. **Communicating Uncertainty:** The results of many earth system simulation or process-based models are deterministic values for their component variables. Since all modeling manipulates and produces uncertainty and the number of unknowns is perhaps greater in ES modeling than in many other disciplines, special care should be taken to preserve the sources of this

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