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A critical assessment of available ecosystem services data according to the Final Ecosystem Goods and Services framework

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Abstract

The last decade has seen a proliferation of studies describing the benefits people accrue from natural processes by translation of spatially explicit land use and landcover data to ecosystem service provision. Yet, critical assessment of systemic bias resulting from reliance on land use and landcover data is limited. Here, we evaluate an extensive collection of ecosystem service-related data based on land use and landcover according to a broadly applicable ecosystem service framework—Final Ecosystem Goods and Services (FEGS). In this framework, ecosystems are viewed from the perspective of a comprehensive set of beneficiaries and the biophysical features directly relevant to each. In this examination, we create a database identifying over 14,000 linkages between 255 data layers from EnviroAtlas and FEGS beneficiaries. Through these linkages, we identify major gaps in beneficiary identification and systemic biases resulting from the utilization of translations from land use and landcover data. Importantly, we find that for many beneficiaries there is an absence of data on FEGS at extensive scales in the United States. We provide a roadmap for the integration of extant ecosystem service research efforts using the FEGS classification scheme and critically appraise this scheme, highlighting inconsistent specification among beneficiary categories and environmental classes. We also explore the benefits of crosswalking different ecosystem service data and frameworks for researchers, by reducing the otherwise high buy-in cost of data exploration, and for data developers, by increasing the exposure of their work.

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Keywords

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Introduction

We present a case study to assess the following research question: Are biases introduced to assessments of ecosystem goods and services by reliance primarily on land use and landcover data? To do so, we crosswalk extant data sets with a global ecosystem goods and services accounting framework. Specifically, we assess data from the EnviroAtlas, a popular Web-based ecosystem services platform, according to the Final Ecosystem Goods and Services Classification System (FEGS-CS). We map data layers developed and hosted by EnviroAtlas onto the FEGS-CS and investigate key areas of success and deficiency of land use and landcover data in addressing the needs of specific categories of beneficiaries. We then address the utility of the FEGS-CS as a vehicle for interdisciplinary collaboration and data sharing.

Description of EnviroAtlas and land use/landcover data

The availability of land use and landcover data has grown in recent decades and been increasingly applied to estimate the provision of ecosystem goods and services. Because changes in land use and landcover are among the most salient forces in the human management of ecosystems, measuring and managing their effects as drivers of changes of ecosystem goods and service provision is essential (Lawler et al. 2014, Tang et al. 2014, Tashie et al. 2016). Further, landcover is commonly the only spatially explicit data type available over large geographic extents (Ivanov and Eigenraam 2015, Kindu et al. 2016) and many studies therefore rely exclusively on landcover data to assess the geospatial distribution of ecosystem goods and service provision (Reyers et al. 2009, Wang et al. 2015, Tolessa et al. 2016). Most studies linking ecosystem goods and service provision to (changes in) landcover are qualitative in nature because of a lack of global comprehensive measurements of services and methods for translating those services into quantitative units (Reyers et al. 2009, Wang et al. 2015, Kindu et al. 2016, Tolessa et al. 2016), with very few studies including dynamic valuations (Tang et al. 2014) and econometrics capable of including the marginal value of dynamic services (Lawler et al. 2014). Instead, quantitative assessments tend to rely on tables relating to global (Costanza et al. 1997) or regional (Xie et al. 2008) estimates of ecosystem goods and service provision per unit area of a particular landcover class simplified into the most basic of units (Lawler et al. 2014, Wang et al. 2015, Tolessa et al. 2016) or disaggregated based on locally available data (Reyers et al. 2009). While translation of (changes in) landcover and land use to ecosystem goods and services provision remains the most common methodological framework by which ecosystem goods and services valuation and policy studies are performed at the regional (or larger) scale, little work has been published assessing its capacity to address a holistic accounting of ecosystem goods and services.

EnviroAtlas is a Web-based, geospatially explicit collection of tools, data, and resources centered on the concept of ecosystem goods and services (enviroatlas.epa.gov/enviroatlas;

Pickard et al. 2015). Developed by the U.S. Environmental Protection Agency and partners in response to the 2011 report from the President's Council on Science and Technology, EnviroAtlas brings together environmental, demographic, and economic data on a geographic information system platform. Most data layers hosted by EnviroAtlas are developed internally or in partnership with other federal programs, and are designed to be readily accessible to academic, professional, and lay audiences.

Data are available at either the national level (continental U.S.) or community level (for 24 metropolitan areas, including over 950 cities and towns), and consist of four primary types: indicator data summarized by 12-digit Hydrologic Unit Code (at the national scale) or census block group (at the community scale); raster data at 1- or 30-m resolution; vector data hosted from outside sources; and socioeconomic reference data.

National-level ecosystem goods and services metrics are generally derived by cross-analysis of publicly available geospatial data, including the National Land Cover Database, the U.S. Department of Agriculture Cropland Data Layer, the U.S. Geological Survey National Map for 30-m resolution elevation data, Federal Emergency Management Agency flood zone maps, National Hydrography Data for water bodies and stream impairment, the Soil Survey Geographic Database and State Soil Geographic Database for hydric soil delimitation, and U.S. Census Bureau demographics. For example, the data layer "Percent Stream Buffer Zone as Natural Land Cover" for the coterminous United States clips landcover according to a 30-m buffer of water bodies and then summarizes the data by 12-digit Hydrologic Unit Code. Similarly, the data layer "Acres of Pollinated Crops with No Nearby Pollinator Habitat" clips pollinator habitat, derived from forested landcover, to a 2.8-km buffer of pollinator-dependent crops, based on crop data and a literature review of bee foraging behavior, and then summarizes the data by 12-digit Hydrologic Unit Code.

Many community-level data layers are developed similarly by using higher resolution (1 m) landcover data developed from U.S. Department of Agriculture National Agricultural Imagery Program, LiDAR, and other data, then summarized according to U.S. census block groups. Additionally, community-level data utilize output from two ecosystem goods and services models. The U.S. Department of Agriculture Forest Service model i-Tree estimates carbon sequestration and reductions in annual air and water pollutants, stormwater runoff, and ambient air temperature based on local tree cover and environmental conditions from U.S. Environmental Protection Agency air monitors and U.S. Geological Survey stream gages. The joint U.S. Environmental Protection Agency and Forest Service tool BenMAP calculates the distributed human health and economic benefits from the reduction of air pollutants from tree cover, i-Tree outputs, and demographic data. While EnviroAtlas continues to generate new data layers every year, at the time of our original analysis in January of 2017, EnviroAtlas hosted 255 unique layers relevant to ecosystem goods and services which relied in whole or in part on land use or landcover data.

Description of Final Ecosystem Goods and Services

Final Ecosystem Goods and Services is a systems-based framework for ecosystem goods and services description and valuation which applies production theory to ecological systems and accounts for the value of these systems in the biophysical forms and locations where they directly benefit people (Ringold et al. 2013); that is, FEGS represents ecosystems according to the goods or services they produce which are directly used, consumed, or enjoyed by people in the specific ways in which they directly interact with ecosystems rather than the broader set of important intermediate ecosystem features that support or regulate those FEGS. These final ecosystem goods and services, or FEGS, facilitate social interpretation of ecological conditions and change by representing those things that directly affect people's welfare (Boyd et al. 2016). Indicators of FEGS (alternatively known as linking indicators) integrate measures of biophysical features of the environment which benefit people, thereby linking biophysical systems to social systems of production (Ringold et al. 2009, Boyd and Krupnick 2013). In building on decades of economic research, this framework aims to avoid known pitfalls (such as double counting), bridge the typological gap between the social and natural sciences, and represent the benefits that ecosystems provide to a potential beneficiary in a manner they may appreciate at face value (Ringold et al. 2011, Boyd and Krupnick 2013).

The relationships between public policy, environmental stressors, biophysical processes, FEGS, and human well-being are illustrated in a decision context in Fig. 1. Here, changes in policies (e.g., changes in riparian management or changes in emissions from automobiles) lead to changes in stressors (e.g., changes in the flow of materials into streams, or changes in particulate or ozone concentrations in the atmosphere) lead to changes in biophysical features (e.g., changes in stream temperature or water clarity, or changes in lung function) leading to changes in human well-being. Final Ecosystem Goods and Services are a subset of those biophysical features whose quantities or qualities are directly understood or experienced by people. It is important to note that when we quantify FEGS, we quantify what nature makes available, not what is used or is co-produced with human labor or capital (Palomo et al. 2016). It is a potential that people may (or may not) use, enjoy, or appreciate. Analysis of whether the ecosystem goods and services that are available are used, enjoyed, or appreciated is assessed independently.

The FEGS-CS was designed to formalize or standardize the FEGS concept. While it intends to provide a holistic accounting of ecosystem goods and services from a human perspective, it is not intended to abrogate or override other frameworks. Further, due to its reframing of ecosystem goods and services according to their potential direct benefits for humans, FEGS benefits categories are unlikely to map directly onto the structure of other frameworks defined in terms of ecosystems themselves. Landers and Nahlik (2013) provide a full description of FEGS classification system.

The FEGS-CS provides a standardized list of beneficiaries according to two levels (Fig. 2). There are ten categories at the highest level: Agriculture; Commercial/Industrial; Government, Municipal, and Residential; Commercial/Military Transportation; Subsistence; Recreational; Inspirational; Learning; Non-Use; and Humanity. Thirty-eight sub-categories are listed in the second level of this classification system (Table 1). The system also divides ecosystems into three environmental classes (Aquatic, Terrestrial, and Atmospheric) and 15 sub-classes (Table 2). These beneficiary sub-categories and environmental sub-classes are numerically coded in the FEGSCS, and it was these codes which we linked with data in the EnviroAtlas.

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Crosswalk: Methods

First, we assessed each data layer available in the EnviroAtlas to identify metrics or indicators of FEGS. We refer readers to the FEGS-CS for a detailed discussion of delineation of FEGS from non-FEGS. Here, we provide a summary of those methods along with a few salient examples.

A FEGS is identified when a data layer indicates a product or function of the natural environment which is directly used, consumed, or enjoyed by a specific beneficiary; that is, the data layer must indicate a feature of process which (1) is not intentionally influenced by human activity and (2) is directly used, consumed, or enjoyed by a specific human beneficiary.

To the first point, the FEGS-CS acknowledges that all aspects of the modern world are influenced by human activity to some degree, yet a systematic accounting of ecosystem goods and services demands an internally consistent, objective framework for differentiating the natural from the human-influenced. According to the FEGS-CS, ecosystem goods and services are those whose generation is directly connected to the lithosphere or hydrosphere and either self-sustaining within a human lifetime or an incidental by-product of human management. For instance, potted plants are dependent on human intervention (e.g., watering or fertilizing) and coal is not renewable in human lifetime; therefore, neither is a FEGS despite their reliance on certain ecosystem processes. Examples of natural, renewable goods according to the FEGS-CS may include water in streams, wild berries, and birds, fish, and other fauna.

To the second point, FEGS are differentiated from intermediate goods or services by consideration of the degree of abstraction or calculation necessary to identify features of the natural world which matter directly to people. Succinctly, a FEGS is appreciated by people without any need for interpretation. For instance, that wild turkey in a woodland benefit hunters of wild turkey directly is evident without any intervening technical translation. In contrast, wild turkey habitat is important to wild turkeys and therefore to wild turkey hunters, but the habitat must be translated to wild turkey abundance to be directly meaningful to a wild turkey hunter. Conversely, many concepts commonly considered in ecosystem goods and services frameworks are not appreciated directly but are rather proxies for or amalgamations of final goods and services. For example, while estimates of global sea level rise integrate temporal trends in a manner relevant to and useful for natural scientists, for non-specialists the direct utility of these estimates is realized only in their application to a specific FEGS, for example, in estimating flood risk for property owners or the presence (or extinction) of healthy coral reefs for recreational snorkelers.

The first step in our crosswalk was to inspect the metadata of each data layer in the EnviroAtlas to identify which FEGS-CS beneficiary subcategories might directly use, consume, or enjoy the components of the good(s) or service(s) it described. Where a data layer failed to describe or illustrate any potential FEGS, we collated the point(s) and reason(s) for this failure. For example, we noted that a data layer describing pollinator habitat was not a FEGS because pollinator habitat is not directly used, consumed, or enjoyed by a beneficiary; instead, the potential value of pollinator habitat is accounted for in the FEGS of crop pollinators on cropland, which is directly enjoyed by Farmers in Agroecosystems (i.e., FEGS-CS code 22–0106). Similarly, we noted that the data layers in EnviroAtlas which describe annual crop yields (e.g., cotton, fruits, or grain) were not FEGS because crops are not self-sustaining in the environment but instead dependent on extensive inputs of capital and labor by Farmers.

For data layers which did describe or illustrate candidate FEGS for a specific beneficiary, we inspected their metadata to identify every environmental sub-class where the object of its description occurred. For example, data layers describing the extent of tree cover are potential metrics of several categories of FEGS as trees directly benefit many people, like Recreational Experiencers and Viewers (-0601) and Commercial Timber Extractors (-0202). However, while the potential benefits provided by tree cover may be enjoyed by Recreational Experiencers and Viewers in both Forests (21-) and Created Greenspaces (23-), Commercial Timber Extractors would be excluded from utilization of Created Greenspaces, for example, parks, cemeteries, and lawns. By this process, we were able to identify 449 unique linkages of data layers in EnviroAtlas with potential FEGS, generated by 18 data layers in EnviroAtlas and serving 27 beneficiary subcategories (Table 1) across 8 environmental subclasses (Table 2).

Crosswalking EnviroAtlas data with metrics of non-FEGS

There remained 237 data layers in EnviroAtlas which described non-FEGS. We reassessed these data layers for categorization according to a binary decision tree provided by the FEGS-CS for differentiating FEGS from non-FEGS. Broadly, a data layer may fail to indicate a FEGS because what it describes is either (1) dependent on intentional human influence or activity or (2) not directly used, consumed, or appreciated by a specific human beneficiary. Data where the good or service described depended on intentional human management is defined as a social or economic outcome (SEO), and data where the biophysical feature described would not be directly used, enjoyed, or appreciated by a non-specialist are defined as an intermediate ecosystem goods and services (IEGS).

The FEGS-CS accounts for IEGS as ecological stocks and processes (i.e., ancillary goods, services, and the processes that transform them into other goods or services) the value of which is embodied in the value of FEGS (Fig. 3). They describe a chain of linkages whereby ecosystem ancillary goods or services are transformed into the goods and services which directly benefit humans. We inspected the metadata of every data layer in the EnviroAtlas to apply this model for developing discrete causal linkages which identify the FEGS or set of FEGS which might reasonably be affected by or be dependent on the IEGS in question. For example, pollinator habitat is a feature of certain landscapes which does not directly benefit humans and, therefore, is an IEGS. The act of pollination, performed by pollinators, however, does directly benefit Farmers of some crops. Therefore, pollinator habitat feeds into the FEGS framework by providing a necessary condition for the production of FEGS 22.0106, that is, the presence of pollinators of crops in agroecosystems.

A key consideration in the development of these causal linkages arose regarding how inclusive we were to be. It could be argued that the interconnectedness of the natural world implies that any IEGS affects all FEGS in some manner. An overly broad definition of this sort yields results too expansive to be useful. Both for pragmatic reasons and so as to consistently apply the framework outlined in the FEGS-CS, we limited the scope vis-à-vis causal linkages to causalities which were simple and generally applicable; that is, we linked IEGS to a specific FEGS only where it materially alters the distribution, quantity, quality, or timing of that FEGS. This dependence on first-order effects was essential to the development of an internally consistent framework, which is generally applicable and transparent to non-specialists.

Similarly, we linked a SEO to a specific FEGS only where its distribution, quantity, quality, or timing is materially altered by that FEGS. To do so, we assessed the metadata of every data layer designated as a SEO according to its point of failure in the binary decision tree provided by the FEGS-CS. For example, agricultural groundwater withdrawals are dependent on human capital and labor to install the infrastructure necessary to extract and transport water from the subsurface (e.g., groundwater wells and pumps), but are also dependent on natural stocks (i.e., groundwater). This dependence on human effort precludes classification of groundwater withdrawals as a FEGS. However, the FEGS of the presence of Groundwater for Agricultural Irrigators (16.0101) is itself a necessary condition for the SEO of groundwater withdrawal. As when linking IEGS to FEGS, limiting the scope of the causal linkages to direct linkages between SEO and the FEGS necessary or sufficient for some aspect of their production was essential to the development of a transparent, generally applicable framework.

As there is often a spatial mismatch between the production of ecosystem goods and services and the location of their beneficiaries (Bagstad et al. 2012), it is a common point of inquiry regarding how the FEGS-CS defines a FEGS's environmental class. Specifically, the FEGS-CS defines the environmental class of a FEGS as being the environmental class where the FEGS is ultimately enjoyed, consumed, or used, not where it is initially produced or the locations through which it is transported. For instance, while improvements in water quality (e.g., denitrification) may be produced in wetlands, the FEGS of potable water may ultimately be enjoyed elsewhere (e.g., streams or lakes). Ecologists tend to devote their greater efforts to measuring stocks and production in particular ecosystems, and much ecosystem goods and services data are traditionally classified accordingly. To accommodate these alternative classification methodologies, we included a designator for the environmental class of ecosystem goods and services production (ESP) additional to IEGS, FEGS, and SEO. Unlike IEGS, FEGS, and SEO classifications, which are mutually exclusive and uniquely identify potential beneficiaries, the designation of ESP was made without reference to a beneficiary and always in conjunction with an IEGS, FEGS, or SEO whose benefit is enjoyed elsewhere of its production.

Results

We identified 14,158 linkages to IEGS, SEO, ESP, and FEGS and catalogued these linkages in a crosswalk database alongside supplementary information. This crosswalk database is publicly available in Data S1. Users of the crosswalk database are provided with a description of each dataset, its original classification in EnviroAtlas, the spatial resolution of the data, a weblink to the metadata, a brief explanation for its reclassification within the FEGS-CS, and coding defining its linkage to IEGS, SEO, ESP, or FEGS. While the high number of linkages precludes a comprehensive perusal of the crosswalk database, the coding structure provided by the FEGS-CS is such that users may navigate to data more specific to their interests with relative ease. Combined with our use of designators of IEGS, SEO, FEGS, and ESP as well as supplementary information relating to scale and resolution, it is possible to search the 255 data layers of EnviroAtlas to retrieve the several layers relevant to a highly specific need. For instance, a search for SEO data available at the national scale relevant to the needs of resource-dependent businesses on lakes and ponds yields a manageable 11 results. The crosswalk database itself is coded as a comma separated value file format (.csv), easily readable by a variety of software.

Linkages between EnviroAtlas data and the FEGS-CS

Analysis of the metrics in relation to the broader scope of beneficiary sub-categories in the FEGS-CS allowed us to identify beneficiaries for whom there is an abundance of data for some point in their production function even though it may not be for the FEGS in that system, and beneficiaries for whom data are lacking. Recreational Experiencers and Viewers (0601) are the most frequently served beneficiaries by EnviroAtlas (194 data layers), followed by Spiritual and Ceremonial Participants (0701), Artists (0702), Educators and Students (0801), Researchers (0802), and Non-Use beneficiaries (0901 and 0902; 185–187 data layers) then Residential Property Owners (0303), and Resource-Dependent Businesses (0206; 144–151 data layers). While most beneficiary sub-categories were directly served by between 40 and 70 data layers, fewer than 12 data layers were directly relevant to the needs of Industrial Dischargers (0204) or Wastewater Treatment Plant Operators (0302), and fewer than 30 data layers directly addressed the needs of Agricultural Processors (0104), foresters (0107), Commercial Timber, Fiber, and Ornamental Extractors (0202), Industrial Processors (0203), Pharmaceutical and Food Supplement Suppliers (0207), Recreational Food Pickers and Gatherers (0602), or Recreational Anglers (0602).

The majority of data layers (168) intersected with IEGS for at least one beneficiary category. Fewer data layers intersected with SEO (63) and fewer still with FEGS (18). Indeed, 7 beneficiary sub-categories are exclusively served by IEGS, while 5 are served by only IEGS or SEO. Only the broad sub-category of All Humans (1001), which was designated to capture benefits derived from the atmosphere, is directly served by more data layers intersecting with SEO than IEGS, and for no sub-category are there more data layers intersecting with FEGS than IEGS.

Though beneficiaries of ecosystem goods and services in all aquatic and terrestrial environments were similarly served by data relevant to SEO (between 13 and 37 data layers), IEGS relevant data were much more sporadic. Intermediate ecosystem goods and services in Rivers and Streams (11), Wetlands (12), Lakes and Ponds (13), Forests (21-), Agroecosystems (22-), Created Greenspace (23), Grasslands (24), Scrublands/Shrublands (25), and Barren/Rock and Sand (26) were served by at least 84 data layers, in Tundra (27), Ice and Snow (28), and Atmosphere (31) by fewer than 18 data layers, and in Open Oceans and Seas (15) and Groundwater (16) by only 3–5 data layers. While FEGS were described primarily in terrestrial environments, the environmental sub-class which most frequently intersected with FEGS was Wetlands (12). Ecosystem goods and services production were described at only 7 environmental subclasses, with the vast majority occurring in Wetlands (12), Forests (21), Agroecosystems (22), Created Greenspace (23), and Scrublands/ Shrublands (25).

Discussion

Analysis of EnviroAtlas data

Our results indicate that many beneficiaries with well-defined, highly specific needs are poorly served because of the absence of data directly relevant to their needs. Specifically, the beneficiary sub-categories served by most EnviroAtlas data layers primarily benefit from non-extractive use of the environment where both the benefits and their environmental classes are broadly defined. For example, Researchers (0802), Artists (0702), and People Who Care (Existence; 0901) may appreciate or benefit from the existence in themselves of deserts, forests, wetlands, etc., while the environmental interests of Irrigators (0101; e.g., users of water resources for agriculture) are narrowly defined. Further, nearly all of the data layers which did meet the definition of a FEGS provided services in the form of their existence or bequest to future generations (Fig. 4). While ecosystem goods and services of this type are certainly essential to a full accounting of the benefits provided by the ecosystems, it is especially complex to estimate their social or economic value; not only are their prices not observable, but the lack of a measurable mechanism of beneficiary interaction with existence or bequest means estimates of their value may only be made with stated preference studies (i.e., contingent valuation), which are notoriously difficult to implement with accuracy (Arrow et al. 1993). That the crosswalk yielded no metrics directly relevant to beneficiaries with highly specific demands on ecosystems was an illuminating result though not entirely surprising. This result is likely a by-product of EnviroAtlas's dependence on geospatial data and the definition of FEGS according to human beneficiaries as opposed to biophysical features. Potential metrics designed to address the demands of beneficiaries with highly specific needs would require additional data. For instance, while the mere existence of a forest land class (as defined by the National Land Cover Database) may be relevant to the needs of a recreational hiker, a timber extractor's valuation of a forest depends on finer details, including the stand density, species composition, timber diameter, and quality.

Similarly, a preponderance of data relates IEGS, as compared to FEGS or SEO, while there are substantially more SEO than FEGS data. This is the result of EnviroAtlas's dependence primarily on three broad categories of data: land classifications, habitat-as-proxy, and socioeconomic metrics. Land classifications, as discussed above, do not tend to address the needs of specific beneficiaries, except in the rather rare cases where a beneficiary's needs are abstract or coarsely defined. Thus, landcover classes and their derivatives (e.g., landcover connectivity or viewscapes) may most often be interpreted as metrics of stocks of IEGS, as opposed to the flow of services to human beneficiaries. Similarly, habitat-as-proxy depends on land use and landcover classifications, but also employs a species-specific inductive model. The likely (or possible) presence of specific flora or fauna is unlikely to address the needs of a particular beneficiary, though. For instance, duck hunters are directly interested in the timely presence of ducks, not in potential duck habitat. Though habitat may be of great interest to decision makers and to duck hunters, especially when species abundance data are not available, habitat is generally a IEGS, not a FEGS for beneficiaries who directly value individual taxa that are supported by specific combinations of landcover (Cade et al. 1999). Conversely, socioeconomic metrics are measured aspects of human economies dependent upon the natural world. These are, for instance, retail sales of fish, annual cotton yields, or indeed nearly all facets of human economic activity. Being dependent to some extent on human effort or their effects on human welfare, socioeconomic metrics are metrics of SEO, not FEGS.

Where EnviroAtlas does include results from physically based models (e.g., i-Tree Tools and BenMAP-CE), the model output often describes processes or physical loadings of great interest to natural scientists and engineers, but poorly understood or appreciated by the general public. These IEGS include the reduction by trees of sediment loads to streams or atmospheric NO_x concentrations, for example. Alternatively, the modeled loadings are converted to a unit of general interest which intersects with human economies. These SEO include the annual reduction of healthcare costs due to tree uptake of asthma-inducing concentrations of NO_x, for example.

The dependence of EnviroAtlas on the National Land Cover Database either directly or via derived products and models shows itself in several ways (Fig. 5). Most immediately, the FEGS-CS environmental sub-classes overwhelmingly represented in EnviroAtlas have immediate corollaries among the National Land Cover Database classes. Meanwhile, environmental sub-classes not directly translatable into National Land Cover Database classes, like Groundwater (16) and Tundra (27), are comparably underrepresented by an order of magnitude. This effect is magnified in regard to IEGS and muted in regard to SEO because much data relating to the production of ecosystem goods and services may be estimated using only land use and landcover as a proxy, while data relating to the utilization of ecosystem goods and services are more likely to depend on additional information garnered from economic and public health databases, like agricultural yields or demographics.

Incongruities in the delineation of land use and landcover classes and ecosystems had the curious effect of enhancing the perception of ecosystem goods and services generation in several cases, especially in ecosystems where a salient component of that ecosystem spans several land use and landcover classes. For instance, the FEGS-CS sub-class Agroecosystems (22) overlaps with multiple National Land Cover Database classes, including not only cropland and pastureland, but also orchards and tree farms (i.e., National Land Cover Database classes 41, 42, 43, 81, and 82); that is, agroecosystems intersect not only with every data layer in EnviroAtlas, which describes benefits related to National Land Cover Database cultivated lands, but also with many data layers related to National Land Cover Database forests. This results in more data layers intersecting with Agroecosystem ecosystem goods and services than with any other landbased environmental sub-class. Similarly, as Wetlands (12) includes areas of flowing water, emergent vegetation, grassy vegetation, and tree cover, more data layers intersect with it than with any other environmental sub-class.

The environmental sub-classes best represented with ESP in EnviroAtlas describe landscapes where trees dominate (i.e., forests) or are likely present (e.g., wetlands, orchards, parks, or scrubland), while ESP is generally absent from grassy and snowy landscapes. This results from a reliance of modeled ecosystem goods and services output on i-Tree Tools, which calculates the impact of tree cover on stormwater and air quality using a benefit transfer method. While capturing the production of ecosystem goods and services by trees is certainly worthwhile, the failure to describe ESP by other flora may result in their undervaluation in a policy context. Particularly west of the Appalachians, where grasslands and scrublands are indigenous, the exclusive reliance on tree-based ecosystem goods and services models may have the perverse effect of encouraging alteration of native ecosystems in pursuit of increased ESP.

Extending the methodologies

Final Ecosystem Goods and Services-based researchers have been using the crosswalk database (Data S1) to identify data in EnviroAtlas for the development of indicators of FEGS, that is, descriptions of the quantity of goods and services that nature makes available to people in a manner directly relevant to them. The option to target data using a familiar coding structure has relieved researchers otherwise unfamiliar with the compendium of data offered by EnviroAtlas of the rather daunting task of manually inspecting the metadata of hundreds of data layers. Even where the search provides null results, the ease with which this conclusion is reached has relieved researchers of hours of tedious labor. Further, the knowledge of the ease with which the crosswalk document can be searched has had the ancillary effect of encouraging the use of EnviroAtlas as a go-to resource by researchers who might otherwise have overlooked it. In this respect, the FEGS-to-EnviroAtlas crosswalk can be seen to have accomplished two complementary goals: easing the burdens on FEGS-based researchers and broadening the user base of EnviroAtlas.

Well-designed, integrated measures of ecosystem features directly relevant to the self-perceived well-being of stakeholders have been shown to influence perceptions of and desires for future community development (Quyen et al. 2017). While original research in the natural and social sciences tends, by design, to generate narrowly delimited data, a nuanced understanding of particular ecosystem goods and services often demands indicators composed of agglomerations of data from multiple sources (Tran et al. 2005). The aggregation and normalization of data for the development ecosystem goods and services indices is a complex, burgeoning field of research (Pollesch and Dale 2016), yet the essential first step of the discovery of extant component data often remains fraught with difficulty. While hundreds of datasets and at least 68 ecosystem goods and services tools have been developed to address the need for incorporating an accounting for them in decision-making processes (Bagstad et al. 2013), the parochial nature of many tools and datasets obscures their discovery and contextualization (de Groot et al. 2012), resulting in valuable data sitting underutilized or undiscovered.

The development of meaningful, holistic ecosystem goods and services indicators depends not simply on the proliferation of data, but on the effective integration of complementary data (Muller and Burkhard 2012). The option to plug extant data from various sources into the FEGS framework allows researchers the opportunity to begin to assimilate available ecosystem goods and services data into an internally consistent, readily searchable crosswalk document. Organizing ecosystem goods and services data from various sources according to an internally consistent framework helps relieve the buy-in cost of researchers' learning a new tool, relieving opportunity cost for the tool user and expanding the potential user base of the tool developer (Bagstad et al. 2013). As the ecosystem goods and services community—and the data and tools available to them—continues to grow, the ability to identify data relevant to their needs should prove increasingly valuable.

We have provided a use case for crosswalking the FEGS-CS with a large suite of datasets designed without the FEGS approach in mind. However, there exist several ecosystem goods and services frameworks apart from FEGS, each of which has utility and a unique role to play in furthering our understanding in this field (Nahlik et al. 2012). Many classification schemes are specific to the particular ecosystems or landscapes under consideration, and on the decision-making context by which their development was guided (Fisher et al. 2009). Organizing ecosystem goods and services data and tools according to FEGS should not be seen as an attempt to repudiate these other approaches, but rather as one approach among others (Landers and Nahlik 2013). Similar efforts to crosswalk extant ecosystem goods and services data and tools according to alternative classification systems would be a healthful advance in the field.

Conclusions

We analyzed a large compendium of data and tools (EnviroAtlas) for biases in the reliance on land use and landcover data for the estimation of ecosystem goods and services. We found that land use and landcover data provide few metrics which describe the FEGS which people directly use, consume, or appreciate. Data relevant to the specific needs of beneficiaries who consume or abstract goods and services from nature were underrepresented. Also, reliance on models which translate a specific class of landcover into estimates of service provision may overvalue that landcover class in relation to other landcover classes which are not as commonly included in ecosystem service models. Specifically, we found that the services provided by tree cover were well represented while the services provided by grassland, scrubland, and snowpack were underrepresented.

To perform our analysis, we first crosswalked data in the EnviroAtlas with the FEGS classification system (FEGS-CS), and compiled our results into a readily searchable, publicly available database. This database has been used both by the FEGS community to quickly navigate valuable EnviroAtlas data and benefited the EnviroAtlas community by encouraging the discovery and use of their data by researchers otherwise unfamiliar with it. We recommend future efforts to integrate data and resources according to comprehensive ecosystem services accounting frameworks to allow for their dissemination more broadly, and to help relieve the steep buy-in costs for new researchers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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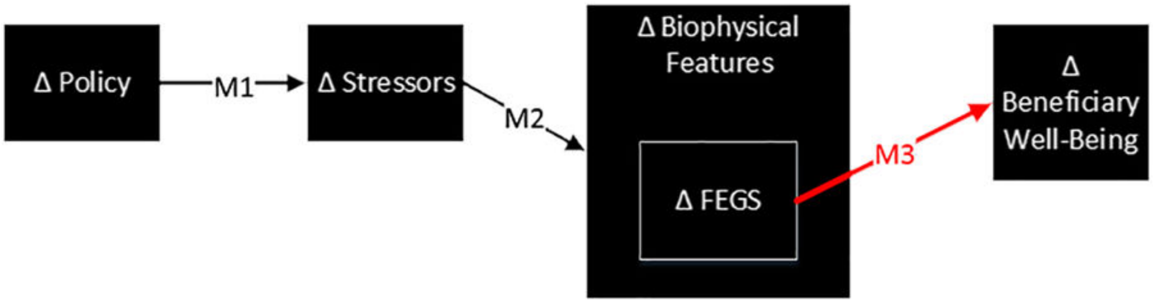

Fig. 1.

Conceptual model identifying the linkages between public policy, environmental stressors, Final Ecosystem Goods and Services, and human well-being via socio-biophysical models (M1, M2, and M3).

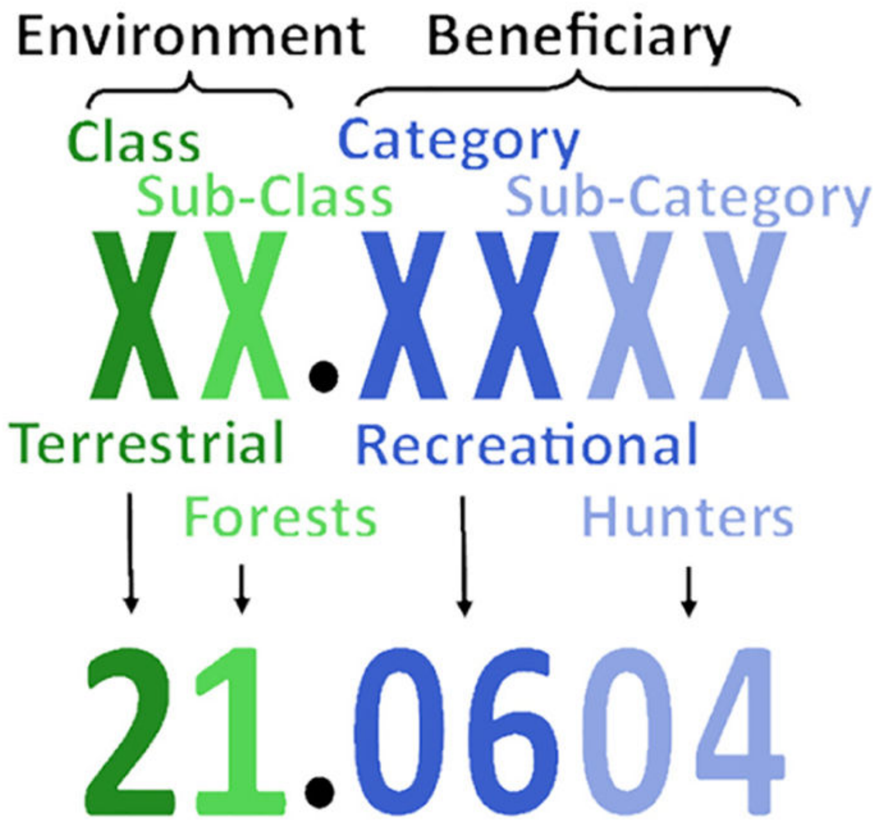

Fig. 2.
General Final Ecosystem Goods and Services classification structure. Adapted from Landers and Nahlik (2013).

Fig. 3.

Conceptual model showing production function linkages between intermediate ecosystem goods and services (IEGS), Final Ecosystem Goods and Services (FEGS), and social or economic outcome (SEO). Biophysical features (IEGS) may be transformed by natural processes into goods or services which are directly used, enjoyed, or appreciated by beneficiaries (i.e., FEGS). Final Ecosystem Goods and Services themselves may in turn be transformed by human labor or capital into social or economic goods or services (SEO).

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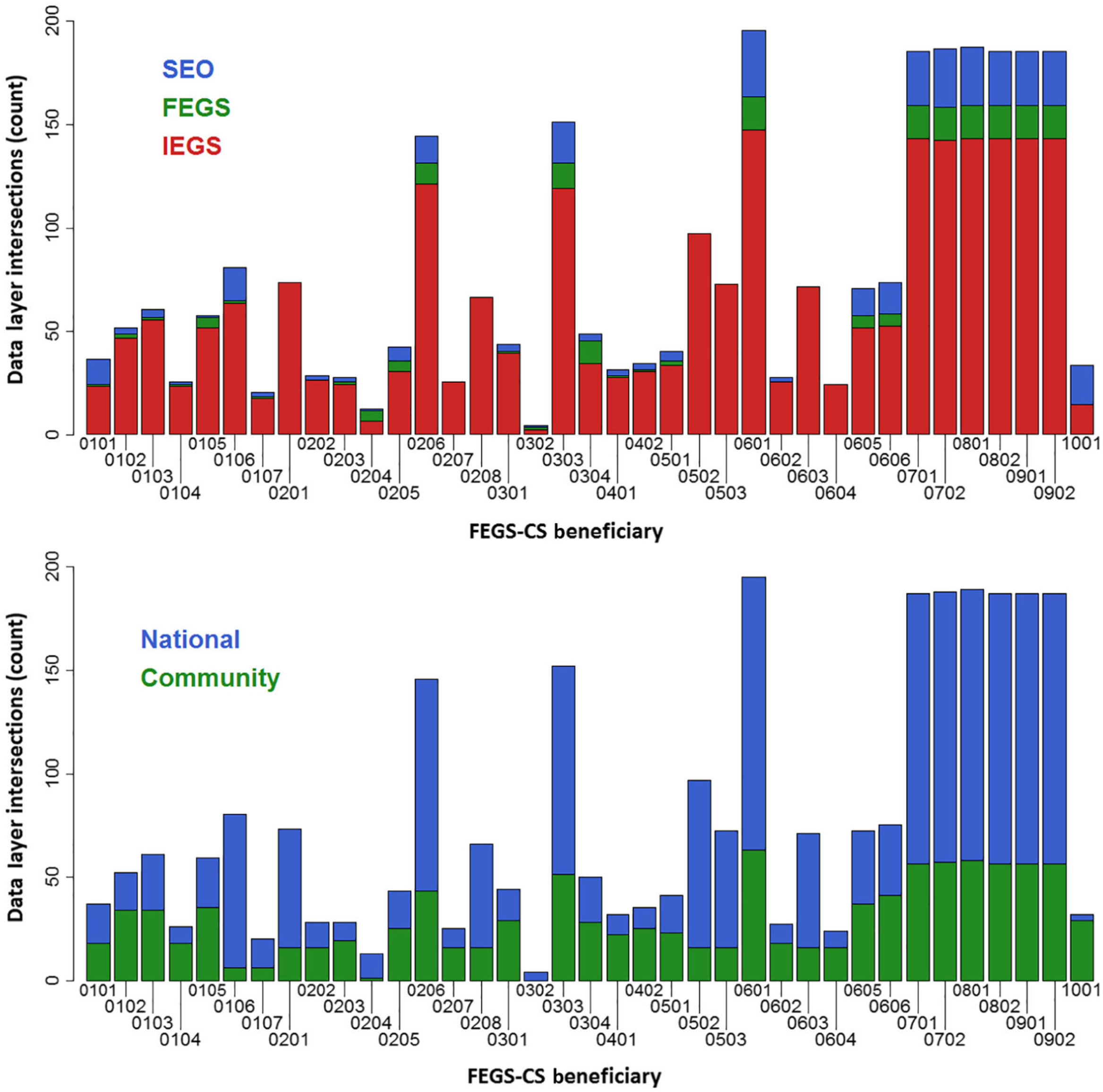

Fig. 4.

Number of data layers linking with Final Ecosystem Goods and Services Classification System (FEGSCS) beneficiary categories (see Table 1 for category names). Plot on top is organized according to intermediate EGS (IEGS), FEGS, and social or economic outcomes (SEO; red, green, and blue). Plot on bottom is organized by the scale of data availability provided by EnviroAtlas, with community-scale data in green and national-scale data in blue.

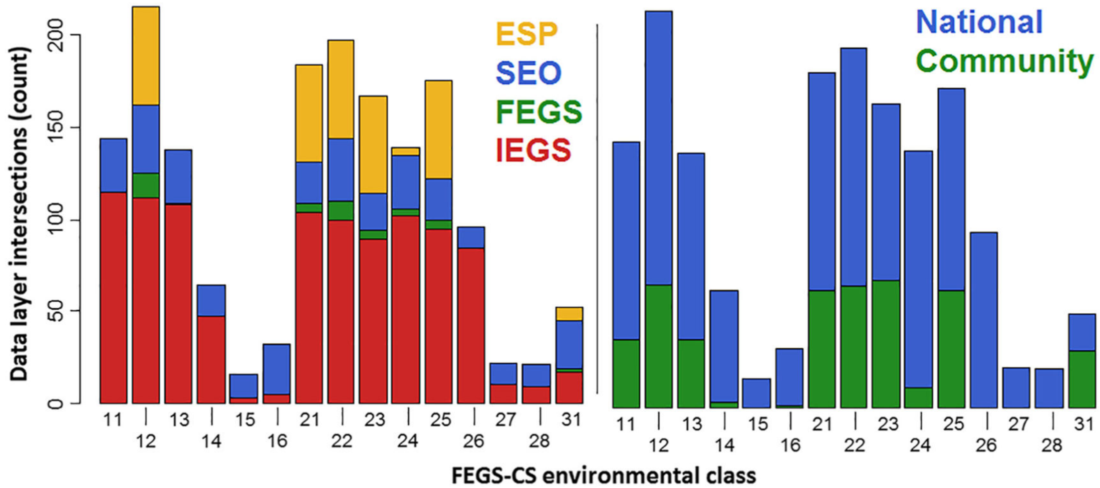

Fig. 5.

Number of data layers intersecting with Final Ecosystem Goods and Services Classification System (FEGS-CS) environmental sub-classes (Rivers and Streams (11), Wetlands (12), Lakes and Ponds (13), Estuaries and Near Coastal Marine (14), Open Oceans and Seas (15) Groundwater (16), Forests (21), Agroecosystems (22) Created Greenspace (23), Grasslands (24), Scrublands/Shrublands (25), Barren/Rock and Sand (26), Tundra (27), Ice and Snow (28), and Atmosphere (31)). Plot on left is organized according to intermediate EGS (IEGS), FEGS, social or economic outcomes (SEO), or location of EGS production (ESP; red, green, blue, and yellow). Plot on right is organized by the scale of data availability provided by EnviroAtlas, with community-scale data in green and national-scale data in blue.

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Table 1.

FEGS-CS beneficiary codes, names, and count of linkages with EnviroAtlas.

FEGS-CS Code	FEGS-CS beneficiary categories	IEGS linkages	FEGS linkages	SEO linkages
01–	**Agricultural**			
0101	Irrigators	23	1	12
0102	CAFO operators	46	2	3
0103	Livestock grazers	55	1	4
0104	Agricultural processors	23	1	1
0105	Aquaculturists	51	5	1
0106	Farmers	63	1	16
0107	Foresters	17	1	2
02–	**Commercial/Industrial**			
0201	Food extractors	73	0	0
0202	Timber, fiber, and ornamental extractors	26	0	2
0203	Industrial processors	24	1	2
0204	Industrial dischargers	6	5	1
0205	Electric and other energy generators	30	5	7
0206	Resource-dependent businesses	121	10	13
0207	Pharmaceutical and food supplement suppliers	25	0	0
0208	Fur/hide trappers and hunters	66	0	0
03–	**Government, municipal, and residential**			
0301	Municipal drinking water plant operators	39	1	3
0302	Waste water treatment plant operators	2	1	1
0303	Residential property owners	119	12	20
0304	Military/coast guard	34	11	3
04–	**Commercial/military transportation**			
0401	Transporters of goods	27	1	3
0402	Transporters of people	30	1	3
05–	**Subsistence**			
0501	Water subsisters	33	2	5
0502	Food subsisters	97	0	0

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FEGS-CS Code	FEGS-CS beneficiary categories	IEGS linkages	FEGS linkages	SEO linkages
0503	Timber, fiber, and fur/hide subsisters	72	0	0
06–	**Recreational**			
0601	Experiencers and viewers	147	16	32
0602	Food pickers and gatherers	25	0	2
0603	Hunters	71	0	0
0604	Anglers	24	0	0
0605	Waders, swimmers, and divers	51	6	13
0606	Boaters	52	6	15
07–	**Inspirational**			
0701	Spiritual and ceremonial participants	143	16	26
0702	Artists	142	16	28
08–	**Learning**			
0801	Educators and students	143	16	28
0802	Researchers	143	16	26
09–	**Non-use**			
0901	People who care (existence)	143	16	26
0902	People who care (option/bequest)	143	16	26
10–	**Humanity**			
1001	All humans	14	0	19

Notes: FEGS-CS, Final Ecosystem Goods and Services Classification System; IEGS, intermediate ecosystem goods and services; SEO, social or economic outcome.

Table 2.

FEGS-CS environmental codes, names, and count of linkages with EnviroAtlas.

FEGS-CS Code	FEGS-CS environmental classes	IEGS linkages	FEGS linkages	SEO linkages
1-	**Aquatic**			
11	Rivers and streams	115	0	29
12	Wetlands	112	13	37
13	Lakes and ponds	108	1	29
14	Estuaries and near coastal marine	47	0	17
15	Open oceans and seas	3	0	13
16	Groundwater	5	0	27
2-	**Terrestrial**			
21	Forests	104	5	22
22	Agroecosystems	100	10	34
23	Created greenspace	89	5	20
24	Grasslands	102	4	29
25	Scrublands/shrublands	95	5	22
26	Barren/rock and sand	84	0	12
27	Tundra	10	0	12
28	Ice and snow	9	0	12
3-	**Atmospheric**			
31	Atmosphere	17	2	26

Notes: FEGS-CS, Final Ecosystem Goods and Services Classification System; IEGS, intermediate ecosystem goods and services; SEO, social or economic outcome.