The Metrics of Making Ecosystem Services

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ABSTRACT: Ecosystem services (ES) are increasingly used as the conceptual driver for conservation and development actions, largely following from the influential Millennium Ecosystem Assessment. Scholars skeptical of the neoliberal turn in conservation have critiqued the use of economic values for nature's services. What has been less well understood and reviewed, however, is how concepts of ES are enacted by technologies of calculation, as well as how calculative practices move through networks and among stakeholders. This review traces how definitions and metrics of ES have evolved and how they are used, such as in biodiversity offsetting and wetland mitigation programs. Using the idea of the creation and deployment of calculative mechanisms, this article discusses how these processes proceed in different ES contexts, assesses what work has to happen ontologically to make ES commensurable and circulatable, and speculates on what the opportunities for future pathways other than commodification are.

KEYWORDS: calculation, carbon, commodification, ecosystem services, measurement, metrology

The concept of ecosystem services (ES) has rapidly become the dominant approach to understanding and prioritizing the natural world for conservation and development decisions. Major international assessments like the Millennium Ecosystem Assessment (MEA), the Economics of Ecosystems and Biodiversity (TEEB) report, and the new Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have all taken up as key concerns the identification, valuation, and preservation of ES, which are described in the broadest definition as the "benefits people obtain from ecosystems" (MEA 2005: 5). Yet, despite the ample attention to ES, there remain major challenges in operationalizing the concept. These challenges include identifying what counts as an ecosystem service, given that discussions range from physical goods like timber to more intangible cultural services (B. Fisher et al. 2009), how these services could be valued either economically or nonmonetarily (Raymond et al. 2013), and how payments, compensation, or exchange for conservation or provision of ES might be designed and delivered, where appropriate (Engel et al. 2008).

This article reviews a growing literature concerned specifically with the politics of defining and measuring ES, and how decisions about measurement may result in specific types of outcomes, such as commodification. Attention to measurement, standards, and indicators has grown in the larger social science literature, often emerging out of governmentality and actor-network theory (Bowker and Star 2000; Timmermans and Epstein 2010). This article reviews the state of literature on ES measurement, and aims to heed the call by Jessica Dempsey and Morgan Robertson to "contribute to the already existing debates about these tools … by examining what these 'calculative devices' do, how they translate parts of nature into calculable beings, and the implications of this translation" (2012: 768).

Most critical social science attention on ES has primarily focused not on measurement but on economic valuation; many have noted that the rise in ES discourse has accompanied moves toward neoliberal conservation and accumulation (Arsel and Büscher 2012; Büscher et al. 2012; Igoe and Brockington 2007; Smith 2007). This literature on "neoliberal natures" has focused primarily on the negative impacts of reducing the natural world to economic values (Holmes and Cavanagh 2016), homing in on processes of commodification in particular (Castree 2003); less attention has been paid to how ES are identified, assessed, or measured as a first step to commodification. In fact, both measurement and valuation are largely inseparable, as one informs the other. Therefore, this review steps back to confirm that "before a commodity or service such as carbon storage can be exchanged, it must be calculated and made transparent: it must be known, counted, expressed in standardized units, and, ultimately, made commensurable with monetary value" (Turnhout, Neves-Graça et al. 2014: 582).

I focus this article on how definitions and measurements of ES by different communities can be understood as practices that rely on calculative mechanisms to define what ES should be, and for whom. In looking at these calculative mechanisms, I follow Bruno Latour's suggestion to pay attention to how objects, like a mathematical equation or computer model, are "visible, distributed, accounted mediators before becoming invisible, asocial intermediaries" (2005: 80). In other words, we need to see how a calculation happens (who does it, with what means, and for what ends) before it disappears from view. We also need to understand the implications of the replacement of ideas of actual physical things, like forests or rivers, with the representation of these things in the form of circulating calculations, like allometric equations or water flow maps, which may have practical material consequences for those living near and using ES.

Much of the knowledge work that has been necessary to understanding ES has promoted standardization and equivalence: that is, making complex ecological processes amenable to assessments that can be used and compared across wider landscapes, different policy actors, and multiple stakeholders. Yet, as this review finds, actual metrics for ES are diffuse, often incommensurable, and widely contested within the scientific community. As a result, ES ideas function more like a "boundary object" (Star and Griesemer 1989), which are defined as "objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet be robust enough to maintain a common identity across sites" (393). ES as a boundary object tie multiple perspectives and ideas together, many of which may be mutually contradictory, but in the process, potentially provide room for contestation, discussion, participation, and coproduction (Barnaud and Antona 2014; Kull et al. 2015). I argue that this porousness of ES discourse provides rich opportunities for social scientists to be engaged in understanding and shaping how these concepts will be deployed in the future.

Why Care about Calculation?

The importance of calculation and measurement in understanding both society and nature has been emphasized by two bodies of literature in recent years: governmentality and actor-network theory (ANT). Both approaches share an attention to the development of the underlying metrics that are used to help govern populations and circulate knowledge, respectively. The body of work labeled "governmentality" studies, after Michel Foucault's formulation, has focused attention on relations and subjectivities in governance that influence the "conduct of conduct," which are accomplished through "apparently humble and mundane mechanisms which appear to make it possible to govern" (Miller and Rose 2008: 32), such as the ability to enumerate citizens through censuses and statistics or to make people visible and legible through the use of patronyms or street names (Scott 1998). Such "humble" tools have been used to delineate natural worlds as well: cartographers to fix borders and boundaries, geological explorations of the best soils for cash crops, or the use of statistics to represent forests, leading one article to propose the idea of "measurementality" as an important part of governmentality of the environment (Turnhout, Neves-Graça et al. 2014).

Similar to Foucault's interest in conduct and calculation, scholars in science and technology studies (STS), specifically in the field of actor-network theory, have also been interested in how classifications and devices of measurement lead to particular types of social knowledge and action. For these scholars, classification is a ubiquitous process and helps create the infrastructure through which networks can form (Bowker and Star 2000). These networks allow actors and things to engage with one another through processes of "translation," whereby objects and ideas are transformed into the "possibility of equivalence" (Law 1992: 386). This concept of "equivalence" has also been termed commensurability or standardization, and refers to the attempt to make broadly comparative categories from objects or information that might be initially quite different (Merry 2016). As Anne-Marie Mol notes, "Generating numbers locally in such a way that they are comparable from one site to the other depends on large networks in which standards, techniques, objects, and references are shared and may be transported" (2002: 251). Social scientists have paid attention in recent years to this science of measurement, or "metrology" (Latour 1987). Metrology operates as an enterprise that allows scientific knowledge to travel and be replicated; in other words, "it helps to prepare the 'landing strips' that are needed for phenomena to be reproduced, or for instruments to work, away from their place of origin" (Golinski 1998: 173). As another author confirms, "Doing 'critical metrology', as an analytical approach, directs attention to the social, political, and scientific conditions under which measurement and commensuration occur as well as the consequences or effects of these processes" (M. Cooper 2015: 1787–1788).

Latour (1987) refers to tools of measurement as "calculative devices," while Michel Callon calls them "calculative mechanisms" (Callon and Muniesa 2005); these apparatuses are often obscure and opaque, but they render problems into discrete parts amenable to solutions, and turn an intangible idea into an actual material "thing," like a number or map. Callon and coauthors theorize the steps by which this happens: first, entities must be detached from their contexts and moved into a single space; then they are "taken into account" or manipulated in some way; finally, "a new entity must be produced (a sum, an ordered list, an evaluation, a binary choice, etc.) that corresponds precisely to the manipulations effected in the calculative space and, consequently, links (summarizes) the entities taken into account" (Callon and Muniesa 2005: 1231). They emphasize decontextualization, dissociation, and detachment followed by arrangement and reordering as key processes in the eventual circulation of calculative results, and the loss of contextual data in this process of simplification ignores the idiosyncrasies of practice that make up much of scientific experimentation (Porter 1994).

These final calculations and measurements are not just simplified but also mobile, stable, and combinable, obscuring the original specificity from which they emerged. Latour's (1987) well-known reference to "immutable mobiles," objects that move around but are stabilized, mirrors this concept. Donald MacKenzie (2009) refers to this process as "making things the same": that is, establishing equivalence between things of different constitutive elements (or "substitutability" in the words of economists) and activities to "fix" and "stabilize" imply the ability to mobilize power (Callon and Muniesa 2005). Yet the deployment of power that creates the stabilization is often submerged behind the end result: a seemingly objective measurement, such as an indicator, which are often, although not exclusively, quantitative (Merry 2016). As Sabine Hohler and Rafael Ziegler note, "Numerical statements and forecasts … stand in for blurred and biased political judgments, to substitute for the uncontrollable social and political negotiations that lay beneath them … Accounts are considered objective since they are rule-governed, distanced (impartial) and quantitative … Today expert judgement expressed numerically has become a widely accepted form of scientific objectivity" (2010: 425). Callon (1998) has noted that this expertise is often invoked in terms of "hot" political issues meeting "cool" objective metrics devised through technical calculations. Yet increasingly, both critical social scientists and lay publics are contesting the idea that such technical mechanisms are objective and value-free, and are asking important questions about how expertise is enacted through these calculative devices (Whatmore 2009). It is this approach I bring to the study of ES in the following sections, through a detailed examination of how different types of ES are defined, measured, and made commensurate.

The Emergence of Ecosystem Services

Histories of the concept of ES trace the idea back to the late 1970s and writings on the extinction crisis, with concern that loss of species might cause loss of valuable benefits to humankind (Lele et al. 2013; Mooney and Ehrlich 1997). Globally, attention expanded rapidly after the Millennium Ecosystem Assessment (2003)**,** which drew attention to ecological services for supporting ecosystems, provisioning food, regulating climate and carbon cycles, and cultural services (MEA 2005). Networks of environmental economists particularly promoted the idea that the tools of economics could be used to provide cost-benefit analysis of ecosystem functions for human use, thereby giving policy makers incentives to protect ES (Gómez-Baggethun et al. 2010). The linkages between ES and economic valuation of those functions received a boost from the global study the Economics of Ecosystems and Biodiversity (Ring et al. 2010; TEEB 2009), and have since been incorporated into national-level policies like natural capital accounting and payments for environmental services (PES) (Engel et al. 2008). Currently ongoing regional and global assessments organized by the new IPBES platform are furthering the attention to ES (Díaz et al. 2015). The ES approach is increasingly used in national policy making, including assessments like the United Kingdom National Ecosystem Assessment (Watson 2012), and the Obama administration in late 2015 issued a memo on "Incorporating Ecosystem Services into Federal Decision Making" that asked US federal agencies to take ES into account in all their activities.

The expansion of ES into the policy realm has required a move from ES as a metaphor for the interlinkages of humans and ecosystems to a set of tangible indicators that can be measured, mapped, packaged, and then potentially valued (Gómez-Baggethun and Ruiz-Perez 2011; Norgaard 2010; Raymond et al. 2013). Yet, despite thousands of articles and several major assessments on ES, there remain serious challenges and disagreements over the different definitions and concepts that underpin the idea of ES (Danley and Widmark 2016; B. Fisher et al. 2009; Groot et al. 2002; Nahlik et al. 2012; Schröter et al. 2014; Seppelt et al. 2011; Wallace 2007). Much of this can be attributed to the fact that ES are first and foremost a general concept (e.g., "the benefits to people from ecosystems," whereby benefits, people, and ecosystems all have to be further defined and measured). Further, *new* things (indicators, statistics, maps, or economic values) must be created to stand in for the actual ecosystem processes, functions, and products that are considered beneficial or valuable (Barnaud and Antona 2014; Kull et al. 2015). In other words, ES are material-semiotic relations, constructed from discursive apparatuses but influenced by material forms (Law 2007). By tracing the emergence of how ES came to be thought of, and how they are calculated for, we can see how knowledge, networks, conflict, and values come together.

Definitions and Debates

There are several competing definitions of ES: the MEA defines them as "the benefits that ecosystems provide to people," while TEEB defines them as "the direct and indirect contributions of ecosystems to human well-being" (Potschin and Haines-Young 2016). Studies of how these particular definitions arose, while alternatives were discarded, is lacking in the literature, as there is little ethnographic information about either the TEEB or MEA processes, with the exception of Colin Filer (2009) and Chad Monfreda (2010). Even providing definitions of concepts is a process of bounding, as several authors remind us, and therefore involves values, even if such a process is couched in objective scientific language (Tadaki et al. 2015).

Some of the debate over ES definitions relates to the problem of comparing apples and oranges: Should ES be defined as services, processes, benefits, stocks, flows, or goods? And what is the relationship between these categories? Economists have argued that the MEA confused different concepts, like economic goods (timber), ecosystem functions (detoxification), and general benefits (aesthetic enjoyment of landscapes) (J. Boyd and Banzhaf 2007). Ecologists have argued for a more processual approach to ES, focusing particularly on fixing "ecological production functions," which are used to "define how the spatial extent, structure, and function of ecosystems determine the production of ecosystem services" (Tallis and Polasky 2011: 35). Yet, despite extensive attention, both fields of "ecology and economics have failed to standardize the definition and measurement of ecosystem services. In fact, a brief survey of definitions reveals multiple, competing meanings of the term" (J. Boyd and Banzhaf 2007: 617). For some, ES terminology functions as a boundary object to tie competing conceptions together (Kull et al. 2015); Daniel Suarez and Catherine Corson argue that ES as a discourse affords a type of "political project that defuses antagonisms between competing logics, agendas, and constituencies engaged in biodiversity conservation politics" (2013: 67). Given the contested nature of the definition of ES and the ambiguity that has come to be associated with the term, some authors even claim it "has become a catchall phrase that is now used to refer to anything from or within an ecosystem that is beneficial to any living thing," leading them to ask, what isn't an ecosystem service? (Nahlik et al. 2012: 28).

Given the lack of a stable and circulating definition of ES, there are competing categorization schemes for classifying ES, among which are the MEA, TEEB, Common International Classification for Ecosystem Services (CICES), IPBES, and the US Environmental Protection Agency's (EPA) Final Ecosystem Services and Goods Classification System (FEGS-CS). The MEA rubric for categorizing ES is the most widely followed and cited, though it has also been strongly criticized (J. Boyd and Banzhaf 2007; Wallace 2007). The MEA groups ES into four main categories of supporting services, provisioning services, regulating services, and cultural services (see Table 1). An alternative rubric by CICES has proposed that supporting and regulating services be folded together and focuses on different scales of services and drawing distinctions between levels of detail (Potschin and Haines-Young 2011). The focus of the current IPBES approach is to emphasize the coproduction of social and ecological systems working in tandem through the concept of "nature's contributions to people" (Díaz et al. 2015), which IPBES authors have defined as "all the positive contributions, or benefits, and occasionally negative contributions, losses or detriments, that people obtain from nature. It resonates with the original use of the term ecosystem services in the MA [Millennium Assessment] and goes further by explicitly embracing concepts associated with other worldviews on human-nature relations and knowledge systems (e.g. 'nature's gifts' in many indigenous cultures)" (Pascual et al. 2017: 9). This more expansive view is an attempt to respond to critiques of the ES concept that it is reductionist, economistic, imperialistic, and incommensurate with many local world views (Sullivan 2009, 2010).

A larger metacritique in the literature reflects the fact that within conservation communities that increasingly use the word, there are mixed feelings about use of ES terminology, and if an instrumental or utilitarian approach to conservation is the right one (Redford and Adams 2009; J. Fisher and Brown 2014). Although they are most closely associated with the spread of ES discourse, economists in particular have engaged in robust debates about if ES terminology must necessarily lead to monetary evaluation, and what the ethical dimensions of this are (Gómez-Baggethun et al. 2010; Gómez-Baggethun and Ruiz-Perez 2011; Farley 2012). A recent review of criticisms of the concept of ES grouped concerns into seven main categories: ethical critiques, such as the intrinsic value of nature; human-nature critiques, particularly that non-Western world views of nature are different than those represented by ES; critiques that biodiversity conservation will lose out to ES; critiques of economic valuation; critiques of commodification; and critiques of the definition itself for either vagueness or for normative aims (Schröter et al. 2014). Critical social scientists have tended to make the human-nature and commodification/economic valuation critiques most often (Barnaud and Antona 2014); many articles on ES in journals such as *Geoforum, Environment and Planning, Antipode,* and *Development and Change* are discussions of the association of ES with neoliberal approaches to economic governance (Arsel and Büscher 2012; McAfee 2012, 2015; Robertson 2004). As one representative article puts it, "Ecosystem Services discourse promotes a technocratic and economic perspective on biodiversity" (Turnhout et al. 2013: 156). Yet, as noted previously, this strong focus on valuation of ES, rather than their definitions and measurement, has left out a missing piece of the puzzle for social scientists.

Table 1: MEA Classification of ES

Type of ecosystem service	Examples
Supporting services	Nutrient cycling Seed dispersal Soil formation Primary production
Provisioning services	Food & forage provisioning Timber Water Energy (e.g., hydropower) Genetic resources
Regulating services	Carbon sequestration Waste decomposition Purification of water/air Crop pollination Pest and disease control Flood control Erosion control
Cultural services	Recreational services Spiritual and aesthetic enjoyment

Source: MEA (2005).

Measuring and Making ES

In a comprehensive literature search to understand how ES are measured and what the implications of this metrology are in both the scientific and critical social science literature, I undertook a keyword search on Web of Science using ("ecosystem service*" OR "environmental service*")

AND (assess* OR identif* OR measure* OR estimat* OR calculat* OR monitor* OR report* OR validat* OR verif* OR audit*), resulting in more than nine thousand articles mentioning some sort of ES and measurement. Confining my search to titles alone reduced the literature to around five hundred articles, from which a review of the most recent and relevant hits from this search was conducted, the vast majority of which came from the natural science, rather than social science, literature. Several key points emerge from this review related to issues of calculability, standardization, commensuration, and circulation.

Missing Metrics

Despite the common representation of ES as a hegemonic conservation approach, there is in fact no standard metric or even overall guidance on how most ES might be measured (Danley and Widmark 2016; Dempsey and Robertson 2012; Seppelt et al. 2012). Unlike in other fields, where universality has been a key goal of metrology (O'Connell 1993), the stabilization and transfer of ES indicators shows no sign of converging toward universally accepted metrics. As one review put it, "quantification and valuation studies have been conducted in different ecosystems and at different scales (e.g., local, regional, and national) around the world … The approaches and methods vary so much among these studies that it is questionable if they can be compared or aggregated" (Nahlik et al. 2012: 28). Even ES that might seem straightforward and rather narrowly defined, like pollination services, suffer from a lack of consistency in definitions of ES, poor identification of the different components that contribute to that ES, and no clear metrics for empirical work (Liss et al. 2013). Some attribute the lack of standardization to the problematics with the definition of ES discussed earlier; very rarely is the pluralistic use of multiple definitions and approaches embraced as a possible strength of the ES approach, although one article does note that standardized "categories can serve to differentially legitimate, stabilize, and marginalize particular views and values, and we highlight how mainstream practices of scientific measurement can effectively reproduce top-down power relationships, unless this is carefully guarded against" (Tadaki et al. 2015: 168). The lack of legal or standardized guidance for ES measurement, particularly in the United States, is in notable contrast to older conservation approaches that rely on landscapes rather than services; for example, there are extensive federal regulations and definitions of "wetlands" that are embedded in laws like the Clean Water Act and have evolved and stabilized over many years of calculation and contestation (Robertson 2000).

Ecologists particularly attribute the lack of clear ES metrics to incomplete understanding of the underlying ecological functions that go into services. These ecological production functions are a useful shorthand for quantitatively assessing how any change in an ecosystem's condition, structure, or function will result in related impacts on ES (Nelson et al. 2009). For example, a loss of mangrove habitat would result in changes in ecosystem function (providing shelter to juvenile fish), which would contribute to fewer commercial fish landings (the actual ES) (NRC 2012). Thus, there is strong interest in techniques, models, and calculative devices that could lower uncertainty around the provisioning and regulating of ES by "fixing" ecological functions to one or more specific indicators that can be more easily seen, measured, or manipulated (Dempsey and Robertson 2012). Llael Cox and colleagues (2013) estimate that more than half of all US federal funding for ES approaches by numerous regulatory agencies is aimed at producing indicators, checklists, and other devices of simplification for ES production functions. Studying how ecologists derive such ecological production functions would seem a fruitful area of study for social scientists, but as of yet there does not appear to be much critical social science literature on the topic. As authors have noted for the process of fixing carbon emissions measurement, turning processes into indicators is likely to be "part science, part modelling, part guesswork and part negotiation" (M. Milne et al. 2010: 27).

Establishing Equivalence

Establishing equivalency among ES is the first step to potential commodification. Yet, as long as ES are measured in diverse and inconsistent ways, making ES incommensurate with each other, standardized units for valuation will also be challenging and might provide a barrier to commodification (Chan et al. 2012). However, understanding how incommensurability is reduced and equivalence established is incomplete for much of the ES literature. Instead, we might look at other classification approaches to see how problems of measurement and equivalence have been overcome. One potential source of information are studies of "offset" programs, whereby "the destruction of one habitat would be 'offset' by the conservation, restoration, or creation of another" (Benabou 2014: 103); these policies also go by names such as compensatory mitigation; biodiversity, species, or habitat offsetting; or "no net loss" policies. Offsetting policy predates the concept of ES by several decades (Coralie et al. 2015), but offsetting also often involves attempts to conserve functions, like species diversity or water flow, that are similarly important to ES policies.

Equivalence is particularly essential for offsets to represent themselves as functionally the same as something else, and thereby able to be traded off (Benabou 2014; Quétier and Lavorel 2011). Therefore, understanding how offsetting projects have measured the "thing" to be offset, and how the equivalence to something else is established, is important. Oftentimes, such measurements are almost absurdly simple; Sian Sullivan (2013) outlines biodiversity mitigation projects in the United Kingdom, which rely on assessments of quality of land on a scale of 1 to 3 (for poor to good condition) and a scale of 2 to 6 (for "biodiversity distinctiveness"). These two numbers are combined to allow lands to be traded "like for like," although this number "may or may not provide a 'good fit' with the material natures they represent, and thus may or may not adequately represent the ecological measures being lost through development in specific places" (86).

Morgan Robertson's work on wetlands mitigation banking (Robertson 2000, 2004, 2006, 2012) and Rebecca Lave's work on stream restoration (Lave 2012; Lave et al. 2008, 2010) both take detailed looks at how processes of definition, measurement, comparison, and equivalence in offsets are made, and provide a template for how similar studies of ES quantification might operate. Both wetland mitigation banking and stream restoration markets have emerged from the US Clean Water Act (CWA) section 404 program, which aims at no net loss of wetlands (Hough and Robertson 2009). The need to mitigate impacts from development led to a boom in assessments of what wetlands and streams were, how they could be rapidly and easily characterized, and how they could then be replicated elsewhere. As Robertson notes, "What all assessments and taxonomies have in common is that they produce a number or a tag by which the ecological unit can be named, categorized, and otherwise treated as ordinal data" (2000: 473). The metrology primarily used for wetlands are "rapid assessment methods" (RAMs) that employ algorithms to take "easily measured site characteristics (e.g., plant species diversity or water levels) to make inferences about harder-to-measure 'wetland functions' (e.g., habitat provision or peak flow attenuation). Most wetland RAMs use algorithms which translate an empirical observation ('25% canopy cover') into a score ('0.5'), and most produce a series of scores—one for each function. These numeric scores then stand for the wetland" (Robertson 2004: 367). Not surprisingly, the RAMs tend to privilege some types of knowledge over others; while water quality in wetlands is an important characteristic, measuring this is expensive and can require laboratories. However, abstracted hydrological models "can demonstrate the flood-storage capacity of the site given a minimum of topographic data, without even a site visit," and vegetation can be visually assessed, leading to "plant lists [that] have become surrogates indicating the ability of a site to provide nearly all wetland functions" (Robertson 2006: 374). Robertson's (2006) ethnographic work with ecologists hired to evaluate wetlands shows the individualistic, indeterminate, idiosyncratic, and irregular patterns of sampling, identifying, and measuring that go into selecting these indicators and then using them during site assessments. These technological manuals and wetlands "checklists" consisting of scoring of morphological features (e.g., riverbanks, certain vegetative species, and other visual cues) then come to stand for the wetlands themselves (Nost 2015).

In the case of streams, the CWA demands there be "some kind of ecological equivalence between impact and mitigation: the stream to be destroyed and the stream to be restored. Assuring equivalence, however, is a task of measurement, and this has drawn scientists into the task of establishing metrics that can be used to anchor ecosystem service markets. These metrics attempt to express stream ecology and geomorphology in simple schemes that can be used to convert riparian ecosystems into 'credits'" (Lave et al. 2010: 691). The metric that has been designed to stand for the thing in this instance is the "stream mitigation unit," or SMU. A measurement of a quantity of SMU is easily obtained by measuring linear feet of stream, but quality has proved problematic, since the mitigation action needs to replace lost functions, not just areas. SMUs therefore are designed to "bundle" together the "perceived benefits of stream restoration to aquatic habitat, nutrient retention, and flood abatement into a unified measure," leading to an outcome of form equaling function (Lave et al. 2008: 288).

Recent metareviews of multiple offsetting programs highlight these challenges of metrology: one review noted that "habitat banking and the underlying offset schemes can only function properly with an effective measurement of biodiversity values gained and lost. Reliable methods for this purpose are still lacking, however, and data availability could be a constraint" (Santos et al. 2015: 299). Another noted that "information on the approach used to estimate conservation benefit (or 'credits') at an offset site was unavailable … or no systematic approach for calculating conservation benefit at offset sites existed" (Maron et al. 2013: 363). Other studies of offset markets have noted that rapid assessment methods, particularly ones that can be used visually, are nearly always championed by proponents (Cochran 2011), which of course raises questions of how dynamic ecosystem functions, flows, and processes can be assessed in this way. Online sources of information that can easily be "plugged in" to GIS maps and models are also preferred by policy makers (Olander 2016). Not surprisingly, the end results are usually overly abstracted and simplified measurements. This has resulted in "highly reductionist" approaches to offset metrics, leading to "a narrowing of focus to isolated parts of an ecosystem" that can be tallied up in a score (Apostolopoulou and Adams 2017: 24). Accordingly, assuming acre for acre or linear foot for linear foot as the "fungible" currency of offsets, in the parlance of economists, has created many more questions than those that originally arose in pollution markets, where a unit of exchange (amount of CO_2 or sulfur) was more broadly comparable. As a review of environmental trading points out, "More times than one might think, we are trading Macintoshes for Granny Smiths, apples for oranges, and, in some cases, apples for Buicks" (Salzman and Ruhl 2000: 613) because of the incommensurability of space, type, and time between habitat types, ES flows, and other systems. The anti-offset argument is strongly based in these complexities of equivalence: "No single surrogate (or even a series of them) can entirely capture biodiversity, since not all biodiversity attributes are measurable, and therefore it is impossible to guarantee that no biodiversity is lost" (Apostolopoulou and Adams 2017: 24).

The creation of standard measurements in mitigation offsetting (albeit oversimplified) has been a fundamental step toward enabling trades and purchases of credits; for example, the US

Department of Agriculture (USDA) set up an Office on Environmental Markets in 2008 to standardize definitions and measurement units for ES expressly in order to stimulate the offset credit market (Boisvert et al. 2013). These markets have primarily taken the form of "banks," new institutional forms (both private and public) where developers who have obligations to mitigate an action can buy "credits." A 2010 review found 39 different types of biodiversity banks with a total value of $3 billion worldwide (Madsen et al. 2010). Many of these banks can be found through online searchable databases that aggregate them, including the RIBITS (Regulatory In-lieu Fee and Bank Information Tracking System), which provides access to wetland and stream credits and banks (Martin and Brumbaugh 2011), and SpeciesBanking.com, which lists species and habitat banks mostly authorized by the US Endangered Species Act (Pawliczek and Sullivan 2011). In terms of measurement units for establishing "credits," the species banks are the simplest; most rely on acres of habitat for a species, while some banks measure number of animals or breeding pairs at a site. Assessing units for habitat banking is more complex, as the above discussion on wetlands and stream units shows. However, at the point at which a buyer of a credit encounters a bank, the complexity of measurement has disappeared from view, and projects appear as only "credit type" (such as wetland, stream, or species) and "credit classifications," usually represented by a single number.[1]

Payments for environmental services (PES) schemes are quite different than offset banks in terms of buyers and sellers, location of projects, and types of "goods" valued (Boisvert et al. 2013), although critiques of market-based environmental policy often conflate the two (Fletcher et al. 2014). Nonetheless, PES projects have run into similar problems of measurement; as an article in *Science* notes, "Reviews of designs, metrics, analytical methods, and perceptions of PES interventions reveal a need for greater coordination among scientific researchers, practitioners, ecosystem service providers, and beneficiaries. Collecting metrics for ecosystem services varies enormously in cost, utility, and complexity. Without tools for identifying the best and most affordable metrics, PES proponents may struggle to collect scientifically meaningful, cost-effective baseline data and implement effective monitoring programs" (Naeem et al. 2015: 1206). Although PES projects do not need to establish equivalencies as offset projects do (PES does not exchange "like for like"), it is common to encounter oversimplified, single metrics in PES markets as well; for example, it is common to see itemization of only one or two ES, which ignores the complexity of ecosystem functioning (Kosoy and Corbera 2010). It is also common to find PES projects that do not even measure a single ES at all, relying instead on units of land under vegetation cover as a proxy for ES supply, rather than on detailed information about actual ES provisioning, such as volume of water flows or number of pollinators protected (McElwee 2016b).

Problematic Proxies

In order to get around problems of incommensurability and immeasurability that have been encountered in establishing equivalencies, as the literature above shows, the use of simplified proxies to stand in for something else is widespread. These proxies include units of area (e.g., linear feet of stream or hectares of land cover), numbers of species (e.g., keystone species presence standing in for a type of habitat), or topographic features substituting for ecological functions (e.g., slope indicating water flow). Proxies are fundamentally important in ES modeling in particular (Seppelt et al. 2011); for example, "because ecological production functions are unavailable, scientists use species (ecosystem function) values from past studies not intended for ecosystem services, and land cover as ecosystem characteristic proxies to estimate ecosystem services at policy sites with similar land cover to the study sites" (Wong et al. 2014: 110). Yet this reliance on proxies has resulted in things that may not represent what they are supposed to represent: for example, dissolved oxygen is often taken as an indicator of water quality, but this rarely captures the true state of all water's facets or benefits to people (W. Boyd 2010). Yet this use of a single measure "comes to substitute the complex ecosystems, the value of which it seeks to represent. When that happens, the measure becomes what is valued, not what the measure represents" (Turnhout et al. 2013: 157).

The use of proxies dominates in models of how ES interact, which are achieved using integrated software packages with slews of acronyms: InVEST, STELLA, ARIES, TESSA, GUMBO, and MIMES. (These acronyms stand for Integrated Valuation of Ecosystem Services and Tradeoffs; Systems Thinking, Experimental Learning Laboratory with Animation; Assessment and Research Infrastructure for Ecosystem Services; Toolkit for Ecosystem Service at Site-Based Assessment; Global Unified Metamodel of the Biosphere; and Multiscale Integrated Model of Ecosystem Services) (Bagstad et al. 2013). These integrated models rely mostly on inputs of proxy indicator data and existing known ecological production function models for individual ES combined with algorithms (Bagstad et al. 2013; Peh et al. 2013). These integrated ES models, many designed primarily for policy makers, face the tension of being "sufficiently complex to represent system dynamics, yet simple enough to be understood and appropriately parameterized with often limited data" (Tallis and Polansky 2011: 254). Most of these models are constrained in how many ES they can incorporate (e.g., InVEST generally uses less than 20), and what they use to represent ES (Kareiva et al. 2011). As an example, InVEST uses proxy data on phosphorus runoff to stand in for all nonpoint water pollution impacts, and in order to include production functions for hydrology and soil erosion, InVEST uses older equations like the Universal Soil Loss Equation (USLE) and Soil and Water Assessment Tool (SWAT) within its modeling universe, both of which have been criticized for overgeneralization and outright misuse (Forsyth and Walker 2008; Nagle et al. 1999). Dempsey (2016) also points out that models like InVEST can be seen as a way to "render technical" and apolitical the challenges of valuation and contestation that often accompany ecosystem management in the real world.

New Knowledges

Many of the articles by ecologists discussing the chaos and inconsistencies between different ES classifications and measurement systems usually propose a "systematic" and scientific approach to reconcile competing definitions; for example, one article notes that a system could be said to be useful when it can rely on "(a) natural scientists to quantify, (b) social scientists to qualify and validate, (c) economists to value, and (d) policy managers to incorporate" ES into their work, while community input is usually left to determining beneficiaries of ES downstream (Nahlik et al. 2012: 30). Dempsey, however, stresses that this focus on systematizing ES concepts "attempts to create a new universal in conservation, a neutral, objective, apolitical approach that can determine the value of particular socioecologies … [which] seek to solve complex problems of socioecological justice by transforming them into questions of accounting, with accounting systems designed by an elite group of Northern experts" (2016: 20). Recognizing this, the MEA and, more recently, the IPBES have both emphasized the need to incorporate "local knowledge," not just scientific expertise, into ES assessments, although participating authors noted the "flattening" of alternative voices to scientific knowledge during MEA deliberations (Filer 2009). Yet, despite these calls for decentering "expertise" in ES knowledge making, new technologies, instead of new voices, have tended to dominate the ES literature, with increasing attention to the use of remote sensing to assess ES. While in some studies land cover change stands in for ES functions, increasingly some individual ES, such as vegetation and biomass growth, rates of soil erosion, and levels of water pollution, can be detected with satellite imagery (Araujo Barbosa et al. 2015). This raises questions regarding if technologies themselves might lead to certain types of ES being more easily calculable than others.

Carbon calculations seem to be a clear example of technologies driving measurement, which in turn drives standardization. For example, measurement of carbon sequestration processes and potentials can be done at the landscape scale (through remote sensing), at the forest scale (through airborne radar known as LIDAR or from flux towers that measure atmospheric carbon exchange), or at the tree scale (by tree diameter measurements and stand densities) (Goetz et al. 2015). William Boyd (2010) argues that advances in remote sensing and LIDAR were particularly relevant in helping to visualize tropical deforestation as a target of concern leading to a focus on calculability of carbon. Each of these techniques is promoted as establishing widespread equivalence across forest types; basically, any forest can be turned into a "carbonized" forest through a figure representing the total carbon sink capacity, a form of spatial abstraction par excellence (Lansing 2010).

Even within the most tangible and physical of these methods, the touching and measuring of actual trees, the carbon in the tree quickly becomes converted to an abstraction through the use of allometric biomass regression equations, an expression of the amount of carbon likely to be found in particular species, based on average stand density, wood volume, wood density, bark-to-wood ratio, and other factors, whereby carbon is estimated at 50 percent of total biomass. These equations allow foresters to estimate carbon without having to actually cut down trees, which would be required if one wanted to get the most accurate estimation possible (Brown 2002). However, as Heather Lovell and Donald MacKenzie (2014) point out, these tables of allometric equations are highly abstracted and derived from mostly temperate woods, but have been rather uncritically adopted for forest carbon markets that tend to predominate in tropical areas, mostly because it is time consuming and costly to measure large numbers of trees directly (Lovell 2013b).

The simplified, "carbonized" forests can then be made commensurable with other forms of carbon, so an individual, company, or country wishing to reduce carbon footprints from industrial emissions can buy credits from either forest carbon sequestration through afforestation (which has been available through the Clean Development Mechanism [CDM] and the voluntary market) or avoided deforestation (in the form of a policy known as REDD+, Reduced Emissions from Degradation and Deforestation) (Gutiérrez 2011; Stephan 2012). In this way, a forest carbon emissions reduction or offset is a material-discursive apparatus: the buyer pays not for the actual carbon itself, but for a representation of that carbon in the form of numerical values about total carbon related to biomass in a given area. The replacement of ideas of actual physical forests with the representation of forests in the form of allometric equations has practical material consequences. If certain trees are represented as more valued because of higher carbon content, those trees may be favored for management and replantation above others, as has happened in some areas where forest carbon markets are emerging (Kosoy and Corbera 2010; McElwee 2015, 2016a).

Discussions of the links between metrology and governance of these forest carbon offsets have revolved around questions of the socionatural relations needed to create tradable credits (Corbera and Martin 2015). Aarti Gupta and colleagues express concern that "when forests are rendered legible through their carbon content only, other forest-related values and governance objectives, such as securing biodiversity or local livelihoods, may be obscured" (2012: 727), and they urge attention to "accountability" to local knowledge and rights in carbon accounting. Other studies stress failed attempts to standardize offsets across many platforms (Lovell 2010) and inaccuracies in how carbon savings are calculated (Wang and Corson 2015), as well as the social costs and negative consequences of commoditization (Corbera and Brown 2010), such as projects designed for emitters rather than the local places in which the offsets would be implemented (Wittman and Caron 2009). These social and distributional consequences of forest carbon offsetting have been labeled as "accumulation by decarbonization" (Bumpus and Liverman 2008) and as yet another example of global "green grabbing" (Wittman et al. 2015).

The work of assessing tree carbon also points to the fact that metrology is always performative. Forest carbon policies have created work for "carbon calculators" and third-party verifiers as new networks of actors, privileging certain types of expertise in the work of measurement, reporting, and verification (known in climate lingo as MRV) (Gupta et al. 2012; Lansing 2012; Lovell 2015). MRV is required for carbon markets to operate efficiently, as purchasers of offsets "must constantly employ measurement, certification, and accounting technologies in order to assure the consumers of carbon offsets that they are, in fact, purchasing something that exists" (Cavanagh and Benjaminsen 2014: 57). Foresters have pointed out that expertise in MRV for forests could potentially be democratized, especially at the tree scale, where local communities could participate in mensuration; indeed, projects for "participatory carbon monitoring" have sprung up in some places (Palmer Fry 2011; Pratihast et al. 2014). However, the overall complexity of rules for MRV under the UN climate convention, which governs CDM and REDD+, has created a significant barrier to entry for most local communities (E. Boyd et al. 2007), including a trend toward "checklistification" whereby complicated formal requirements for MRV are followed only by rote and without real participation (McElwee 2015). Mary Felker and colleagues provide a further example from Indonesia of how measurement of forest carbon needs to go beyond simply participation and be linked to an understanding of local land tenure systems for the calculations to be perceived as more legitimate; they argue that dropping "abstracted, transnational toolkits as MRV into situated socio-ecological contexts" is likely to be unsuccessful (2017: 12). Instead, they urge that measurement of forest carbon needs to be linked to an understanding of how different communities might be impacted by MRV, and what might influence motivations for participating in MRV.

Discussion: Circulations or Roadblocks for Calculation?

Some common themes emerge from this review of ES measurement, and I use Michel Callon and Fabien Muniesa's (2005) discussion of the ways in which metrology attempts to achieve first objectification and singularization, or standard units, and then detachment and dissociation, as these units move away from the specificity from which they were born, to examine the barriers to more widespread "fixity" and circulation of ES.

Objectification and Singularization: Not So Fast

Callon describes objectification as the process of turning something—a thing, or a process—into a good presentable for future transactions through stabilization, that is, into something delimited and definable (Callon and Muniesa 2005). On the surface, the replacement of ideas of actual physical forests with a representation of forests in the form of carbon storage maps typifies objectification. But as much of the literature makes clear, definitions of most ES are variable and unstable, and the measurements for ES unknown or unreliable, meaning that many ES never make it to objectification. For example, in the US EPA FEGS classification, out of 589 different ES identified, only around 60 have any measurement standard associated with them.[2] And despite decades-long US federal attempts to create a simple wetlands classification system down to a single scale of value, in reality the system has remained idiosyncratic, complicated, and "almost bespoke" (Robertson 2012: 393). Objectification has hit a roadblock somehow.

What accounts for the fact that we see objectification occurring in some ES, like forest carbon sequestration, and not in other ES functions, like pollination, soil regulation, or temperature modulation? One possible explanation is that the physical and material properties of different ES themselves helps explain their resistance to measurement or commodification. Despite fears of "nonhuman nature … being made docile through a conceptual transformation" (Sullivan 2012: 14), it may be that nature is pushing back. For example, Bruce Braun (2008) argues that it is the "inventiveness" of life itself that sets up methodological and political challenges for experts to condense this to measurable, tradable features. Karen Bakker (2005) identifies the "uncooperative" nature of water; although measurement of cubic volume is fairly easy, standardizing exchange units and stabilizing pricing has been much more difficult. William Boyd and colleagues note that nature itself "poses a unique set of obstacles, opportunities, and surprises to firms as they seek to subordinate biophysical properties and processes" for commodification (2001: 556). Robertson has noted how difficult it is to assign values to ecological complexes involving many different species and relationships, as "place-specificity in ecological services creates a signature tension within the process of commodity abstraction" (2000: 466). As he concludes, there are some ecological aspects that capital cannot "see." Clear patterns appear to emerge in the literature, with regulation of water flows and carbon sequestration as ES that appear somewhat "fixable" (although not without controversy), while others do not. As an example, the USDA Office of Environmental Markets promotes ES tools to farmers in just three areas: to assess water quality (such as agricultural runoff), estimate greenhouse gas emissions, and preserve wetlands (see USDA 2017). Other ES of immense importance to agriculture, such as soil erosion regulation, soil fertility, or pollination, have not been easily captured in metrics and markets.

Many ES do not lend themselves to "singularization" well either, which Callon describes as the creation of standardized "goods" that are highly substitutable for one another (Callon and Muniesa 2005). These standards function as a technology to help direct the "conduct of conduct" in markets and exchanges (Lovell 2013b). Sullivan, reflecting common concerns in the neoliberal natures literature, states that ES discourse itself can create a "model of infinite substitutability" (2010: 116). Yet the empirical challenges of standardization have been raised by many scholars, in, for example, biodiversity (Dempsey 2016), forests (Carton and Andersson 2017; Lovell 2013b), and carbon accounting (Ascui and Lovell 2011; Lohmann 2009, 2014). Gupta and colleagues go so far as to argue that lack of standardization in "carbon accounting systems may empower marginal actors in unexpected ways, and thereby counteract the managerial ambitions of international science and policy elites" (2012: 729). The literature on ES standardization is still underdeveloped, as this review has shown, but would do well to follow studies in which singularization has been closely examined, such as studies on the creation of carbon offsets. In this market, a "hemming in" occurs in which clear baselines, accurate measurements, monitoring, and guarantees of additionality serve to create higher-value offsets that are commensurate between different types of carbon. But even in this, markets have been unable to affix standard values to these offsets, given high variability in their creation and quality, raising questions of how successful the singularization has been (Bumpus 2011).

The processual nature of many ES as ongoing activities, as opposed to direct and fungible benefits or goods like a cubic meter of timber, is likely to complicate standardization and singularization in interesting ways. For example, although a carbon offset tries to fix a single unit of presumed carbon sequestration to an object and value, in reality, the biological and material processes of carbon sequestration vary over space and time (e.g., plant carbon sequestration follows seasons, and can be affected by fires, heat, or other physical variations in growing conditions). This means that there is an element of nonpermanence to any attempt to measure, value, or pay for many ES (Gutiérrez 2011; Knox-Hayes 2010); the ES could be changed in the future even after the calculation is fixed, a value is toted up, and a payment is made. This instability has been one of the major hindrances to the development of approaches like REDD+, which has been in discussion for more than 10 years but has yet to be finalized (Fletcher et al. 2016).

Decontextualization, Dissociation, and Detachment: Incomplete Processes

In addition to being difficult to regularize and standardize, many ES are also hard to decontextualize, dissociate, and detach from their social and physical contexts and circulate as stable entities; often ES "transactions deal in objects, such as 'foregone emissions' and 'water quality,' that are challenging to even define, much less recognize as an object of utility. The successful ecosystem entrepreneur must be so lucky as to operate in a world where such things are understood to exist in a stable and widely-acknowledged form" (Robertson 2012: 387). While calculations undertaken for ES production have indeed produced new objects—such as maps, checklists, and equations—the degree to which these new forms circulate detached from their origins is often contested (Corbera and Martin 2015; Twyman et al. 2015). For example, carbon sequestration as an ES generated by trees is embedded in socioecological complexes of communities and people who plant and nurture these trees (Osborne 2015; Paladino and Fiske 2016), and cannot easily be dissociated from ideas of justice around forest politics (Forsyth and Sikor 2013; McElwee 2016a) or the fact that forests (let alone the carbon in them) are already governed by extensive systems of property rights (Mahanty et al. 2012; S. Milne 2012).

Some of the neoliberal natures literature focuses on the idea of abstraction as a form of this process of decontextualization (Igoe 2016). Such authors have asserted that ES concepts lead to "nonhuman natures [that] tend to become flattened and deadened into abstract and conveniently incommunicative and inanimate objects, primed for commodity capture in service to the creation of capitalist value" (Büscher et al. 2012: 23). Related concerns include "spectacularization," combining processes of speculation and attention to exaggerated and simplified representations of nature that come to stand for something else (Cavanagh and Benjaminsen 2014; Igoe et al. 2010). Such a process has also been identified as "virtualism" (Carrier and West 2009), "in which buyers consume images and other abstractions of nature, such as internet purchased carbon offsets, rather than nature itself" (MacDonald and Corson 2012: 161). For these authors, ES concepts slip very easily into abstract representations that are then quickly turned into exchange values.

One potential roadblock to this, however, is that it has been nearly impossible to dissociate ES concepts from controversies over how they are created and measured. Calculatory practices make both statistics and indicators but also people as actors, spaces, and relations (Lansing 2010; Lovell 2015); the actors in the networks that make ES are themselves constituted by calculative practices such as measurement and classification (Lansing 2012). This can be seen in, for example, the creation of "carbon foresters" (Stephan 2013) and the new communities of practice around MRV (Lovell 2015). The performative nature of expert modeling of ES has been noted by others as well (Nost 2015). These actors will be crucial in determining how metrics translate into values, particularly for commodification, and there are many instances where scientists themselves have pushed back against abstraction (Dempsey 2016; Dempsey and Robertson 2012; Robertson 2012). Future ethnographic studies of measurement and abstraction for different ES among different actors will thus be crucial to answering this question.

Finally, in the literature on ES, metrological practices do not appear to "cool" disagreement, as has been asserted with regard to practices of accounting in economics. Rather, particularly with regard to nature, metrics can amplify dissent when there are disagreements over particular techniques and assumptions, such as those around carbon accounting (M. Cooper 2015; Eden 2013; Gillon 2014). Measurements can also lead to claims about rights, which are controversial; Felker and colleagues (2017) note that motivations for participating in MRV for forest carbon often include expectations that forest tenure rights will be strengthened or protected if forests are measured formally. On the flip side, David Lansing (2011) gives an example from Costa Rica, where attempts to standardize carbon units for the CDM shifted goals of a project toward replacing indigenous agriculture, potentially leading to dispossession. Thus, it seems likely that measurement will continue to be about claims and counterclaims, as much as it is about standardization and decontextualization, and future studies would do well to pay attention to this.

Future Financial Directions

Many scholars of neoliberal natures have proposed that ES terminology and concepts are easy pathways to capital accumulation (Corson et al. 2013; Suarez and Corson 2013), particularly as ES discourse imagines commodification, if not outright authorizes it (Turnhout, Waterton, et al. 2014). However, it is important to realize that while definitions and measurements of commodities are always necessary in order to then determine how to sell those goods in a market (M. Cooper 2015; Lovell and MacKenzie 2014), they are hardly a sufficient condition (Bakker 2005). It is certainly possible to discuss, and even value, ES without taking the next step and transferring these values into a market (Gómez-Baggethun and Ruiz-Perez 2011). In other words, more steps are required to move from an abstracted idea to then affixing any form of either nonmonetary or economic value to it; ES have not, contrary to predictions, become "instantaneously" financialized (Smith 2007). Indeed, one of the key founders of the ES approach, Walter Reid, has expressed skepticism that economic or market opportunities are bound up in the concept (Dempsey 2016). To move from an abstracted ES to a commodity requires additional steps, including economic framing, monetization, appropriation, and commercialization, but this "is not necessarily unidirectional or irreversible" (Gómez-Baggethun and Ruiz-Perez 2011: 620). Thomas Hahn and colleagues (2015) argue that six "degrees of commodification" are possible for ES, ranging from use of an instrumental framing of ES (but no monetizing or privatizing) to the strongest degree, where a new form of financial instrument is created from an ES (e.g., biodiversity derivatives), although they do not speculate on which types of ES might result in weaker or stronger commodification.

A key step in commodification is establishing value, and a growing body of literature is looking closely at how measurements and pricing are co-linked, particularly in the ethnographic study of emerging markets in carbon (Descheneau 2012; Lovell 2013a; Lovell and MacKenzie 2014; Paterson 2013). These approaches can be a useful basis for examining the future linkages between ES measurement and marketization, which is beyond the scope of this article alone. More attention to measurements and calculations would similarly better inform much of the literature on "fictitious commodities" and "commodity fetishism" that has arisen in recent examinations of the extension of market values to new areas of nature, including ES (Brockington 2011; Kosoy and Corbera 2010). Much of this literature pays particular attention to the social relations that inform commodification but less attention to the specifics of how metrics fit in or help explain this process (Peluso 2012; Sullivan 2012). Numerous examples in the literature point out that the danger is that economic values of ES are taken as a measurement of the actual ecosystem service, rather than the other way around (Laurans et al. 2013). Indeed, there is some evidence that the jump to economic valuation as a means to compare across ES may happen precisely because there is no standard way to measure ES, let alone compare them directly—that is, to avoid the apples and oranges problem, monetary valuation becomes the universal currency (Olander et al. 2016; Salzman and Ruhl 2000). As Robertson notes, "We are moving from a point where nature can merely be represented by money, to a point where money becomes the more perfect abstract reality of the community of nature" (2012: 388).

But the substitution of money for value does not need to be inevitable. The literature on noneconomic values that can be associated with ES is also very rich and growing rapidly (N. Cooper et al. 2016; Edwards et al. 2016; Irvine et al. 2016; Kenter et al. 2016). There are promising examples of local participation by nonexperts in ES measurement and monitoring, including assessments focused on identifying appropriate indicators for local situations, such as value pluralism (Spash 2008), or in thinking about ES as practices of care (Jackson and Palmer 2014). There are also institutional mechanisms of "ground truthing" and evaluation of alternative management options for ES that do not rely on cost-benefit analysis, such as through multicriteria analysis, citizen juries, or public referenda, among others (Jacobs et al. 2014; Vatn 2009).

Nonetheless, the strong ES policy focus at the US federal level, and in states like Oregon, as well as in the United Kingdom and elsewhere, indicate that standardizing ES measurement is firmly on the agenda, and social science needs to follow this closely, and see how certain pathways may lead to commoditization (or not). We need studies of how the calculation itself in some cases may lead to economic valuation and commodification, while in other cases these processes are actually stymied by incalculability. Currently, there is insufficient literature with a social science focus that compares different ES that have been the target of policies that could lead to commodification (e.g., PES, mitigation offsets, species banking, conservation easements, and other modes) to understand how different ES are measured and then translated into values at different sites, and to assess the implications of this metrology for governance. Lovell and MacKenzie give an indication of these patterns when they note that in cases where calculatory practices are able to be stabilized (such as in the use of allometric equations to measure forest carbon) this helps "grease" the way in which to smooth market transactions, as without these stabilizations "market fluctuations and instability because of inaccurate data" would occur (2014: 77). But how these stabilizations may vary among different ES still remains to be further studied. Despite understandable worries that the use of ES concepts leads to "'billable hours' and bankable assets, whose release onto markets in variously derived forms is facilitating an expanding and spectacular investment frontier" (Sullivan 2012: 12), there are indications the neoliberal project is not working nearly as quickly or strongly as might be imagined, as there are actually very slow and small private capital flows into ecosystem conservation (Dempsey and Suarez 2016). To what degree this slowness is a function of challenges in ES objectification, simplification, and decontextualization therefore remains an area of fertile research.

Conclusions

While it is perhaps surprising to those who only see the ubiquity of the term, the definition of what counts as an ES and how it should be measured is a matter of considerable debate, particularly among those who are called on as experts to assess such matters. There is a lack of "fixity" in the metrology of ES, given no standard methods for measurements and valuation. Just as the terms "neoliberal" or "market-based instruments" can be deployed as a catchall that hides a great deal of difference, so too can the term ES, and we need to better understand the formation of these material-discursive apparatuses, given that they operate as a boundary object tying many different, and at times contradictory, concepts together. We need more comparative studies of how similar ideas and definitions of ES are measured and valued in different ways in different places by different actors, and the power dynamics involved (Felipe-Lucia et al. 2015). Unfortunately, as noted, we lack many ethnographic studies of science in practice in the making of ES, akin to what has been done more extensively in the discussion of carbon measurements for emission markets (Lövbrand and Stripple 2011; Ormond and Goodman 2015; Stephan and Paterson 2012). Perhaps academic attention to measurement only happens after markets have been constructed, which is an unfortunate way to draw attention to issues—at the point at which it may be too late to alter trajectories.

Can the existing system of differing and overlapping approaches to defining and measuring ES continue to exist indefinitely, and thereby provide some potential freedom and space for local or idiosyncratic views on ES to coexist? Or will a top-down system eventually come to dominate (Tadaki et al. 2015)? Many natural scientists consider definition complexity to be a challenge to be fixed, and call for "robust, efficient and versatile methods for procuring data" to define and classify ES (Naeem et al. 2015: 1207). Social scientists have instead warned against creating standardized measures, which may serve to delegitimize multinatural ways of relating to nature (Turnhout et al. 2013); against imposing top-down "social rationalities" (Tadaki et al. 2015); and against examples of measurement systems leading to reductionist values (Tadaki and Sinner 2014). Currently, the IPBES does not seem to have in its remit the sort of standardization of methodologies that the Intergovernmental Panel on Climate Change (IPCC) has come up with for carbon accounting (Ascui and Lovell 2011), although some warn that IPBES's inception documents stress effectiveness, efficiency, and transparency, in a managerial and "science-based linear model of science-society relations" (Turnhout, Neves-Graça, et al. 2014: 591). Nonetheless, if economists, ecologists, and policy makers have all advocated for standardized accounting units for ES, whether through IPBES or other fora, and yet these still do not exist for most ES, then this tells us something about both the process of accounting and the resistance of ES themselves to standardization.

This lack of measurement and standardization leading to objectification of most ES also seems to fly in the face of critiques that the very concept of ES may be a slippery slope to commodification of everything in nature. Rather, much as Brett Christophers (2015) has shown for the ways in which the concept of "financialization" has become overly vague, and which should be replaced by more targeted outlines of how specific financial transactions are occurring in specific places, we are perhaps better off noting that some ES may be more easily commodifiable in some places (e.g., forest carbon sequestration, or water flow regulation), while other ES will be much slower to be defined and valued. We need to ask which ES lend themselves, through their materiality or representability or other factors, to valuation and commodification, and which ES do not. Any commodification will clearly require complex interactions between multiple actors—scientists, bureaucrats, communities, consumers, and the financial sector (Robertson 2012). Additional social science studies of how for these actors ES are understood, considered, and represented in different assessments and policies will surely be valuable in this regard. It is quite possible that the difficulties of defining ES satisfactorily to multiple audiences, let alone measuring them, will lead to a more limited focus on commodification of a far narrower range of services than might originally have been imagined (Dempsey and Robertson 2012). The future is likely to be not the neoliberalization of nature, but rather the neoliberalization of certain kinds of nature (Bakker 2010).

Overall, the literature indicates that the concept of ES has both promise and pitfalls. While it is a truism to say that both social systems and material nature are imbricated in ES production, it is an important point. The very root of ES—the idea of services—is an acknowledgment of humanity's role in interactions with the natural world, and the increasing attention to the idea of the Anthropocene fits with attention to the human-natural exchange or coproduction that is embedded in ES. Indeed, some of the key founders of the ES approach have asserted that ES were originally conceptualized to find ways to "reach across the North-South divide and … more effectively address development and equity issues" (Dempsey 2016: 96). Given this, can the concept of ES potentially be empowering to think of human-nature assemblages in creative ways (Kolinjivadi et al. 2017)? More studies on this in the social science literature are needed in order to look for potential futures, lively possibilities, and spaces for hope in which attention to ES and their identification itself can avoid overly commodified approaches. Timothy Forsyth expresses some optimism here in his call to pay attention to how "explanations of socially valued outcomes such as ecosystem services should not be taken to represent permanent and universal explanations of underlying biophysical properties of ecosystems, but rather specific configurations of valued outcomes and social participation, which can also be reconfigured using alternative values and participation" (2015: 227). IPBES is also taking a similarly pluralistic approach to valuation and participation, noting that policies for ES will vary given different "values in terms of biophysical, socio-cultural, economic, health, or holistic perspectives" (Pascual et al. 2017: 11).

Part of the coproduction of ES moving forward will come from the critical social science literature, but as this review has noted, there are glaring gaps. While certain ES functions, like carbon sequestration, and certain landscapes providing ES, like wetlands and streams, have received the lion's share of critical attention, other ES, like pollination or water purification services, are virtually ignored by social scientists. There is also an absence in the literature of ethnographic or ANT-focused descriptions of how integrated modeling like InVEST takes place and the practices involving production of knowledge, calculative mechanisms, and networks that bring such a model and ideas of ecological production functions into action. Further, unlike various multilateral agreements for which we increasingly have histories and ethnographies (e.g., (Brosius and Campbell 2010; Campbell et al. 2014), there are no ethnographies of the major ES assessments, and the MEA process suffered from a lack of (noneconomist) social science engagement (Reid and Mooney 2016). The creation of new global and regional assessments under IPBES, and the inclusion of social scientists (including this author and several others cited here), may signal a new opportunity to see ES assessment from "the inside" and to provide the ethnographic accounting that helps us understand how definitions give way to measurements, which may give way to valuations. Given that formalization of standards for ES has not yet happened in most cases, now is the time for critical social scientists to contribute their knowledge to understanding these processes. In this way, we can more fully appreciate the social aspects of the making of ES by engaging with it ourselves.

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NOTES

1. See, e.g., the RIBITS searchable database at https://ribits.usace.army.mil.
2. The searchable database is located at https://gispub4.epa.gov/FEGS/FEGS_checkboxes_fegs.html.

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