OBSERVATIONAL AND MODELING METHODS TO INFORM ECOSYSTEM SERVICE MARKETS

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ABSTRACT

Interest in quantifying the impacts of land management on ecosystem services has grown as governments, environmental organizations, and corporations have pledged to reduce greenhouse gas emissions, nutrient leaching, and other environmental impacts of human activities. Ecosystem service markets were formalized in the 1990s and originally deployed to mitigate point sources of air and water pollution. Associated protocols were fairly simple and easy to implement because quantification of point sources is easy as is verification of mitigation practices. In contrast, protocols to quantify agricultural sinks and sources of pollutants are more complicated because these sources are more diffuse and often cannot be measured directly because required sampling intensity is not economically or technologically feasible. One approach to transcend this limitation is for protocols to employ pay for practice, i.e., land mangers/owners are paid a standard amount per unit of land area enrolled in a specific conservation practice and no attempt is made to quantify outcomes achieved at the entity level. Another strategy is for protocols to imbed models that calculate entity level greenhouse gas, carbon storage, and nutrient loss outcomes. But up to now, estimates generated by these models are not very accurate at the entity level. However, recent advances in data availability, geographic information systems, precision agriculture and remote sensing combined with model applications and ground and atmospheric based measurements can reduce these uncertainties. Protocols that integrate pay for practice and entity and larger scale quantification methods are expected to approach optimal cost:benefit ratios.

INTRODUCTION

Ecosystem services improve air and water quality, sequester carbon, and provide land for wildlife habitat and recreational activities. Although conservation programs that enhance ecosystem services have existed for decades, it was not until the 1990s that market-based payment for ecosystem services mechanisms were formalized (Gómez-Baggethun, et al., 2010). Markets designed to improve air and water quality emerged before markets designed to sequester carbon and reduce greenhouse gas (GHG) emissions (Bayon, 2004; Salzman et al., 2018). One reason for this is that legislation such as the Clean Water and Clean Air Acts include regulations and permitting so some level of compliance is mandated. On the other hand, GHG markets in the US are based almost entirely in voluntary commitments. Lack of a mandates leads to fluctuating and typically low prices for reduction credits and limited participation (Paustian et al., 2019).

Although markets for individual ecosystem services have existed for decades, a recent resurgence of interest has pushed the development of payment programs. Payments for ecosystem service programs are currently estimated at \$36–42 billion in annual transactions at the global scale (Salzman et al., 2018). For the US, a recent report estimated the potential demand for ecosystem service credits at about \$5.2, \$4.8, and \$3.9 billion for GHG, nitrogen, (N), and phosphorous (P) mitigation, respectively (https://ecosystemservicesmarket.org/wp-content/uploads/2019/09/Informa-IHS-Markit-ESM-Study-Sep-19.pdf). Functioning Ecosystem Service Markets (ESM) require various basic components including buyers, sellers, protocols to verify participation and quantify outcomes, and mechanisms to transfer funds. Buyers include governments (California, Alberta) and corporations such as Bayer, General Mills, Cargill, Amazon, and Google. Commitments made by corporations include reductions of GHG emissions, N, P and other pollutants, both directly within their supply chains (insets) and payments to other entities to provide mitigation benefits (offsets). Sellers include property owners and land managers who oversee crop and livestock operations. Various methods and protocols have been developed to quantify services provided (e.g., Niles et al., 2019). In this paper, we explore why some ESM have been more successful than others, summarize current knowledge, and show how currently available conservation programs, measuring and modeling methods can be combined to help landowners and managers exploit market opportunities.

WHY ARE SOME ESM MORE SUCCESSFUL THAN OTHERS?

Markets to improve air and water quality have been more extensively used than C sequestration and GHG reduction markets for various reasons. These include government mandates, availability of dedicated capital, and feasibility of measuring, reporting, and verifying practices and outcomes. For example, a large portion of industrial air and water pollution is from point sources (e.g., exhaust pipes) so can be quantified with high accuracy at reasonable costs. In contrast, agricultural sources and sinks of GHG and pollutants are typically diffuse. Agricultural emissions and sinks also tend to be highly variable in space and time so it is not technically and economically feasible to directly measure emissions from all relevant land parcels (Niles et al. 2019; Tonitto et al. 2018). Consequently, different methods based on models have been developed to quantify the impact of agricultural practices (Tonitto et al. 2018). However, these methods are usually characterized by high uncertainty, so the accuracy of predicted outcomes is compromised. In addition, predicted outcomes depend highly on the choice of method (Schild et al., 2018a; 2018b). In addition to low C prices and lack of accurate quantification methods, poor communication across various stakeholder groups have limited agricultural sector participation in the U.S.

PROROCOLS FOR AGRICULTURAL SYSTEMS

Protocols have been developed to measure, report, and verify the adoption of different land use practices and the ecosystem service outcomes they provide. The accuracy of these protocols varies widely. At one extreme, protocols for major land use changes such as reforestation can be readily verified using remotely sensed imagery which can be combined with ground truthing to accurately estimate C sequestration in above ground biomass. At the other extreme, it is difficult to quantify how practices such as changes in tillage intensity or use of different fertilizer types affect soil C changes and GHG fluxes. In the middle are water quality protocols. For example, deploying cover crops and buffer strips has been incentivized in the Chesapeake Bay watershed to decrease nitrate and phosphorus loading. This provides an example of pay for practice because land managers/owners are paid a set price for every acre enrolled (Bowman and Lynch, 2019). In this case, it is relatively easy to verify the land area converted cover crops or buffer strips. Similarly, the aggregated outcomes, i.e. NO_3 and P concentrations in the Bay, can be accurately assessed (Woodbury et al., 2018). However, the contributions of individual land managers/owners to NO_3 and P loading cannot be quantified or verified (Bowman and Lynch, 2019).

To address the limitations of pay for practice more complex protocols that imbed empirical and/or process-based models (e.g., Paustian et al., 2018) and sometimes integrate ground-based measurements have been developed. A simple empirical approach is used by the Province of Alberta to estimate the soil carbon change and GHG consequences of different management practices without direct measurements. Modern computing power, user interfaces, and availability of GIS referencing for model inputs allow for relatively cheap and easy calculation of entity level GHG emissions, soil C changes, and nutrient losses using more sophisticated process-based models (Paustian et al., 2019). However, estimates based on these tools, whether empirical or process-based, are characterized by high uncertainty and accuracy cannot be assured, especially without site level validation (Richards, 2018; Tonitto et al., 2018). Uncertainty can be reduced by aggregating outcomes across space and time and taking measurements to increase accuracy of model inputs and/or to validate model outputs (Tonitti et al., 2018). Aggregation is straightforward and inexpensive to achieve but there is a tradeoff between increased accuracy as more measurements are taken and increased costs which could exceed the price of the credit.

CURRENT STATE OF KNOWLEGDE AND WAYS FORWARD

Ass stated above, markets based on point sources or sinks of pollution have the advantage of easy verification an quantification. Although many agricultural sources and sinks of GHG and pollutants are highly diffuse, some are point sources. One example is methane emissions from managed manure systems. Methane that would other wise escape to the atmosphere can be captured with anaerobic digestors and used to offset fossil fuel emissions. The resulting reductions in emissions can be easily verified and quantified with high accuracy but the systems are expensive. However, credits generated by policies in California can be large enough to cover some producer costs and help make anaerobic digesters profitable (e.g., https://www.governing.com/next/Minnesota-Could-Be-Moving-to-Farms-for-Renewable-Energy.htm).

Advances in precision agriculture and precision conservation (Delgado et al., 2019) are leading to some agricultural sources and sinks becoming more point like. For example, data and technologies exist to spatially and temporally target fertilizer and pesticide applications to increase yields while decreasing inputs (Delgado et al., 2019). Mitigation efforts can also be targeted at fine spatial resolution, for example databases for soil properties, topography, and land use have recently been combined identify where saturation buffers should be located to filter out nutrients that would otherwise contribute to water pollution (Tomer et al, 2017; McLellan et al. 2018) and credits can be calculated using available tools (Saleh and Osei, 2017). In addition to GHG and nutrient fluxes, precision conservation can also assess impacts of land use on wildlife habitat (McConnell and Burger, 2017).

To move forward we suggest that formal comparisons of the overhead costs of programs like EQIP (Environmental Quality Incentives Program) should be compared more sophisticated model-based protocols. Producers currently receive about 10-15% on average of every dollar spent on food but this is highly variable depending on commodity (https://www.ers.usda.gov/data-products/price-spreads-from-farm-to-consumer/price-spreads-from-farm-to-consumer/); this portion will likely need to be much higher for ecosystem service credits to have a good chance of widespread adoption. Outcomes quantified by using different approaches also need to be formally compared and uncertainty rigorously calculated. Cost and accuracy information can then be combined to identify the combination of pay for practice, modeling, measuring, and verifying methods that optimize economic and ecosystem outcomes.

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