Valuing water purification and crop pollination services for ecosystem accounting: a multi-country study[1]

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Abstract

This paper summarizes a four year collaborative and multi-country research program (Ecosystem Service Accounting for Development (ESAfD) that aims at enhancing ecosystem accounting methods by developing and testing empirical methods of economic valuation of ecosystem services. We focus on assessing two regulating services, water purification and crop pollination, in seven different countries; China, Costa Rica, Ethiopia, Kenya, South Africa, Sweden and Tanzania. In each country, our objective is to develop empirical estimates of the value of ecosystem services using methods consistent with both economic theory and SEEA. Moreover, the assessments aim at producing nationally or sub-nationally representative estimates. More specifically, our methodological approaches involve first compiling spatial and temporal panel data on specific economic outcomes of interest (water treatment costs, agricultural production outputs and revenues), land cover (forest, wetland, grassland, etc.) as a proxy for ecosystems, and other relevant environmental and socioeconomic drivers of the value of ecosystem services. Then, using panel estimation methods, we measure the marginal contribution of ecosystems to the economic outcome of interest (water treatment cost, agricultural revenue). Moreover, by examining land cover (ecosystems) at different distances from the place of economic activity (water intake, agricultural field), we develop spatial measures of the value of ecosystem service generated by a specific area of land. The results show that changes in forest cover statistically significantly affect both surface water treatment costs and agricultural revenues. We also find that the effect of marginal forest gradually diminishes as the distance to the water treatment plant or agricultural field increases. The analysis can support the construction of statistically based transfer functions that can help to

[1] The ESAfD project is a collaborative project conducted through the Environment for Development research centers, including project partners at each center: Byela Tibesigwa (University of Dar es Salaam, Tanzania), Dambala Gelo Kutela and Jane Turpie (University of Cape Town, South Africa), Dawit Woubishet Mulatu (Environmental and Climate Research Center, Ethiopian Development Research Institute, Ethiopia), Richard Mulwa and Michael Ndwiga Jairo (University of Nairobi, Kenya), Per Strömberg (Swedish EPA, Sweden), Zhaoyang Liu (Peking University, China).

transfer values across different countries and their sub-regions. The studies in different countries are directly comparable, enabling between-country comparisons and learning.

I. Introduction; Motivation, Purpose, Objectives,

This paper summarizes a four year collaborative and multi-country research program, Ecosystem Services Accounting for Development (ESAfD), to develop and test empirical methods of economic valuation of ecosystem services. The ESAfD program was initiated in 2014 in response to the need of national empirical testing of ecosystem valuation techniques to support the development of the Experimental Ecosystem Accounts. The ESAfD focuses on monetary ecosystem accounting, a priority area identified by the expert group on ecosystem accounting under the auspices of the Committee of Experts on Environmental-Economic Accounting (UNCEEA). The ESAfD program entails collaborations with several research and policy institutes under the auspices of the Environment for Development Initiative (EfD) in seven different countries, including China, Costa Rica, Ethiopia, Kenya, South Africa, Sweden and Tanzania.

Non-market goods such as regulating services and cultural services are poorly understood when it comes to monetized valuation that also fits the accounting framework. Accordingly, the ESAfD program chose as its focus to examine *two regulating services*; water purification and crop pollination and *one cultural service*; green urban amenities.

In this paper, we explain case studies to value water purification and crop pollination services. We have examined their value using the same a general framework, *production function method*, though the underlying data and other specifics vary by service and country. Within the production function framework, our analyses encompass profit functions, revenue functions and costs functions. When implementing each study, our goal was to draw from existing data sources, though in some cases this required considerable efforts to gather the data already recorded but not stored or distributed in any centralized fashion. Focus on existing data sources also helps test how amendable the general approach is within different country contexts with considerable differences in data quality, availability and accessibility.

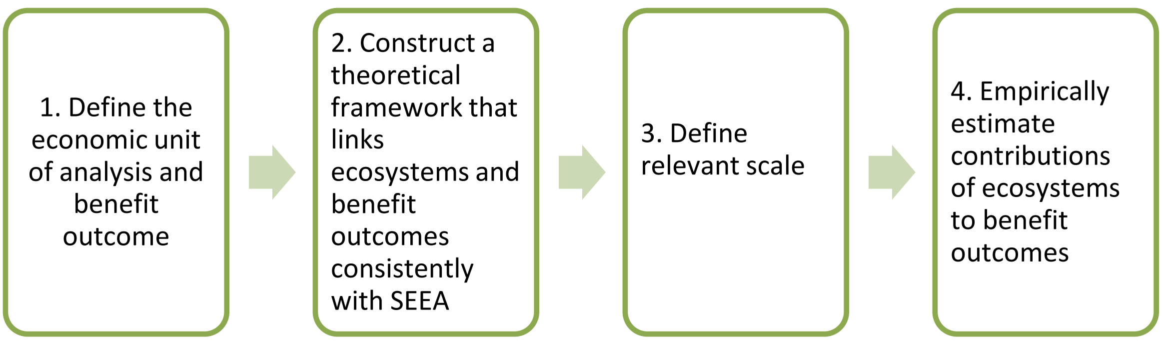
Because one of our key objectives is to support ecosystem accounting in different countries, we sought valuation results that are both spatial and representative at national level, as opposed to addressing a specific localized ecosystem as is common in the valuation literature. Moreover, we searched for data on actual economic outcomes so that the results accurately account for economic behavior, including possible adaptation of economic agents using or benefiting from the service to changes in environmental quality. Though adaptation to changing production or consumption environments is a key feature of economic behavior, such behavioral responses are typically not considered by valuation approaches based on biophysical modeling. Finally, several ecosystems (forest, wetlands, grasslands, and so forth) often contribute towards the same ecosystem service, so it can be difficult to parse out how much of the service a particular ecosystem provides. Our goal is assess and establish the degree and monetary value provided by the respective systems.

In the rest of this paper, we first present the general approach the ESAfD program. Thereafter, we explain more specifically the approaches developed for the valuation of water purification and crop pollination services. We conclude by a discussion and questions about how our assessments can help inform the System of Environmental-Economic Accounting – Experimental Ecosystem Accounting (SEEA – EEA) (UN, 2012). Note that ESAfD is work-in-progress so the discussions about studies and estimation results in this paper are preliminary. Moreover, in what follows, we explain different studies developed under the ESAfD umbrella mostly in general terms and without thorough assessments and references to the current literature. More detailed documentation will be available in papers and reports currently under preparation by the ESAfD group members.

II. Methodological overview

We use a similar general framework in separate assessments of the contributions of ecosystems to water purification and pollination of crops (Figure 1). First, we define the economic units that receive benefits from ecosystem service and define a measure that embodies this benefit. For example, for water purification services, we use measures associated with the cost of water treatment required to produce potable water. For crop pollination services, we examine crop production and revenue outcomes. Then, we construct conceptual economic models to link ecosystems and ecosystem service outcomes.

Figure 1: Process to design the analysis of ecosystem services valuation



After defining the conceptual framework, we specify the relevant scale of analysis to match the economic activity and units assessed. Once the scale is defined, we empirically measure how changes in land cover (equivalent to land-cover/ecosystem functional units, LCEU in SEEA - Ecosystem Experimental Account framework) changes the benefits that the different economic units receive. The spatial resolution (basic spatial unit, BSU) within each LCEU changes from study to study, and data source to data source. It is relevant to mention that we have not focused in our work so far on defining Ecosystem Accounting Units (EAUs) as defined in the SEEA experimental accounts. We analyze changes in benefits from ecosystem flows to our economic units, but we are not defining a scale of accounting.

In the empirical assessments, we compile spatial and temporal panel data on the economic outcomes of interest (water treatment costs, agricultural production outputs and revenues), land cover (forest, wetland, grassland, and so forth), as well as other relevant environmental and socioeconomic drivers of the value of ecosystem services assessed. The purpose of the use of panel data is to enable robust empirical identification of the contributions of ecosystems to the ecosystem services outcomes of interest (panel data estimation allows for a high degree of control for potential unobservable confounders). Using this approach, we are also able to measure the marginal contributions of ecosystems to the ecosystem service (crop pollination, water purification).

We develop a spatial approach by measuring land cover (ecosystems) at different distances from the unit of analysis (agricultural field, water treatment facility intake) and then measuring the contribution of ecosystems within different distances on the ecosystem services outcome. The advantage of this methodology is that it enables the identification of marginal contributions of different types of ecosystems at different distances from the location of economic activity. Our use of spatial and geographically representative data allows the derivation of spatially determined and nationally representative unit values of benefits from the ecosystem services examined.

II.1 Water purification service

Wide evidence exists on the decrease of the operational costs of water treatment plants when water quality increases (Forster, Bardos and Southgate, 1987; Holmes, 1988; Piper, 2003; Elsin, Kramer and Jenkins, 2010; Montoya *et al.*, 2011; Telles, Guimarães and Dechen, 2011). Also, evidence from hydrological studies shows that runoff from forests tends to have lower concentration of suspended solids and other pollutants than the runoff from other land uses (Bruijnzeel 2004; Auquilla & Jiménez 2005; Varanka & Luoto 2012; Carlson et al. 2014). The literature suggests that water quality is an important mechanism linking forest cover and water treatment costs. There exists scarce evidence exploring forest cover and both endpoints in the econometric literature. Some studies explore the links between land use and water quality finding that the degree of forest cover increases water quality (O'Dwyer *et al.*, 2013; Curtis and Morgenroth, 2014; Donoghue *et al.*, 2015). Curtis and Morgenroth (2013) and O' Donoghue et al. (2015) use panel data with short time periods, annual data, estimating only between variation models. O'Dwyer et al. (2013) analyzes only one catchment. In the existing econometric literature, studies linking forest cover and water treatment costs (Ernst 2004; Freeman n.d.; Vincent et al. 2015), find a significant inverse relationship, depending on location, control, and sample size. Mcdonald et al. (2016) provide a statistical analysis on the relationship between land cover and water treatment costs in urban areas at a global scale during the last century. However, the analysis uses secondary data to conduct correlation analysis rather than empirically estimating marginal effects of land cover change.

In our assessments, water treatment plants using surface water for intake water constitute the economic units of analysis for measuring benefits from water purification services by ecosystems. The outcome variables vary somewhat across countries, depending on data availability. Table 1 summarizes the scale and variable used to measure the benefits in each country. In some countries, we examine the impacts using multiple outcome measures.

Using panel data analyses, we scrutinize how ecosystems upstream from water intakes to water treatment plants contribute towards reduced water treatment expenses. Using geo-referenced information of the location of the surface water intakes, and the delineation of the upstream watershed from the water utilities, we estimate how changes in upstream land cover affect water quality and water treatment expenses experienced at the water treatment plants.

Our conceptual framework links changes in land cover with changes in the costs of surface water purification. This is a revealed preference approach which produces a conservative estimate of benefits because it does not account for the capital costs of investments potentially required for increasing technological capacity to address low quality of raw water. Table 1 shows the measures of water purification costs we use in different countries.

Table 1: Summary of ecosystem accounting unit and measure of the benefits of ecosystems water purification service

<table>
<tr><td rowspan="5">Scale</td><td>Political boundaries</td><td></td><td></td><td></td><td>China</td></tr>
<tr><td rowspan="3">Whole watershed</td><td>Costa Rica</td><td>Costa Rica</td><td>Costa Rica</td><td></td></tr>
<tr><td>Sweden</td><td></td><td>Sweden</td><td>Tanzania</td></tr>
<tr><td></td><td></td><td>Ethiopia</td><td></td></tr>
<tr><td>Intersection of the watershed and round buffers centered in the water intake</td><td>Sweden</td><td></td><td>Ethiopia</td><td></td></tr>
<tr><td></td><td></td><td>Water quality</td><td>Water purification chemicals volume</td><td>Chemicals for water purification cost</td><td>Total water treatment cost</td></tr>
<tr><td></td><td></td><td colspan="4">Measure of the benefit</td></tr>
</table>

Also, the value of forest can vary between location, e.g. closer or further from the water intake or the water streams. To consider this, we estimate the impact of ecosystem change in water quality and water purification costs at different water treatment plants using intersections of the upstream watershed with round buffers at different distances from the water intake, and riparian buffers at different distances from the water streams.

As an example of the results of this analysis, we estimated marginal water quality improvements as a consequence of change in upstream land cover. Fig. 2 shows the marginal reduction of raw water turbidity as a consequence of increasing one hectare of forest in the upstream catchment in Costa Rica, graphed by baseline forest area in the catchment. The curves show a decreasing path, indicating that one additional hectare of forest produces greater and greater reductions in turbidity when fewer and fewer hectares of forest exist in the catchment. In other words, marginal changes in forest cover mean larger changes in water quality in catchments with small forest areas, vice versa. This is intuitive as one hectare of forest typically represents a larger share of the whole catchment the smaller the catchment is.

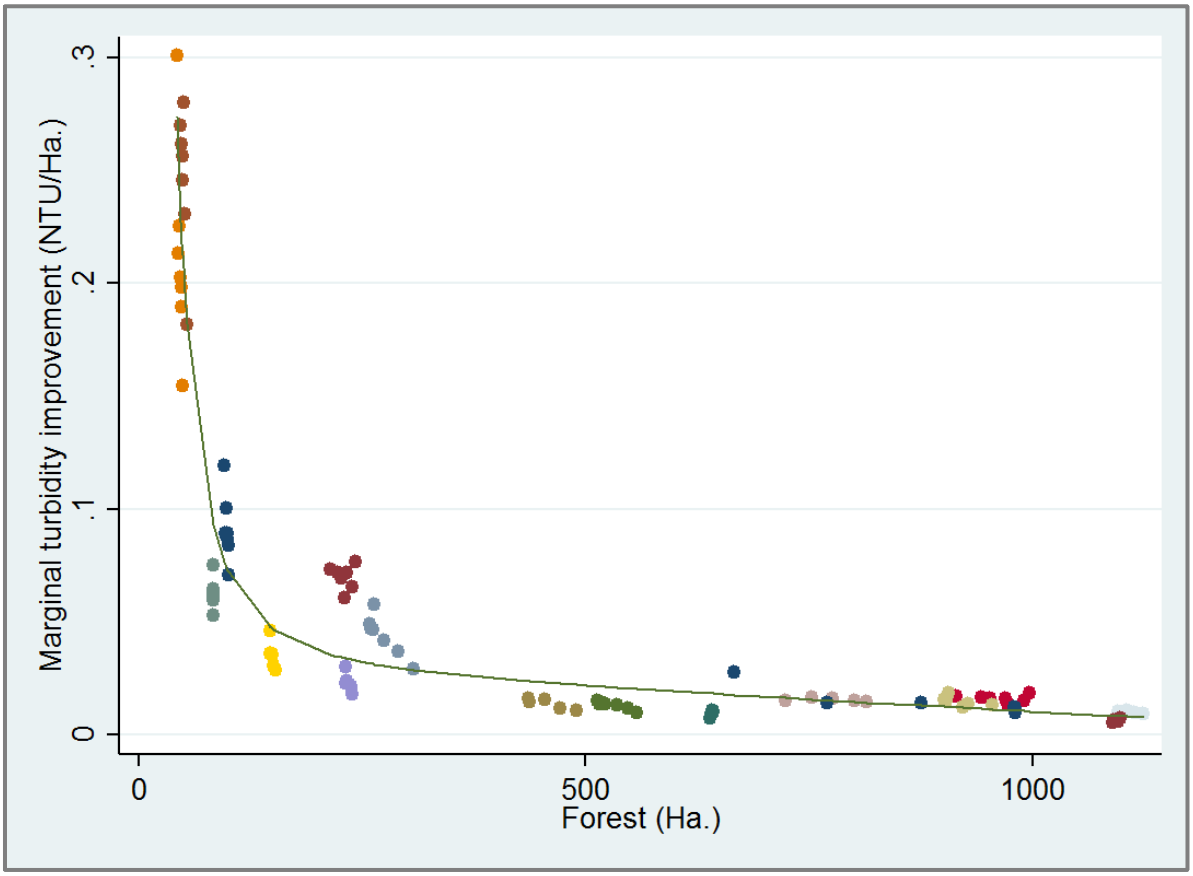


Figure 2: Reduction in the turbidity of raw water (vertical axis) when adding one hectare of forest in the upstream catchment, examined by the baseline areas of forest (hectares) in upstream catchment area (horizontal axis). Note: Each color represents a different catchment area.

II.2 Crop pollination service

Global agricultural production depends on pollinators, primarily wild bees, honey bees, and other insects but some cases also bats and other vertebrates. While some plants are self-pollinated or wind-pollinated, most flowering plants require pollinators to produce fruit and seed. As a consequence, it has been estimated that up to 75% of the world's food crops, with an estimated value between $235 billion and $577 billion annually, depend at least partially on pollinators (Garibaldi *et al.*, 2013). Given agriculture's dependency on pollinators, the emerging evidence about steadily declining pollinator populations creates concerns about food production and security. Evidence regarding diminishing pollinator populations concerns not only the managed pollinators, such as honey bees, but is also emerging for wild pollinators that are perhaps yet more critical to agriculture (Kleijn *et al.*, 2015). Drivers of the observed declines of pollinators vary, but include issues such as agricultural intensification and pesticide use, habitat degradation and loss, climate change, bee keeping practices and diseases, and air pollution (Garibaldi *et al.*, 2013; Kleijn *et al.*, 2015) .

Academic literature on crop pollination services is rich, including empirical assessments of the contributions of ecosystems to yields of specific crops (e.g. Ricketts *et al.*, 2004) and assessments of landscape effects on crops pollination services (Ricketts *et al.*, 2008). Economics assessments of pollination services are less common, but include Winfree et al. (2011) who review economic theoretical models and empirical applications to value crops pollination services and Hanley et al. (2015) who review empirical studies on pollination services valuation. To our knowledge, no previous assessments have empirically assessed the economic contribution of ecosystems to crop pollination services by using representative and comprehensive (all crops) data from actual farming systems.

In our assessments, farm plots or farms constitute the economic unit of analysis. The scale relevant for the crop pollination service is the distance and amount of pollinators' habitat (different ecosystems such as forest, grassland, wetland etc.) to the farm plot. For Tanzania, Ethiopia, Costa Rica, and Sweden, we have information of the location of the farm plot (the centroid, or the entrance of the farm), but not the polygon. For defining the scale, we estimate land cover in round buffers of different sizes centered in the centroid of the farm plot.

Our overall estimation strategy is based on a generalized production function approach, where the availability of pollination services factors into the production function. By aggregating production outcomes across all crops into agricultural revenues, we examine the contributions of crop pollination on economic outcomes that emerge as a product of agricultural production decisions and environmental conditions, accounting for the various options to adapt farmers have to adjust to changing local conditions. Using panel estimation methods we develop a predictive model of agricultural revenues, including estimates of the contribution of forests—chief natural habitats of wild pollinators—nearby agricultural plots to agricultural revenues. Farmers grow an array of crops: fruits, vegetables, tubers, grains, nuts and seeds, each with a specific dependency on wild pollinators. To help identify whether the estimated contribution of pollinator habitats on agricultural revenues is indeed related to crop pollination, rather than other ecosystem services, such as hydrological services or pest control, also potentially supported by pollinator habitats, we use information from agro-ecological assessments to separate these crops into those that depend on insect pollination and those that are self-pollinated or mostly depend on wind for pollination.

Table 2: Summary of ecosystem accounting unit and measure of the benefits of ecosystems pollination service

<table>
<tr><td rowspan="4">Scale</td><td rowspan="3">Round buffers centered in the location of the farmer or centroid of the farm plot</td><td>Costa Rica (TBC)</td><td>Ethiopia</td><td rowspan="3">Ethiopia</td></tr>
<tr><td>Sweden</td><td rowspan="2">Sweden</td></tr>
<tr><td>Tanzania</td></tr>
<tr><td>Buffers in the sides of the farm plot</td><td>Sweden</td><td>Sweden</td><td></td></tr>
<tr><td colspan="2"></td><td>Farm revenues from pollinated crops</td><td>Farm net benefits from pollinated crops</td><td>Agricultural production from pollinated crops</td></tr>
<tr><td colspan="2"></td><td colspan="3">Measure of the benefit</td></tr>
</table>

The assessments of crop pollination servces in different countries are still underway, but our existing estimation results reveal distinct and robust contributions by forests to plot-level agricultural revenues. When contrasting pollination dependent and non-dependent crops, we find that the positive effects of forests emerge only for pollination dependent crops and total revenues. Wind or self-pollinated crops show no benefits from the proximity to forests. Therefore, our results suggest that the positive effect from the proximity of forests is associated with the ability of forests to support pollinator populations.

We also uncover a distinct distance-gradient in the contributions of forests to pollination services. Figure 3 demonsrates this results using preliminary estimation results from Tanzania. As the figure shows, forests in near proximity to agricultural plots contribute to agricultural revenue through crop pollination much more than those more distanced from the plot. The change in the value of pollinator services from forests, by distance of forests to the plot, strikingly resembles an exponential decline. Figure 3 also illustrates that forests benefit only pollinator dependent crops. Non-pollinator dependent crops experience no statistically significant increases or decreases associated with the presence of forests regardless of the distance between them and agricultural fields.

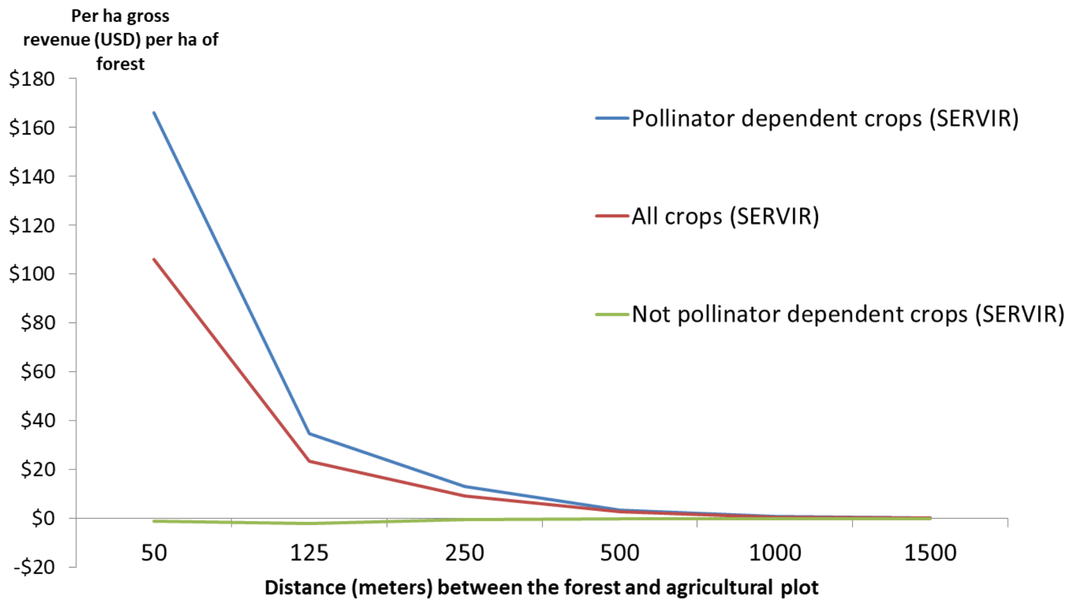


Figure 3: Marginal contribution of forest (per ha) near agricultural fields to agricultural gross revenues (per ha), by distance between the forest and agricultural plot. Preliminary estimates from Tanzania estimated using Tanzania National Panel Survey (NPS) and NASA Servir land cover data for East Africa.

III. Discussion

The purpose of the ESAfD program is to enhance the methodology in ecosystem service accounting by empirically testing valuation methods in a number of countries for a given service. More specifically, the program aims to develop spatially determined and representative values of ecosystem services using approaches that are consistent with economic theory and economic accounting principles. In our conceptual framework, we combine spatially determined ecosystems (land uses) and economic agents benefiting from the services provided by the ecosystems. We measure the value of the service by analyzing the effect of changes in the ecosystem (removing one ha of forest for example) on the production/revenue/profit.

The assessments conducted as part of this program have revealed several important considerations and practical limitations. For example, the ability to implement the general estimation framework varies greatly by country and service considered. The availability and quality of data is often a key consideration and limitation. Another important consideration is how the assessments relate to the accounting framework and how it can contribute to the SEEA-Ecosystem Experimental Account. For the latter, we raise the following questions for discussion:

- How would one incorporate our results into the SEEA-Ecosystem Experimental Account?
- How would one best define spatial units to align with accounting?
- Ecosystem services do not only depend on the presence of the ecosystems but also on their condition. We see this as an important subject for future research. But in general, how does ecosystem quality currently factor into ecosystem accounting?
- Ecosystem accounting requires regular updates. We envision various ways of implementing this, including annual updates using data on changes in the extent of ecosystems throughout the landscape. Over longer periods of time, one could also re-estimate the empirical linkages between ecosystems and economic outcomes of interest to control, for example, for changes in production technologies. But what are the ways currently used to update ecosystem accounts? How would our empirical approaches fit within that framework?
- Could the general approach be extended to other ecosystem services? For example, water quantity provision?

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